University of South Australia
Division of Information, Technology, Engineering and the Environment
School of Engineering

A Robust Optimisation Framework for the Simultaneous Cost-Risk Reduction in Just-in-Time Systems

by

Faraj Farhat Eldabee
BSc, MSc Eng.

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Dedication

I especially dedicate this thesis to the immaculate souls of my father and brother 'Abdunnasir' May Allah have mercy upon them. I also dedicate this thesis to my beloved mother who has missed her son while praying for his success. Finally, I dedicate my thesis to my wife and my daughters who have patiently persevered with me during my research study.

Abstract

In today's competitive global markets, customers seek to minimise their supplies regardless of where they are produced. To improve their competitiveness, organisations can use significant lean manufacturing tools such as Just-in-Time (JIT). JIT can improve the flow of materials and information and lead to cost reductions and the elimination of waste. Many international organisations have implemented JIT in their processes to reduce costs and improve efficiencies. They tend, however, to ignore the risks arising from these benefits. These risks will impact on their processes disrupting the entire supply chain. To minimise these costs and risks in the supply chain, this research investigates how JIT can be used in production systems to eliminate their wastes. This research aims to simultaneously reduce the costs and risks in production systems under a JIT environment in order to increase the organisations' efficiencies.

A robust framework for a simultaneous cost-risk reduction in JIT systems (SCRRJITS) is developed. This framework includes two main stages: development and validation. The development stage includes two parts: modelling and optimisation of the SCRRJITS in production systems. A mathematical model for calculating the overall cost of the final product in the production system is developed. The total product cost comprises production and risk costs. Risk costs arise from implementing the JIT approach in these organisations to manage their process. An optimisation approach is then proposed using a genetic algorithm (GA) to solve the SCRRJITS problem in the production systems under the JIT adoption. A genetic algorithm (GA) is selected for this purpose. The developed optimised model is validated to evaluate the effectiveness of the model in solving the SCRRJITS optimisation problem. This optimisation model is implemented in a real case study using an inventory management approach by testing it in three different case scenarios.

Some experimental studies using different values of the basic parameters of the proposed GA are applied to ascertain the proper values of these parameters solving the SCRRJITS problem. The results show that the proposed optimisation model can find the optimal or near-optimal solution in a short time. The design solution achieved from the proposed optimisation model is compared with the results of the original company case. The results illustrate that the proposed optimised SCRRJITS model converges to optimality consistent with a reduction of 29.6% in the overall cost using the inventory management approach. Sensitivity analyses are also performed to determine the impact of design decision variables on the overall cost of the final product in the production system under a JIT adoption. The findings show the efficacy of the proposed optimisation model in solving such issues. The statistical analyses using the analysis of variance (ANOVA) also confirm that the designed decision variables have a significant impact on the objective function of the proposed optimisation model.

This study has found a research gap exists in supply chains using lean manufacturing techniques such as JIT for managing their systems. There is an absence in the literature addressing the simultaneous cost-risk reduction in production systems under a JIT environment. This gap is the main contribution of this work. The proposed optimisation framework is the first approach used for solving the SCRRJITS optimisation problem.

Declaration

I hereby declare that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university. To the best of my knowledge, this work does not contain any materials previously published or written by another person except where due reference is made in the text.



Faraj Farhat Eldabee

Australia, 2015

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List of Publications

The following is the list of research papers out of this thesis. This list is categorised into three groups as shown below:

Journal papers

1. El Dabee, F., Marian, R. & Amer, Y., 2015, 'A robust Optimisation Approach of a Simultaneous Cost-risk Reduction under a Just-in-Time Environment using a Genetic Algorithm', *Applied Mechanics and Materials*, vol. 743, pp. 307-316.

2. El Dabee, F., Marian, R. & Amer, Y., 2014, 'A Genetic Algorithm for Simultaneous Optimisation of Cost-risk Reduction under Just-in-Time Adoption', *Journal of Computer Science*, vol. 10, no. 12, pp. 2507-2517.

3. El Dabee, F., Marian, R. & Amer, Y., 2013, 'A Novel Optimisation Model for Simultaneous Cost-risk Reduction in Multi-suppliers Just-in-Time Systems', Journal of Computer Science, vol. 9, no. 12, pp. 1778-1792.

4. El Dabee, F., Marian, R. & Amer, Y., 2013, 'Development of a Model for Simultaneous Cost-Risks Reduction in JIT Systems Using Multi-External and Local Backup Suppliers', *Automation, Control and Intelligent Systems*, vol. 1, no. 3, pp. 42-52.

5. El Dabee, F., Marian R. and Amer Y., 2013, 'An Optimisation Model for a Simultaneous Cost-Risk Reduction in Just-in-Time Systems', *Australian Journal of Multi-Disciplinary Engineering*, vol. 9, no. 2, pp. 139-147.

Peer-reviewed conference papers

6. El Dabee, F., Marian, R. & Amer, Y., 2014, 'Simultaneous Cost-risk Reduction Optimisation in JIT Genetic Algorithms', *IEEE International Conference on Control System. Computing and Engineering*, pp. 83-88.

7. El Dabee, F., Marian R. and Amer Y., 2013, 'A Novel Model for Simultaneously Minimising Costs and Risks in Just-in-Time Systems Using Multi-backup Suppliers: Part 1- Modelling', *World Academy of Science, Engineering and Technology*, Vol. 74, pp. 332-337.

8. El Dabee, F., Marian R. and Amer Y., 2013, 'A Novel Model for Simultaneously Minimising Costs and Risks in Just-in-Time Systems Using Multi-backup Suppliers: Part 2- Result', *World Academy of Science, Engineering and Technology*, Vol. 74, pp. 338-345.

9. El Dabee, F., Marian R. and Amer Y., 2012, "An Optimisation Model for a Simultaneous Cost-Risk Reduction in Just-in-Time Systems", *in the 11th Global Congress on Manufacturing and Management, GCMM2012*, Auckland, New Zealand, pp. 190-201.

One book chapter and one journal paper are under review.

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List of Abbreviations

TPM	Total Productive Maintenance
TOC	Theory of Constraints
JIT	Just-in-Time
SCRRJITS	Simultaneous cost-risk reduction in Just-in-Time systems
GA	Genetic Algorithm
TPS	Toyota Production System
MTF	Make to Forecasting
MTO	Make to Order
QCD	quality, cost and delivery
TPM	Total Productive Maintenance
SDWT	Self-directed work team
DEA	Data envelopment analysis
JPM	Japanese production management
TOC-SCRS	Theory of constraints supply chain replenishment system
DBR	Drum-Buffer Rope
CCR	Capacity constrained resource
GE	General Electric
DMAIC	Define, Measure, Analyse, Improve and Control
JITPS	JIT production system
JITD	JIT distribution
JITP	JIT purchasing
SCC	Supply chain costs
VMI	Vendor-managed inventory
RMI	Retailer-managed inventory
SCRM	Supply chain risk management
EOQ	Economic order quantity
EMQ	Economic manufacturing quantity
MOLIP	Multi-objective location-inventory problem
EVA	Economic value added
CVaR	Conditional value-at-risk
ENPV	Expected net present value
DGSCN	Defective good supply chain network

EPQ	Economic production quantity
ALOEC	Appropriate length for each cycle
HGA	Hybrid Genetic Algorithm
ASCS	Agile supply chain schedulling
ANOVA	Analysis of variance
MINLF	Mixed non-linear formulation
P-D	Production-distribution
SA	Simulated annealing
TS	Tabu search
FLGA	Fuzzy logic genetic algorithm
S-PPL	Serial-parallel production line
IRP	Inventory routing problem
MILP	Mixed integer linear programming
EAs	Evolutionary Algorithms
RCGA	Real-coded genetic algorithm
DGSCN	Defective good supply chain network
WWAL	Walking worker assembly line
VRP	Vehicle Routing Problem
TSP	Travelling salesman problem
ssGA	Steady-state genetic algorithm
NP	Non-deterministic polynomial-time hard
CFA	Capacity and Flow Assignment
PSP	Pooladin Sazeh Persian
BOM	Bill of material
WIP	Work-in-process
FTA	Fault tree analysis
FMEA	Failure modes and effect analysis
PSO	Particle swarm optimisation

1. Introduction to Lean Manufacturing Concept (Cost and Risk) in a Supply Chain

1.1. Introduction

Today's increasingly competitive global marketplace places a constant pressure on organisations to adopt more effective and efficient business strategies that will ultimately lead to an increase in their performance levels (Cai et al. 2009). This can be achieved by the continuous improvement and optimisation of their processes and operations, cost reduction of their services and products, and an increased output capacity with satisfactory product quality and production rates. Organisations need to implement new techniques for managing their businesses in order to dramatically increase their revenue and reputations (El Dabee, Faraj & Hokoma 2012; Hokoma, RA, Khan & Hussain 2008). One of these techniques which can be adopted by industries to achieve their goals is lean manufacturing (Hodge et al. 2011).

The lean policy focuses on managing the supply chain efficiently by cooperating with the other parties of the supply chain on some significant operational factors such as inventory levels and lead time (Qi 2009). The core of lean manufacturing is the elimination of hidden wastes in production and manufacturing through an active process of continuous improvement (Ferdousi; & Ahmed 2009). Within a lean manufacturing philosophy, wastes are being discovered which are removed from the system so that the process of increased value creation can be ensured within the organisation. Waste or muda is defined as "anything other than the minimum amount of equipment, materials, parts, and space and time which are absolutely essential to add value to the product" (Taylor & Russell 2009, 2011). Monden, Y. (2000) also defines waste as anything that does not improve the system performance or does not add any value to it.

Tools that are used to eliminate waste within organisations include Kaizen, Total Productive Maintenance (TPM), Six Sigma, 5S, Theory of Constraints (TOC) and Just-in-Time (JIT) (Tourki 2010). They lead to continuous improvement in material flow and information, better management of human resources, improved throughputs, cost reductions and the elimination of wastes and non-value added activities. Each technique will be discussed in Chapter 2. However, JIT as a technique used in production systems for procuring raw materials or components from their suppliers to reduce the final product costs will be given more attention

than the others. This is due to its impact on the supply chain caused by certain disruptions such as the tsunami in Japan and floods in Thailand in 2011 (Revilla & Sáenz 2013).

The remainder of this chapter is organised in the following ways. Background information is initially presented in Section 1.2 outlining the cost and risk reduction in the supply chain. Section 1.3 highlights the problem statement of this research. The research motivations are discussed in Section 1.4. The research questions are then introduced in Section 1.5. In Section 1.6, the research objectives are presented. Section 1.7 focuses on the research scope of this thesis. Next, the organisation of this thesis is presented in Section 1.8. Finally, a summary of this chapter is described in Section 1.9.

1.2. Background

The history of lean manufacturing systems can be traced back to the Toyota automobile system in Japan in the years after World War II. The main objective of lean philosophy is to achieve more by using less through eliminating or minimising wastes and non-value added activities within the system (Womack & Jones 2003). Lean manufacturing is a philosophy, which has been developed over a long period of time. The main task of lean manufacturing system is to locate the major sources of waste which would then be eliminated by the application of a large number of tools such as continuous improvement, JIT, production smoothing and others. (Abdullah 2003). Monden, Y. (2000) points out that core to the Toyota Production System (TPS), or lean manufacturing as it is called in the US, is the elimination of all kinds of wastes concealed within a company through continuous improvement activities.

1.2.1. *Cost Reduction in the Supply Chain*

In the supply chain context, organisations are required to pay a substantial attention to the cost management due to its impact on their performances. Therefore, cost may be considered as a function of strategic selections of the organisation's competitive position, rather than a function of output volume (Min & Zhou 2002). Organisations attempt to meet their global competition requirements by implementing modern concepts of lean manufacturing such as Just-in-Time (JIT) in order to simplify their processes in the supply chain (Childerhouse et al. 2003). The key benefits of this implementation lead to the minimisation of production costs, an increase in outputs and a reduction in production lead times (Agus & Hajinoor 2012). This can be achieved by a close collaboration between customers and suppliers but such a process

may lead to high vulnerability as a result of inventory elimination within the entire supply chain warehouses (Thun, Jörn-Henrik & Hoenig 2011).

Lean manufacturing has been defined by The National Institute of Standards and Technology Manufacturing Extension Partnership's Lean Network as "A process of identification and elimination of waste by way of achieving improvement on a continuous basis and flowing it at the pull of customers in the desire to attain higher efficiency in the process" (Kilpatrick 2003). JIT is defined as a manufacturing pull system that can be used in production systems to procure/produce the exact amount of raw materials/products when they are needed and from/to the right place. The principle of JIT in its basic meaning is the elimination of all kinds of non-value adding activities (waste) by organising the entire system of operations and activities (Chan, H, Yin & Chan 2010; Hokoma, R, Khan & Hussain 2010).

Wastes regardless of the forms they take and where they could be hidden (in policies, procedures, process, and product designs and in operations) must be identified and eliminated. Basically, seven common types of waste appear in the literature, and they are (Hines & Rich 1997; Kilpatrick 2003; Monden, Y. 2000):

- Overproduction – Producing more than the customer demands directly resulting in excessive inventory.
- Waiting – An ineffective use of time accounts for this waste and it mostly occurs when goods are queuing or being worked on.
- Transportation – Excessive movement of goods and information that add no value to products. Material should be delivered to its point of use.
- Non-Value-Added-Processing – The use of overly complicated machines/ solutions/ techniques to handling simple procedures. Over complexity generally tends to produce more waste and make workers uneasy.
- Excess Inventory – Born out of overproduction, inventory beyond that needed to meet customer demands has an adverse effect on cash flow (requires more manpower and equipment) and uses valuable floor space. It also acts as a barrier to identifying and eliminating waste.
- Defects – Defects in production and service waste resources and impact negatively on cost. When defects occur considerable resources of materials, labour and time consumed cannot be recovered.

- Excess Motion – This occurs when the ergonomics of production comes into play resulting in occupational health and safety issues.

Kilpatrick (2003) in addition adds another type of waste: underutilised workforce which is the underutilisation of mental, creative, and physical skills and abilities resulting from the organisational culture, inadequate hiring practices, poor or non-existent training, poor workflow and high employee turnover.

Waste in any industry can be attributed to the existence of excessive production resources, which could result from unutilised labour, facilities and inventory. Overproduction which is closely tied to surplus inventory is regarded as the worst form of waste at Toyota Motor (Monden, Y. 2000). Defects as a source of waste negatively impacts on bottom-line costs and must be avoided. Abdullah (2003) indicates that producing defective parts from the start of manufacturing has an enormous impact on productivity. Resources such as raw materials, labour and time are wasted when defective products and service errors occur. When defects occur, labour consumed initially in the production of goods or rendering of services becomes irrecoverable and further additional labour will be required to fix defective parts to meet customer requirement (Hayes, Clark & Review 1986).

The Toyota philosophy however, considers defects as an opportunity to improve productivity rather than something to be traded off against what is eventually poor management (Hines & Rich 1997). Production defects can be eliminated or reduced to the barest minimum through quality improvement activities. However, waste in some cases has a potentially positive effect as it decouples processes making the control of the production process significantly easier. Hines and Rich (1997) argue that transportation though a source of waste sometimes becomes a necessary evil and as such its minimisation rather than complete elimination must be sought. It is highly necessary to fully eliminate waste or reduce it to the barest minimum regardless of the form it takes. This will enhance companies' competitive edge in the global market as they produce high quality goods at the lowest cost possible.

1.2.2. *Supply Chain Risk Management of Disruptions*

In the global business, competitive environment characterised by high uncertainty, organisations are forced to effectively manage their supply chain to increase efficiency and to ensure their reputation in the marketplace (Thun, Jörn-Henrik & Hoenig 2011). Risks are categorised based on environmental factors (natural disasters, strikes, political instability,

fires and terrorism), industrial factors (input market, product market and competitive uncertainties), organisational factors (operating, credit, liability and agency uncertainties), problem-specific factors (risk interrelationships and task complexity) and decision-maker factors (knowledge/skill/biases of decision makers, bound rationality, and others) (Rao & Goldsby 2009). These risks in the supply chain have been raised as a result of implementing modern techniques such as lean management approaches (i.e. Just-in-Time) (Pochard 2003). Lean management approaches play a significant role in the supply chain in order to be competitive in industry fields such as the automotive industry. However, they lead to many potential disruptions which make the supply chain more vulnerable (Thun, Jörn-Henrik & Hoenig 2011). The consequences of these disruptions might be financial losses, a negative corporate image or a bad reputation leading to a loss in demand and damage in security and health (Jüttner, Peck & Christopher 2003).

Supply uncertainty has recently received substantial attention and the concern of supply chain managers and researchers particularly as a consequence of their vulnerability to modern manufacturing tendencies and complex supply networks (Tajbakhsh, Zolfaghari & Lee 2007). Disruptions have a negative impact on customer service if suppliers are not able to supply their products to their customers at the right time. Disruptions lead to increasing the costs associated with expediting, premium freight, obsolete inventory, additional transactions, overtime, storage and moving, selling and penalties paid to customers (Hendricks & Singhal 2008).

Jüttner, Peck and Christopher (2003) state that supply chain risk management includes four key aspects: assessing the supply chain risk sources, defining the supply chain adverse consequences, identifying the risk drivers and mitigating the supply chain risks. According to the MIT Research Group on "Supply Chain Response to Global Terrorism" (cited in Pochard 2003), failure modes in the supply chain management are categorised into six different levels of disruption. Table 1.1 lists them as disruption in supply, disruption in transportation, disruption at facilities, freight breaches, disruption in communications and disruption in demand.

Table 1.1 Supply Chain Failure Modes (Pochard 2003)

Failure Mode	Description
Disruption in supply	Delay or unavailability of materials from suppliers, leading to a shortage of inputs that could paralyse the activity of the company.
Disruption in transportation	Delay or unavailability of the transportation infrastructure, leading to the impossibility to move goods, either inbound or outbound.
Disruption at facilities	Delay or unavailability of plants, warehouses and office buildings hampering the ability to continue operations.
Freight breaches	Violation of the integrity of cargoes and products, leading to the loss or adulteration of goods (can be due either to theft or tampering for criminal purpose, e.g. smuggling weapons inside containers).
Disruption in communications	Delay or unavailability of the information and communication infrastructure, either within or outside the company, leading to the inability to coordinate operations and execute transactions.
Disruption in demand	Delay or disruption downstream can lead to the loss of demand, temporarily or permanently, thus affecting all the companies upstream.

Based on the supply chain failure modes illustrated in Table 1.1, it is important for researchers to pay greater attention to supply chain disruptions and to develop the skills, expertise and systems essential to develop greater capability to manage and mitigate these disruptions. Suppliers with a high probability of risk event occurrences have a substantial impact on an organisation's ability to generate revenue. Therefore, it is crucial that organisations have the capability to analyse the risks associated with a supplier of outsourced materials.

1.3. Research Problem Statement

Many organisations particularly the global firms, have implemented lean manufacturing techniques such as Just-In-Time (JIT) to manage their process in order to improve their performance and to ensure their position in the global marketplace. However, there are many potential risks arising from this implementation which causes significant disruptions to the entire supply chain. Biswas (2007) recommends that some issues which have a significant impact in the supply chain can be considered in future research. These are: time varying demand, variable production capacity, transportation costs and multi-stage systems. Kumar, S, Tiwari and Babiceanu (2010) also mention that costs and their risks should be minimised in multi-product environments with outsourcing choice as a further research direction. The

potential occurrence of disruptions such as natural disasters can interrupt not only the manufacturing industry production and its suppliers but also the transportation and distribution centres. Consequently, implementing lean manufacturing techniques such as JIT exposes businesses to many risks particularly those arising from the supply base.

The supply of raw materials by a single supplier may lead to the disruption and/or shutdown of the production system at short notice (Sodhi & Lee 2007). Accordingly, it is necessary to have a backup supplier in order to minimise the impacts of these potential risks in the supply chain (Coronado 2007). The earthquake and tsunami for instance in Japan in March 11, 2011 severely disrupted the supply sources of numerous industries in north-eastern region which led to many problems in their production, logistics, and distribution processes (El Dabee, F., Marian, R. & Amer, Y. 2013a; Sodhi & Tang 2012).

Given the paucity of research on cost and risk minimisation in the supply chain using the JIT approach, considerable gaps and scientific challenges persist when it comes to the development of a robust and optimised simultaneous cost-risk reduction in JIT systems. This research will enhance our understanding of the impact of different scenarios on production systems under a JIT adoption in the event of disruptions.

1.4. Research Motivations

The motivation for this research is the increasing competition in the marketplace that requires businesses to be effective in efficiently meeting their complex customer requirements. This can only become possible for organisations by achieving a reduction in their overall manufacturing costs and also by reducing the risk levels in their production system processes, especially in JIT systems.

By conducting this study, it would become possible to ensure efficiency in the production process system as the research will introduce a robust framework for ensuring reduction in the overall manufacturing cost of products as well as their risks.

In light of the research motivations, the major contributions of this research, which will be discussed in detail in Chapter 8, are highlighted as follows:

- Developing of a robust framework that can be utilised for simultaneously minimising the cost of products within production systems under a JIT adoption and the risks arising from this reduction;

- Developing a mathematical model used for the purpose of simultaneously reducing the cost in production systems under a JIT regimen to manage their processes and the risks arising from these benefits;
- Adopting a robust optimisation meta-heuristic technique for solving a robust simultaneous cost-risk reduction in Just-in-Time systems (SCRRJITS) optimisation problem in production systems. This research has proposed an optimisation approach (GA); and
- Solving a multi-echelon supply chain using the proposed GA by implementing the developed optimisation model in a real case study to validate it.

Although this research study has shown its efficiency in minimising the total cost of the final product under a JIT adoption, it is conducted in view of the following limitations:

- Lack of data required in the optimising design on a whole system of the SCRRJITS. Consequently, some needed data will be assumed based on the developed model;
- Focusing on one the fundamental objective function in the design process of the SCRRJITS optimisation framework; and
- Lack of a fully comprehensive approach for the SCRRJITS optimisation design.

1.5. Research Questions

In order to effectively perform the research work, there are certain research questions that are being developed. These research questions are discussed below.

- How can disruption be systematically handled in supply chains under the JIT adoption?
- What is the impact of performance improvement in the supply chain functions of the organisation in terms of cost-risk reduction in JIT systems?
- How can the development of a robust optimisation framework be utilised for the purpose of cost-risk reduction in JIT systems?
- How can we assess the fitness of appropriate models developed to better-inform decision-making in handling disruptions in JIT systems?
- What specific role does a SCRRJITS optimisation framework play in producing feasible solutions to present the minimum cost of the final products in JIT systems?

1.6. Research Objectives

The main research objective, in light of the limitations of the literature review related to the implementation of JIT techniques in production systems, is to develop a robust optimisation framework which addresses the impacts of JIT implementation on production facilities for procuring the raw materials from their suppliers to minimise the overall cost of the final product.

The main research objectives of this thesis with reference to the above questions are:

- To demonstrate that lean manufacturing tools such as JIT can be used to eliminate waste and the need to simultaneously control risk.
- To develop a framework for a simultaneous cost-risk reduction in JIT systems by developing and testing a mathematical model. The developed framework should provide the tools leading to a full understanding of the interrelationship between decision variables to avoid local optimisation.
- To develop an optimisation procedure, which is based on genetic algorithm (GA), in order to achieve a better product quality and better overall financial and operational processes within the organisations in the supply chain.
- To validate the optimisation model by implementing the proposed model in an industrial case study.

1.7. Research Scope

This research targets a supply chain system as shown in Figure 1.1, which includes four main echelons: suppliers, manufacturers, warehouses and distribution centres and end-customers. Figure 1.1 incorporates multiple suppliers, multiple manufacturing plants, multiple distribution centres and multiple end-users all in different geographical locations. The model proposed in this research includes the procurement of raw materials from the selected suppliers (external/local), the transportation of raw materials from the suppliers (vendors) to the manufacturers and the distribution of the final product to the end-customers.

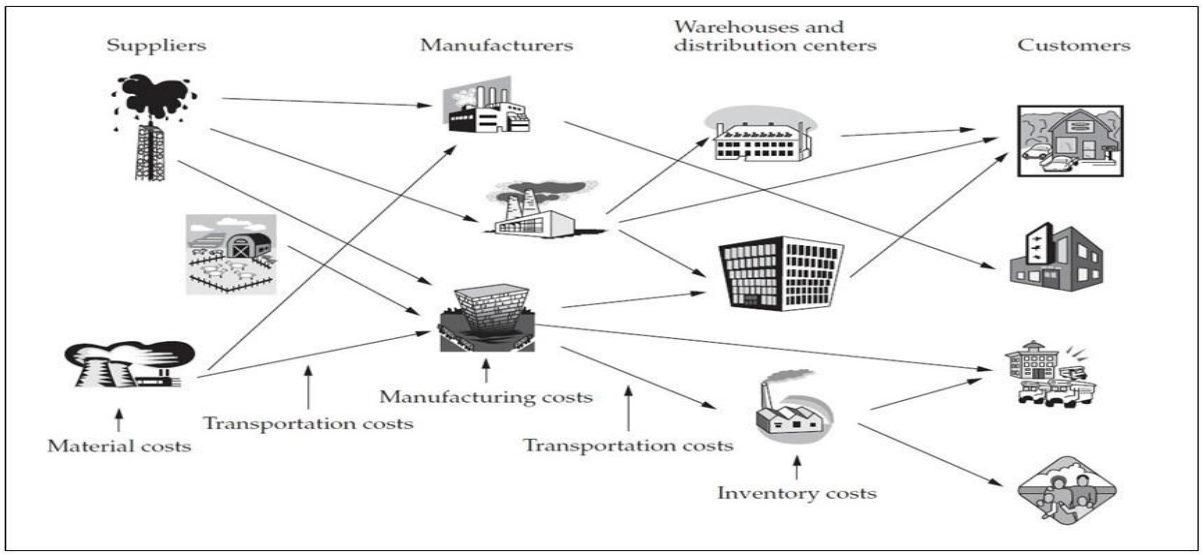


Figure 1.1 The schematic diagram of considered echelons in the supply chain (Simchi-Levi, Kaminsky & Simchi-Levi 2008)

Figure 1.1 illustrates that the supply chain includes four-echelons with four nodes that exist to move raw materials and products from suppliers to the end-customers. The nodes for these four-echelons are as follows:

Suppliers - supplying raw materials to the production system;

Assembler/Manufacturer - assembling/producing the raw materials procured from the supplier;

Warehouse and Distribution centre - distributing the final products produced by the manufacturer to the end customer; and

Customer - where demand is backordered at the end of each period.

The first echelon includes multiple suppliers (external/local) used to supply raw materials to the manufacturing system. The second echelon consists of multiple manufacturers who produce their final products and move them to their distribution centres. The third involves the distribution of the final products procured from their manufacturers to the end-customers to meet their satisfaction. Finally, the fourth echelon is the end-customer/s who produce/s the final product.

1.8. Thesis Organisation

This thesis is organised into 7 chapters. Chapter 1 discusses the research background and the concept of the lean manufacturing approach in a supply chain including the seven common types of waste. The chapter then presents the problems studied in the research accommodating the gaps identified in the literature. The motivations that led to this research are next outlined and the objectives and the scope of this research are finally highlighted.

The organisation of this thesis from Chapters 2 to 8 is summarised as follow:

Chapter 2: Literature review

This chapter surveys the literature on the research relating to individual cost and risk reduction in supply chain systems particularly in JIT systems. This is done in order to provide an overview of a simultaneous cost-risk reduction in production systems adopting a JIT approach for managing their processes. The main concepts of a lean and agile supply chains are debated. The background of some of the key lean manufacturing tools is then highlighted alongside the kinds of costs arising from producing the final products within organisations and the risks that might occur arising from these costs. The review of the cost and the risk reduction modelling and optimisation in the supply chain and in JIT systems are presented in subsequent sections of this chapter. The shortcomings of these models are identified as a basis to develop a robust model.

Chapter 3: Development of a robust framework for a simultaneous cost-risk reduction in JIT systems (SCRRJITS)

Chapter 3 presents the theoretical foundations and details about construction and phases of the developed framework as well as a brief description on how the framework can be implemented to tackle the design requirements in JIT systems. Elements of this framework code namely a robust framework for a SCRRJITS have been adopted for solving the design problem. In this research, the characteristics of the design problem were examined and consequently the major techniques for the purposes of modelling and optimisation in the JIT approach have been adopted. A Genetic Algorithm (GA) will be selected as the suitable optimisation technique for simultaneously reducing the cost in production facilities and the potential risks under a JIT adoption.

Chapter 4: Development of a novel model for a simultaneous cost-risk reduction in JIT systems

This chapter presents the modified mathematical model proposed in this research for simultaneously minimising the cost in production systems under a JIT adoption to manage their processes, and the risks arising from these benefits. This model includes three elements: parameters, decision variables and performance measures. The first step is to identify the performance measures and dominant decision variables while in the next step, functional relationships, need to be established between the decision variables and the performance measures. From these functional relationships, an index is derived to describe the system performance. A simplified example will be used to verify the performance of the proposed model.

Chapter 5: A simplified application of the developed SCRRJITS model

This chapter presents the application of the proposed model to demonstrate the effectiveness of the SCRRJITS model developed in this research for solving this problem. This chapter describes a simplified example assumed for this purpose. The results obtained from this example are then discussed in detail.

Chapter 6: A robust Genetic Algorithm for optimising a simultaneous cost-risk reduction in JIT systems

A detailed development of a novel genetic algorithm (GA) for a simultaneous cost-risk reduction in JIT systems is presented in this chapter. An effective chromosome representation is employed using an array of discrete and positive real-coded numbers which is capable of finding the optimal or near-optimal solutions. This can be achieved by using simple but customised genetic operators.

Chapter 7: Performance evaluation of the SCRRJITS framework: An industrial case study

Chapter 7 presents a case study of an assembly line for a specific product to determine the effectiveness of a SCRRJITS approach. This chapter describes the validation of the framework and how challenges are solved. The obtained results from the case study will be discussed and analysed in this chapter. A comparative analysis is also presented to evaluate

the performance of the proposed model by comparing the findings achieved with the results of the real case study.

Chapter 8: Conclusions, scientific contribution and further research

The overall findings in this chapter and the scientific contributions of this study are presented. Suggestions for future work are also outlined. Figure 1.2 shows the outline structure of the thesis.

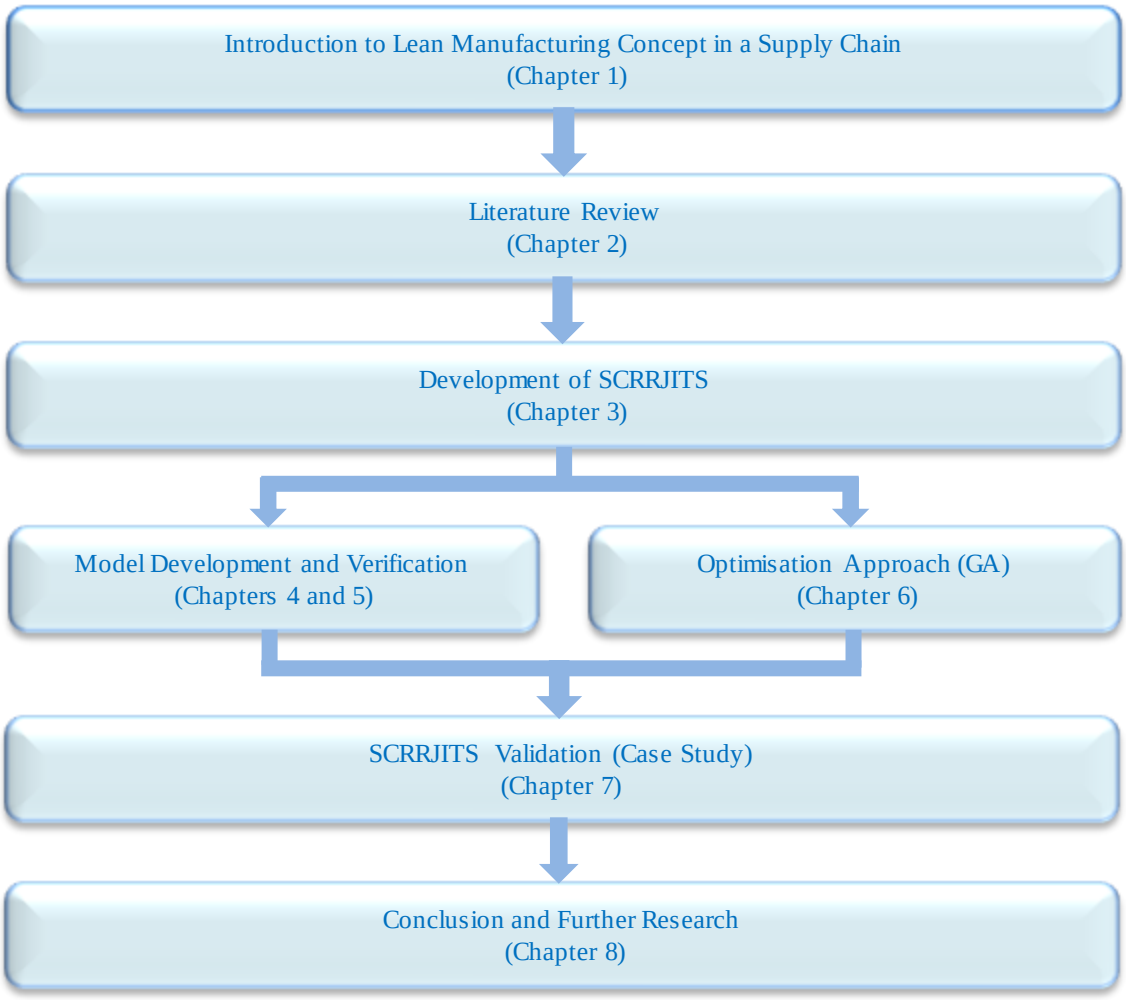


Fig. 1.2 Outline of the thesis structure

1.9. Concluding Remarks

Lean manufacturing is considered as one of the production and business approaches that has received much attention in the research field. It is an approach that can assist organisations by improving their processes (Perumal, Tian & Muhamad 2011). Its main task is to locate the major sources of waste which are then to be eliminated by the application of a large number of tools such as Just-in-Time (JIT) and production smoothing. JIT as a lean manufacturing

tool has been used within organisations to improve their efficiency, speedup their production process and increases their delivery performance. Consequently, the right quantity of products/raw materials can be produced/supplied with the right quality level at the right place when they are needed (Chan, H, Yin & Chan 2010). However, the impacts of the potential risks arising from adopting a JIT have been neglected, which might affect the entire supply chain.

The aim of this research is to develop a robust optimisation framework for simultaneously reducing the cost of the product in the production systems and the risks arising from this reduction. The review of this topic is outlined in Chapter 2.

2. Cost-Risk Reduction Optimisation Model in Just-in-Time Supply Chain Systems: A Literature Review

2.1. Introduction

Recently, many organisations within the supply chain environment have implemented a JIT approach to increase their efficiency and to ensure their position in the competitive global marketplace (Ho & Kao 2013; Roy, Sana & Chaudhuri 2012; Uthayakumar, R. & Rameswari 2013). Supply chain management always manages its processes effectively to meet customer satisfaction (Manzouri et al. 2013). JIT as a lean manufacturing technique can be used to improve the quality of organisations and to reduce the product cost by eliminating all production facility waste and non-value added activities (Fahimnia, Marian & Motevallian 2009; Hokoma, R, Khan & Hussain 2010). JIT can be defined as a lean subset that is mainly associated with the elimination of waste through planning, scheduling and sequencing of operations in manufacturing industries (Inman et al. 2011). It is a critical tool for managing the external activities associated with an organisation and its purchasing and distribution includes three elements: JIT production, distribution and purchasing (Mishra, Kumar & Garg 2013).

Globally, many organisations have incorporated a JIT technique into their processes to achieve their goals. However, some have ignored certain significant risks which arise from its implementation. Businesses are exposed to various risks, particularly those originating from the supply base. These risks potentially affect their processes by disrupting all supply chain parties involved (El Dabee, F., Marian, R. & Amer, Y. 2013b; Eldenburg & Wolcott 2011; Konecka 2010; Sodhi & Lee 2007). In this context, risk may be defined as the combination of possible consequences and associated uncertainties (Aven & Vinnem 2007). It is also defined as the probability of a specific event occurrence that may negatively influence the organisation (Neureuther & Kenyon 2009). Generally, supply chain risk is an event exposure that causes disruption affecting the efficient management of the whole supply chain network (Ghadge, Dani & Kalawsky 2012). Therefore, the result of implementing lean manufacturing techniques such as JIT within the organisations affected has led to the disruption of their processes and of the whole supply chain. Consequently, the lack of specific tools that can be utilised to achieve a simultaneous cost-risk reduction leads to significant problems for businesses. The major problem can be stated as the relationship between the reduction of costs and the increase of risks arising from this reduction. Previous researchers have focused

solely on the reduction in the overall product cost. This thesis analyses the simultaneous cost-risk reduction in production systems under a JIT adoption.

The rest of this chapter is organised as follows: some of the key lean manufacturing tools are described in Section 2.2; Section 2.3 discusses the kinds of costs arising from the changing relationship between the volume of economic activity and the risks which might occur arising from these costs; the modelling of cost and risk reduction in the supply chain are presented in Section 2.4; Section 2.5 presents the review of the optimisation stage using different tools to find the optimal solution obtained from the developed models; Section 2.8 summarises the chapter.

2.2. Lean and Agile Supply Chain Concepts

In early 1950s, the idea of lean production was devised at the Toyota Production System (TPS). The main purpose of lean philosophy is to use less but achieve more by eliminating or minimising non-value added activities within organisations, in order to improve efficiency (Hajmohammad et al. 2012; Tourki 2010). Lean is a systematic approach that focuses on the continuous improvement of quality, cost and delivery within organisations by eliminating or reducing all kinds of waste and increasing their capability to meet customers' satisfaction (Behrouzi, Wong & Behrouzi 2011). It is considered to perform better in cases of high capacity, low diversity and an expected constant demand (Agarwal, Shankar & Tiwari 2007). Key lean principles include eliminating unnecessary waste, reducing large inventory stocks using a JIT approach for supplying materials and products between supply chain members and involving employees within organisations for improving their own work (Holden 2011). Lean has become a strategic approach adapting the challenge of the competitiveness of the marketplace in supply chain systems, not only for manufacturers, but also for suppliers and wholesalers (Barac, Milovanović & Anđelković 2010).

Lean thinking is defined as a managerial approach that improves customer perceptions by adding product/service features and by continuously removing non-value added activities such as waste, which are hidden in any kind of process (Bonaccorsi, Carmignani & Zammori 2011). It is also defined as a set of tools which are necessary to be properly selected to improve the needs of organisations (Behrouzi & Wong 2011). Businesses seek several improvements, which have direct or indirect impacts on the logistics performance in the supply chain networks such as waste elimination and zero inventory approaches (Moyano-

Fuentes & Sacristán-Díaz 2012). The application of lean philosophy in the manufacturing industries has spread widely and numerous techniques have been developed in many research studies (Piercy & Rich 2009). Lean production is considered to be based on four principles: waste elimination, high quality, flexible production lines and continuous improvement (Marian 2003). Lean production includes lean development, lean procurement, lean manufacturing and lean distribution (Demeter & Matyusz 2011). The main objective of implementing a lean philosophy within organisations is to improve the flow- rate of materials by eliminating or minimising the wastes and non-value added activities. These wastes are overproduction, transportation, waiting, inventory, motion, over-processing and defects (Tourki 2010).

Agile management means the use of market information and cooperation to leverage the lucrative opportunities in an unstable competitive environment (Stump & Badurdeen 2012). It can be considered as needed motivation for the integration of flexible and core available resources within organisations to provide customers with value-added products and services (Wadhwa, Mishra & Saxena 2007). It should be related to flexibility, responsiveness and the cost and quality of goods and services (Gunasekaran, Lai & Edwin Cheng 2008). Agile management includes the implementation of a diversification strategy within organisations used to supply the product to the customers, which might not be available elsewhere (Konecka 2010). Agile management entails having a flexible organisation able to manage changes in the market and to embrace competitiveness and customer satisfaction as goals (Groover 2008). The quick response to demand changes plays a significant role in providing the end customer with a high level of service. The effectiveness of agile management may be measured by the ratio between the products delivered and of those products ordered, the number and kind of errors made during the monitoring process, the amount of damage and the risk of cancelled orders and finally the ability to prepare the products to fill orders (Konecka 2010).

An agile supply chain involves integrating business partners so as to enable new proficiencies to respond to and embrace rapidly diversifying markets. The main factors of the agile supply chain are the policies of arrangements and the relationship between members, the end-to-end visibility of information and event-driven and event-based management (Baramichai, Zimmers Jr & Marangos 2007). It is also defined as the capability of a rapid supply chain response to changes in the environmental global market demand (Swafford, Ghosh & Murthy

2006). Agile supply relies on some variables which might affect its members' efficiency such as customer satisfaction, quality improvement, cost reduction, delivery speed, new product introduction, service level improvement and lead time reduction (Agarwal, Shankar & Tiwari 2007). Organisations need to survive and thrive in a competitive environment with continuous and uncertain rapid demand changes in the marketplace. Top management participation plays a significant role in effective supply chain engineering. The relationship and interaction between the suppliers who supply products and services to their customers should also be flexible and responsive (Gunasekaran, Lai & Edwin Cheng 2008).

The main focus in the lean supply chain is entirely on waste elimination. In agile supply chains, however, the main attention and focus is on the delivery of a high level of service and the rapid response to marketplace changes. The significant difference between lean and agile concepts is that lean supply is based on predicted demand, whereas agile supply is based on volatile demand (Carvalho & Cruz-Machado 2009). From one perspective, the lean approach can be utilised for some special production and supply strategies such as Make to Forecasting (MTF) under certain demand forecasting. The agile concept on the other hand can be accomplished using a Make to Order (MTO) strategy with a quick response ability in an environment of uncertain demand (Xiaomei et al. 2008). In the case where the lead time is long and demand is predictable, the lean concept can be employed in the supply chain system. However, when lead time is short and demand is uncertain, the agile concept is the most effective (Moyano-Fuentes & Sacristán-Díaz 2012). The application of lean production and agile manufacturing within manufacturing systems can be successful for producing the final product only by considering and adopting two critical requirements: the delivering of their raw materials when they are needed; and at the right price (Groover 2008). It is generally accepted that the lean concept can be efficient in organisational management. In cases, however, where there are eventual disruptions arising from unforeseen economic, political and environmental crises, the agile concept is the most effective (Azevedo & Machado 2008).

2.3. Lean Manufacturing Tools

Lean manufacturing can be considered as one of the production and business models, which seeks to deliver quality products to the customer at minimum production cost. It is an approach that can assist organisations to improve their processes (Perumal, Tian & Muhamad 2011). Lean manufacturing can be defined as a set of practices focused on reducing waste and

non-value added activities from an organisation's manufacturing operations (Yang, MG, Hong & Modi 2011). It is a multi-dimensional management practice used in organisations that uses tools such as Just-in-Time, quality systems, work teams, cellular manufacturing, supplier management and others. Applying a lean strategy has a significant impact on competition in the marketplace (Eswaramoorthi et al. 2011). It can be characterised by reference to some key factors and terms such as scheduling inventory, material handling, equipment, work processes, quality, employees, suppliers, customers and tools and techniques (Sujatha & Rao 2013). All these different techniques have the same ultimate goal of eliminating waste and non-value-added activities at every production or service process in order to meet customer satisfaction (Hodge et al. 2011).

The following section lists the key lean manufacturing tools and shows how they can improve the manufacturing process.

2.3.1. *Kaizen*

Kaizen is primarily a word that means "continuous improvement" and it has been given much credit for Japan's competitive success (Barraza et al. 2009; Manos 2007). It is concerned with achieving improvements on a continuous basis to simultaneously facilitate enhanced production operations and to foster a supportive working environment in order to attain overall efficiency. It is a method used to mitigate adverse working conditions and to improve employees' morale and satisfaction. Kaizen is about creating a positive cooperative and innovative workplace culture focusing on increasing productivity and improving quality (Tariq & Aslam 2011). Imai (cited in Al Smadi, 2009) defined it as "the process of gradual and incremental improvement in a pursuit of perfection of business activities". It is in addition, a general outlook and mode of approach involving everyone within an organisation, from upper management down to each employee, to improve quality on all levels; not product quality alone, but total quality of jobs, workers, training, processes and standards (Gopalakrishnan 2006). The key elements of kaizen are teamwork, empowerment and training, which augment and facilitate the process of change. Kaizen is an on-going process that never ends. It puts emphasis on communication and trust between workers and management (Zulfiqar, Rajeev & Nilmini 2007). A Kaizen event or Kaizen blitz is considered as a focused and organised improvement project which is managed by a professional team work, in order to improve a targeted work region with particular objectives and in an appropriate timeframe (Letens, Farris & Van Aken 2006). It is a more focused

event than the normal Kaizen approach. It also improves work processes and implements lean manufacturing within the supply chain. This can be achieved by adapting continuous U-shaped flow production lines (Neese 2007). Farris et al. (2009) investigated the empirical relationships between input variables and initial human resource outcomes in Kaizen events. A sample of 51 events in six organisations was used to identify the set of input factors associated with the development of employee attitudinal results and their capabilities for solving the problems relating to Kaizen events.

As Taylor and Russel (2009) point out, Kaizen has been implemented by many organisations for achieving continuous improvements and the evidence shows that those organisations benefitted considerably from a Kaizen implementation. One such organisation is Dana Corporation's Spicer Driveshaft division which considers the Kaizen principle in its process where each employee gives three suggestions for workplace improvement per month and 80% of the employees' suggestions are implemented. This has resulted in significant improvements within the organisation. In addition, Al Smadi (2009) states that the overall cost of producing and selling a product, when considered from the manufacturer's perspective, is a major factor in Kaizen principles. Here, a significant factor lies in eliminating the waste from many aspects of work such as production, inventory, repair, rejects, motion and processing. Furthermore, a lean Kaizen approach which is based on a combination of lean production or lean thinking and Kaizen tools concentrates on the quality of the processes' improvements in organisations. This results in a reduction of their cycle time and operating costs, the creation of continuous flows, customer satisfaction and the elimination of waste (Suárez-Barraza & Ramis-Pujol 2010).

Many researchers report that kaizen can be considered as a continuous improvement leading to a high quality and increased efficiency in manufacturing industries. It has not, however, been simultaneously used for reducing total cost and risk involved within production systems.

2.3.2. *Total Productive Maintenance (TPM)*

In 1971, TPM started in Japan through Nippon Denso Company which is a part of the Toyota group. It can be considered as an evolution of preventive maintenance, which was essentially conceived in the United States in the 1950s. The TPM concept is an attempt to deploy certain approaches, which can assist organisations to achieve cost-effective benefits such as eliminating waste, consistently obtaining the best performance from the equipment and decreasing stoppage (Lazim & Ramayah 2010; Teeravaraprug, Kitiwanwong & SaeTong

2011). It is a stratagem for improving productivity and achieving safety requirements with the end result of producing high quality goods by minimising wastages and thereby reducing costs through three zeroes: zero breakdowns, defects and accidents at work (Chong, Chin & Hamzah 2012; Gajdzik 2009; Poduval, Pramod & Jagathy 2013). By motivating participating employees within organisations, TPM looks at increasing the effectiveness of the equipment during its lifetime by maintaining it in optimal working-condition so as to avoid any unexpected breakdowns and quality defects in products (Ahuja & Khamba 2008b; Teeravaraprug, Kitiwanwong & SaeTong 2011). In addition, it tends to increase employees' efficiency by improving their skills and knowledge and distributing responsibility (Chong, Chin & Hamzah 2012).

Poduval et al. (2013) mention that there are many barriers which may face organisations in the case of implementing TPM such as lack of top management commitment, manpower costs, lack of TPM knowledge, maintenance management process, need for training, attitude towards manufacturing process and keeping large inventories. The impacts of TPM as a lean manufacturing tool on an organisation's effectiveness is defined by working out the correlation between its pillars, in order to analyse the significant structures, and to identify the most proper policy arising from implementing this technique (Thun, Jörn - Henrik 2006). The use of different initiatives of TPM implementation in Indian manufacturing industries by Ahuja and Khamba (2008c) resulted in strategic benefits which helped these firms to cope with the challenges posed by global competition. The role of TPM success factors are also investigated to improve the performance within manufacturing industries. This study focuses on some success factors such as top management leadership and involvement for achieving its objectives. It discloses that these initiatives have a significant impact on manufacturing performance improvement when compared with traditional maintenance practices. TPM efficiency can be measured by a self-directed work team (SDWT) using data envelopment analysis (DEA) considering the overall process of TPM implementation. This process has been done in a three-stage model. The results can offer productive implications for managing and implementing TPM more efficiently (Jeon, Kim & Lee 2011).

Although total productive maintenance is crucial, high quality productivity would ensure the delivery of quality products to customers which in turn increases the overall productivity and profitability of the organisation. No research, however, has implemented this tool in the manufacturing industries for the purpose of the simultaneous cost-risk reduction.

2.3.3. *5S*

5S is a systematic Lean tool, which is generally considered as one of the most appropriate tools for implementing lean manufacturing, contributing towards waste reduction and improving quality and safety (Ablanedo-rosas et al. 2010; Kilpatrick 2003). 5S is a tool used for creating a self-sustaining culture that preserves a neat, clean and efficient workplace (Protzman, Mayzell & Kerpchar 2011). It is considered as one of the Toyota Production System (TPS) components and TPS is an essential part of Japanese production management (JPM) (Schonberger 2007). It is also considered as one of the lean manufacturing tools used to analyse and solve the equipment and process issues that arise in the total productive maintenance (TPM) in the supply chain (Ahuja & Khamba 2008a; Scherrer-Rathje, Boyle & Deflorin 2009). It is in addition, an effective technique for worksite management originating from Japan, with five Japanese words starting with 'S': Seiri (Sort) refers to sorting through the worksite contents and eliminating unnecessary things. It is useful in reducing the workload of employees and human errors by simplifying the existing processes which ultimately helps in maximising efficiency; Seiton (Straighten) means setting the essential things in their place and providing easy access; Seiso (Sweep and Clean) ensures workplaces are kept clean and the worksite and equipment are checked from any defects; Seiketsu (Systemise) refers to creating visual controls and procedures for maintaining an organised and clean workplace enhancing transparency; and Shitsuke (Standardise) involves training and discipline to improve the level of worker confidence and to ensure that everyone follows the 5S standards, which are considered as the basis for lean production (Ablanedo-rosas et al. 2010; Gapp, Fisher & Kobayashi 2008; Hoseus & Liker 2008).

In the last two decades, numerous Mainland Chinese organisations have carried out 5S. many of them however failed to achieve their original targets, because they use a 5S only to increase profits over a limited time and ignored the other essential components of 5S which referred to the local culture (Lixia & Bo 2008). In their article, Lixia & Bo (2008) report that the key reasons for Chinese organisations failing to effectively use the 5S technique are misunderstandings and errors when implementing this tool. They therefore, suggest successfully deploying the 5S program in stages and focusing on how to establish 5S as a culture. According to Gapp (2008), 5S, when applied appropriately within production corporations, provides a strategy which allows the organisation to satisfy several international standards with minimal costs.

Gapp (2008) further states that 5S, applied appropriately within production corporations, provides a strategy which allows the organisation to satisfy several international standards with minimal costs. It is clear, nevertheless, that this technique has not been used for the simultaneous reduction of costs and their risks within production systems.

2.3.4. *Theory of Constraints (TOC)*

In 1984, Goldratt developed the theory of constraints (TOC) as a scientific process to assist management in achieving a high performance within their organisations (Ye & Han 2008). It is a highly advantageous technique for implementing the continuous improvement of management attitudes within organisations. It is an approach able to identify and solve bottlenecks in production systems. This can be achieved by focusing attention on the system's constraints (Cai et al. 2009). It is also a global managerial procedure which helps managers to focus on the most critical issues in their organisations. The theory of constraints supply chain replenishment system (TOC-SCRS) is considered as one of the most effective inventory replenishment methods useful for dealing with conflicts in the management of the supply chain (Wu, H-H, Huang & Jen 2012; Wu, M et al. 2013).

Tourki (2010) has stated that every kind of system suffers from certain constraints and those constraints act as a major barrier to achieving an improvement in the overall system performance. One of the major TOC applications in production systems is to identify and exploit the constraint resources Drum-Buffer Rope (DBR). Tourki (2010) states that DBR is highly beneficial in ensuring improvement in production lines by improving the performance of the weakest link which is also referred to as the constraint or the drum. It is an appropriate application highly useful in cases where production system performance is constrained by a lack of supply at a capacity constrained resource (CCR) or bottleneck (Wu, H-h & Liu 2008). According to DBR, the production line is comprised of more than one limited resources and these have the potential to control the overall throughput. The schedule of the entire system operates in relation to this constraint of one or more limited resources. There are three main fundamental principles that are included in a case of DBR. A 'drum' is the rate of production (bottleneck) of the heavily loaded workstation. Bottleneck, as the name indicates, is a type of constraint that restricts the smooth flow of material within the entire system. A 'buffer' is used to protect the production system from any issues that might be caused by internal disruptions that may occur in the production processing over time. It is generally explained as the duration of the material flow rate. The third term 'rope' is a signal used by the constraint

resource for the purpose of changing the system process. By the application of rope, it can be possible to regulate the upstream processes at a faster or slower rate. The process can also be stopped (Tourki 2010).

There is no doubt that TOC has been used for improving profit through organisational changes. It has not been, however, applied for reducing the total cost and risk at the same time within manufacturing systems.

2.3.5. *Six Sigma*

In the mid-1980s, Six Sigma developed by the Motorola Company as a business management strategy, was implemented by General Electric (GE) on a full scale. It is a statistical unit used to measure the standard deviation of a population (Barac, Milovanović & Anđelković 2010; Taylor & Russell 2009). The main objective of Six Sigma is to reduce defects in order to improve the quality of process output by minimising any variability in manufacturing processes. This in turn leads to improved customer satisfaction and to an increase in net income (Barac, Milovanović & Anđelković 2010). Six Sigma is also used to identify the organisation's most beneficial business due to any improvement (Chalamcharla & Kunte 2012). It is defined as a significant process that is beneficial to companies in achieving improvement with respect to their bottom line (Andersson, Eriksson & Torstensson 2006). It is also defined as an operational management strategy that can be shared usefully through customers, stockholders, workers and suppliers (Tjahjono et al. 2010). This can be achieved by continuously monitoring the business activities on a regular basis to ensure waste minimisation and to effectively produce a high degree of customer satisfaction (Chary 2009). Based on the success achieved by major companies such as Motorola, GE, Sony, Nokia, and IBM, many other companies have implemented Six Sigma to achieve similar objectives (Liu, Y & Li 2011).

Lean thinking and Six Sigma working together in parallel, have been widely used in management and service sections of industry, but their application has been limited in the manufacturing industries (de Koning & Does 2008). They are considered as the two most effective improvement process techniques available at present. However, many companies still struggle to harness one or both disciplines to achieve the desired results (Alsmadi & Khan 2010). Both approaches support the larger goal of achieving product, process and operational excellence to better serve the customer (Näslund 2008). DMAIC refers to a data-driven life-cycle approach to Six Sigma projects for improving processes. It is an integral and

essential part of an organisations' Six Sigma programme (Sokovic, Pavletic & Pipan 2010). It is an acronym for five stages: Define, Measure, Analyse, Improve and Control. These are listed as follow (Alsmadi & Khan 2010; Sokovic, Pavletic & Pipan 2010):

- Define the process that needs to be improved. Define also which team is suitable to work with this improvement. In addition, define the client for the process, its requirements and create a map of this process, which should then be developed.
- Measure the key characteristics for the process involved and collect relevant data throughout a data collection plan; and identify features which are affecting customer rate.
- Analyse the factors and data collected to determine the root causes of variations and identify gaps for improvement.
- Improve the target process which needs improvement and implement the best solution by using Cost-benefit analysis.
- Control and monitor the new improvements to preserve the processes on a new track by following given approaches such as staffing and training.

Six Sigma is a powerful technique which enables the organisation to reduce manufacturing defects in the production process. However, it has not been implemented to reduce both the overall costs and risks in production systems.

2.3.6. *Just-in-Time (JIT)*

Due to the recent increase of competition in the global marketplace, organisations need to develop a supply chains capable of meeting customer needs (Uthayakumar, R. & Rameswari 2013). JIT is one of the lean manufacturing tools, which evokes ideas of efficiency and the reduction of unnecessary cost and as such is a valuable tool for many corporations. It can also be considered as one of the lean manufacturing tools used within organisations to improve their efficiency, speedup their production process and increase their delivery performance (Danese, Romano & Bortolotti 2012; White, Ojha & Kuo 2010). There are three elements that are included in a situation where JIT is used as a lean manufacturing tool: JIT production, JIT distribution and JIT purchasing. Moreover, JIT is a critical tool that can also be used for managing organisations' external activities including purchasing and distribution (Eldenburg & Wolcott 2011). It can be defined as a comprehensive policy that integrates the main strategic basics of JIT production and JIT purchasing, namely the elimination of waste

and optimal use of resources in the supply chain. It is also defined as a comprehensive strategy supporting organisations towards effective waste elimination, continuous improvement of productivity, customer satisfaction and the involvement of employees in decision making (Thapa, Dhamala & Pant 2011). Generally, the JIT philosophy focuses more on manufacturing efficiency improvement through eliminating non-value added activities, minimising inventory and solving issues of limited space and capacity (Roy, Sana & Chaudhuri 2012). Some critical principles are used for successfully implementing JIT systems such as people involvement, training and education, supplier relations, waste elimination, Kanban or pull system, uninterrupted work flow and total quality control (Tourki 2010). JIT is highly beneficial for a large number of companies, as the literature indicates that the efficiencies gained from the consideration of JIT principles in the production processes are in terms of accelerated productivity. In the US, the inventory levels of manufacture dropped from 50 days to 40 days during 1999 and 2000. This demonstrates the importance of JIT implementation in the production processes of companies in achieving operational efficiency (Eldenburg & Wolcott 2011). In their article, White et al. (2010) investigated the holistic implementation of JIT manufacturing using the theory of competitive progression based on four JIT practice packages: conformance quality, distribution consistency, capacity flexibility and low cost related practices. Data was collected from US manufacturers to define the effects of JIT practices on their production improvement. The findings illustrated that by improving the non-added value performance, operational performance can be improved. In the words of Biswas (2007), JIT can be implemented successfully by frequently shipping high quality parts to customers and ordering raw materials in small batches whenever required to process finished products. To visualise the JIT approach, a simple diagram of a multistage production process is depicted in Figure 2.1.

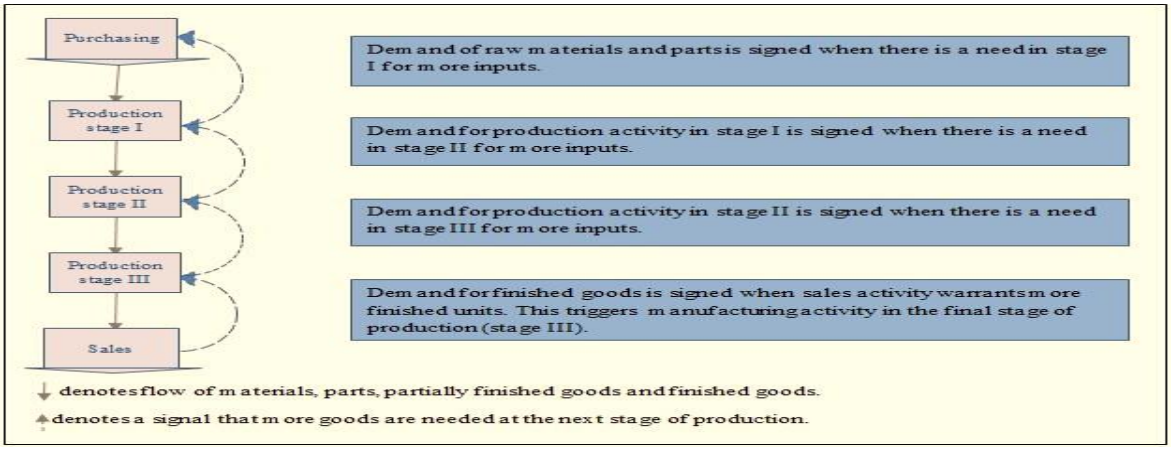


Figure 2.1 JIT production and inventory management system (Hilton 1994)

The flow of the manufacturing process is shown by the solid arrows running down from one stage to the next stage. The process starts with the purchasing stage, which is transferred to the production stages and finally to the sales stage. However, the signal that activates more production activity in each stage arises from the next stage of production, which is illustrated by the broken arrows. In case the organisation is able to produce more final products, this process starts with the sales stage, which sends a signal to production stage III that more goods are required and the same for the other previous stages. Based on this process, more raw materials are required to be purchased in the first stage to meet customer demand (Hilton 1994).

As per Sodhi and Lee (2007), Konecka (2010), Eldenburg and Wolcott (2011), Revilla (2013) and El Dabee et al. (2013a), implementing a JIT technique in production systems has a significant impact on the final product cost where any disruption has occurred in the supply chain. This technique therefore will require more attention than the others to simultaneously reduce the cost and risk in supply chain systems. The three JIT elements mentioned previously will be described in some detail below.

2.3.6.1. Just-in-Time Production

JIT production is concerned with improving the efficiency of the production process by ensuring there is no excess capability of raw materials or labour in the entire production process (Inman et al. 2011). The primary concept of a JIT production system can be defined as 'producing and/or supplying only the right items in the right quantities at the right time' (Biswas 2007). It is also a "demand pull" manufacturing system that produces each component in a production line when they are needed by the next process, in the line (Horngren, Datar & Rajan 2012). It focuses on identifying and eliminating all waste forms in the production system, including excess inventories, material movements, production steps and scrap losses (Inman et al. 2011). For effective JIT production, certain modifications to provider relations, distribution, product design, product processing and plant layout are necessary (Kinney & Raiborn 2011).

A JIT production system (JITPS) is a manufacturing pull production system used by manufacturing industries for planning and scheduling their production with other supply chain parties before the end products are sold. It may be defined as a strategy used in production systems to continuously improve products. The process includes three sequential

components: people involvement, total quality control and JIT flow (Thapa, Dhamala & Pant 2011). The implementation does not require any buffer inventories because JITPS starts when the company initially receives its order (Roy, Sana & Chaudhuri 2012). In JITPS, each process produces its parts when they are needed, and then moves them to the next process to produce the final product (Iwase & Ohno 2011). In their article, Danese et al. (2012) focus on JIT production and JIT supply mitigation and their impact on efficiency and delivery performance. They concluded that the JIT production practice had a positive impact on both of the above. The JIT supply practice also moderates the relationship between JIT production and delivery. It needs to be noted that it has no significant impact on efficiency.

In the words of Chary (2009), JIT production is a material planning system where the production as well as the procurement closely follows the actual demand. Therefore, on the basis of demand, the production function is performed so that customer requirements can be met on a timely basis.

2.3.6.2. Just-in-Time Distribution

In supply chain management, JIT delivery plays a significant role in the effective distribution of goods. Cost and delivery are considered as the main key factors in the supply and procurement of orders between supply chain parties (Farahani & Elahipanah 2008). JIT distribution (JITD) is an approach, which can be used to renew demand pull, in order to improve customer satisfaction and to control inventory risk within the supply chain (Atrill & McLaney 2007). It is one type of distribution mode capable of enabling distribution to keep up with the final product output in manufacturing systems (Zhongfu & Jianshuang 2008). The concept of JITD is included in models because earliness and tardiness costs are inconsistent with the minimisation of the final product cost (Farahani & Elahipanah 2008).

The relationship between JIT distribution with customers and each of the organisational structures both internally and externally plays a significant role for the successful development and integration of JIT with customers (Kazak & Wing 2009). To attain full JIT delivery, both the integral quality of entire internal operations, along with that of external partners, requires necessary assurances (Vanichchinchai & Igel 2011). Biswas (2007) considers that in order to reduce the organisation idle time, the production of finished goods in one cycle starts directly after the end of the production in its preceding cycle.

JIT distribution has a significant role to play as JIT itself is concerned with the immediate availability of raw materials made possible through an effective distribution system.

2.3.6.3. Just-in-Time Purchasing

JIT purchasing (JITP) is yet another key player in the supply chain system. It can reduce lead time, inventory and material costs by using small lot sizes and frequent deliveries (Yang, J-s, Chen & Pan 2010). It can also improve organisational quality and lead time reliability (Mackelprang & Nair 2010). It is a stratagem used for integrating procurement- production cooperation between suppliers and manufacturers, in order to mutually share both obtained benefits and predicted risks in the supply chain (Chen, ZX & Sarker 2010). The long-term purchase agreements with the suppliers will diminish the customers holding cost of inventory under JIT manufacturing environment (Biswas 2007). The main objective of JITP is to ensure that production is considered as a continuous process from the receiving of the raw materials by reliable suppliers on time until the shipping of the finished goods to the end customer. This is done in order to minimise order costs and to reduce or eliminate inventory, which results in the payment of holding costs (Isa & Keong 2008; Sultan Singh & Garg 2011). JITP techniques incorporate regular small lot size delivery from closed suppliers, shared information, supplier education, reduced assessment, and early participation in process design (Inman et al. 2011).

JITP is defined as a set of tools and concepts that can be used in organisations to eliminate wastes in their purchasing processes. These techniques and concepts include the daily delivery of supplies, shared information, supplier education, reduced inspection and early supplier involvement in product/process design (Inman et al. 2011). JITP requires accurate schedules and depends on the frequent transportation of procured raw materials from their suppliers in smaller lots from the best local suppliers to the point of their consumption at the required time in the correct quantity and quality (Wu, M et al. 2013). Most companies in the automotive industry have implemented JITP for procuring their raw materials from suppliers within the supply chain (Narasimhan, Kim & Tan 2008). Numerous Chinese organisations are currently recognising the significant role of JIT purchasing implementation in improving efficiency in their JIT production systems (Chen, Z & Tan 2013). There are four basic principles of JITP: waste elimination, employee's involvement in decision making, supplier participation and total quality control (Sultan Singh & Garg 2011).

The role of purchasing in JIT is also crucial, as all the material required for the production process should be readily available ensuring efficiencies in the purchasing process. This can be achieved by carefully choosing suppliers and developing long-term supplier relationships (Horngren, Datar & Rajan 2012). Delay in purchasing would adversely affect the JIT philosophy of business.

In conclusion, there is no doubt the above lean manufacturing techniques have an influential role to play in improving the performance of manufacturing systems. These result in reducing the cost of products as well as increasing their efficiency. They have not, however, been simultaneously applied for reducing the total cost and risks involved within these manufacturing systems. Owing to the reasons previously mentioned, this research will focus on a JIT technique and its impact on the supply chain network by simultaneously reducing the cost of the final product in the production system and the risks arising from these benefits.

2.4. Cost Management

In a globally competitive environment, cost plays a significant role in satisfying customer requirements in the marketplace. It can also be considered as an issue in engineering management fields. Cost management is an approach for improving the organisation's cost effectiveness by understanding and managing the reasons for real cost reasons (Langfield-Smith, Thorne & Hilton 2012). It is used to define the methods and activities of managers for managing resources, in order to increase value to customers and to achieve organisational objectives (Horngren, Datar & Rajan 2012). It consists of a set of approaches used for planning and controlling an organisation's costs associated with short-term objectives and long-term strategies (Kinney & Raiborn 2011). Cost management programs can lead to cost reduction by either eliminating the spare production capacity created, in order to decrease its causes, or by using it to take on other value-adding activities (Langfield-Smith, Thorne & Hilton 2012). Kinney and Raiborn (2011) state that the roles of cost management systems consist in evaluating product performance and the service life cycle, improving process understanding, controlling costs, measuring performance and facilitating the pursuit of organisational policies.

Engineering management is fundamentally concerned with the application of engineering tools and techniques so that cost efficiency in production processes may be achieved. By applying engineering tools, engineers should be capable of ensuring a reduction in the cost

encountered in performing the manufacturing function (Eisner 2011). The resources that are measured in financial terms are considered as costs and they are being utilised to achieve specific objectives such as producing a particular product or providing a specific service (Atrill & McLaney 2007). Costs are generally incurred to achieve longer term benefits. If these benefits exceed the current accounting period they are documented as assets. As the benefits from a cost are limited during the current period, the cost is recorded as an expense rather than a benefit. An expense is the cost which is used to generate returns (Langfield-Smith, Thorne & Hilton 2009). Using a JIT technique in production systems, operations managers and financial accountants use cost information to understand and define the cost of the various products produced. The economic justification of JIT arises from the trade-off between the setup cost of orders and the inventory holding cost (Lanen, Anderson & - 2011). In manufacturing systems, models are used for improving upper management's understanding of costs and profits, in order to face two key challenges: achieving short-term profitability and maintaining long-term competitiveness in the marketplace (Kinney & Raiborn 2011).

Pettersson and Segerstedt (2013) presented a model for measuring the total supply chain costs (SCC). They considered that the total costs are: the manufacturing cost, warehouse cost, distribution cost, capital cost, administration cost and installation cost. An empirical study comprising 30 organisations was done to validate the developed model. The achieved results illustrated the difference between the measurement of SCC based on the calculated standard cost and the actual cost. Wang, I-C (2012) developed a cost model to analyse the impacts of a purchasing lead-time reduction on the overall costs of the supply chain. These costs are direct labour cost, material cost, ordering cost, holding cost, transportation cost, capacity cost and stock out cost. The proposed model was validated in an illustrative case study of a flexible printed circuit boards. The findings show the effectiveness of the lead-time reduction on the overall supply chain costs. Kocsoy, Gurdal and Karabayir (2008) also investigated whether the target costing used in many Turkish manufacturing systems is based on its principles. This was done by applying this technique to the top 500 manufacturing systems in Turkey to determine the basic difference between these businesses. The results illustrated that this technique has a significant effect on increasing the efficiency of these manufacturing systems.

Huang, C-K (2010) reduced the ordering processing cost and incorporated a permissible delay in payments in developing an integrated inventory model. By using a numerical example, it was observed that the proposed model is efficient for minimising the overall cost. Uthayakumar, Ramasamy and Parvathi (2011) also developed a two-stage supply chain model with a single vendor and a single buyer. This model was used to minimise the ordering cost in the supply chain. Numerical examples with an exponential ordering cost function were used to determine the performance of the proposed model. The findings illustrated the effectiveness of this model on minimising the joint overall cost. Rad et al. (2014) constructed a two-echelon supply chain model with a single vendor and two buyers. This model developed an integrated vendor-managed inventory (VMI) and traditional retailer-managed inventory (RMI) strategies to ascertain the optimal order quantity and the total inventory cost of the supply chain. Numerical experiments were carried out in detail to illustrate the efficiency of the developed model. The findings showed that applying a VMI strategy is more beneficial than the traditional RMI strategy for minimising the total supply chain costs.

In their article, Sarkar and Majumder (2013) designed an integrated vendor-buyer supply chain model to minimise the overall cost of the system. This was achieved by considering the setup cost reduction of the vendor. Some numerical examples were used to define the efficacy of the proposed model. The results illustrated that the developed model had a direct impact on the total cost reduction. Kim, S-H and Netessine (2013) developed a game-theoretic model to reduce the unit cost of the final product. This is based on the influence of the manufacturer and supplier and their collaborative efforts in the supply chain. They concluded that the manufacturer's selection of a procurement contracting strategy has a significant impact on the incentives of the supplier and manufacturer which lead to the minimisation of the total cost of the products. Hoque (2011) also proposed two generalised single-vendor multi-buyer integrated inventory models synchronising the production flow in the supply chain. The objective function of this model is to obtain minimal cost solutions of the problem to be solved. As a result of implementing the developed model, it was observed that this model is more efficient in minimising the overall costs.

2.4.1. *Types of Costs in Supply Chain Network*

Costing systems record the cost of resources obtained such as materials, labour and equipment and track how these resources are used to produce and sell products or services

(Horngren, Datar & Rajan 2012). Costs are categorised in different ways based on their behaviour. One of these techniques is related to how they behave to changes in the volume of economic activity. These changes are listed below.

2.4.1.1. Fixed Costs

Fixed costs are independent costs in the current activity level and cannot be expected to change with short-term fluctuation in business such as production, sales and service (Eldenburg & Wolcott 2011). Langfield-Smith et al (2012) report that fixed costs can also be reset when the volume of activity is changed. This means that if an activity increases or decreases by 20 per cent, total fixed cost remains the same. Fixed costs can be classified into three main types: firstly, committed costs resulting from continuing legal or contractual obligations that typically cannot be terminated in a short period; secondly, managed costs including employee wages, which are essential to ensure the continuance of current activity together with other support costs incurred by the organisation; and finally, programmed fixed costs including the cost of services not directly related to current production operations or activity, but are nevertheless supportive of the organisation's development policy (Abraham et al. 2008).

2.4.1.2. Variable Costs

Variable costs are the organisation's expenses which vary depending on the volume of activity. They comprise those costs which vary directly in proportion to the level of economic activity (Abraham et al. 2008; Atrill & McLaney 2007). Overall, they change in direct proportion to changes in the level of activity or to increasing cost (Eldenburg & Wolcott 2011; Langfield-Smith, Thorne & Hilton 2012). The key variable costs are the costs of labour and the costs of bought-in stocks consumed in production. These are the 'prime costs' of the organisation's operations. Some overhead or indirect cost, however, can be measured and controlled as variable costs because they are directly associated with operational activity (Abraham et al. 2008).

2.4.1.3. Mixed Costs

There are certain costs that cannot be easily classified into either fixed costs or variable costs. They are defined as semi-fixed and semi-variable costs and they are identified as 'mixed costs' (Eldenburg & Wolcott 2011). Semi-fixed costs, also called 'step costs', are the costs of a fixed or constant character that are increased at intervals as economic activity rises and they can be more accurately measured than other costs. At low outputs, labour efficiency

might be decreased, particularly on new product runs where a 'learning curve' can be expected before full efficiency is reached. In addition, labour and machinery productivity can be decreased, and waste can be increased by high outputs (Abraham et al. 2008).

Costs can also be classified as direct or indirect costs, depending on whether they can be traced to cost objects. A direct specification is possible for a direct cost or it can easily be identified in specific cost units. The main examples of direct costs are direct material and direct labour costs (Atrill & McLaney 2007; Eldenburg & Wolcott 2011).

2.4.2. *Risks in Supply Chain systems*

As systems become increasingly integrated, disruptions cannot be arrested in the functional area of origin and are consequently propagated throughout the production and distribution system. The reduction of waste (muda), as inventory or extra production capacity, exposes adjacent activities and may affect the whole supply chain. Costs are associated with all risk factors that may potentially disrupt the supply of goods when they are required from their origin in the supply chain (Kumar, S, Tiwari & Babiceanu 2010). Generally, risk is defined as the probability that an action may negatively influence the organisation (Huang, X 2008).

In supply chain systems, risk is defined as a potential deviation from the initial overall objective, which leads to a lack of value-added activities at different stages (Kumar, S, Tiwari & Babiceanu 2010). In supply chain operations, it is not easy to discriminate risk and uncertainty. That is because risk is interpreted as an unreliable resource that might causes some disruptions in the supply chain. Uncertainty in the supply chain, however, can match risk between supply and demand processes (Tang, O & Nurmaya Musa 2011). Supply chain risk management (SCRM) is an approach which seeks to identify, evaluate, analyse and treat the disrupted areas arising from risks in a supply chain (Neiger, Rotaru & Churilov 2009). It is defined as "the management of supply chain risk through coordination or collaboration among the supply chain partners so as to ensure profitability and continuity" (Tang, O & Nurmaya Musa 2011). It is a formal process which integrates identifying predicted damages, understands the potential occurrence for these damages and allocates priority to them (Trkman & McCormack 2009).

Top management is responsible for managing and mitigating the impact of expected risks in an organisation. Even though good risk management practices can reduce the possibility of negative consequences, it is impossible to ensure that all risks have been recognised and

mitigated (Eldenburg & Wolcott 2011). Risks can be categorised into four groups, depending on the reasons that lead to their occurrence in the supply chain. They comprise operational risks, arising as direct and indirect adverse consequences of shortfalls originating from operations and services not performing to set expectations; external risks that result from external events over which the organisations within the supply chain have little control such as weather hazards, earthquakes and financial markets risks; strategic risks, which arise significantly as a result of poor or infrequent communication among supply chain members; and risks externalities, which result from an uncertainty or negative effect (Kogan & Tapiero 2007; Tapiero & Grando 2008).

According to Kumar et al. (2010), risk factors in supply chains are classified as internal and external risks. The internal operational risk factors arise within the supply chain from inappropriate coordination among different levels such as demand risk, production risk and supply risk. An external operational risk arises due to the interaction between the supply chain and its environment such as a terrorist attack, natural disasters or exchange rate fluctuations. Consequently, both internal and external risk factors are categorised as demand, production and distribution, supply and interaction risks. Based on the classification of sources, risks are also classified under six main headings: supply, demand, manufacturing, logistic, information and environmental risks (Punniyamoorthy, Thamaraiselvan & Manikandan 2013).

Recently, the amount of literature on supply chain disruptions has increased as a result of a number of disasters in different regions in the world. However, the applications in multi-echelon supply chains are limited because of the complexity of those systems (Schmitt & Singh 2009). Risks, according to the classification of Kumar et al. (2010), have an adverse impact on organisations' performance, leading to an increase in their total costs whilst simultaneously reducing their efficiency. Risks therefore, should be assessed by identifying, evaluating and measuring them, in order to reduce their undesired effects within these organisations.

2.5. Modelling of Supply Chain Cost-Risk Reduction

Model development is considered as an effective methodology used for assisting researchers to define, predict and test complex systems. Models provide a framework for research, which may contain different forms such as drawings, mathematical equations and charts (Shafique

& Mahmood 2010). Cost optimisation and risk management models can assist supply chain networks to manage their processes in all stages such as supply, transportation, manufacturing and distribution (Gaivoronski, Alexei, Sechi, Giovanni & Zuddas, Paola 2012; Punniyamoorthy, Thamaraiselvan & Manikandan 2013). To this end, a quantitative model was developed in order to assist a resource management authority (RMA) working under conditions of uncertainty and inconsistent demand. It took into account the general approach of stochastic programming optimisation and utilised risk management techniques to achieve its objective functions. Numerical tests were implemented in the developed models and they proved that this approach is more effective than a deterministic scenario optimisation approach (Gaivoronski, Alexei, Sechi, Giovanni & Zuddas, Paola 2012).

An economic order quantity (EOQ)/economic manufacturing quantity (EMQ) model was proposed to find the optimal solution for an integrated one-seller, one-purchaser shipment system under a controlling lead time. Two numerical examples were implemented and the findings showed that combining a shipment stock strategy with a lead time failure could provide results more effectively than when using any of these individual strategies (Yi & Sarker 2013). A robust optimisation model for handling uncertain data in a closed-loop supply chain network design problem was used to find robust solutions. Firstly, it was developed as a mixed-integer programming model. It was extended to cope with uncertain data by considering the returned goods from the first customer, the second customer request and uncertain transportation costs. The obtained solutions from the model were compared with the solutions found by the deterministic mixed-integer linear programming model under different test situations (Pishvaee, Rabbani & Torabi 2011).

Liao, Hsieh and Lai (2011) developed a multi-objective location-inventory problem (MOLIP) model to determine the impact of the location, distribution and inventory issues in organisations using a vendor managed inventory (VMI) management system. It was used to improve the supply chain efficiency and to authorise suppliers to inspect their inventory levels and to determine their customers' inventory replenishment. An economic order quantity (EOQ)/ economic manufacturing quantity (EMQ) model with four decision variables was proposed. It was used to find the optimal solution for an integrated one-seller, one-purchaser shipment system under a controlled lead time. The results obtained from applying the model on a numerical example illustrate that combining shipment stock strategy with lead time failure chances can provide results more effectively than when using any of them

separately (Liu, X & Çetinkaya 2011). An optimal integrated vendor-buyer inventory model was built to minimise the order processing time and the allowable postponement in payment. By implementing the proposed model in a numerical example, the results show that the model can determine an optimal investment cost for order processing time, order quantity and delivery interval (Huang, C et al. 2010).

A continuous review inventory model with respect to the variety of lead time, order quantity, backorder discount and safety factor was constructed. The key reason for using this model is to reduce the total cost per annum based on the above mentioned decision variables. By implementing the developed model in a numerical example, the optimal solution can be found using a minimax distribution free procedure (Lo 2009). An inventory model was formulated to reduce inventory levels and to maximise the profit in supply chain systems. It was a centralised decision-making process that included a three-level (players) supply chain: multi suppliers, multi manufacturers and multi end-customers. Owing to the coordination between supply chain parties, the cost of players might be minimised (Jaber & Goyal 2008). Inventory models are developed for two different distribution situations: perfectly matching conditions where no finished goods remain after an order is shipped; and imperfect matching conditions where some produced finished goods remain after shipment. The optimum number of orders and deliveries and optimum lot sizes are evaluated to minimise the entire costs. A sensitivity analysis was implemented to show the effects of cost factors such as delivery sizes, raw material conversion for both perfect and imperfect matching cases (Biswas 2007).

Table 2.1 summarises the characteristics of the proposed cost reduction models in the supply chain. The tick (√) in front of a model indicates that the characteristic is accommodated in the concerned model. However, a cross sign (×) demonstrates that the characteristic is disregarded in the proposed model. These definitions will remain the same for all the other tables in Sections 2.5, 2.6 and 2.7.

Risk management is an activity process for identifying sources of uncertainty, estimating the risks effects, analysing them and treating the interrupted phases to ensure that the organisation goals are met (Zavadskas, Turskis & Tamošaitiene 2010). In adopting a modelling approach in supply chain networks, the disruption vulnerability can be reduced by identifying and improving operational processes (Neiger, Rotaru & Churilov 2009). A multi-objective model for a forward/reverse logistic network design under an undefined environment was developed. It included three forward echelons (suppliers, manufacturers and

distribution centres) and two backward echelons (collection centres and disposal centres). It was modelled to increase the profit and quality, and to meet customer satisfaction within the supply chain network. This set of Pareto optimal solutions was generated and the financial risk associated with these solutions was calculated (Ramezani, Bashiri & Tavakkoli-Moghaddam 2013). A conceptual model was proposed for upstream supply chain risk management linking risk identification, risk assessment and risk mitigation to enhance performance. It was tested using data collected from 162 organisations in Germany. The findings support the sequence of risk identification, assessment and mitigation processes and focused the attention of scientists on risks such as these (Kern et al. 2012).

Table 2.1 Classification of the literature on cost reduction models in the supply chain

Author(s), Year	Dimensions of the proposed model				Methods Applied
	Total Cost Minimisation	Modelling	Multi-suppliers/ Multi-manufacturers / Multi end customers	Lead-time minimisation	
Yi and Sarker (2013)	√	√	×	√	An economic order quantity (EOQ) / economic manufacturing quantity (EMQ) model.
Pishvaee, Rabbani and Torabi (2011)	√	√	×	√	A mixed-integer programming model for handling uncertain data in a closed-loop supply chain network design.
Liao, Hsieh & Lai (2011)	√	√	√	√	A Multi-objective location-inventory problem (MOLIP) model was proposed to determine the impact of the location, distribution and inventory issues in organisations using a vendor managed inventory (VMI) management system.
Liu, X and Çetinkaya (2011)	√	√	×	√	An integrated production-inventory model for both single manufacturer and retailer considering the non-defective percentage items for shipment as a random percent.
Huang, C et al. (2010)	√	√	×	√	An optimal integrated vendor-buyer inventory model.
Lo (2009)	√	√	√	√	A continuous review inventory model with respect to the variety of lead time, order quantity, backorder discount and safety factor was constructed.
Jaber and Goyal (2008)	√	√	√	√	An inventory model includes three-level (players) supply chain with a centralised decision process: multi suppliers, multi manufacturers and multi end customers.
Yu, Chen and Chu (2008)	√	√	√	√	An approximate approach includes split distribution using a Lagrangian relaxation method coping with many vehicles.
Biswas (2007)	√	√	√	√	Inventory models are developed for two different distribution situations: that of perfectly matching conditions where no finished goods remain after an order is shipped and imperfect matching conditions where some produced finished goods remain after the shipment.

A developed model was constructed for controlling the pricing and production decision in a two-period dual channel supply chain which includes one manufacturer and one vendor with a disruption in demand. The problem was considered in a centralised and decentralised dual-channel supply chain setting. In both cases, no demand disruption scenario was used as a base line (Huang, S, Yang & Zhang 2012). A holistic framework of value-based performance and risk management in supply chains was proposed for coping with the potential operational risks in the physical and the economic supply chain management. This was possible by applying robust optimisation approaches such as economic value added (EVA) in terms of value creation (Hahn & Kuhn 2012). An approach for considering a cost–risk balanced process to manage the scarcity of water resources under uncertain conditions was formulated. A new technique was modelled regarding a re-optimisation phase that permits users to organise emergency strategies by adopting the barycentric value as a new target, resulting in a drastic risk reduction for resource delivery (Gaivoronski, A., Sechi, G. & Zuddas, P. 2012).

An existing article in addition, clarifies how risk management sources in a project's innovation can be better managed through a modelling process. Although the innovation management relevance is uncertain, several methods of risk management have been proposed. This article focuses on the formulation and management of uncertainties in context and the deployment of risk management techniques. By using a general model of innovation to manage the parameters of risk creation, the risk management process is applied in a specific case (Vargas-Hernández 2011). Kumar, S, Tiwari and Babiceanu (2010) debate the optimal operating strategies for an international corporation conducting business in various countries. Many risk factors such as late deliveries, exchange rates, customs delays, quality control issues, logistics and transport breakdowns and production risks have a significant impact on the corporation strategies, which increase the total cost of operating within the supply chain. For this reason, a model was developed to offer optimising operational strategies for the supply chain based on the expected given risks factor. This was done in order to allocate order quantities across the supply chain parties so as to minimise the risk as well as the total costs of the supply chain operation. A stochastic model which included two stages was developed to optimise investment portfolios within an oil supply chain in Brazil. In order to minimise the expected net present value (ENPV) in the supply chain, three sources of uncertainty were considered by adopting the conditional value-at-risk (CVaR) as a risk measure within six oil refineries, (Carneiro, Ribas & Hamacher 2010).

Furthermore, twelve possible approaches to disruption management in the context of a two-product newsvendor were also assessed. Some features of the organisation, its supplier(s) and its products, such as supplier reliability and supplier failure correlation were investigated. Common dual sourcing can protect an organisation from any disruptive impacts when deliveries are received from different suppliers if one supplier source is disrupted (Tomlin 2009). A single manufacturer and a one dominant retailer coordination model of a supply chain was developed to investigate the coordination mechanism for the supply chain with a dominant retailer facing demand disruption. The proposed model considered a linear quantity discount schedule and Grove wholesale price schedule. It was concluded that after demand disruption, the manufacturer was required to adjust the maximum variable wholesale price. This disruption to demand also had a direct impact on the supply chain's profit (Chen, K & Xiao 2009).

A single-period, multi-stage model of a two-echelon supply chain with two competing risky suppliers and a single manufacturer was constructed. It was used to define the effects of the postponement of option values in supply chains, manufacturer procurement and production decisions, supplier pricing decisions and channel profits, arising from supplier default risks and default co-dependence. The results highlighted the role of timing in deferment decisions for the suppliers and manufacturers. The latter needed to find their optimal policies and to compute the deferment option value and other statistics (Babich, Birge & Linetsky 2006). In Table 2.2, the characteristics of the proposed models of risk reduction in the supply chain are recorded.

According to the above literature illustrated in Table 2.1 and Table 2.2, all the reviewers address either the minimisation of the separate cost or the individual risk arising from the cost reduction in the supply chain networks. Kumar, S, Tiwari and Babiceanu (2010) recommend that future research into the cost and risk reduction in the supply chain should include multi-product systems.

Table 2.2 Classification of the literature on risk models in the supply chain

Author(s), Year	Dimensions of the proposed model				Methods Applied
	Total Cost Minimisation	Modelling	Multi-suppliers/ Multi-manufacturers / Multi-end customers	Lead-time minimisation	
Ramezani, Bashiri and Tavakkoli-Moghaddam (2013)	√	√	√	×	A multi-objective model for forward/reverse logistic network design under an undefined environment.
Kern et al. (2012)	√	√	√	×	A conceptual model for upstream supply chain risk management. It was tested using data collected from 162 organisations in Germany.
Huang, S, Yang and Zhang (2012)	√	√	×	×	A one manufacturer- one retailer dual-channel supply chain model with a disruption in demand.
Hahn and Kuhn (2012)	√	√	×	×	A robust framework of value-based performance and risk management in supply chains.
Gaivoronski, Sechi, and Zuddas (2012)	√	√	√	×	A new approach regarding a re-optimisation phase that permits users to organise emergency strategies.
Vargas-Hernández (2011)	√	√	√	×	A general model of innovation to manage the parameters of risk creation.
Kumar, Tiwari and Babiceanu (2010)	√	√	√	×	A multi-echelon global supply chain model considering different locations for suppliers, manufacturers, stores and marketplaces.
Carneiro, Ribas and Hamacher (2010)	√	√	√	×	A stochastic model includes two stages to optimise investment portfolios in the presence of uncertainty in the oil supply chain.
Tomlin (2009)	√	√	×	×	An optimisation model considering the whole supply chain.
Chen, K and Xiao (2009)	√	√	×	×	A one manufacturer-one dominant retailer coordination model of supply chain.
Babich, Birge and Linetsky (2006)	√	√	√	×	A single-period, multi-stage model of two-echelon supply chain with two competing risky suppliers and a single manufacturer.

2.6. Modelling of Cost-Risk Reduction in JIT Systems

In today's highly competitive global environment, a JIT approach has received substantial attention within organisations to minimise the costs and increase the performances of their products and services supplied to the global marketplace. However, there are many potential risks that cause significant disruptions to all supply chain members. This section presents the models developed to reduce the costs and risks arising from this reduction in production systems under a JIT adoption.

Recently, researchers have searched for an economic quantity model for a production system following the JIT philosophy for ordering and shipping raw materials. Various kinds of models may be utilised for the purpose of reducing the level of cost in JIT systems (Agrawal

2010; Fateha, Nafrizuan & Razlan 2012). For instance, one such model type that can be utilised for achieving cost efficiency is the lot size reduction model. This model demonstrates that by ensuring a reduction in the lot size, it is possible to achieve a reduction in the level of the cost required to deliver the finished products to the final consumers (Eldenburg & Wolcott 2011). This approach includes five stages to determine the key parameter effects of a JIT technique in automotive industries. Different scenarios were done by using ProModel simulation and modelling software to define the influence of the variables used on the objective functions (Sandanayake, Oduoza & Proverbs 2008).

Ho and Kao (2013) designed an innovative model for integrating the reduction of inventory and wastes within a JIT supply chain with a single buyer and a single vendor. They proved that by using the developed model, the expected total annual costs were calculated easily. Using JIT logistics, a new mathematical model for a three-echelon defective good supply chain network (DGSCN) was developed. This model can ascertain the economic production quantity (EPQ) and lead time, additionally reducing all production, distribution and holding costs (Ghasimi, Ramli & Saibani 2014). A JIT model and conceptual architectural framework was developed to improve the service quality based on a JIT approach. Theoretically, implementing such a framework in service organisations can improve the service quality and it can be validated by collecting data to define the impact of a JIT attitude on service quality (Gupta, A 2011). A periodic inventory model was used to reduce the lead time and setup cost under a normal interval of demand distribution. It was concluded that although the setup cost was high, the predicted total cost of running an inventory system would be minimised (Jaggi & Arneja 2011).

Yang, J-s, Chen and Pan (2010) also constructed an integrated model under lead time control using a JIT purchasing approach between both seller and buyer. This model considered the ordering and the setup cost as a decision variable to minimise the total costs of the product. The proposed model was implemented in a simplified example to simultaneously find the optimal order quantity, lead time, order and setup cost and the number of shipments. A structural framework model and a mathematical programming model for an agile supply chain were proposed to meet the marketplace requirement using a JIT technique. For this reason, suppliers were selected by the multi-stage supply chain system based on suppliers' lead time and production, transportation and holding costs (Jianhua & Xianfeng 2010). An integrated inventory model for high-tech industries in a JIT environment considering a

continuous decrease in the price over a limited planning horizon was coded. An effective algorithm was proposed to ascertain the optimum lot sizes for procuring raw materials and producing the required products when they were needed. The developed model was implemented with numerical examples (Mungan, Yu & Sarker 2010).

An integrated supply chain management model in addition, was constructed based on market demand in order to address the issue of increasing costs in production systems. This model integrated three strategies, which were purchase, production and sale with logistic plans using a JIT approach. To analyse the planning feasibility, a comparison between the planned and the predicted cost was made. It was concluded that the developed model can effectively optimises and minimises the supply chain cost within production systems (Guo & Tang 2009). Farahani and Elahipanah (2008) developed a JIT distribution model for a three-level supply chain network. The main objective of this model was to minimise the product cost, the sum of backorders and of products surpluses during all stages. It also considered distribution lead time and capability restrictions in multiple periods, products and channel networks. Furthermore, based on the JIT purchasing model of Yang, JS and Pan (2004), two integrated inventory models were proposed in order to estimate the total profit and minimise the total cost. The first model represented the annual demand as a fuzzy number. However, the other model considered the uncertainty of the production rate. It was concluded that in some cases, the developed models could improve the supply chain performance (Pan & Yang 2008).

The supply chains vulnerability to the risks arising from disruption is increased by global growth and certain business initiatives such as JIT. However, the literature relating to such risks has increased since events such as September 11, 2001 and Hurricane Katrina have occurred which drew attention to the necessity for addressing such risks. This means that not all risks are negative, but organisations should be conscious of needing to address such risks (Schmitt & Singh 2012). As systems move towards increasing integration, disruptions that may occur cannot be arrested in the functional area of origin as these disruptions may happen anywhere throughout the entire production and distribution system. The reduction of waste (muda), as inventory or extra production capacity, exposes adjacent activities and may affect the whole supply chain. A higher lot size unnecessarily increases cost and some components of risk, while reducing others. Consequently, the lot size risk reduction model can be used to ensure an optimal lot size therefore ensuring that efficient risk management and cost efficiencies of the lot sizes are possible (Roy, Sana & Chaudhuri 2012; Simchi-Levi,

Kaminsky & Simchi-Levi 2008). Simchi-Levi et al. (2008) emphasised the risks associated with a JIT system in cases where unforeseen disasters disrupts the supply chain in a similar manner to those experienced by some auto manufacturers following Sept. 11, 2001. They highlighted that there is a significant impact for members when risk-sharing occurs throughout the supply chain.

A few research studies were presented to address the potential risks arising from minimising the total cost of the final product in production facilities which adapted a JIT approach in their management systems. A new EOQ-JIT indifference point model was constructed to generate the alternative formulas between the EOQ with a price discount purchasing system and the JITP system assessing stockout risks. By implementing the proposed model in the Chinese RMC industry, it was concluded that an EOQ purchasing system was more effective than JITP system in the case of stockout risks (Wu, M et al. 2013). A defect prediction model based on a combination of established and new standards was built to assess a JIT quality assurance approach to find its risk impacts on supply chain systems. The results showed the effectiveness of the proposed model, by applying it to 11 projects from several fields. It was concluded that the diffusion factors have a significant impact on the supply chain (Kamei et al. 2013).

A mathematical model was proposed to diminish the total cost of the products and also to reduce the risks arising from this cost reduction within production systems. Raw materials required to produce the final product in the production system were supplied by external suppliers. A comparison between using JIT and EOQ approaches for procuring raw materials to the production system was made. The findings illustrated that keeping a specific amount of stock for in-house inventory during a limited period of time had a direct impact on the production system (El Dabee, F., Marian, R. & Amer, Y. 2013). In other research, El Dabee et al. (2013b) extended their model using multi external and local suppliers under a JIT approach for procuring raw materials required to make products within a manufacturing facility. Comparing the use of local suppliers with the use of external suppliers to supply raw materials to the production system adopting a JIT technique significantly impacted on the total cost of final product. This increase, however, could lead to other benefits such as preserving the reputation of the production facility intact with end-users (El Dabee, F., Marian, R. & Amer, Y. 2013a). The characteristics of the proposed cost and risk reduction models in JIT systems are summarised in Table 2.3.

Table 2.3 Classification of the literature on modelling of cost-risk reduction in JIT systems

Author(s), Year	Dimensions of the proposed model					Methods Applied
	Cost Minimisation	Modelling	Multi-suppliers/ Multi-manufacturers/ Multi-end customers	Lead-time minimisation	Risk reduction	
Ho and Kao (2013)	√	√	√	√	×	An integrated single-vendor and single-buyer model was developed to minimise the total cost of the product within a JIT supply chain.
Ghasimi, Ramli & Saibani (2013)	√	√	√	√	×	Using JIT logistics, a new mathematical model for three-echelon defective good supply chain network (DGSCN) was developed.
Wu, M et al. (2013)	√	√	√	√	×	A novel EOQ-JIT indifference point model was constructed to generate the alternative formulas between the EOQ with price discount purchasing system and the JITP system assessing stockout risks.
Kamei et al. (2013)	√	√	√	√	×	A defect prediction model based on a combination of established and new standards was built to assess a JIT quality assurance approach to find its risk impacts on supply chain systems.
El Dabee, Marian, and Amer (2013)	√	√	√	√	√	A mathematical model considers that external suppliers supply raw materials the production system in JIT systems was proposed.
El Dabee, Marian, and Amer (2013b)	√	√	√	√	√	A mathematical model using multi external and local suppliers under the JIT approach for procuring raw materials required to make products within a manufacturing facility was developed.
Gupta (2011)	√	√	√	√	×	A JIT model and conceptual architectural framework was developed to improve the service quality based on JIT approach.
Jaggi and Arneja (2011)	√	√	√	√	×	A periodic inventory model under service level constraint was proposed to minimise the lead time and setup cost under a normal interval of the demand distribution using JIT philosophy.
Yang, J, Chen and Pan (2010)	√	√	√	√	×	An integrated model under lead time control using JIT purchasing approach between both seller and buyer.
Jianhua and Xianfeng (2010)	√	√	√	√	×	A structural framework model and the mathematical programming model of an agile supply chain were proposed to meet the marketplace requirement using JIT technique.
Mungan, Yu and Sarker (2010)	√	√	√	√	×	An integrated inventory model for high-tech industries in JIT system considering a continuous decreasing in the price over limited planning horizon was coded.
Guo and Tang (2009)	√	√	√	√	×	An integrated supply chain management model was constructed based on market demand.
Farahani and Elahipanah (2008)	√	√	√	√	×	A JIT distribution model for three-level supply chain network was developed.
Rau and OuYang (2008)	√	√	√	√	×	An integrated production–inventory model under a specific planning horizon and a linear trend in demand was formulated.
Pan and Yang (2008)	√	√	√	√	×	Two integrated inventory models were proposed to estimate the total profit and minimise the joint total expected annual cost.

JIT can be used for the purpose of cost reduction, as it helps in smoothing the process of production and can also lead to a reduction in setup time. By facilitating workflow flexibility, JIT ensures a reduction of the work in progress and a reduction in lead time which ultimately reduces the overall process cost (Monden, Yasuhiro 2012). However, except for Kamei et al. (2013), the literature review has not presented a single case where a JIT is deployed for simultaneous cost-risk reduction within production systems. These researchers expected that

the use of "Just-In-Time Quality Assurance" should lead to a minimisation of the costs of building high quality software.

2.7. Optimisation of Supply Chain Cost-Risk Reduction

Supply chain management and optimisation has a significant impact on supply chain networks by managing their process in all stages (Papageorgiou 2009). In the supply chain literature, a number of different techniques have been developed to optimise models which may be used for developing a framework for a simultaneous cost-risk reduction in supply chain systems. These include mathematical techniques, artificial intelligence techniques and heuristic techniques (Akanle & Zhang 2008). A genetic algorithm (GA) is considered as an innovative and proper approach for reducing the Bullwhip Effect in supply chain networks (Lu et al. 2012). It is widely used in numerous industrial applications in the field of control engineering, because it is able to deal with nonlinear constraints and multiple objective complex problems (Kanthalakshmi & Manikandan 2011).

Ghasimi et al. (2013) utilised GA and CPLEX solver to optimise their developed defective goods supply chain network model. They considered the applied parameters as probabilities with normal distribution, in order to find the optimal solution using the proposed model. The model outputs were compared to determine their performance and to find the proper length for each cycle (ALOEC). They considered the applied parameters as probabilities with a normal distribution, in order to find the optimal solution using the proposed model. Jianhua and Xianfeng (2010) designed a Hybrid Genetic Algorithm (HGA) by merging GA with a greedy algorithm to solve the agile supply chain schedulling (ASCS) problem. They stated that practical production and transportation schedules ensure the implementation of JIT, which reduces operation costs in the supply chain. They also assumed that transportation between supply chain parties in both upstream and downstream processes are in bulk and direct.

Also, a hybrid genetic algorithm (HGA) representing the dynamic behaviour of a system and its limitations was proposed to improve an existing JIT manufacturing system. This approach was tested and validated using an analysis of variance (ANOVA) test on an auto industry production line to find the optimum or near-optimum number of Kanban cards at different stations within the system. A comparison was made between the results obtained and the practical JIT, successfully illustrating the efficacy of the proposed approach (Azadeh,

Ebrahimipour & Bavar 2010). A GA was proposed to solve real-size problems of the developed model which applied a GA as an optimisation stochastic search approach to deal with the proposed JIT model. The findings showed the efficacy of the proposed approach compared with the results obtained by LINGO optimisation software (Farahani & Elahipanah 2008). A mixed-integer optimisation approach was modelled and used for conjoining the optimisation of multi-buyers and a single supplier in the supply chain. All the decision variables used were executable integers in fixed period application and all appropriate constraints were easily added. Results obtained from implementing the proposed approach in a computational experiment illustrated that costs can be minimised using a small batch strategy for procuring materials from the supplier instead of accessing supply in a single lot (Chang, C-T et al. 2008).

Additionally, a mixed non-linear formulation (MINLF) for a complex production-distribution (P-D) plan was proposed based on the integration of an aggregate production and distribution plan. The developed model incorporated a number of real-world variables and constraints to find the optimal solution using Genetic Algorithm approach. By implementing this model in a real-world case study (PSP Co.) to investigate its effectiveness, it was concluded that the optimised model played a significant role in minimising the entire production and distribution cost (Fahimnia, Luong & Marian 2012). A collaborative supply-chain planning model for decision-makers was constructed to select the optimal cooperative members and determine the production and distribution quantities in a supply chain. The combined cycle time estimation and genetic algorithm (EctGA) procedure was used to solve the proposed model. A real case study was presented, which clarified its effectiveness by using this approach (Che & Chiang 2012). Using GA, a novel approach was effectively adopted to find the optimal total inventory cost in the supply chain. It was built in the platform of MATLAB software using certain recorded data to inspect its performance. The findings show the effectiveness of this approach, which provided the production systems with a better prediction of inventory levels to the entire supply chain members (Perumalsamy & Natarajan 2012).

An optimisation model for a disassembly sequence of automotive components was built based on a GA approach. It is used to increase the efficiency of the disassembly process by obtaining the optimal or near-optimal disassembly sequence. By implementing the proposed model in a simplified example, it was concluded that the algorithm provided an optimal disassembly sequence in a limited time. It considered also additional constraints in the

product structure (Go et al. 2010). A novel solution approach based on steady state genetic algorithm (ssGA) was presented to find the set of Pareto-optimal solutions for designing a single source, multiple products and multi-stage supply chain to diminish the total cost using a heuristic approach based on GA. For evaluating ssGA effectiveness, its results were compared with the results obtained by Cplex, Lagrangean heuristic, hybrid GA and simulated annealing with various parameters (Altiparmak et al. 2009).

An inventory control system model was proposed for determining the inventory order policy of each supplier's store in a supply chain to minimise the holding cost using an immune genetic algorithm. The main purpose of this model was to address such problems by merging the features and structure of the distributed inventory issue, and analysing the process and the consequences of the algorithm. It was concluded that this approach was more flexible than the others (Liu, L, Su & Xu 2009). A fuzzy logic genetic algorithm (FLGA) approach was designed to minimise the cost in the supply chain network considering simultaneously supplier selection, lateral trans-shipment and vehicle routing decisions. The key reasons for using this approach were: to select the appropriate supplier(s) with a minimal ordering cost; to maximise different products savings; and to find the optimal arrangement for procuring different kinds of products from different vendors. Other methods such as branch and bound, standard GA, simulated annealing (SA) and tabu search (TS) were applied and compared with the FLGA technique and illustrated that it is more effective than the others (Lau et al. 2009).

Furthermore, a GA approach was formulated to solve a large scale three-stage, two-echelon, multi-product, single sourcing production-distribution network problem. For this purpose, the developed approach considered a roulette wheel selection combined with a novel crossover and mutation mechanism, in order to minimise the total cost of the entire production-distribution network. By implementing the proposed approach in a case study, it was clear that it was able to solve this issue (Lai, Kim-Teng, Luong, L. & Marian, R. 2008). Another new GA-simulation-based method was formulated to obtain the near optimal design for the serial-parallel production line (S-PPL) approach. It was implemented in a simplified example using the gene family arrangement method (GFAM). Three decision variables: buffer size between each two workstations; machine numbers and kinds in the workstations, were used for this purpose. The findings illustrated that the chances of arriving at the nearest optimal solution of a S-PPL design was achievable with comparative ease (Abu Qudeiri et al. 2008).

In another study, Yu, Chen and Chu (2008) used an approximate approach including a split distribution and a Lagrangian relaxation method. This approach used many vehicles to solve a large scale inventory routing problem (IRP) with a deterministic demand to find a near-optimal solution. The proposed approach found, in a short time, a near-optimal solution for the IRP using up to 200 customers. Genetic algorithms and a fuzzy set approach were applied to generate JIT schedulling to optimise the fabric-cutting process in the apparel industry to minimise the total cost of the final product. Using data collected from fabric-cutting department of a Hong Kong-owned apparel manufacturing company in China, the findings illustrated the effectiveness of this approach for improving the performance and minimising the production cost in the organisation (Wong et al. 2006).

El Dabee, F, Marian and Amer (2014b) proposed a genetic approach for optimising a novel mathematical model for simultaneously minimising the total cost of a final product and the potential risks related to these benefits. A comparison of four selection methods was performed to determine the best proposed algorithm based on some experiments in a simplified example. The findings illustrated the effectiveness of the proposed approach in the JIT system focusing on a simultaneous cost-risk reduction. The authors extended their research in another two articles by defining the best rates of the GA basic parameters. These are population size, maximum generation, crossover and mutation rates. A comparison of the genetic operators used was made by evaluating different rates and defining the most suitable rate of crossover and mutation. By using the GA achieved parameters, the real-coded GA produced, in a short time, the optimum solution for minimising the total cost of the final product and the risk effects in JIT systems (El Dabee, F, Marian & Amer 2014a, 2015).

From the literature review presented above, it can be very clearly seen that researchers have used different optimisation approaches for independently minimising either the cost or the risks. The exception was the study by El Dabee, Marian and Amer (2014 a; b; 2015) who proposed a GA approach for a simultaneous cost-risk reduction within production systems under a JIT adoption.

Table 2.4 summarises the characteristics of the optimisation of cost-risk reduction in the supply chain.

Table 2.4 Classification of the literature on the cost-risk reduction optimisation in supply chain systems

Author(s), Year	Dimensions of the proposed model					Methods Applied
	Cost Minimisation	Modelling	Multi-suppliers/ Multi-manufacturers / Multi-end-customers	Lead-time minimisation	Risk reduction	
El Dabee, F, Marian and Amer (2015)	√	√	√	√	√	A genetic approach for optimising a novel mathematical model for a simultaneous cost-risk reduction in JIT systems was proposed.
El Dabee, F, Marian and Amer (2014b)	√	√	√	√	√	A comparison of four selection methods was carried out to define the best proposed algorithm based on some experiments in a simplified example for the proposed GA of a simultaneous cost-risk reduction in JIT systems.
(El Dabee, F, Marian and Amer (2014a))	√	√	√	√	√	By using the selected GA parameters, the real-coded GA produces the optimum solution for minimising the total cost of the final product and the risk effects in JIT systems in a short time.
Ghasimi, Ramli and Saibani (2013)	√	√	√	√	×	A novel mathematical model for three-echelon defective good supply chain network (DGSCN) was built.
Jianhua and Xianfeng (2010)	√	√	√	√	×	A Hybrid Genetic Algorithm (HGA) was proposed by merging GA with the greedy algorithm to solve the agile supply chain schedulling (ASCS) problem.
Azadeh, Ebrahimipour and Bavar (2010)	√	√	√	√	×	(HGA) representing the dynamic behaviour of a system and its limitation was proposed.
Farahani and Elahipanah (2008)	√	√	√	√	×	A GA was proposed to solve real-size problems of the developed model to apply a GA as an optimisation stochastic search approach to deal with the proposed JIT model.
Chang et al. (2008)	√	√	√	√	×	A mixed-integer optimisation approach for multibuyer and single supplier in the supply chain was used.
Wong et al. (2006)	√	√	√	√	×	Genetic algorithms and fuzzy set approach was applied to generate JIT schedulling to optimise the fabric-cutting process in apparel industry.
Che and Chiang (2012)	√	√	×	√	×	A collaborative supply-chain planning model for decision-makers was constructed to select the optimal cooperative members.
Perumalsamy and Natarajan (2012)	√	√	√	√	×	Using GA, a novel effective approach was adopted. It was built on the platform of MATLAB software using certain recorded data to inspect its performance.
Fahimnia, Luong and Marian (2012)	√	√	√	×	×	A mixed non-linear formulation (MINLF) for a complex production-distribution (P-D) plan was proposed based on the integration of aggregate production and distribution plan.
Go et al. (2010)	√	√	×	×	×	An optimisation model for a disassembly sequence of automotive components was built based on GA approach.
Altiparmak et al. (2009)	√	√	√	×	×	A novel solution approach based on a steady state genetic algorithm (ssGA) was presented to find the set of Pareto-optimal solutions for designing a single source, multiple product and multi-stage supply chain network.

Liu, L, Su and Xu (2009)	√	√	√	×	×	An inventory control system model was proposed for determining the inventory order policy of each supplier's store in a supply chain.
Lau et al. (2009)	√	√	√	√	×	A fuzzy logic genetic algorithm (FLGA) approach was designed to minimise the cost in supply chain.
Abu Qudeiri et al. (2008)	√	√	×	×	×	A new GA-simulation-based method was formulated to obtain the near optimal design for the serial-parallel production line (S-PPL) approach that lead to maximise its efficiency.
Lai, Luong and Marian (2008)	√	√	√	×	×	A GA approach was formulated to solve a large scale of three-stage, two-echelon, multi-product, capacitated single sourcing production-distribution network problem.
Yu, Chen & Chu (2008)	√	√	×	×	×	An approximate approach includes split distribution using a Lagrangian relaxation method coping with many vehicles was used.

All models of JIT systems presented above independently reduced either the cost or the risk. It is clear that risks have a significant impact in organisations' performance, which leads to an increase in their total costs and at the same time reduces their efficiency. Risks should therefore be assessed by being identified, evaluated and measured in order to reduce the undesired effects they cause within organisations; and JIT models are needed to simultaneously consider costs and risks.

2.8. Concluding Remarks

Over the last two decades, numerous manufacturing systems have implemented lean manufacturing tools such as JIT in their operations management. In using these methods, they seek to minimise the total product cost to ensure their competitive positions in the global market. However, they overlook the consequences that resulted from these techniques. Based on the study of the literature, a gap in the research, which deals with cost and risk management in the supply chain have been identified. Subsequently, this chapter focused on cost-risk reduction optimisation in JIT systems and its effect on the entire supply chain capacity. This was achieved by a detailed classification of risks arising from a reduction in the cost of production, while highlighting further potential key risk factors in the production systems and the supply chain as a whole. Finally, the review of the literature recommends that researchers should consider examining the effects of disruptions to the supply chain by unforeseen circumstances, such as natural and man-made disasters and economic crises, to achieve a high product quality within the supply chain.

3. Development of a Robust Optimisation Framework for a Simultaneous Cost-Risk Reduction in JIT Systems (SCRRJITS)

3.1. Introduction

The importance of optimisation in supply chain management systems has become one of the most pressing issues and as such has attracted considerable attention. Any optimisation process aiming at effective cost reduction in a supply chain is particularly complicated because of its need to focus on the potential risks arising from such a reduction. For this reason, academics and researchers have proposed many mathematical and heuristic approaches in the attempt to solve engineering optimisation issues. In the field of supply chain management, various approaches to meta-heuristics optimisation have been recently applied to solve these issues.

This research presents a framework developed for modelling and optimising a simultaneous cost-risk reduction in JIT systems. To handle such a problem a robust optimisation model is required. The increased deployment of JIT approaches within the manufacturing process of production systems can lead to unforeseen and other potential risks throughout the entire supply chain.

This chapter outlines the development of such a robust framework for optimising a simultaneous cost-risk reduction in JIT systems.

The objectives of this chapter are as follows:

- To develop a systematic conceptual framework for simultaneously optimising the cost-risk reduction under a JIT adoption; and
- To provide an overview of the techniques selected for that systematic approach.

The remainder of this chapter is organised in the following way: Section 3.2 presents the architecture of the structure developed for optimising the SCRRJITS framework; Section 3.3 presents the development stage including two main parts (a mathematical model and a genetic algorithm); the validation stage for implementing the developed optimisation model in a case study is introduced in Section 3.4; the summary of this chapter is presented in Section 3.5.

3.2. The Adopted JIT Supply Chain Structure and Interactions

The physical structure of the JIT supply chain proposed in this research is as illustrated in Figure 3.1. Specifically, this figure includes a four-echelon JIT supply chain representing the supplier, manufacturer, distribution system and end customer. The JIT supply chain consists of a combination of a number of suppliers that supply their raw materials and components to a number of production systems. These manufacturing systems assemble numerous components into their final products before sending them out to the distribution centres which consists of a number of sites that distribute the final products to the end customers.

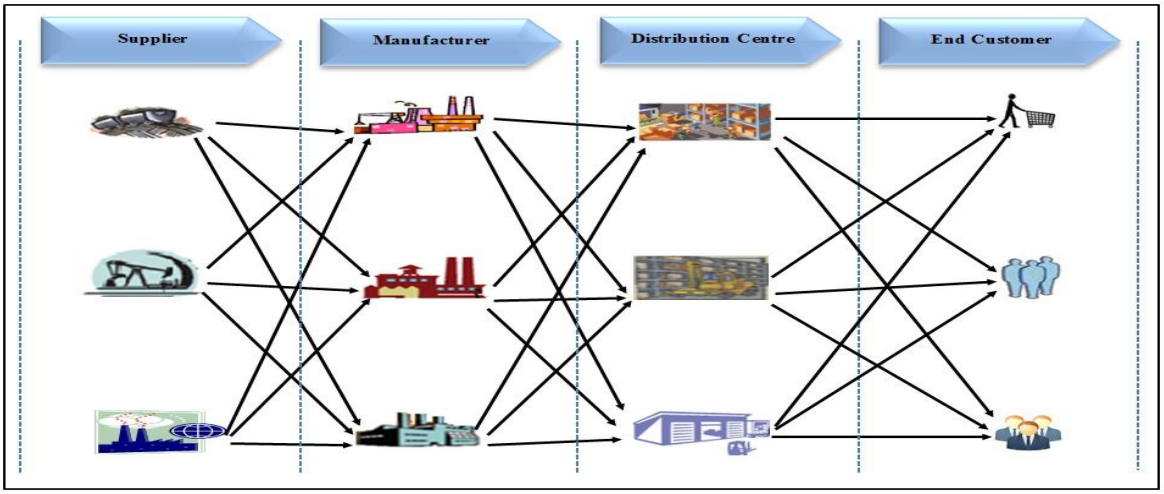


Fig. 3.1 The structure of the JIT supply chain

Figure 3.1 shows the interaction between the three-echelon members in terms of the flow occurring within the JIT supply chain. Each supplier, for instance, can supply the raw materials to all manufacturers (production systems). Each manufacturer can also sell their final products to all distribution centres, which distribute these products to the end customers based on demand.

3.3. The structure of the developed SCRRJITS framework

The designed framework is divided into two main stages: development and validation, as illustrated in Figure 3.2. The conceptual framework summaries the methodology used to optimise the simultaneous cost-risk reduction in the production facilities adopting the JIT approach. Figure 3.2 indicates that Stage 1 is the development stage, which includes two parts: modelling and optimisation of the SCRRJITS in the production systems. The first part is to develop a mathematical model which provides the basis for calculating the total cost of

the final product in the production system. This model includes the cost of the product and the risk cost arising from the implementation of the JIT approach in these facilities.

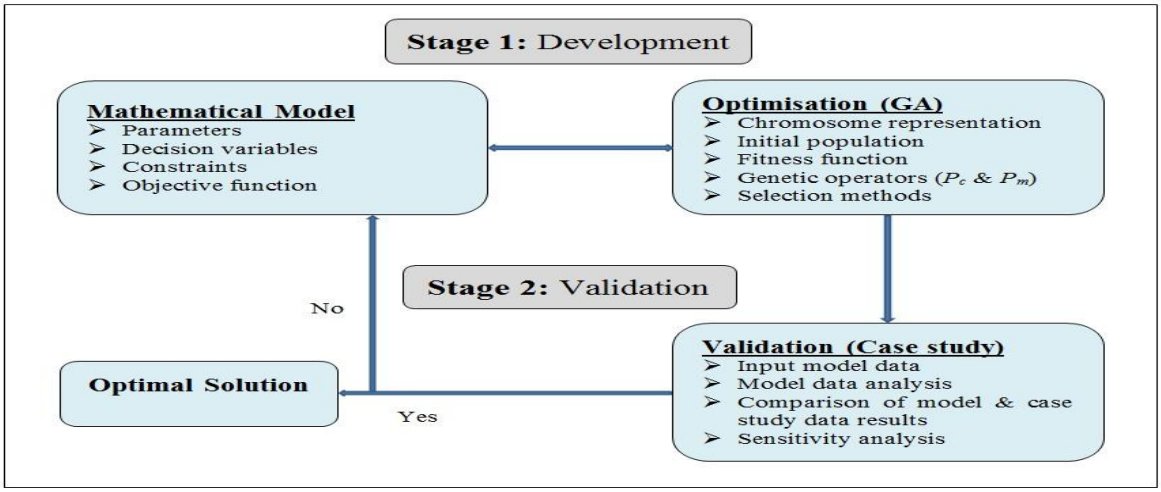


Fig. 3.2 The architecture of the SCRRJITS optimisation framework

The product cost incorporates the ordering cost (C_O), the holding cost (C_H), the purchasing cost (C_P), the transportation cost (C_{tr}), duties cost (C_D), the transfer price cost (TP), the worker cost (C_W) and utility costs (C_U). The second part of Stage 1 is the development of an optimisation system for solving the SCRRJITS problem in the production systems using the JIT approach for managing their process. A genetic algorithm (GA), as an optimisation technique that can be used for this purpose, has been selected owing to its robustness and efficiency. The second stage is the validation of the developed optimisation model. This can be achieved by applying some experiments using a case study to determine the effectiveness of the proposed model for solving such problems.

3.4. Development Stage

As mentioned above, the development stage includes two parts: modelling and optimisation. The first part is to develop a mathematical model for simultaneously minimising the total cost of the final product in production systems and the risks arising from this reduction in JIT systems. This model will be explained in details in Chapter 4. The second part is about developing an optimisation approach (GA) for the proposed JIT model which will be explained in detail in Chapter 5.

3.4.1. *Mathematical Model*

Models for supply chain design and analysis are generally classified into different schemes. One of these schemes classifies models into four categories: deterministic, stochastic, economic and simulation models. Deterministic models which have single or multiple objective functions assume that all parameters are certainly known and fixed. Stochastic models consider those parameters which are uncertain and random (Beamon 1998). Economic models concentrate mostly on the cost relationship between the buyer and supplier in a supply chain. Simulation models use computer applications for representing the real-world interactions and are suitable for what-if analysis (Ganapathy, Narayanan & Srinivasan 2003). In another classification, models are divided into deterministic, stochastic, hybrid and IT-driven models. Hybrid models have elements of both deterministic and stochastic models which are able to deal with certainty and uncertainty parameters. IT-driven models are the models that apply software to integrate and coordinate different phases of supply chain planning on a real-time basis (Min & Zhou 2002).

Mathematical models are considered based on the representation of the necessary features of actual system using mathematical language. Basically, mathematical models require sufficient details to answer the questions of a specific problem (Banks 2004). Many mathematical techniques can be used such as linear programming, non-linear programming, mixed integer programming and Lagrangian relaxation (Chinneck 2004). Various mathematical models have been used to solve supply chain problems (Mula et al. 2010). The mathematical programming approach seeks to optimise the objective function which is usually restricted by a set of constraints to specify feasible solutions to the problem (Heragu 2008). Linear programs can model numerous problems in manufacturing industries and can combine with optimisation tools to find optimal solutions to the problems that have a large number of constraints and variables. The four fundamental elements of the MILP are briefly described as follows.

3.4.1.1. Input Parameters

Parameters are the input constant data used in the system to solve the given problem (Hillier & Lieberman 2005). Model parameters are fixed numbers that are supplied by the modeller or calculated from other values to describe the developed model to mimic the real case of the given problem (Fourer, Gay & Kernighan 2003).

3.4.1.2. Decision variables

Decision variables symbolise the unknown decisions of the given problem that is required to be determined by the system. Decision variables are represented using symbols such as (X_1, X_2, X_3, ….., X_n). They differ from the input parameters which are fixed values (Chandrakantha 2008).

Defining the variables of the problem is considered as one of the most significant steps in formulating a problem as a linear program. In some cases, a creative variable definition is used to dramatically diminish the size of the problem (Fourer, Gay & Kernighan 2003).

3.4.1.3. Objective function

The objective of the problem is stated as a mathematical expression of the decision variables (Chandrakantha 2008). Each problem generally has one or more objective function which is to be minimised or maximised. The coefficients of the objective function present how each corresponding variable contributes to the objective function value optimised for solving the given problem ('Basic Linear Programming Concepts' 1998).

3.4.1.4. Constraints

Constraints are presented as equations in the decision variables of the problem. Every mathematical model also has constraints limiting its feasible solutions. These constraints differ from model to model based on its limitations (Chandrakantha 2008). Constraints are classified into three categories: general constraints which are all other restrictions, requirements and interactions that could limit the values of the decision variables, and variable bounds that have affected the system outputs. In the design of the mixed integer linear programming (MILP) supply chain model with numerous generic constraints are taken in consideration such as the balance constraint of materials and products, capacity limit constraints, throughput limit constraints and the service limit constraints (Yan, Yu & Edwin Cheng 2003).

Within the constraints as outlined in this section, a MILP model is developed for simultaneously minimising the cost of the final product and the risks arising from implementing the JIT approach in production systems. A general MILP usually comprises a set of variables, objective functions indicating the contribution of each variable to the required outcome and a set of constraints describing the limits of decision variables (Paschos

2010). The MILP provides the basis for calculating the cost and fitness functions that are required for optimising the simultaneous cost-risk reduction in JIT systems.

3.4.2. *Genetic Algorithm*

Modern supply chains require effective strategies that minimise the total cost of their products. Concern arises however over how the optimal quantity of inventory levels (e.g. raw materials, products) is determined within the entire supply chain (Siradej 2008). This concern led to the development of an efficient technique for finding the optimal flow patterns (e.g. such as choosing appropriate suppliers and transportation modes), which is known as supply chain design optimisation (Moncayo-Martı´nez & Zhang 2011). Optimisation can cope with issues regarding minimising or maximising an objective function which has many variables usually dependent on equality/ inequality limitations. Optimisation also plays a significant role in operations research, management science and engineering design (Sivanandam & Deepa 2008b). Optimisation, in addition, is considered as a process that can be used in the supply chain design to find the best flow patterns, such as the selection of distribution channels and transportation modes (Paksoy & Özceylan 2012). As well as this, optimisation problems are used for acquiring good component parameters to be set into activities undertaken by humans or machines (Malhotra, Singh & Singh 2011).

GA has recently received much attention as a novel optimisation technique and has wide applications in process control systems (Malhotra, Singh & Singh 2011; Sivanandam & Deepa 2008b). GA is a search based approach that mimics the process of natural selection (evolution) and has been used to generate useful solutions for optimisation and search problems (Singh, Gupta & Sinhal 2012). GA is considered as a part of Evolutionary Algorithms (EAs) which also comprise Evolutionary Programming and Evolutionary Strategies and it is an iterative stochastic algorithm in which natural evolution is used to model the search process (Marian 2003).

EAs are population-based meta-heuristic optimisation algorithms in which biology-inspired mechanisms and survival of the fittest theory is used in order to iteratively refine a set of solutions (Rawal & Inamdar 2014). Genetic Algorithm (GA) is the key paradigm of evolutionary computation and is inspired by Darwin's theory of the survival of the fittest (Zhu & Kwong 2010). It retains a population from a different solution allowing them to mate, produce offspring, mutate and fight for survival. The principle of survival of the fittest ensures that the derived populations tend towards optimisation (Wang, K & Wang 2008).

The optimum solution of such problems considered as NP-hard problems can be achieved using optimisation techniques such tabu search, simulated annealing, ant colony algorithm, genetic algorithm (GA) and hybrid intelligent algorithms (Lau et al. 2009). However, this might takes a long period of time and differs from technique to another technique used for this purpose. Owing to the capability of a GA for solving the complex problems that have a large number of solutions in a short time, this research selects this technique to find the optimal or near-optimal solution of a SCRRJITS problem. This section presents the structure of GA used for optimising the simultaneous cost-risk reduction in production systems under JIT adoption. The main components of the standard GA are: chromosome (solution) representation, generation of initial population, reproduction operators (crossover and mutation), fitness function, selection operator and termination criterion (Reeves & Rowe 2003).

The following sub-sections describe the key components of the proposed GA model for optimising the simultaneous cost-risk reduction in JIT systems.

3.4.2.1. Chromosome Representation

Representation is considered to be one of the most significant issues affecting the performance of GA. There are three relevant issues required to be considered: encoding the problem into chromosomes, decoding the evaluation function process and permitting the operations of the relative genetic operators efficiently. Figure 3.2 illustrates the relevant issues in GA representation (Chang, C & Ge 2005).

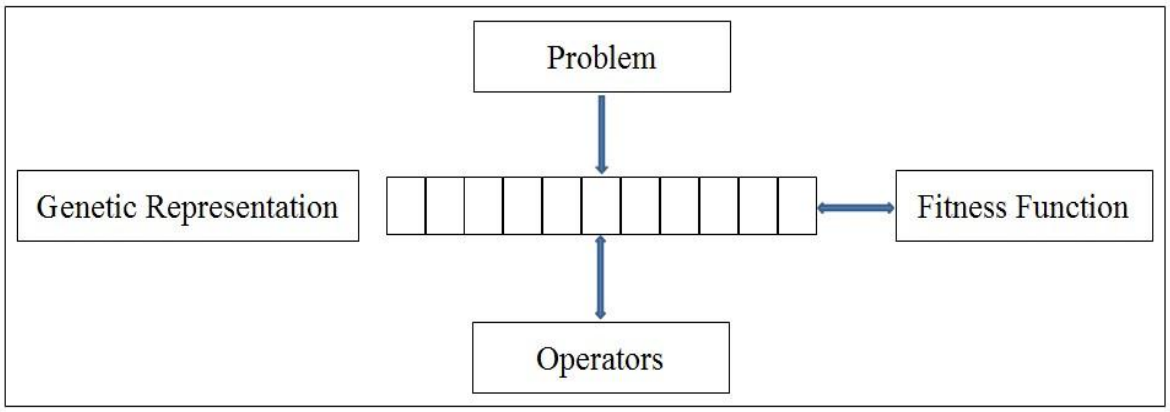


Fig. 3.2 Representation issues of a standard GA (Chang, C & Ge 2005)

In GA, each solution is represented in the form of a finite length array called a chromosome. A chromosome is composed of a set of locations called genes and it is a string of symbols that can be coded in different forms such as binary, integer and real numbers (Gen & Cheng 2000). The chromosome refers to the random population of encoded candidate solutions to which the Genetic algorithm initiates (Radhakrishnan, Prasad & Gopalan 2009).

A coding strategy should be developed to ensure compact chromosomes totally characterise the related solution. The chromosome process generally includes selection of the internal individual objects representation, which are usually represented as binary or real coding, and the design of the chromosome shape (Rothlauf 2002). Many research studies related to the supply chain have adopted a real coding system for chromosome representation (Al-Zuheri, Luong & Xing 2014; Liang & Huang 2006; Mahmudy, Marian & Luong 2012; Moon et al. 2008; Naso et al. 2007).

3.4.2.2. Initial Population

GA starts by generating a number of solutions (chromosomes) called a population. This stage is a key consideration for GA approaches because the population significantly impacts on the subsequent stages of the process. There are usually two issues to be considered for population initialisation: the population size and the method used to create the chromosome/individual in the initial population of the first generation (Mohd-Lair 2008). Selecting a good initial population with an appropriate population size can greatly improve the GA efficiency (Torabi, Fatemi Ghomi & Karimi 2006). There is no efficient technique useful for determining the appropriate population size. For this reason, the determination of the parameters value becomes an art instead of science (Michalewicz 1996). For generating the initial population, two methods can be used: creating random chromosomes and creating better chromosome that are located within the vicinity of the global optimum space. The latter is rarely used for this purpose because it can be used only if the problem is well understood (Kumar, T, Singh & Gupta 2012; Moon et al. 2008; Naso et al. 2007). Based on the dimensions of the decision variables and the nature of the problem, it is possible to determine the efficient population size experimentally (Fahimnia 2011).

3.4.2.3. Pairing Technique

Pairing technique is used to select two chromosomes that will undergo crossover. Many types of pairing techniques can be used in a GA approach such as pairing parents from top to bottom, random pairing, weighted random pairing (rank and cost weighting) and tournament

selection (Haupt & Haupt 2004). The random pairing technique is used in this research study. It works by randomly selecting two chromosomes from the population.

3.4.2.4. Reproduction Operators

This stage includes the creation of new offspring for each generation. Genetic operators (crossover and mutation) are used to explore the search space in order to create new chromosomes (offsprings). These operators are briefly described below.

Crossover

The crossover operator is the basic operator for producing new chromosomes in GA by recombining two chromosomes (parents). The key purpose of using a crossover operator is to recombine the features of two parents selected randomly from the mating pool to produce a new chromosome (Abdelmaguid & Dessouky 2006). During the crossover, one or more genes will be exchanged between this pair of chromosomes. The crossover points are usually determined in a random manner. The crossover rate is another significant parameter in the GA approach. A marginally higher crossover rate permits greater exploration of the solution space and minimises the opportunities for searching for a local optima (Mohd-Lair 2008).

Mutation

Mutation is the second operation in a GA which creates spontaneous random changes in numerous chromosomes. It is used to enhance the exploratory character of the algorithm and to avoid trapping the GA in local optima. A mutation operator enables the GA to avoid premature convergence and to find the optimal solution in the search space based on the mutation rate (P_m). The main purpose of a mutation operator is to minimally agitate the chromosomes in order to maintain the diversity in the population.

3.4.2.5. Fitness Function

In GA optimisation, the two evaluation functions available are objective and fitness functions. An objective function provides a measure of how individuals have performed in the problem domain. This measured value can be used directly if the value is always positive and the problem is at its maximum such as in Croxton et al. (2002). Transformation into a fitness function is however necessary for the objective function in some cases with negative measured values (Osyczka 2002). This negative measured value can create problems for GA, especially when a fitness-proportional selection is adopted. This fitness-proportional selection

requires positive values to indicate chromosome fitness during the evaluation process (Osyczka 2002; Zalzala & Fleming 1997). The transformation of this objective function into a fitness function is essential to ensure a returned positive value during the chromosome fitness evaluation.

Determining the chromosome's fitness value for survival is an important issue in multi-objective optimisation. The main objective of the fitness evaluation is to calculate the optimal or near-optimal solutions in the population with reference to the objective function and constraints of the developed model. There are different tools that can be used to define fitness function (Gen & Cheng 2000). One of the simplest approaches is the weight-sum technique. By considering m objective functions, fitness function (f) is obtained by combining the objective functions

$$eval\,(f) = \sum_{i=1}^{m} w_i f_i \qquad \textbf{(3-1)}$$

where W_i is the constant representing weight for f_i and $\sum_{i=1}^{m} w_i = 1$.

3.4.2.6. Selection

The selection operator implements the idea of "the survival of the fittest". It is responsible for selecting chromosomes from the solution pool into a mating pool for generating offspring (Abdelmaguid & Dessouky 2006). A selection operator describes the process of selecting a part of the chromosomes from the initial population keeping their features for the next generation (Zhou, Min & Gen 2002). The main objective of selection strategy is to select only the best chromosomes from the parents and offspring pools that can represent the solution space (Mohd-Lair 2008). Many research studies used different selection methods based on their applied GA experiments such as roulette wheel, binary tournament, elitist, replacement and ranking selection (Ghasimi, Ramli & Saibani 2014; Goldberg & Deb 1991; Hasan, S 2009; Kannaiah, Thangavel & Kothari 2011; Khorshidian et al. 2011; Mahmudy, Marian & Luong 2013; Mohd-Lair 2008).

3.4.2.7. Termination criterion

Termination is the criterion by which the GA decides whether to continue searching or to discontinue the search. Termination criteria are usually the main problem of EAs. They are not equipped with automatic termination criteria. In fact, EAs may find an optimal or near-

optimal solution in an early stage of the search. They are unable, however, to determine whether they can terminate at that point. Therefore, each of the enabled termination criterion is tested for any iteration to see if it is time to stop. In a standard GA, three kinds of termination conditions have been used. Firstly an upper limit on the generations' number is achieved; secondly an upper limit on the evaluation number of the fitness function is achieved; and finally the chance of achieving significant changes in the next generations is excessively low (Michalewicz 1996). Many research studies used the upper limit on the number of generations' method in their GA approach. A GA is run over a number of generations until the termination criteria is reached (Fahimnia 2011; Kim, J-L 2013; Mohd-Lair 2008; Rimcharoen, Sutivong & Chongstitvatana 2006).

3.5. Validation Stage

Validation is the process of making sure that the model or solution approach is suitable for solving a real case problem (Chinneck 2004). Model validation is usually defined as "Substantiation that a computerised model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model" (Schlesinger et al. 1979). A simplified version of the model development process is proposed including three phases: the problem entity, the conceptual model and the computerised model. The problem entity considers the system that is modelled. The conceptual model is the mathematical/logical representation of the problem entity proposed for this study. The computerised model is the application of the conceptual model through computer programming (Sargent, R. 2013a).

Conceptual model validation is defined as the process of deciding whether the theories and assumptions underlying the conceptual model are correct and the model representation of the problem entity is appropriate for the intended model objective (Sargent, R. 2013b). A conceptual model, therefore, comprises of a description of the mathematical equations and the flow process which are required for the modelling purpose (Refsgaard & Henriksen 2004). There are numerous techniques used in model validation such as historical data validation, historical methods (rationalism, empiricism and positive economics), comparison to other models and parameter variability-sensitivity analysis validation (Sargent, R. 2013b).

In this research, the proposed optimisation model is implemented in a case study to determine its accuracy and efficiency for solving the SCRRJITS optimisation problem. Some

experimental studies are also carried out to determine the impacts of the basic parameters on the objective function of the developed optimisation approach (sensitivity analysis). This stage will be explained in details in Chapter 6.

3.6. Concluding Remarks

A Just-in-Time (JIT) approach plays a significant role in minimising costs and optimising the performances of products and services supplied to the global marketplace. The complexity of JIT supply chains leads to a need for a robust optimisation design. This chapter presents a novel framework for a SCRRJITS optimisation design. The foundation of the adopted JIT supply chain consists of a structure and interactions across the adopted JIT supply chain. The structure includes a three-echelon JIT supply chain between the supplier, manufacturer, distributor and end-customer. Effective interactions offer a sound base for the relationship between the JIT supply chain entities.

The developed SCRRJITS framework incorporates two stages: development and validation. The development stage consists of two parts: the mathematical modelling and optimisation. The former was proposed to map the input parameters and decision variables with the objective functions. The latter adopted the GA approach to find the optimal value of the objective functions of the simultaneous cost-risk reduction in JIT systems. The purpose of the validation stage is to demonstrate that the proposed optimisation model, by implementing it in a case study and obtaining results, fits its purpose.

4. Development of a Novel Model for Optimising a Simultaneous Cost-Risk Reduction in JIT Systems

4.1. Introduction

Supply chain management, in the last decade or so, has emerged as a popular and useful approach in the global marketplace. It provides organisations with significant opportunities to improve their profit margins and to reduce their service/ product costs. This has been led by organisations adapting different lean manufacturing attitudes for managing their businesses. Currently, model development can be considered as an effective research technique to assist researchers and investigators in describing and predicting complex systems or actions. Models have a significant role in research work by providing researchers with guidance required to achieve their goals. Validation is also a crucial stage after developing a model to ensure that it was developed accurately. Models in addition, can often invite overgeneralizations unless care is taken (Busha & Harter 1980).

This chapter describes the development of a mathematical model for simultaneously reducing the costs of the final product in the production systems and the risks arising from these benefits using the JIT approach for procuring raw materials from their suppliers. The developed model will also be used for optimisation purposes using a Genetic Algorithm in the following chapter.

The rest of this chapter is organised in the following way. The model development which incorporates the problem description, model notations, assumptions, parameters, decision variables and formulation is described in Section 2. In Section 3, the developed model is tested with a simplified example to evaluate the performance of the model. Section 4 discusses the results which include the model verification, further analysis of results using different cases of occurrence for disruptions, and a random selected case of disruption occurrence using different levels of decision variables. Finally, Section 5 summarises the chapter.

4.2. Model Development

In this section, all problem statements, assumptions, notations, decision variables, parameters, and mathematical formulations will be described.

4.2.1. *Model Problem Description*

A general cost model is developed in this thesis for simultaneously reducing the cost and risks effects in organisations that use a JIT approach. This model involves three main parties which are supplier, manufacturer, and end user. It is assumed that a distribution network consists of multiple external suppliers used to supply raw materials to the production system to produce the final product. This assumption is made because of pricing variations for the same product in different markets. The materials are transported from numerous manufacturers to the production system which in turn produces the final product for sale to wholesale or retail outlets. The raw materials are also instantaneously replenished in the production system to meet JIT operations. The products are delivered to the end-customers with no holding capacity to store the products. These customers may include wholesalers or retailers.

Many risks may result from the occurrence of unforeseen disruptions such as natural and man-made disasters and economic crises affecting external suppliers. All of these risks would have a significant impact as well, on the production facility and the entire supply chain. To avoid the impact of these risks, it is assumed that during a time of disruption, the production system can procure its raw materials required to produce the final product from a local backup supplier, at a higher price but with a low risk and with a shorter lead time (El Dabee, F., Marian, R. & Amer, Y. 2013b, 2013a).

The model also considers scenarios where orders for a set amount of raw materials, to satisfy customer requirements, are shipped by both external and local suppliers using different transportation modes: waterways, railways, roadways and airways (Murphy & Wood 2011). The appropriate transportation mode can be selected depending on some key criteria such as the lead time and the transportation cost needed to bring raw materials into the production system.

4.2.2. *Notations*

The following notations are used in the proposed model:

C_T: Total cost required to produce one product in monetary units (MU);

C_{pt}: Final product cost excluding the risk cost in monetary units (MU);

C_{RM}: Raw material cost required for producing one product (MU);

C_O: Ordering cost of raw materials (MU);

C_H: Holding cost of raw materials within the production system stores (MU);

C_R: Risk cost arising from disruption occurrence (MU);

C_{tr}: Transportation cost for delivering raw materials to the production system (MU);

C_P: Purchasing cost of raw materials required to produce the product (MU);

C_U: Utilities cost of the final product (MU);

C_D: Duties cost arising from procuring raw material from an external supplier (MU);

TP_i: Transfer price required for procuring raw material i from an external supplier i (MU);

S: Origin of ordered raw materials;

v: Destination of required raw materials;

m_i: Transportation mode for transporting raw material i to its customer;

N_T: Number of transportation modes used for shipping raw materials to the production system (unit);

N_K: Number of raw materials ordered to the production system in each patch (unit);

N_{LT}: Number of days required to provide the production system with raw materials in each patch (unit);

S_{Ej}: Raw material external supplier j;

S_{LBs}: Raw material local backup supplier s;

IF: Indicator function for duty with a value 1 or 0. 1 if the supplier and the production facility are in the same country and 0 otherwise;

M_i: Raw material type required in producing one unit of product i;

H_k: Expected risk k occurs on the supply chain production system;

LH: Likelihood of occurrence for risk in the supply chain; and

I: Impact of risk occurrence in the supply chain.

4.2.3. *Model Assumptions*

The model formulation is based on the following assumptions:

- The ordering cost of raw materials is a fixed rate for each order regardless of the order size.
- The utilities cost of the final product is a percentage of total cost of the product that can be changed by the inventory batch size.
- The final product price is a fixed rate regardless of the inventory batch size.
- The raw materials are supplied by the regular external supplier if no disruption occurs.
- The raw materials can be purchased from the local backup supplier when one or more of the regular external suppliers have been disrupted.
- The cost of raw materials procured from local backup supplier S_{LBi}, depending on its reliability (R_{SLBj}), is a percentage of their cost when they are purchased from the regular external supplier S_{Ei}.
- The transportation cost is proportional to the transportation distance and the used transportation mode.
- The worker or labour cost, required for producing the final product per unit of time, is a fixed rate.
- The cost arising from the likelihood of risk occurrence is a percentage rate depending on its impact on the production system.
- The duties cost is incurred if raw materials are supplied by external supplier S_{Ei};
- The transfer price cost required to procure raw material from the regular external supplier S_{Ei} is a percentage of its total cost C_{RM}.
- The reliability of local backup supplier j reflects the availability for supplying raw materials at the planned time if the regular external supplier has disruption (0- 1).
- Each external and local backup supplier is able to supply some of raw material types.
- The purchasing price for raw materials may vary from supplier to supplier depending on the negotiations, order sizes, discounts, historical relationships and other factors.

4.2.4. *Model Parameters, Decision Variables and Constraints*

The developed model focuses completely on the input data and decision variables that can be used for calculating the total cost of the final product which reduces the cost and their impact on JIT systems. The following sub-sections further describe the input parameters and decision variables which are used in formulating the performance measures of the developed model.

4.2.4.1. Model Parameters

Parameters are considered as input data that are required for the model. They are variables with fixed given values as inputs to the optimisation system (Mohd-Lair 2008). In this research, the parameters used for reducing the costs of products and the risks arising from these costs in JIT systems are:

N_O: Number of operations required for producing one product (unit);

N_P: Number of parts required to produce one product (unit);

N_{SLB}: Number of local suppliers used for supplying raw materials to the production system (unit);

N_W: Number of workers required to produce one product (unit);

C_{UO}: Ordering costs of raw materials for the final product (MU);

C_{UH}: Holding costs of raw materials of each final product in the production system warehouse (MU/ day);

C_{UMi}: Unit cost of the raw material i at the beginning of each cycle (MU);

d_{RM}: Scheduled demand of raw materials per day (unit);

$\%d_{RM}$: Daily demand percentage of raw materials required to meet customer satisfaction (unit);

N_{WD}: Number of working days per week (unit);

h: Operation time required to produce a product (hr);

C_L: Labour cost rate per time in one operation (MU/hr);

C_{TOmang}: Total managerial ordering cost per order (MU);

C_{THmang}: Total managerial holding cost for keeping raw materials to produce final product during the lead time duration;

N_{wks}: Number of weeks required to keep raw materials in warehouses (unit);

SF: Storage factor for keeping raw materials in the warehouse;

OF: Ordering factor for procuring each order from the supplier;

$\%Util$: Utilities cost percentage of the final product (MU);

t_p: Raw material cost percentage incurred for procuring raw material i from an external supplier j (MU);

LT: Lead-time taken between placing and receiving the placed order (day);

$T_{Sj,\ v,\ m}$: Tensor for transportation cost per critical measurement to transport raw materials from its origin s to its destination v using transportation mode m (MU);

$\%V$: Volume percentage value required for transporting raw materials to their customer;

N_h: Number of working hours per day (hr);

D_i: Duty rate (%) per price of raw material i supplied by external supplier j (MU);

$\%sale$: Sales percentage value offered from selling extra raw materials during the same order;

N_{RM}: Number of raw materials supplied to the production system (unit);

R_{SLBs}: Reliability of local backup supplier s for supplying raw materials at the planned time;

R_{SEj}: Reliability of external supplier j for supplying raw materials at the planned time;

C_W: Worker cost required for producing the final product per time unit (MU);

P_i: Final price per unit of final product i sold to the customer (MU); and

C_{UMSLBi}: Unit cost of the raw material i at the beginning of each cycle (MU)

$\%TRS$ Total risk score percentage value.

4.2.4.2. Model Decision Variables

Decision variables are the variables that represent the design method outputs of the model. They are also called controlled factors. This means that any change in their values may change the results of the model outputs. The decision variables in this research are:

N_{SE}: Number of external suppliers used for supplying raw materials to the production system (unit);

d_P: Customer demand for the final product per day (unit);

t_m: Critical transportation measurement of raw materials shipped using transportation mode m; and

Q_M: The quantity of raw material i ordered in each patch required to produce the final product per week (unit).

4.2.4.3. Model Constraints

The objective function of the developed model is restricted by the following constraints:

- Stack buffer capacity. The amount of raw materials and the finished products for each order in the production system is restricted regardless of the order size.
- Production capacity for regular-time and over-time work. The production system usually works one shift but when demand needs to be increased the production system is able to work with a maximum capacity of three shifts.

4.2.5. *Model Formulation Description*

A general cost model is developed based on the supplier of raw materials. This model is utilised to ascertain an optimal ordering strategy for obtaining the batch size of raw materials, using both external and local backup suppliers, to minimise the total cost of the final products and its risk effect in JIT systems. It is built to determine the total cost of producing the final product within production systems. The total cost of this product can be found by:

$$C_T = C_{RM} + C_W + C_U + C_R \quad \textbf{(4-1)}$$

In this section, each component of the total cost of the final product is described.

4.2.5.1. Raw material Cost (C_{RM})

The raw material cost is the cost used to produce the final product in the production system. The inflation rate in both producing and consuming countries has a significant impact on this cost (Canel & Khumawala 2001). In this research, raw material cost includes the ordering cost C_O, holding cost C_H, purchasing cost C_P, transportation cost C_{tr}, duties cost C_D, and transfer price cost TP. It can be calculated as:

$$C_{RM} = C_O + C_H + C_P + C_{tr} + C_D + TP \quad \textbf{(4-2)}$$

Equation 4.2 can only be used if the production system procures raw materials from a regular external supplier. However, in the case where the production system procures its raw materials from a local backup supplier, the raw material cost only includes C_O, C_H, C_P, and C_{tr}. The production system does not incur any of C_D, and TP. Therefore, C_{RM} can be calculated as:

$$C_{RM} = C_O + C_H + C_P + C_{tr} \quad \textbf{(4-3)}$$

4.2.5.2. Ordering Cost (C_O)

Ordering costs are the costs of ordering and receiving an amount of raw materials for each order such as order and setup costs (Murphy & Wood 2011). These costs include determining how much is required, preparing invoices, inspecting goods upon arrival for quality and quantity against shipping lists and moving the goods to temporary storage. They are generally expressed as a fixed value per order regardless of the order batch size (Chopra & Meindl 2013).

Therefore, C_O can be calculated as:

$$C_{UO} = \frac{C_{TOmang}}{\%d_{RM} \times LT} \quad \textbf{(4-4)}$$

where C_{UO} is the ordering cost per unit.

Then, $\%d_{RM}$ equals

$$\%d_{RM} = \frac{d_p}{d_{RM}} \quad \textbf{(4-5)}$$

$$LT = \frac{t}{LF} \quad \textbf{(4-6)}$$

where t is the time required to procure raw materials from a supplier, and LF is the lead time factor, which has a range between 0 and 1 based on the efficiency level.

For an external supplier,

$$C_O = C_{UO} \times OF \quad \textbf{(4-7)}$$

$$, LT = \sum_{j=1}^{N_{SE}} \sum_{f=1}^{N_{LF}} \frac{t_j}{LF_f} \quad \textbf{(4-8)}$$

, j= *1, 2, 3, ..., N_{SE}* , N_{SE} is the number of external suppliers, and f= *1, 2, 3, ..., N_{LF}*

$$, C_{UO} = \sum_{j=1}^{N_{SE}} C_{UOj} \quad \textbf{(4-9)}$$

Therefore,

$$C_O = \sum_{j=1}^{N_{SE}} C_{UOj} \times OF \quad \textbf{(4-10)}$$

However, if the production system procures its raw materials from local supplier, then

$$C_{UO} = \frac{C_{TOmang}}{\%d_{RM} \times LT_s} \quad \textbf{(4-11)}$$

$$, LT = \sum_{S=1}^{N_{SLB}} \sum_{f=1}^{N_{LF}} \frac{t_S}{LF_f} \quad \textbf{(4-12)}$$

, s= *1, 2, 3, ..., N_{SLB}* , N_{SLB} is the number of local backup suppliers

Thus,

$$C_{UO} = \sum_{s=1}^{N_{SLB}} C_{UOs} \quad \textbf{(4-13)}$$

Therefore, the ordering cost of raw materials procured from local suppliers equals

$$C_O = \sum_{s=1}^{N_{SLB}} C_{UOs} \times OF \quad \textbf{(4-14)}$$

4.2.5.3. Holding Cost (C_H)

The holding cost is the cost of keeping one unit of the raw materials in warehouses for a specified time period (Chopra & Meindl 2013). It is expressed generally as a percentage rate multiplied by the inventory cost rate. Organisations therefore prefer to carry a small amount of inventory to minimise the holding cost of the final product (Murphy & Wood 2011). In this research, this cost includes insurance, depreciation, obsolescence, deterioration, spoilage, breakage, and warehousing costs (heat, light, rent and security).

The rate of C_H, if the production system procures its raw materials from an external supplier, equals

$$C_{UHi} = \frac{C_{THmang}}{N_{RM}} \quad \textbf{(4-15)}$$

Therefore,

$$C_H = \sum_{i=1}^{N_P} \sum_{j=1}^{N_{SE}} (C_{UHi})_j \times \%d_{RM} \times (LT_j + SF) \quad \textbf{(4-16)}$$

, $i = 1, 2, 3, \ldots, N_P$ and $j = 1, 2, 3, \ldots, N_{SE}$

However, if a local backup supplier supplies raw materials to the production facility, then

$$C_H = \sum_{i=1}^{N_P} \sum_{s=1}^{N_{SLB}} (C_{UHi})_s \times \%d_{RM} \times (LT_j + SF) \quad \textbf{(4-17)}$$

4.2.5.4. Purchasing Cost (C_P)

Purchasing cost is the cost of goods acquired from suppliers for the production of the final product in the production facility (Horngren, Datar & Rajan 2012). In this research, it is considered as the unit cost of raw material at the beginning of that cycle (C_{UM}).

For an external supplier, C_P can be calculated as

$$C_{UMSEj} = \%sale \times (C_{UPi})_j \quad \textbf{(4-18)}$$

, C_{UPi} is the purchasing cost per unit.

Then,

$$C_P = \sum_{i=1}^{N_P} \sum_{j=1}^{N_{SE}} (C_{UMSE_i})_j \quad \textbf{(4-19)}$$

However, if raw materials are procured from a local backup supplier, C_P equals

$$C_{UMSLBs} = \%sale \times (C_{UPi})_s \times R_{SLBj} \quad \textbf{(4-20)}$$

Therefore,

$$C_P = \sum_{i=1}^{N_P} \sum_{s=1}^{N_{SLB}} (C_{UMSLB_i})_s \quad \textbf{(4-21)}$$

4.2.5.5. Transportation Cost (C_{tr})

The transportation cost represents the unit cost for transporting raw materials from a supplier to the production system in a time period t. This cost varies depending on the access from the potential location to the production facility. An assumption of this research is that the transportation of raw materials is conducted in batches that meet customer satisfaction. Tensor (T) as a multi-linear form that can be used here for presenting the transportation cost required to transport raw materials from its origin s to its destination v using transportation mode m.

C_{tr} as a component of C_{RM} can be calculated as:

For an external supplier,

$$C_{tr} = \sum_{j=1}^{N_{SE}} \sum_{l=1}^{N_T} \sum_{i=1}^{N_P} T_{SLB_j,V,m} \times t_{m_l} \times \%V_i \quad \textbf{(4-22)}$$

, l= *1, 2, 3 …,* N_T

Nevertheless, for a local backup supplier,

$$C_{tr} = \sum_{s=1}^{N_{SLB}} \sum_{l=1}^{N_T} \sum_{i=1}^{N_P} T_{SE_s,V,m} \times t_{m_l} \times \%V_i \quad \textbf{(4-23)}$$

4.2.5.6. Duties Cost (C_D)

This is the tax incurred by importing goods from a supplier in one country to a customer in another country. It is based on the value of goods or upon some criteria of the item such as weight and dimensions. This work considers C_D as the cost arising from supplying raw materials by a regular external supplier S_{Ej} to the production system. It means that for local backup suppliers S_{LBj} there are no duties arising from supplying raw materials to the production system. It can be calculated as:

$$C_D = \sum_{i=1}^{N_P} \sum_{j=1}^{N_S} C_{UP_i} \left(1 - IF_j\right) \times D_j \qquad \textbf{(4-24)}$$

, IF_j=0 if S_{Ej}=1 & IF=1 otherwise.

4.2.5.7. Transfer Price Cost (TP)

The transfer price is the per unit price of products and services to be charged by independent organisations (Abdallah 1989; Chen, Lihua 2011). It is one of the most significant issues facing multinational companies (MNCs). In a survey of over 200 MNCs, 80% recognised that they are facing *TP* as one of the most important concern (O'Connor 1997). The impact of *TP* on organisations is not only on accounting but also on other functions (Vidal & Goetschalckx 2001). The most current *TP* strategies are based on either external market prices or internal costs which are a concern for tax authorities (Mueller, Gernon & Meek 1997).

In this research, *TP*, as a transfer price for procuring raw materials from a regular external supplier S_{Ej}, can be calculated as:

$$TP = \sum_{j=1}^{N_{SE}} \sum_{i=1}^{N_P} tp_j \times C_{UP_i} \qquad \textbf{(4-25)}$$

Therefore, for external supplier, C_{RM} can be calculated as follows:

$$\begin{aligned} C_{RM} = & \sum_{j=1}^{N_{SE}} C_{UOj} \times OF + \sum_{i=1}^{N_P} \sum_{j=1}^{N_{SE}} (C_{UHi})_j \times \%d_{RM} \times (LT_j + SF) \\ & + \sum_{i=1}^{N_P} \sum_{j=1}^{N_{SE}} (C_{UMSE_i})_j + \sum_{j=1}^{N_{SE}} \sum_{l=1}^{N_T} \sum_{i=1}^{N_P} T_{SLB_j,V,m} \times t_{m_l} \times \%V_i \\ & + \sum_{i=1}^{N_P} \sum_{j=1}^{N_{SE}} C_{UP_i}\left(1 - IF_j\right) \times D_j + \sum_{j=1}^{N_{SE}} \sum_{i=1}^{N_P} tp_j \times C_{UP_i} \end{aligned} \qquad \textbf{(4-26)}$$

However, for local backup supplier, C_{RM} equals

$$C_{RM} = \sum_{s=1}^{N_{SLB}} C_{UOs} \times OF + \sum_{i=1}^{N_P} \sum_{s=1}^{N_{SLB}} (C_{UHi})_s \times \%d_{RM} \times (LT_j + SF) + \sum_{i=1}^{N_P} \sum_{s=1}^{N_{SLB}} (C_{UMSLB_i})_s + \sum_{s=1}^{N_{SLB}} \sum_{l=1}^{N_T} \sum_{i=1}^{N_P} T_{SLB_s,V,m} \times t_{m_l} \times \%V_i \quad \textbf{(4-27)}$$

4.2.5.8. Worker Cost (C_W)

The costs of labour are the wages paid to the employee for performing certain duties in any organisation in a time unit. In this study, each operation requires an operational time h_i (hours) and the time of producing one product is the sum of operational time of all operations. C_W is considered as the rate resulting from multiplying the cost of working time by the time required for producing the final product (hour). This can be calculated as follows:

$$C_W = \sum_{i=1}^{N_P} C_W = \sum_{i=1}^{N_P} C_{L_i} \times h_i \quad \textbf{(4-28)}$$

4.2.5.9. Utilities Cost (C_U)

The utilities cost is the cost arising from using the required utilities such as electricity, gas, heat, water and maintenance to produce the final product in the production facility. This research considers C_U as a percentage of the raw material cost of the final product. It equals:

$$C_U = \sum_{i=1}^{N_P} \% \, Util \times C_{RM_i} \quad \textbf{(4-29)}$$

By considering C_{pt} as the cost of raw materials used to produce one part of the final product it is equal to

$$C_{Pt} = C_O + C_H + C_P + C_{tr} + C_D + TP + C_W + C_U \quad \textbf{(4-30)}$$

4.2.5.10. Risk Cost (C_R)

The risk cost is the cost arising from the likelihood of that any disruptive occurrence might affect either the whole or part of the production process. These risks have a significant impact on the total cost of the system. In this study, each supplier has a different impact on the supply chain of the production system depending on its risk score. Therefore, C_R can be calculated by the following equation:

$$C_R = \sum_{i=1}^{N_P}\sum_{k=1}^{LH_k} \%TRS_{i,k} \times C_{pt_i} = \sum_{i=1}^{N_P}\sum_{k=1}^{LH_k} \frac{LH_k \times I_k}{Max(LH_k \times I_k)} \times C_{pt_i} \quad \textbf{(4-31)}$$

Finally, the total cost of the product is the sum of all mentioned costs which can be found as:

$$C_T = C_{Pt} + C_R \quad \textbf{(4-32)}$$

C_T can be calculated where an external supplier is used for procuring raw materials as follows:

$$\begin{aligned} C_T = {} & \sum_{j=1}^{N_{SE}} C_{UOj} \times OF + \sum_{i=1}^{N_P}\sum_{j=1}^{N_{SE}} (C_{UHi})_j \times \%d_{RM} \times \left(LT_j + SF\right) \\ & + \sum_{i=1}^{N_P}\sum_{j=1}^{N_{SE}} (C_{UMSE_i})_j + \sum_{j=1}^{N_{SE}}\sum_{l=1}^{N_T}\sum_{i=1}^{N_P} T_{SLB_j,V,m} \times t_{m_l} \times \%V_i \\ & + \sum_{i=1}^{N_P}\sum_{j=1}^{N_{SE}} C_{UP_i}\left(1 - IF_j\right) \times D_j + \sum_{j=1}^{N_{SE}}\sum_{i=1}^{N_P} tp_j \times C_{UP_i} \\ & + \sum_{i=1}^{N_P} C_{L_i} \times h_i + \sum_{i=1}^{N_P} \%util \times C_{RM_i} \\ & + \sum_{i=1}^{N_P}\sum_{k=1}^{LH_k} \frac{LH_k \times I_k}{Max(LH_k \times I_k)} \times C_{pt_i} \end{aligned} \quad \textbf{(4-33)}$$

Also, when raw materials are supplied by the local backup supplier, C_T can be found as:

$$C_T = \sum_{s=1}^{N_{SLB}} C_{UOs} \times OF + \sum_{i=1}^{N_P}\sum_{s=1}^{N_{SLB}} (C_{UHi})_s \times \%d_{RM} \times (LT_j + SF) + \sum_{i=1}^{N_P}\sum_{s=1}^{N_{SLB}} (C_{UMSLB_i})_s + \sum_{s=1}^{N_{SLB}}\sum_{l=1}^{N_T}\sum_{i=1}^{N_P} T_{SLB_s,V,m} \times t_{m_l} \times \%V_i + \sum_{i=1}^{N_O} C_{L_i} \times h_i + \sum_{i=1}^{N_P} \%util \times C_{RM_i} + \sum_{i=1}^{N_P}\sum_{k=1}^{LH_k} \frac{LH_k \times I_k}{Max(LH_k \times I_k)} \times C_{pt_i} \quad \textbf{(4-34)}$$

4.2.6. *Model Objective Function*

The total cost of the final product involves both production and risk costs. The former are the costs incurred by producing the final product within the production systems. It comprises ordering, holding, purchasing, transportation, duties, transfer price, worker and utilities costs. On the other hand, the latter, being the risk cost, is the cost arising from using a JIT technique to minimise its production cost. The main objective function of this research is *to minimise the production cost of the final product as well as minimising the risks arising from this reduction in the JIT system*.

Using an external supplier to minimise costs

$$C_T = C_O + C_H + C_P + C_{tr} + C_D + TP + C_W + C_U + C_R \quad \textbf{(4-35)}$$

Using a local backup supplier also to minimise costs

$$C_T = C_O + C_H + C_P + C_{tr} + C_W + C_U + C_R \quad \textbf{(4-36)}$$

4.3. Concluding Remarks

This chapter presented a mathematical model for a simultaneous cost-risk reduction in JIT systems. It was developed to determine an optimal strategy for supplying raw materials to the production systems. Regular multi-external and local backup suppliers were used where disruptions such as natural and/or man-made disasters and economic crises were likely to occur. A model was developed to minimise the total costs of the final product in the

production system and to limit the risks arising from these benefits. The total cost includes raw material, worker, utilities and risk costs.

The mathematical model was coded by using JAVA. In this program, each cost component is coded individually and the total cost of the final product equals the summation of these components outcomes. The decision variable levels were selected to validate the objective functions achieved by this research for simultaneous cost-risk reduction in JIT systems.

5. A Simplified Application of the Developed SCRRJITS Model

5.1. Introduction

In this chapter, a simplified example is presented to demonstrate the application of the proposed mathematical model for the evaluation of the design of a simultaneous cost-risk reduction in production systems adopting a JIT system. The objective of this chapter is to test and verify the effectiveness of the SCRRJITS model developed in this research for solving this problem.

The remainder of this chapter is organised as follows: Section 5.2 presents a description of the simplified example assumed for this purpose; the results obtained from this example are then discussed in detail in Section 5.3; finally, a summary of this chapter is described in Section 5.4.

5.2. Simplified Example

The mathematical model proposed in Chapter 4 has been tested with a simple assembly process for an electric motor with a hollow shaft. It uses multiple and identical operations to assemble twenty five individual parts into the finished product ($N_P = 25$). The main components of this motor are illustrated in Figure 5.1.

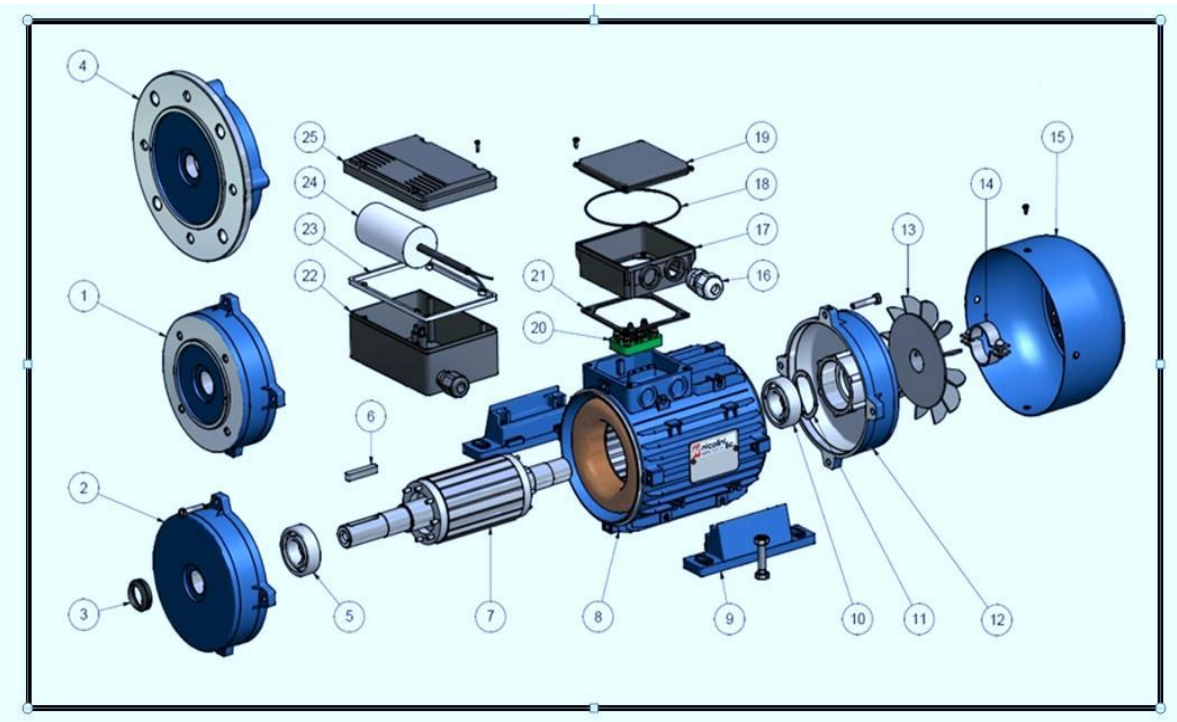


Figure 5.1: Electric motor (Hollow Shaft)

It is assumed that a production system purchases raw materials in a fixed lot size from eleven different regular external suppliers ($N_{SE} = 11$). In such a JIT system, these raw materials are delivered at a fixed interval of time when they are needed and they are supplied by those external suppliers at a limited time as listed in Table 5.1.

Table 5.1: External suppliers used to supply raw materials to the production system and the required lead-time

External supplier No. (S_E)	Part No.	Lead-time (LT)
1	1, 2 & 4	24
2	3, 11 &18	32
3	5 & 10	18
4	6 & 7	38
5	8 & 9	42
6	12 & 15	28
7	13 & 14	35
8	17, 19 & 21	45
9	16 & 20	20
10	22, 23 & 25	28
11	24	21

The production system includes 5 operations conducted by five workers (W_1, W_2, W_3, W_4, and W_5 respectively). The number of working hours N_h is 8 hours a day for 5 days per week. Each worker has a fixed wage C_{Wi} valued at 14 monetary unit (MU)/ hour. Operation 1 assembles Parts 6, 7, 8, 9, and 20 and transfers them to Operation 2, which assembles Parts 5, 10, 11, 12, and 13, and then transfers them to Operation 3. Operation 3 assembles Parts 16, 17, 18, 19, 21, 22, 23, 24, and 25 and then transfer to Operation 4. Operation 4 assembles Parts 1, 2, 3, 4, 13, 14, and 15, and finally transfers the product to Operation 5 which tests and packages the final product into boxes and then sends them to the sales department. It is assumed that the utilities cost C_U is equal to 10% of the raw material cost.

It is furthermore assumed, that in the case of one or more of external suppliers suffering disruption, the production system can procure its raw materials from seven local backup suppliers ($N_{SLB} = 7$) with a higher cost but with a low risk and in a short lead time. Table 5.2 illustrates these local suppliers that provide the production system with their raw materials at a scheduled lead-time.

Table 5.2: Local backup suppliers used to supply raw materials to the production system and the required lead-time

Local backup supplier No. (S_{LB})	Part No.	Lead-time (LT)
1	1, 2 & 4	4
2	3, 11 &18	6
3	5, 10, 16 & 20	3
4	6, 7, 8 & 9	5
5	12, 13, 14 & 15	2
6	17, 19 & 21	8
7	22, 23, 24 & 25	7

For any extra amount of raw materials procured from both of external and local suppliers, discounts are offered to the production system as shown in Tables 5.3 and 5.4.

Table 5.3: Discounts offered by external suppliers for purchasing extra raw materials

External supplier	Discounts rate (%)						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
1	5	10	15	20	x	x	x
2	7	12	15	18	20	x	x
3	5	10	15	x	x	x	x
4	10	12	14	16	18	20	x
5	5	8	10	12	14	16	x
6	5	10	15	20	x	x	x
7	5	9	12	14	15	x	x
8	4	8	10	13	15	18	20
9	5	10	15	x	x	x	x
10	10	14	17	19	x	x	x
11	5	8	10	x	x	x	x

Table 5.4: Discounts offered by local backup suppliers for purchasing extra raw materials

Local backup supplier	Discounts rate (%)						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
1	5	10	15	20	x	x	x
2	7	12	15	18	20	x	x
3	5	10	15	x	x	x	x
4	10	12	14	16	18	20	x
5	4	8	10	12	14	16	x
6	4	8	10	13	15	18	20
7	5	9	12	14	15	x	x

The production facility produces 70 units/ day and it purchases raw materials from different regular external suppliers S_E (if no disruption occurs) and local backup supplier S_{LB} (when one or more of the regular suppliers are disrupted). Each order depends on the lead time from each supplier. These orders can meet customer needs during a fixed interval at normal times. A time delay, however, for the punctual arrival of these materials to the production system can cause many risk factors such as physical, social, legal, operational, economic and political. These factors can affect and disrupt the production system and all the supply chain processes.

The effects of these factors on the production facility are studied in this example. The end-customer purchases the final product at 485 MU. Figure 5.2 illustrates the supply chain relating to this production system.

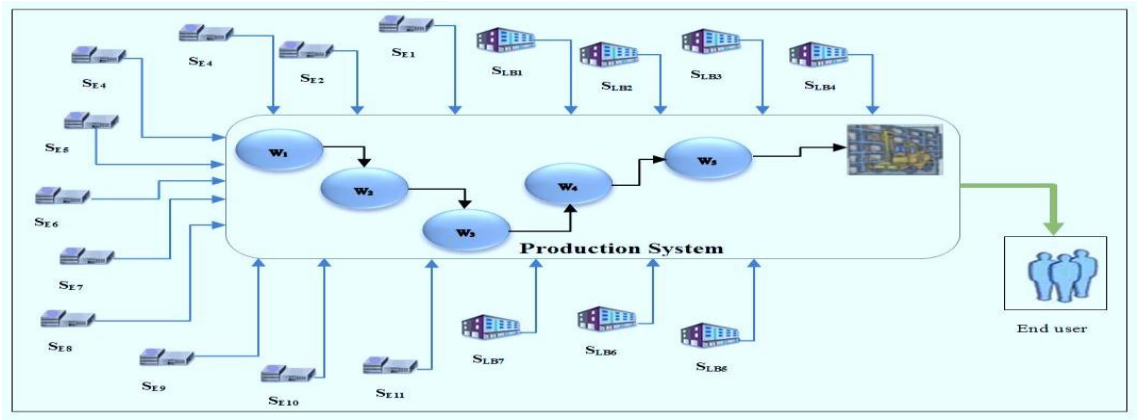


Figure 5.2: The supply chain for the production system

The next step is to identify the supply chain risks facing the production facility. Table 5.5 includes these main potential risks facing the production/ marketing of this product and their impacts within the production system. Risk identification was done by identifying the effect of the disruption or changes in demand that this had on the production facility. It can also be approached by investigating all possible root causes due to malfunction in the supply chain.

According to Bogataj and Bogataj (2007), risk can be assessed by two common approaches: the likelihood of the occurrence of an (undesirable) event and the negative implications of this event. Risk likelihood captures the probabilities associated with the risks of disruption in the supply chain. Respondents reporting on a risk which had already been experienced in the past were asked to document the degree of likelihood of its reoccurrence (Bovell 2012). The risk impact also depends on some factors such as the percentage cost of raw materials and its

effect on the total cost of required raw materials. The total risk score therefore can be calculated by multiplying those scores together.

The risks H_1, H_2, H_3, H_4, H_5, H_6, H_7, H_8, H_9, H_{10} and H_{11} might result from increasing the lead time of the raw materials of external suppliers S_{E1}, S_{E2}, S_{E3}, S_{E4}, S_{E5}, S_{E6}, S_{E7}, S_{E8}, S_{E9}, S_{E10} and S_{E11} respectively to arrive at the manufacturing site at the planned time. Table 5.5 illustrates the risk assessment of the electric motor in the production system. It is possible that natural, economic or man-made disasters may occur, such as floods or earthquakes, changes in currency valuation or industrial disputes. H_{12} may arise from a shortage of raw materials ordered from the external suppliers to the production system. This may result from some factors such as increasing customer demand in the marketplace and inventory elimination by implementing a JIT system within the production facility. The likelihood of its occurrence is low and its impact on the production system will be mostly high. Finally, H_{13} may arise from the lack of customer demand in the marketplace which will incur a holding cost for the production facility by keeping the final products within its warehouses. The likelihood of this occurrence is also very low but conversely, its impact on the production system will be high.

Table 5.5: Risk assessment of the electric motor production system

Risk Symbol	Risk	Product Effect	Likelihood (1 - 10)	Impact (1 - 10)	% Total Risk Score
H_1	Supplier 1 cannot supply raw materials on the scheduled time or is destroyed by disasters.	Parts 1, 2 & 4	2	2	$\frac{4}{100} = 4\%$
H_2	Supplier 2 cannot supply raw materials on the scheduled time or is destroyed by disasters.	Parts 3, 11 & 18	5	1	$\frac{5}{100} = 5\%$
H_3	Supplier 3 cannot supply raw materials on the scheduled time or is destroyed by disasters.	Parts 5 & 10	1	3	$\frac{3}{25} = 3\%$
H_4	Supplier 4 cannot supply raw materials on the scheduled time or is destroyed by disasters.	Parts 6 & 7	3	1	$\frac{3}{100} = 3\%$
H_5	Supplier 5 cannot supply raw materials on the scheduled time or is destroyed by disasters.	Parts 8 & 9	1	5	$\frac{5}{100} = 5\%$
H_6	Supplier 6 cannot supply raw materials on the scheduled time or is destroyed by disasters.	Parts 12 & 15	5	1	$\frac{5}{100} = 5\%$
H_7	Supplier 7 cannot supply raw materials on the scheduled time or is destroyed by disasters.	Parts 13 & 14	4	1	$\frac{4}{100} = 4\%$
H_8	Supplier 8 cannot supply raw materials on the scheduled time or is destroyed by disasters.	Parts 17, 19 & 21	2	2	$\frac{4}{100} = 4\%$
H_9	Supplier 9 cannot supply raw materials on the scheduled time or is destroyed by disasters.	Parts 16 & 20	2	3	$\frac{6}{100} = 6\%$
H_{10}	Supplier 10 cannot supply raw materials on the scheduled time or is destroyed by disasters.	Parts 22, 23 & 25	3	1	$\frac{3}{100} = 3\%$
H_{11}	Supplier 11 cannot supply raw materials on the scheduled time or is destroyed by disasters.	Part 24	1	3	$\frac{3}{100} = 3\%$
H_{12}	End-customer demand is higher than forecasted demand.	All product	4	5	$\frac{20}{100} = 20\%$
H_{13}	End-customer demand is lower than forecasted demand.	All product	5	4	$\frac{20}{100} = 20\%$

All of these risks might disrupt the production system and at the same time affect the other supply chain parties. Their impacts, nevertheless, can be reduced by using local suppliers

even if the total cost of the final product will be relatively high. This policy can dramatically improve the supply chain's efficiency and responsiveness so as to enable it to maintain continuous production during the disruption time and to ensure the organisation's reputation is maintained in the marketplace. Table 5.6 illustrates the list of the external suppliers who can supply raw materials in a normal situation and the local suppliers who can supply raw materials if external supply is disrupted.

Table 5.6: External and local suppliers who can supply raw materials in the normal situation and in the disruption time

Part		External supplier S_E										Part	Local backup supplier S_{LB}						
No.	1	2	3	4	5	6	7	8	9	10	11	No.	1	2	3	4	5	6	7
1	1	0	1	0	0	0	0	1	0	0	0	1	1	0	0	1	0	0	1
2	1	0	1	0	0	0	0	1	0	0	0	2	1	0	0	1	0	0	1
4	1	0	1	0	0	0	0	1	0	0	0	4	1	0	0	1	0	0	1
3	0	1	0	0	0	0	1	0	0	0	1	3	0	1	0	0	1	1	0
11	0	1	0	0	0	0	1	0	0	0	1	11	0	1	0	0	1	1	0
18	0	1	0	0	0	0	1	0	0	0	1	18	0	1	0	0	1	1	0
5	0	0	1	1	0	0	0	1	0	1	1	5	1	1	1	0	0	0	0
10	0	0	1	1	0	0	0	0	0	1	0	10	1	1	1	0	0	0	0
6	0	0	0	1	0	1	0	0	1	0	0	16	1	1	1	0	0	0	0
7	0	0	0	1	0	1	0	0	1	0	0	20	1	1	1	0	0	0	0
8	0	1	0	1	1	0	0	0	0	0	0	6	0	1	0	1	0	0	1
9	0	1	0	1	1	0	0	0	0	0	0	7	0	1	0	1	0	0	1
12	1	0	0	0	1	1	0	0	0	0	0	8	0	1	0	1	0	0	1
15	1	0	0	0	1	1	0	0	0	0	0	9	0	1	0	1	0	0	1
13	0	0	1	0	0	0	1	1	0	0	0	12	1	0	0	0	1	1	0
14	0	0	1	1	0	0	1	1	0	0	0	15	1	0	0	0	1	1	0
17	0	0	0	0	1	0	0	1	0	0	1	13	1	0	0	0	1	1	0
19	0	0	0	0	1	0	0	1	0	0	1	14	1	0	0	0	1	1	0
21	0	0	0	0	1	0	0	1	0	0	1	17	0	0	1	1	0	1	0
16	0	1	0	0	0	0	1	0	1	0	0	19	0	0	1	1	0	1	0
20	0	1	0	0	0	0	1	0	1	0	0	21	0	0	1	1	0	1	0
22	0	0	0	0	0	1	0	0	1	1	0	22	0	0	1	0	1	0	1
23	0	0	0	0	0	1	0	0	1	1	0	23	0	0	1	0	1	0	1
25	0	0	0	0	0	1	0	0	1	1	0	24	0	0	1	0	1	0	1
24	1	0	0	0	0	0	0	0	0	1	1	25	0	0	1	0	1	0	1

The selection of the appropriate supplier depends on its reliability (R_{SLB} / R_{SE}) as shown in Table 5.7. It is considered as a percentage of the purchasing cost of each part supplied by the regular supplier. Table 5.7 also depicts the lead time required for supplying raw materials to the production facility. The main cost drivers in the electric motor using regular external suppliers are shown in Table 5.8. They are a percentage of the total cost of the motor. Table 5.8 also illustrates the cost percentage, incurred duties and the transfer price for each supplier.

Table 5.7: Reliability for external and local suppliers who can supply raw materials if the regular supplier has disruption

Part No.	Reliability for external supplier S_E (%)											Part No.	Reliability for local supplier S_{LB} (%)						
	1	2	3	4	5	6	7	8	9	10	11		1	2	3	4	5	6	7
1			155					160				1	150			160			155
2			155					160				2	150			160			155
4			155					160				4	150			160			155
3							155				150	3		145			150	148	
11							155				150	11		145			150	148	
18							155				150	18		145			150	148	
5				165						165		5	165	163	160				
10				165						165		10	165	163	160				
6						158			160			16	165	163	160				
7						158			160			20	165	163	160				
8		160		157								6		158		155			160
9		160		157								7		158		155			160
12	150				145							8		158		155			160
15	150				145							9		158		155			160
13			145					150				12	150				140	145	
14			145					150				15	150				140	145	
17					155						160	13	150				140	145	
19					155						160	14	150				140	145	
21					155						160	17			155	152		150	
16		165					164					19			155	152		150	
20		165					164					21			155	152		150	
22						155			150			22			150		147		145
23						155			150			23			150		147		145
25						155			150			25			150		147		145
24	150									155		24			150		147		145

Table 5.8: Cost drivers in the electric motor

Supplier	Part No.	Part Name	% Cost	% Supplier rate	%Duty	Transfer price
1	1	Flange B14	4.50	14.00		
	2	Front Shield	4.25			
	4	Flange B5	5.25		0.02	0.015
2	3	Rubber Seal Ring	0.75	2.90		
	11	Split Ring	0.90			
	18	OR Seal	1.25		0.025	0.02
3	5	Bearing	2.50	5.00		
	10	Bearing	2.50		0.015	0.03
4	6	Key	0.75	17.75		
	7	Rotor Shaft	17.00		0.03	0.02
5	8	Casing and Win.	22.00	23.60		
	9	Separate Feet	1.60		0.025	0.015
6	12	Rear Shield	4.25	7.75		
	15	Fan Cover	3.50		0.015	0.025
7	13	Fan	2.00	3.00		
	14	Fan Fixing Ring	1.00		0.02	0.03
8	17	Terminal Box	2.00	4.50		
	19	Cover Box	1.50			
	21	Seal for Cover	1.00		0.025	0.02
9	16	Core Hitch	2.50	6.00		
	20	Terminal Strip	3.50		0.02	0.025

10	22	Capacitor Box	4.50	8.50		
	23	Seal for Box	2.50			
	25	Cover Box	1.50		0.03	0.015
11	24	Capacitor	7.00	7.00	0.025	0.02

5.3. Results and Discussion

The purpose of this section is to analyse the results of the testing of the proposed model. It will be used to ascertain the effect of decision variables on other parameters examined within the production system. The findings of this chapter are divided into four sections. Section 5.3.1 presents the model verification to demonstrate the capability of the developed model in achieving the accurate results. Section 5.3.2 analyses the achieved results in different cases of external suppliers' disruption using different levels of decision variables. Another analysis of the obtained results is presented in Section 5.3.3 in different cases of external suppliers' disruption using the same levels of decision variables. Finally, Section 5.3.4 highlights the model results using different levels of decision variables in a case where some of the external suppliers are disrupted.

5.3.1. *Model Verification*

Verification is an essential part of the model development process designed to ensure that the transformation into a computer model is achieved with a sufficient accuracy, regardless of the optimisation tool and technique used for this purpose. According to Schlesinger (cited in Sargent 2003), model verification can be defined as "substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model". In addition, a model sometimes gains credibility if it satisfies specified accreditation criteria based on a specific process (Sargent, Robert 2003). For this reason, the mathematical equations used to achieve the objective functions of this model were coded in Microsoft Excel as well as a JAVA program.

A comparison between the developed model and MS Excel was carried out where all external suppliers were able to supply their raw materials to the production system. Table 5.9 summarises the developed model results, MS Excel results, the difference between them and the percentage of error arising from these differences. Minor differences shown in some cost types between the two calculations (model results versus MS Excel results) are recorded due to the higher accuracy of the computer-based calculations. By conducting this simplified example, it was concluded that the model programming of the objective function was verified.

Table 5.9: Comparison between the developed model and MS Excel results

Cost type	Developed model results (MU)	MS Excel results (MU)	Difference (MU)	Percentage of error (%)
Ordering cost	3.07367	3.07367	0	0
Holding cost	63.34	63.23	0.11	0.0017
Purchasing cost	229.1767	229.16	0.0167	7.2869×10^{-5}
Transportation cost	48.45	48.45	0	0
Duties	6.6414	6.6407	0.0007	0.0001
Utilities cost	35.06818	35.05544	0.01274	0.00036
Transfer price	5.3333	5.3327	0.0006	0.0001
Worker cost	8	8	0	0
Risk cost	0	0	0	0
Total cost	399.083247	398.9425	0.14074	0.00035
Net profit	85.91675	86.05749	-0.14074	-0.0016
Sales price	485.00	485.00	0.00	0.00

Also, Figure 5.3 illustrates the effects of the required lead time on the total cost and the earned profit of the final product using the regular external suppliers for procuring raw materials to the production facility.

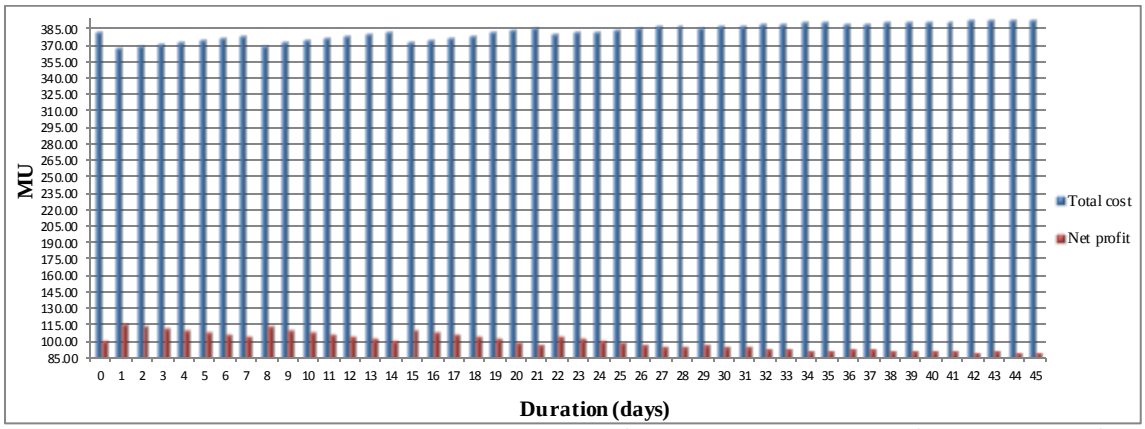


Figure 5.3: Lead time and its impact on net profit and risk cost arising from the use of external suppliers for supplying raw materials to the production facility

5.3.2. *Model Results Analysis in Different Cases of Occurrence for External Suppliers' Disruptions Using Different Levels of Decision Variables*

By using the previously mentioned external and local suppliers (N_{SE}= 11 and N_{SLB}= 7) for supplying raw materials to produce the final product in the production system, many disruptions may occur within the supply chain. It is assumed that if external supplier j has a disruption, then S_{Ej}=0 otherwise, S_{Ej}=1, and the same for the local suppliers. Table 5.10 illustrates a random selection of twenty of these disruptions as a case study to evaluate the performance of the developed model, the obtained results of total cost of the final product and

its components. This means that the selected local backup suppliers will be used for procuring raw materials during external supply chain disruptions.

As seen from the results shown in Table 5.10, the quantity of raw materials procured from the used suppliers (external/ local), customer demand, lead time required for raw materials to be received at the production facility and the transportation mode used for transporting raw materials to the production system, have a significant impact on the total cost of the final product. In the case of any disruption occurrence, it is clear that by changing each decision variable, the result would be different. In cases where all external suppliers are disrupted, using the highest levels of the used decision variables, it is found that C_P is the highest rate compared with the other disruptions. This is based on the local suppliers' reliability. However, C_{tr} is relatively the lowest because of the cost results from transporting raw materials from their origins to the production system. The impact of these disruptions on the related costs of the final product can also be very clearly seen in Figure 5.4.

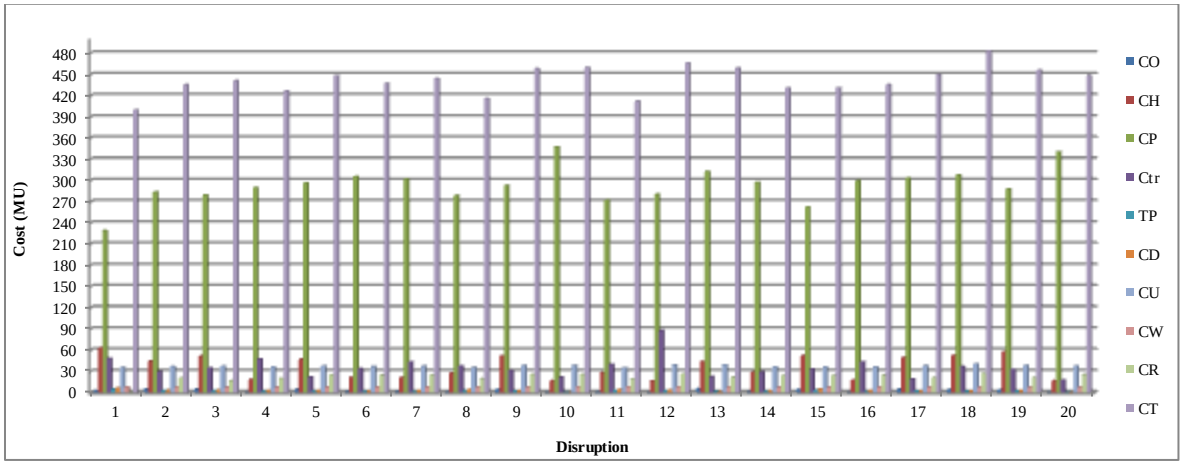


Fig. 5.4 Impact of some expected disruptions on external suppliers using different variables levels

5.3.3. *Model Results Analysis in Different Cases of Occurrence for External Suppliers' Disruptions Using the Same Levels of Decision Variables*

This section analyses the effects of the decision variables taken at the same levels in the event of some disruptions occurring to external suppliers. Table 5.11 illustrates computational results for twenty cases of expected disruptions selected at random. These findings and their impacts on the production cost can be clearly seen in Figure 5.5.

A comparison is made between the case where all external suppliers were able to supply their raw materials to the production system and the case where all suppliers also have disruptions

to their production systems (see Figure 5.6). This comparison illustrates the effects of these disruptions on the cost types which will affect the total cost required to produce the final product. It is clear that using the local backup suppliers to supply raw materials, the total cost is higher than if the external suppliers are used for this purpose. C_P and C_R, where all suppliers are disrupted, are higher than the other cases. However, C_H, C_{tr}, TP, and C_D are the lowest.

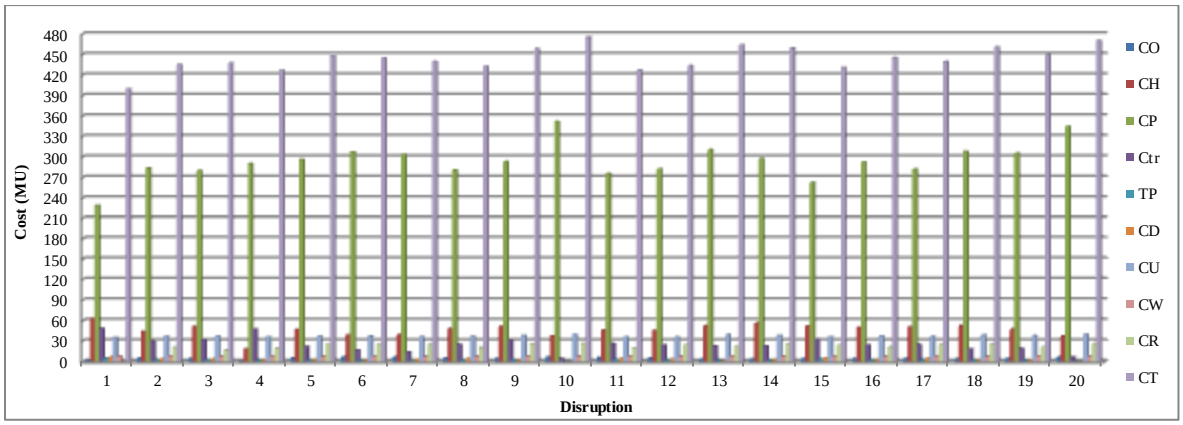


Fig. 5.5 Impact of some expected disruptions on the related costs using the same variables levels

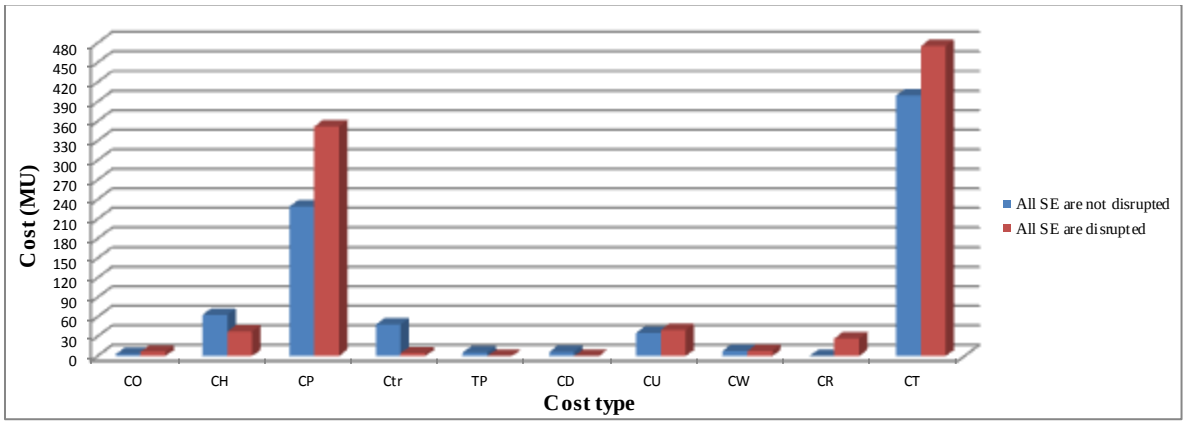


Fig. 5.6 Cost types comparison between the cases of all external suppliers (1) uninterrupted (2) disrupted

5.3.4. *Model Results Analysis in a Case of Some External Suppliers' Disruption Using Different Levels of Decision Variables*

To define the effects of each decision variable on the total cost of the final product, a second disruption is shown in Table 5.12 where S_{E1}= 1, S_{E2}= 0, S_{E3}= 1, S_{E4}= 0, S_{E5}= 1, S_{E6}= 0, S_{E7}= 1, S_{E8}= 0, S_{E9}= 1, S_{E10}= 0, S_{E11}= 1 was selected for this purpose. By changing the used decision variables levels (Q_{RM}, d_P, LT, and t_m), the total cost of the product will be changed depending on the effect of each variable as shown in Table 5.10.

Table 5.10: Computational results for some external suppliers' disruption using different levels of the decision variables

No.	External supplier situation in the supply chain											Q_{RM} / week	d_p / day	t_m	C_O	C_H	C_P (MU)	C_{tr}	TP	C_D	C_U	C_W	C_R	Total cost
	1	2	3	4	5	6	7	8	9	10	11	(unit)	(unit)	(unit)	(MU)	(MU)		(MU)	(MU)	(MU)	(MU)	(MU)	(MU)	(MU)
1	1	1	1	1	1	1	1	1	1	1	1	350	70	1	3.07	57.71	229.16	48.45	6.64	5.33	35.04	8.00	0	393.40
2	1	0	1	0	1	0	1	0	1	0	1	350	70	1	5.52	44.67	283.52	29.65	3.04	3.61	37.00	8.00	20.75	435.76
3	1	1	0	0	1	1	0	0	1	0	1	350	70	2	7.92	25.17	291.84	35.09	3.07	3.76	36.69	8.00	16.46	428.00
4	1	0	1	0	1	0	0	0	1	0	1	1750	210	1	0.41	18.85	290.24	47.88	2.40	2.96	36.27	8.00	20.35	427.36
5	1	0	1	1	0	0	1	1	0	0	0	350	70	1	5.03	47.41	296.61	22.41	2.49	2.95	37.69	8.00	25.36	447.95
6	1	0	1	1	0	0	0	0	0	0	0	700	140	3	1.42	21.73	305.90	34.10	1.99	2.47	36.76	8.00	24.74	437.11
7	0	0	0	1	1	0	0	0	0	0	0	1050	140	4	1.48	21.59	302.32	43.50	1.97	3.12	37.40	8.00	25.16	444.54
8	0	1	0	1	1	0	0	0	1	1	0	1050	140	1	1.05	27.85	278.94	37.77	2.90	4.36	35.29	8.00	19.81	415.97
9	1	0	1	0	0	1	0	1	0	1	1	350	70	1	4.71	51.79	293.13	31.23	2.53	2.81	38.62	8.00	25.97	458.79
10	0	0	0	0	0	0	0	0	0	0	0	2450	210	4	0.47	17.46	347.52	21.95	0	0	38.74	8.00	26.05	460.18
11	1	1	0	1	1	0	0	0	1	0	0	1050	140	1	1.09	28.46	272.48	39.97	3.13	4.43	34.96	8.00	19.63	412.15
12	0	0	1	1	1	0	0	1	0	0	1	2100	210	3	0.52	16.63	280.64	87.66	3.03	4.13	39.26	8.00	26.39	466.26
13	0	1	1	0	0	1	1	0	1	0	1	350	70	1	4.23	50.86	313.01	22.66	2.17	1.72	39.47	8.00	22.11	464.23
14	0	1	1	0	0	1	1	0	1	0	1	700	140	2	1.32	23.28	310.50	31.16	2.17	1.72	37.02	8.00	20.76	435.93
15	1	1	0	1	1	0	1	0	0	1	1	350	70	1	4.77	52.41	262.54	33.44	3.71	5.46	36.23	8.00	24.39	430.95
16	0	0	0	1	1	0	0	0	0	0	0	1050	210	4	0.51	17.20	299.80	34.50	1.97	3.12	35.71	8.00	24.64	425.45
17	0	1	1	1	0	0	0	1	1	0	0	350	70	1	4.95	49.70	303.49	19.35	2.23	2.53	38.23	8.00	21.42	449.90
18	0	1	1	1	0	0	0	1	1	0	0	1400	140	3	1.47	21.56	304.08	54.18	2.23	2.53	38.61	8.00	21.63	454.29
19	1	1	1	0	0	1	0	1	1	1	0	350	70	1	4.01	57.52	288.10	32.63	2.72	2.86	38.78	8.00	21.73	456.35
20	0	0	1	0	0	0	0	0	0	0	0	2450	210	2	0.51	17.15	344.56	15.37	0.16	0.20	37.80	8.00	25.42	449.17

Table 5.11: Computational results for some external suppliers' disruption using the same decision variables levels

No.	External supplier situation in the supply chain											Q_{RM} / week	d_p / day	t_m	C_O	C_H	C_P (MU)	C_{tr}	TP	C_D	C_U	C_W	C_R	Total cost
	1	2	3	4	5	6	7	8	9	10	11	(unit)	(unit)	(unit)	(MU)	(MU)		(MU)	(MU)	(MU)	(MU)	(MU)	(MU)	(MU)
1	1	1	1	1	1	1	1	1	1	1	1	350	70	1	3.07	57.71	229.16	48.45	6.64	5.33	35.04	8.00	0	393.40
2	1	0	1	0	1	0	1	0	1	0	1	350	70	1	5.52	44.67	283.52	29.65	3.04	3.61	37.00	8.00	20.75	435.76
3	1	1	0	0	1	1	0	0	1	0	1	350	70	1	4.75	51.97	279.9	31.90	3.074	3.76	37.54	8.00	16.84	437.73
4	1	0	1	0	1	0	0	0	1	0	1	350	70	1	6.16	41.47	287.17	27.94	2.79	3.45	36.90	8.00	20.69	434.57
5	1	0	1	1	0	0	1	1	0	0	0	350	70	1	5.03	47.41	296.61	22.41	2.49	2.95	37.69	8.00	25.36	447.95
6	1	0	1	1	0	0	0	0	0	0	0	350	70	1	6.53	39.07	307.52	17.05	1.99	2.47	37.46	8.00	25.21	445.30
7	0	0	0	1	1	0	0	0	0	0	0	350	70	1	6.65	39.72	303.94	14.50	1.97	3.12	36.99	8.00	24.89	439.78
8	0	1	0	1	1	0	0	0	1	1	0	350	70	1	5.65	48.47	280.58	25.18	2.90	4.36	36.71	8.00	20.59	432.44
9	1	0	1	0	0	1	0	1	0	1	1	350	70	1	4.71	51.79	293.13	31.23	2.53	2.81	38.62	8.00	25.97	458.79
10	0	0	0	0	0	0	0	0	0	0	0	350	70	1	17.76	10.69	390.75	4.39	0	0	42.36	8.00	28.44	502.39
11	1	1	0	1	1	0	0	0	1	0	0	350	70	1	5.56	46.86	276.02	26.65	3.13	4.43	36.27	8.00	20.35	427.27
12	0	0	1	1	1	0	0	1	0	0	1	350	70	1	5.63	45.68	282.28	24.35	3.03	4.13	36.51	8.00	24.58	434.19
13	0	1	1	0	0	1	1	0	1	0	1	350	70	1	4.23	50.86	313.01	22.66	2.17	1.72	39.47	8.00	22.11	464.23
14	0	1	1	1	0	1	0	0	1	0	1	350	70	1	4.91	50.01	292.91	24.66	2.91	3.03	37.84	8.00	21.21	445.48
15	1	1	0	1	1	0	1	0	0	1	1	350	70	1	4.77	52.41	262.54	33.44	3.71	5.46	36.23	8.00	24.39	430.95
16	0	0	0	1	1	0	1	1	0	1	0	350	70	1	4.88	50.68	282.02	25.14	2.83	4.31	36.99	8.00	24.89	439.74
17	0	1	0	1	0	0	1	1	0	0	1	350	70	1	4.72	51.31	309.14	18.66	2.04	2.65	38.85	8.00	26.12	461.49
18	0	1	1	1	0	0	0	1	1	0	0	350	70	1	4.80	50.47	296.17	23.35	2.62	3.02	38.04	8.00	21.32	447.79
19	1	1	1	0	0	1	0	1	1	1	0	350	70	1	4.01	57.52	288.10	32.63	2.72	2.86	38.78	8.00	21.73	456.35
20	0	0	1	0	0	0	0	0	0	0	0	350	70	1	6.14	42.21	349.08	5.59	0.16	0.20	40.34	8.00	27.12	478.84

Table 5.12: Computational results by changing the decision variables in case of (S_{E1}=1, S_{E2}=0, S_{E3}=1, S_{E4}=0, S_{E5}=1, S_{E6}=0, S_{E7}=1, S_{E8}=0, S_{E9}=1, S_{E10}=0, S_{E11}=1)

No.	External supplier situation in the supply chain											Q_{RM} / week	d_p / day	t_m	C_O	C_H	C_P (MU)	C_{tr} (MU)	TP	C_D	C_U	C_W	C_R	C_T (MU)
	1	2	3	4	5	6	7	8	9	10	11	(unit)	(unit)	(unit)	(MU)	(MU)			(MU)	(MU)	(MU)	(MU)	(MU)	
1	1	0	1	0	1	0	1	0	1	0	1	350	70	1	5.52	44.67	283.52	29.65	3.04	3.61	37.00	8.00	20.75	435.76
2	1	0	1	0	1	0	1	0	1	0	1	350	70	2	7.54	27.69	291.21	32.62	3.04	3.61	36.57	8.00	20.51	430.79
3	1	0	1	0	1	0	1	0	1	0	1	350	70	3	7.92	25.27	293.16	47.44	3.04	3.61	38.04	8.00	21.32	447.80
4	1	0	1	0	1	0	1	0	1	0	1	350	70	4	7.66	25.94	292.74	59.30	3.04	3.61	39.23	8.00	21.98	461.50
5	1	0	1	0	1	0	1	0	1	0	1	700	95	1	2.04	34.27	283.52	37.06	3.04	3.61	36.35	8.00	20.39	428.28
6	1	0	1	0	1	0	1	0	1	0	1	700	140	1	1.19	24.92	281.89	37.06	3.04	3.61	35.17	8.00	19.74	414.62
7	1	0	1	0	1	0	1	0	1	0	1	1050	140	2	1.48	21.59	282.39	48.92	3.04	3.61	36.10	8.00	20.26	425.39
8	1	0	1	0	1	0	1	0	1	0	1	1400	140	2	1.48	21.59	282.39	57.08	3.04	3.61	36.92	8.00	20.71	434.82
9	1	0	1	0	1	0	1	0	1	0	1	1750	115	3	2.04	24.26	284.02	94.88	3.04	3.61	41.19	8.00	23.05	484.09
10	1	0	1	0	1	0	1	0	1	0	1	1750	140	3	1.42	21.82	282.39	94.88	3.04	3.61	40.72	8.00	22.79	478.67
11	1	0	1	0	1	0	1	0	1	0	1	2100	140	4	1.47	21.56	282.39	133.42	3.04	3.61	44.55	8.00	24.90	522.94
12	1	0	1	0	1	0	1	0	1	0	1	2450	140	4	1.43	21.67	282.39	148.25	3.04	3.61	46.04	8.00	25.72	540.15
13	1	0	1	0	1	0	1	0	1	0	1	1050	170	1	0.57	22.56	280.58	44.47	3.04	3.61	35.48	8.00	19.92	418.23
14	1	0	1	0	1	0	1	0	1	0	1	1050	210	1	0.40	19.43	279.37	44.47	3.04	3.61	35.03	8.00	19.67	413.02
15	1	0	1	0	1	0	1	0	1	0	1	1400	210	2	0.47	17.50	279.62	57.08	3.04	3.61	36.13	8.00	20.27	425.72
16	1	0	1	0	1	0	1	0	1	0	1	1750	210	2	0.48	16.89	280.23	65.23	3.04	3.61	36.95	8.00	20.72	435.15
17	1	0	1	0	1	0	1	0	1	0	1	2100	155	3	0.78	21.25	281.45	106.74	3.04	3.61	41.69	8.00	23.33	489.89
18	1	0	1	0	1	0	1	0	1	0	1	2100	210	3	0.45	17.43	279.62	106.74	3.04	3.61	41.09	8.00	23.00	483.98
19	1	0	1	0	1	0	1	0	1	0	1	1050	210	4	0.47	17.48	279.62	88.95	3.04	3.61	39.32	8.00	22.02	462.51
20	1	0	1	0	1	0	1	0	1	0	1	2450	210	4	0.45	17.59	279.62	148.25	3.04	3.61	45.26	8.00	25.29	531.11

The findings illustrated that the highest total cost is obtained when Q_{RM}= 2450, d_p= 140 and 210, and t_m=4. The main affected cost components are: C_{tr} which depends on the transportation mode used for transporting raw materials from the suppliers, both external and local, to the production system; C_U that is considered as a percentage rate of some costs types which was mentioned previously and C_R arising from the used suppliers. As shown in Figure 5.7, these findings demonstrate that the use of different levels of decision variables in the case of any disruption occurrence have direct impacts on the overall cost arising from the production of the final product.

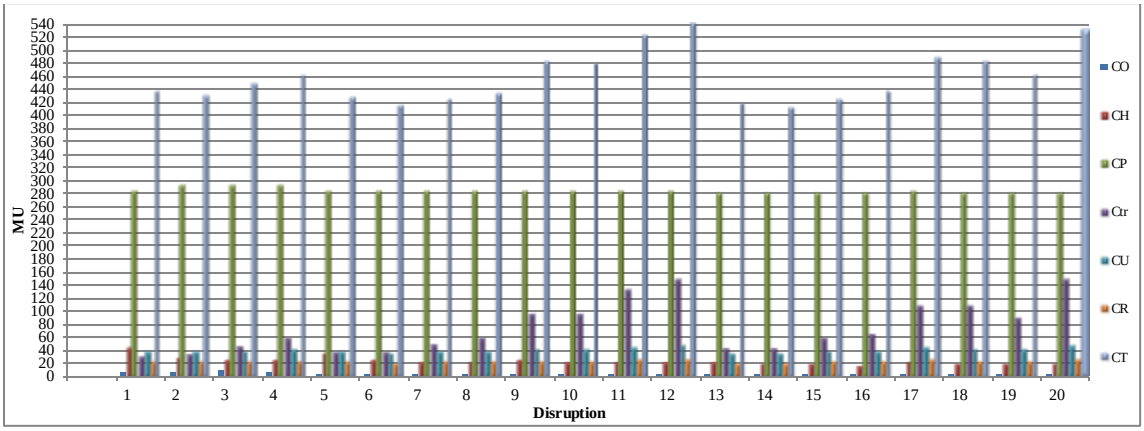


Fig. 5.7 Effects of decision variables on the related costs of the final product in a case of external suppliers disruptions using different levels of variables

5.4. Concluding Remarks

This chapter presented the application of the developed model in a simplified example. The results achieved from this model were compared with the results obtained from the Microsoft Excel program to verify that the model was designed with sufficient accuracy. As they were almost identical the computer programming was successfully validated. A comparison between the use of local backup suppliers supplying raw materials to the production facility in JIT systems and the use of external suppliers had a significant impact on the total cost of final product. This impact however, can also lead to other benefits such as preserving the reputation of the production facility with the end-customer. JIT principles can therefore be effectively applied for satisfying customer requirements with a minimum profit and a minimum level of risk. This developed mathematical model will be considered for optimisation purposes using a genetic algorithm (GA) which will be proposed in the next chapter.

6. A Robust Genetic Algorithm for Optimising a Simultaneous Cost-Risk Reduction in JIT Systems

6.1. Introduction

Optimisation has recently become one of the most pertinent issues in supply chain management and as such has received considerable attention. For this reason, academics and researchers have proposed many mathematical and heuristic approaches to solve engineering optimisation issues. Meta-heuristic optimisation techniques have also been applied in the supply chain management field to solve these issues (Tasan & Tunali 2008; Wang, K & Wang 2008). Such approaches have focused on transportation and distribution networks examining site locations and structures, network configuration and customer satisfaction by minimising the total product cost (Paksoy & Chang 2010). Optimisation is the process of adapting the inputs of a device with mathematical processes to find the minimum or maximum output. It is the main technique available for addressing complex problems. The key purpose of optimisation is to find the global optima (minimum or maximum) of a formulated objective function to a problem (Malhotra, Singh & Singh 2011).

Conventional optimisation approaches are incapable of solving many manufacturing engineering design problems (Marian 2003; Sivanandam & Deepa 2008a). Optimisation problems occur in some discrete cases where it is necessary to find an optimal solution among a limited or infinite number of alternative solutions. Even though the efforts required to solve these issues have recently increased, no universal approach to deal with such issues has yet been found (Tasan & Tunali 2008). Numerous intelligent algorithms have been developed for production decision-making such as tabu search, simulated annealing, ant colony algorithm, hybrid intelligent algorithms and genetic algorithm (GA). The latter is the most commonly used of these approaches (Liu, W et al. 2013; Rabta & Reiner 2012).

Chapter 2 reviewed the literature on the optimisation of cost and risk reduction in the supply chain using key lean manufacturing techniques used for managing their systems. It was noted however that there is a paucity of literature simultaneously addressing the cost-risk reduction using these methods particularly Just-in-Time (JIT) systems.

This chapter describes the development of a robust genetic algorithm approach for optimising a simultaneous cost-risk reduction in JIT systems. The objectives of this chapter are:

- To assess the optimisation technique proposed for solving the simultaneous cost-risk reduction problem in JIT systems;
- To review the GA applications in supply chain systems based on the key components of GA such as initial population, evaluation, and genetic operators functions;
- To define the most appropriate parameters used for finding the optimal or near-optimal solution of the model developed in chapter 4; and
- To present the circumstance of using GA as an optimisation approach for dealing with such an issue.

This chapter starts with a review of the genetic algorithm concept (Section 6.2). Genetic operators are then explained (Section 6.3) and the application of GA on the developed model is described (Section 6.4). Next the role of the key parameters' setting in GA is examined in a simplified example (Section 6.5) and the obtained results are analysed to illustrate the effectiveness of the developed GA (Section 6.6). Finally, a summary of this chapter and a brief introduction to the next chapter are outlined (Section 6.7).

6.2. The Genetic Algorithm Concept

Genetic Algorithm (GA) is considered as one of the most popular approaches that can be used to solve problems, particularly for NP-hard and complex optimisation problems (Gupta, D & Ghafir 2012). It is also a computer based technique, which is adapted and developed for a changing and highly competitive environment (Malhotra, Singh & Singh 2011).

GA therefore has the following advantages over the other meta-heuristic techniques (Gen & Cheng 2000; Goldberg 1989; Haupt & Haupt 2004; Marian 2003):

- GA is a population based approach enabling simultaneous searches from a wide sampling of target space and to optimise problems possessing extremely complex cost surfaces;
- GA works with the coding of the parameters' sets rather than the parameters themselves to increase the solution space;
- GA uses only probabilistic rules for solving complex problems including a large number of variables. These variables may be continuous, discrete or mixed;

- GA works with any kinds of objective functions and constraints in linear/non-linear forms with any solution space;
- GA uses chromosomes for encoding and searching for solutions regardless of the specific inner workings and derivative information of the problem; and
- GA works with numerically generated data, experimental data or analytical functions.

6.3. The GA Structure for Optimising the SCRRJITS Design

This section presents the structure of GA used for optimising the simultaneous cost-risk reduction in production systems under a JIT adoption. The main components of the standard GA are: chromosome (solution) representation; generation of initial population; reproduction operators (crossover and mutation); fitness function; selection operator; and termination criterion (Reeves & Rowe 2003). Figure 6.1 illustrates the cycle of GA used for simultaneously minimising the cost of the final product in production facilities and the potential risks arising from this reduction using a JIT approach. Each cycle produces a new generation which is considered as a possible solution for a given problem and the cycle is repeated until a termination condition is achieved.

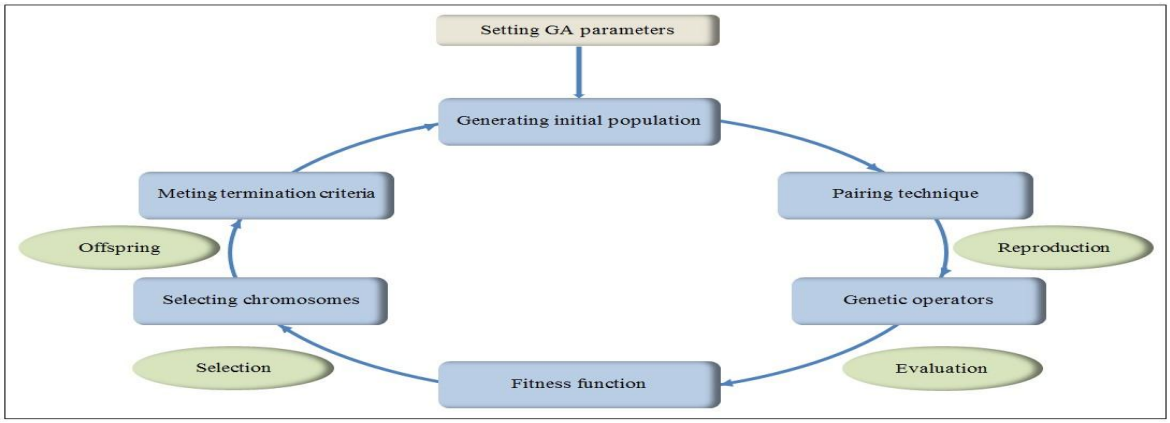


Fig 6.1 The GA scheme of a SCCRJITS optimisation design

Based on the general GA process, the structure of the genetic algorithm is illustrated in Figure 6.1. The proposed GA was coded using Java language and run on a PC Intel® Core™ i5-3210M processor working at speed 2.5 GHz and RAM of 4GB. This research uses a GA to address the simultaneous cost-risk reduction problem under a JIT approach to find the optimal or near-optimal solution of the developed model used for this purpose which has been tested with the simplified example described in Chapter 4. A calculation of computed data is therefore required which will then be inserted into the mathematical model. By

integrating the mathematical model with the proposed GA, an optimal design solution can be obtained. The structure of the proposed mechanism is shown in Figure 6.2.

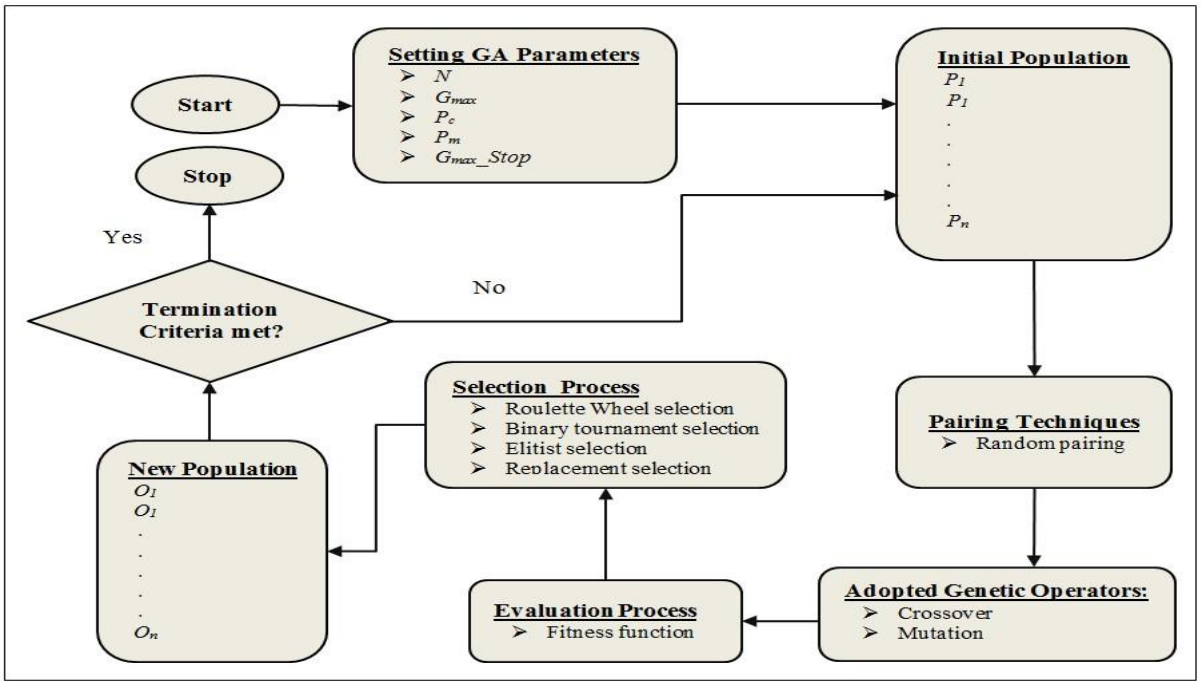


Fig 6.2 The GA structure for optimising SCRRJITS design

6.4. The GA Application for Optimising the SCRRJITS Problems

In this section, the proposed GA is developed to address the problem of simultaneous cost-risk reduction in JIT systems (El Dabee, F, Marian & Amer 2014b, 2014a, 2015). The proposed GA uses real numbers as a chromosome representation for solving this problem which, adopting a JIT approach, is designed to handle different constraints in the simultaneous cost-risk reduction. As a result, the chromosome representation only produces feasible solutions which reduce the computational time required by the proposed GA. The main components of the proposed GA are detailed in the following sub-sections.

6.4.1. *Chromosome Representation*

To start the GA process, the following initial parameters need to be established: population size (N); maximum generations (G_{max}); crossover rate (P_C); mutation rate (P_m); fitness function (F); and the number of generations after which the GA will stop if there is no further improvement for the last best solution (G_{max}_Stop). The next step in applying GA to a particular problem is to encode the variables of a JIT cost-risk reduction problem as a string type structure called a chromosome. Selecting a good chromosome representation facilitates

GA to capture the solution space structure, enabling it to include specific knowledge related to the given problem, to improve its performance (Davidor 1991).

A real coded GA has been indicated as the successful approach/application when dealing with the problem or class problems under consideration with a continuous nature. It also has a chance of increasing the efficiency of GA by exploiting the graduality of the functions with continuous variables (Herrera, Lozano & Verdegay 1998; Mohd-Lair 2008; Osyczka 2002). A real number coding has been applied to solve numerous constrained optimisation problems (Marian 2003). This research uses such a real number representation, called a real-coded genetic algorithm (RCGA). RCGA considers each chromosome as a vector of real numbers. To minimise the computational time required by the RCGA during generations, the chromosome representation is designed to produce only feasible solutions (Abdelmaguid & Dessouky 2006).

A novel meta-heuristic approach based on a hybrid GA combined with a constructive heuristic approach was developed for the proposed model using a real coding system. The main objective of this algorithm is to determine the feasible schedule for any received requests (Naso et al. 2007). Liang and Huang (2006) proposed a multi-agent system in order to simulate a supply chain under a genetic algorithm forecast mechanism adoption using a RCGA system. The main purpose is to find the optimal solution and determine the order quantity for every echelon in the supply chain. Al-Zuheri, Luong and Xing (2014) also adopted a real coding system in their genetic algorithm to address the mixed model walking worker manual assembly line optimisation design problem with multiple objectives. In addition, RCGA was coded to develop a new representation for solving a part type selection and loading problem in a flexible manufacturing system (Mahmudy, Marian & Luong 2012).

For a problem of n variables, the structural representation of a chromosome is considered as $X = (X_1 + X_2 + X_3, \ldots, X_n)$ (Gen & Cheng 2000). Here, the chromosome of 4 genomes (X_1, X_2, X_3 and X_4) represents the main decision variables with 34 genes. X_1 presents the number of external suppliers (S_{Ej}) used for supplying raw materials to the production system which are 11 suppliers (genes) with 2 levels. If $X_1=1$, S_E can supply raw materials and C_T is calculated using Eq. 4.33; and if $X_1=0$, S_E is disrupted and C_T is calculated using Eq. 4.34; X_2 presents the customer demand (d_P) for the final product per day with 1 demand (gene) which has 210 levels ($d_P=1, 2, \ldots, 210$); X_3 presents the critical transportation measurement (t_m) of the raw materials shipped using the transportation mode m with 11 suppliers (genes) which has 4

levels (m=1, 2, 3, 4); finally, X_4 presents the quantity of the raw materials (Q_M) ordered in each batch required to produce the final product per week using 11 suppliers (genes) with 7 levels (Q_M=350, 700, 1050, 1400, 1750, 2100, 2450). A random individual generated for the genetic operation is illustrated in Table 6.1.

Table 6.1 Chromosome construction

X_1	X_2	X_3	X_4
1 0 1 0 1 0 1 0 1 0 1	70	4 3 1 2 1 4 2 3 1 4 2	1 4 2 6 1 3 7 2 5 3 4

By generating the individuals, the number of occurrences of the individual in the previous records is determined. Based on the four decision variables used, the solution space can be calculated as $2^{11}\times210\times4^{11}\times7^{11} = 3.57\times10^{21}$ solutions.

6.4.2. *Initial Population*

GA differs from most of the other optimisation techniques by its ability to search within a population of solutions rather than exploring one single solution (Busacca, Marseguerra & Zio 2001). Chromosomes evolve through successive iterations called generations. The proper selection of chromosomes in the initial population can ensure the higher performance of achieved solutions (Fahimnia 2011). In this research, the initial population is randomly generated and each chromosome/individual is constituted by genes. The population size (N) and the other GA basic parameters (P_c, P_m, G_{max} and G_{max}_Stop) are determined based on experiments that will be conducted for this purpose. Algorithm 6.1 depicts the Pseudo code for the generations of the initial population in the proposed GA.

Algorithm 6.1 Pseudo code for representing the initial population generation

Start
  Set initial number of chromosomes n= 0
  If $n \neq N$
  Then, generate feasible chromosomes
  Set randomly generated values to all genomes in a chromosome representation ($X_1, ..., X_n$)
  Set randomly generated values to all genes for each genome
[End of Algorithm]

6.4.3. *Pairing Technique*

The main reason for implementing a pairing technique is to select two chromosomes before performing genetic operations. Many types of pairing techniques are able to be used in a GA approach such as pairing parents from top to bottom, random pairing, weighted random

pairing (rank and cost weighting) and tournament selection (Haupt & Haupt 2004). The random pairing is the most prevalent technique in supply chain applications (Moon et al. 2008; Naso et al. 2007). This research, for this reason, applies the pairing technique in the proposed GA, which works by randomly selecting two chromosomes from the population.

6.4.4. *Reproduction Operators*

Genetic operators (crossover and mutation) are used for the mating process to create a new generation in a GA procedure. The number of new chromosomes (N) in the offspring pool is determined by the crossover rate (P_C) and the mutation rate (P_m) parameters, considering the formula $P_C + P_m$ = constant.

6.4.4.1. Crossover

This research uses three crossover methods: one-cut point crossover, flat-crossover and extended-intermediate-crossover.

A One-cut point crossover is a simple genetic operator used for a real chromosome representation. The mechanism of this method is represented by randomly selecting one cut point on two chromosomes (parents) and copying the first part of the first parent to be the first part of the first child, and copying the second part of the second parent to be the second part of the first child. The other two parts of the two parents will produce the second child. The interchange process of the one-cut crossover is shown in Figure 6.3.

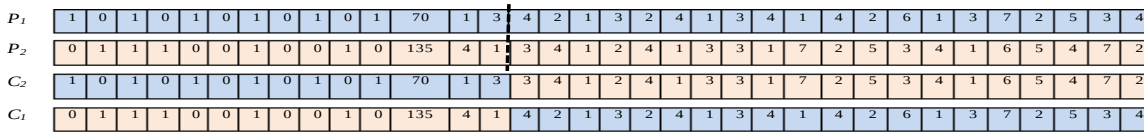


Fig. 6.3 One-cut point crossover

In their article, Khorshidian et al. (2011) used a one-cut crossover operator in a proposed GA to solve the developed model used to find the sequence configuration for minimising the schedulling costs in a JIT single machine scheduling with pre-emption and machine idle time. The one-cut crossover operator was also used in a GA and Cplex solver to optimise the developed defective goods supply chain network model for a three-echelon defective good supply chain network (DGSCN) under JIT logistics (Ghasimi, Ramli & Saibani 2014). Al-Zuheri, Luong and Xing (2014) in addition, adopted the one-cut crossover operator in their proposed GA to solve the walking worker assembly line (WWAL) design problem to find the optimal or near-optimal solution for the designed problem.

A Flat-crossover operator selects parameters for an offspring by uniformly picking parameter values that lie between two points that contain the two parents (Radcliffe 1991). A real coded genetic algorithm combined with a simulation model was developed using a flat-crossover operator. This was used to optimise the operating rule curves of a major reservoir in Taiwan (Chen, Li 2003). Chang, F-J and Chen (1998) also proposed a real-coded and binary-coded GA using a flat-crossover operator for optimising a developed flood control reservoir model. In addition, Mahmudy, Marian and Luong (2013) adopted a flat-crossover operator in their proposal for a hybrid GA for addressing the optimisation of a part type selection and loading problem with alternative production plans in a flexible manufacturing system.

The given method can be applied by selecting two chromosomes (parents) P_1= (P_1^1,…, P_n^1) and P_2= (P_1^2,…, P_n^2). Two children (offspring) are produced C_1= (C_1^1,…, C_n^1) and C_1= (C_1^2,…, C_n^2) by generating a random number C_i on interval [P_i^1, P_i^2]. An example of a flat-crossover is illustrated in Figure 6.4.

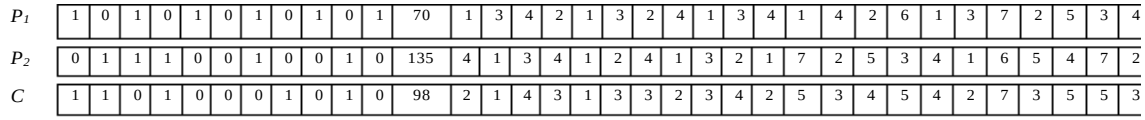


Fig. 6.4 Flat-crossover

An Extended-intermediate crossover is an operator that uses a random linear crossover as its variable-level operator to produce new offspring (Belfiore & Esposito 1998). The offspring C= (C_1,…, C_n) is produced from the two selected parents P_1= (P_1^1,…, P_{n1}) and P_2= (P_1^2,…, P_n^2) by using a formula C_i= P_i^1+α_i (P_i^2- P_i^1), where α_i is randomly selected in the interval [-0.25, 1.25] (Mühlenbein & Schlierkamp-Voosen 1993). Figure 6.5 depicts an example of the extended-intermediate crossover operator.

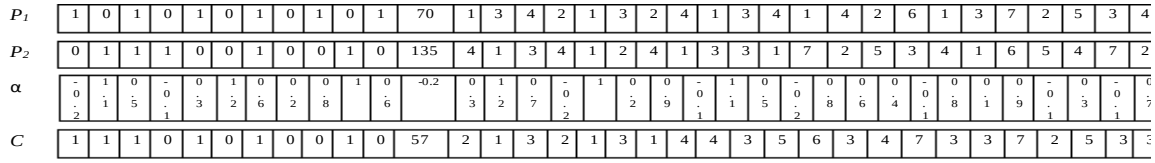


Fig. 6.5 Extended-intermediate crossover

The extended-intermediate crossover operator in the developed GA was used to solve the decision making problem of a tea manufacturer as a multi-objective optimisation problem in an internal environment (Bhuniaa, Biswasa & Senb 2014). It was selected for solving the

problem of a design framework for a robust supply chain considering product development issues (Yadav et al. 2011). Belfiore and Esposito (1998) used the extended-intermediate crossover operator in their proposed GA to solve real number based problems. Mahmudy, Marian and Luong (2012) also adopted the extended-intermediate crossover method using real coded genetic algorithms for solving the part type selection and loading problem in a flexible manufacturing system.

By using the three above crossover methods, one method is randomly selected in each generation to produce varied offspring. The Pseudo code for the three crossover operators is illustrated in Algorithm 6.2.

Algorithm 6.2 Pseudo code for representing the three crossover operators

Input:
  N: Population size
  P: Parents in the initial population pool
  n_C: Number of offspring produced by crossover operator
Output:
  C_i: Offspring i produced by crossover operator
Start
  Select P_1 and P_2 randomly from N
  For i = 1 to n_C
  Select randomly one of
    One-cut point crossover (P_1, P_2)
    Flat-crossover (P_1, P_2)
    Extended-intermediate crossover (P_1, P_2)
[End of Algorithm]

6.4.4.2. Mutation

The mutation rate also plays a significant role in GA development. It is important therefore to define the most appropriate crossover rate. It is usually performed with a low probability of any early convergence. To ensure the feasibility of mutated chromosomes, three methods of mutation are used: simple random mutation, random exchange mutation and random insertion mutation.

A Simple random mutation is a mutation operator used to assure that all possible values have a probability of being included in order to enable the GA to maintain the diversity of chromosomes in the population. The simple random mutation replaces a randomly selected attribute value or class value with a random value in a valid range. It can also change the class value (Chan, C & Nguyen 2003). Adopting a simple random mutation in the proposed GA, the offspring C= (C_1, …, C_n) is produced from the parent P= (P_1, …, P_n) by using the

formula $C_i = P_i^1(1+\alpha_i)$, where α_i is randomly selected in the interval [-0.1, 0.1] (Mühlenbein & Schlierkamp-Voosen 1993). In Figure 6.6, an example of the simple random mutation is illustrated.

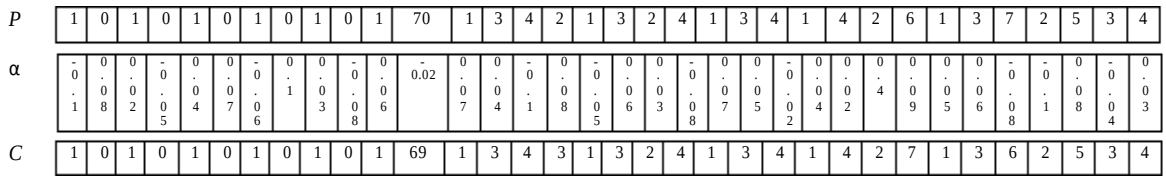


Fig. 6.6 Simple random mutation

Chan, C and Nguyen (2003) adopted the simple random mutation operator in the GA developed for forecasting applications in artificial intelligence techniques. Mahmudy, Marian and Luong (2013) used the simple random mutation method in their proposal for a hybrid GA for addressing the optimisation of a part type selection and the loading problems with various production plans for flexible manufacturing systems. Bjarnadóttir (2004) also designed an efficient Genetic Algorithm using the simple random mutation operator for solving a Capacitated Vehicle Routing Problem (VRP). Furthermore, Mohr (2014) applied a GA meta-heuristic approach using a simple random mutation operator to deal with a model developed for solving a three-index vehicle routing problem with a fixed number of routes.

A Random exchange mutation is an operator used in a GA approach to produce an offspring $C = (C_1,\ldots, C_n)$ by selecting two genes randomly from the parent $P = (P_1,\ldots, P_n)$ and swapping the genes on these positions (Affenzeller et al. 2009). Figure 6.7 depicts the application of this method in the SCRRJITS optimisation problem.

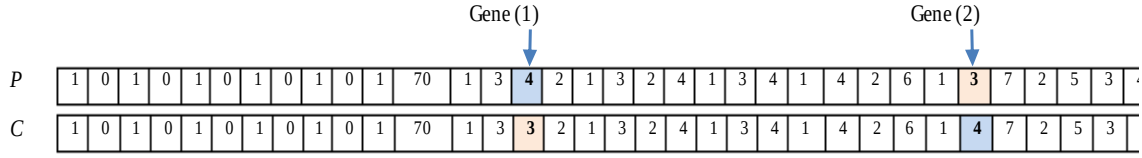


Fig. 6.7 Random exchange mutation

Deep and Mebrathu (2011) combined the random exchange mutation with the inversion mutation operator in their proposed GA to solve a travelling salesman problem in a supply chain. The findings illustrate the superiority of this combination for minimising the costs of the given problem. Affenzeller et al. (2009) similarly proposed a GA approach for solving the travelling salesman problem (TSP) using a random exchange mutation operator. Rani and

Kumar (2014) also developed a GA approach to solve the optimisation problem of a travelling salesman problem (TSP) using a random exchange mutation.

A Random insertion mutation is another mutation operator used to produce a new offspring. An example of this operator as outlined by Affenzeller et al. (2009) and Gen and Cheng (1997) is shown in Figure 6.8 below. Two genes (points 1 & 2 below) are selected. The gene in Point 2 is inserted into the existing gene in Point 1. This modified gene now shifts the remaining genes along the chromosome structure to produce a new offspring $C=(C_1,\ldots, C_n)$ as depicted in Figure 6.8.

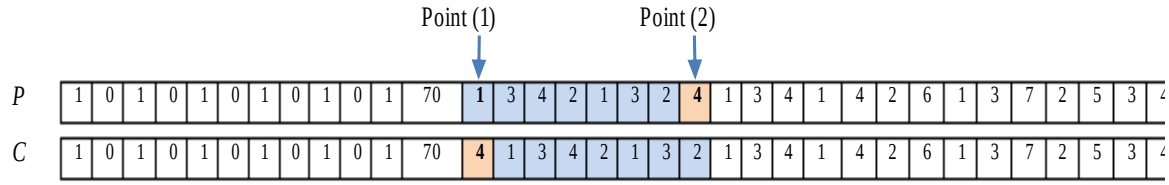


Fig. 6.8 Random insertion mutation

Altiparmak et al. (2009) presented a procedure based on a steady-state genetic algorithm (ssGA) using the random insertion mutation operator for solving the design problem of a single-source, multi-product, multi-stage supply chain network. Hasan, B and Mustafa (2011) designed their GA approach using the random insertion mutation operator to solve non-deterministic polynomial problems (NP). The findings illustrate the effectiveness of random insertion mutation operators for solving such problems. Vaira and Kurasova (2014) also proposed a GA based on a random insertion mutation operator for solving a complex vehicle routing problem. Abdoun, Abouchabaka and Tajani (2012) adopted, as well, the random insertion mutation operator in their proposed GA to solve the above mentioned travelling salesman problem (TSP).

Through the use of the three above-mentioned mutation methods, one method is randomly selected in each generation to safeguard the feasibility of mutated chromosomes. The effective mutation operator can be described in a Pseudo code as shown in Algorithm 6.3.

Algorithm 6.3 Pseudo code for representing the three mutation operators

Input:

N; Population size

P: Parents in the initial population pool

n_m: number of offspring produced by mutation operator

Output:

C_i: Offspring i produced by mutation operator

Start

Select P_1 and P_2 randomly from N

For i = 1 to n_m

Select randomly one of

Simple random mutation (P_1, P_2)

Random exchange mutation (P_1, P_2)

Random insertion mutation (P_1, P_2)

[End of Algorithm]

6.4.5. *Fitness Function*

A fitness function is required to evaluate the quality of each chromosome and strength of each chromosome. In GA optimisation, there are two evaluation functions available: objective and fitness functions. The objective function is used for maximisation purposes. The fitness function, however, needs to be transferred in case the former is used for a minimisation problem. This is to ensure that a positive value is returned through evaluating the fitness of the chromosome (Osyczka 2002). Generally, the fitness function is derived from the objective function and is used in successive processes (Garg 2010). The fitter the chromosome the higher is their probability of being selected to perform genetic operations including crossover and mutation. To ascertain the fitness function of chromosomes in each generation, a one-to-one relationship is established between the chromosome's string representation and the proposed model variables or the values of the objective function.

The aim of the objective function (F) of the proposed model is to minimise the total cost of the final product which includes the product cost and the risk cost resulting from this reduction. To convert the objective function (minimum) to a fitness function (maximum) as illustrated in Eq. 4.33 and Eq. 4.34, the following calculation is performed:

$$F = \frac{100}{(C_T + 1)} = \frac{100}{((\sum_{i=1}^{N_P} C_{pt} + \sum_{i=1}^{N_P} C_R) + 1)} \quad \textbf{(6-1)}$$

The reason for adding the constant 1 to the equation is to prevent dividing the value by zero.

6.4.6. *Selection*

A selection approach is used to describe the process of selecting a part of the chromosomes from the initial population to contribute to their characters. In this research, the following four selection methods are chosen and tested to determine an efficient method for the proposed GA: Roulette wheel; Binary tournament; Elitist; and Replacement selection methods.

6.4.6.1. Roulette wheel selection

The basic idea behind this technique is that all chromosomes in the population enable each offspring an opportunity to be selected as a parent based on the degree of its fitness function value (Davis 1996). Khorshidian et al. (2011) adopted the roulette wheel selection method in their developed GA to solve the JIT single machine schedulling with preemption and machine idle time. Palaniappan and Jawahar (2011) also used the roulette wheel selection method in a proposed GA based heuristic approach. The authors examined an integrated cost model of a simultaneous optimisation for procuring a lot sizing and schedulling in a flow line assembly. It can be adopted for no-back-order and JIT environments. The roulette wheel selection method was applied by Leuveano, Jafar and Muhamad (2012) in their GA to optimise an integrated inventory model of multi-vendors with a single manufacturer sharing a transportation and a JIT delivery system. Furthermore, Lai, Kim-Teng , Luong, L. and Marian, R. (2008) adopted the same roulette wheel selection method in the proposed GA to solve the optimisation problem of multi-stage production-distribution networks.

6.4.6.2. Binary tournament selection

The binary tournament selection method is a sampling process for selecting the fittest chromosomes among a number of random selected individuals from the parent population (Dimitriou, Tsekeris & Stathopoulos 2008). This method randomly selects one chromosome from the current population and one from the offspring pool. It compares their fitness function to select the fittest function to be the best chromosome for the next generation.

This binary tournament selection method was used in the proposed GA to solve the development of a JIT distribution model for a three-level supply chain network to minimise the total cost during all stages (Farahani & Elahipanah 2008). Fahimnia (2011) also adopted the binary tournament selection method using a GA procedure to optimise the aggregate production-distribution (P-D) plan in a supply chain. In addition, (Mohd-Lair 2008) proposed a hybrid GA using the binary tournament method for solving a supply chain scheduling problem. Furthermore, the tournament selection method was adopted in the designed GA for solving the optimisation problem for a reliable network resource allocation (Dimitriou, Tsekeris & Stathopoulos 2008).

6.4.6.3. Elitist selection

The Elitist selection method considers all chromosomes in the parents and offspring pools for selecting the best candidates based on their fitness function (Amodeo, Chen & Hadji 2008).

Elitist strategy is used in a multi-objective GA approach to address the optimisation design problem of the mixed model walking worker manual assembly line (Al-Zuheri, Luong & Xing 2014). Amodeo, Chen and Hadji (2008) adopted the elitist selection method in their proposed GA combined with a Petri net-based simulation approach to optimise the supply chain inventory strategies. Wang, Minhong et al. (2008) also adopted e-business solutions for solving a multi-agent constraint-based approach problems in an on-demand e-business supply chain integration using the elitist selection strategy. Wang, M et al. (2009) in addition, designed an agent-mediated approach using the elitist selection strategy to automate the supply chain formation in dynamic and uncertain environments.

6.4.6.4. Replacement selection

Replacement selection strategy is one of the selection methods in the GA approach, which replaces all parents with their offspring after all offspring have been produced and mutated. Using the replacement selection strategy, each chromosome in the offspring pool has a chance to replace its parent in cases where its fitness is better than its parent (Mahmudy, Marian & Luong 2013). By adopting this strategy, real coded genetic algorithms were proposed to solve the part type selection and loading problem in a flexible manufacturing system (Mahmudy, Marian & Luong 2012). Lozano, Herrera and Cano (2008) also developed a generational replacement strategy that measures the contribution of diversity to the population and the fitness function in steady-state genetic algorithms. As well as this, Wille et al. (2005) adopted the replacement selection strategy in the proposed metaheuristic algorithm

to solve the nonlinear mixed-integer programming formulation for the Capacity and Flow Assignment (CFA) problem. Algorithm 6.4 illustrates the Pseudo code for representing the four selection methods.

Algorithm 6.4 Pseudo code for representing the four selection methods

Input:

N: Population size

P: Parents in the initial population pool

C_S: List of chromosomes in offspring pool produced by crossover and mutation operators

n_O: Number of offspring produced by crossover and mutation operators

Output:

Pop: list of chromosomes in population pool after the selection process

Start

For i = 1 to n_m

Select the best method of

Roulette wheel selection method

Binary tournament selection method

Elitist selection method

Replacement selection method

[End of Algorithm]

6.4.7. *Termination Criterion*

A termination criterion is the final step in the GA process, which occurs after a fixed number of generations or when any significant improvement in the solution is obtained (Leuveano, Jafar & Muhamad 2012). The whole process of the evaluation and the new population generation are repeated until the solution is satisfied. Some criteria have a direct impact on the number of generations such as the nature and size of the problem (Palaniappan & Jawahar 2011). Two common methods are applied for the termination criteria: termination after a chromosome reaches a fixed fitness level and termination after a predetermined number of generations (Teng 2011). According to the GA in the supply chain literature, the termination criteria are mostly determined after a limited number of generations (Mahmudy, Marian & Luong 2012; Mohd-Lair 2008; Moon et al. 2008; Naso et al. 2007). Therefore, this research adopts a predetermined number of iterations for stopping the proposed GA process.

6.5. The Experimental Design of the Proposed GA on the SCRRJITS optimisation

Applying the GA process for solving a problem requires a good selection for the basic parameters such as population size (N), crossover probability (P_C), mutation probability (P_m) and maximum generations (G_{max}). This might enable the proposed GA to easily find the optimal or near-optimal solution of the given problem and within a limited time. Therefore, the aims of this section are:

- To ascertain the appropriate basic parameter values of the proposed GA used to solve the simultaneous cost-risk reduction problem in JIT systems; and
- To illustrate the effectiveness of the proposed GA for finding the optimal or near-optimal solution to solve such issues using the simplified example described in chapter 5.

To avoid any premature convergence and to keep the balance of the GA's exploration and exploitation, this research adopts the injection strategy. This strategy injects 20% of the new random chromosomes into the population at every 50 generations in order to sustain the population diversity.

A simplified example is used to assist the above aims, which is similar to the case study that will be used in Chapter 7. The obtained basic parameter settings will therefore be applied in the real case study used to validate the developed GA for solving the simultaneous cost-risk reduction in JIT systems.

6.5.1. *The Significance of Basic Parameters in the Proposed GA*

The optimisation process of the GA is generally divided into two phases: selecting the appropriate basic parameters and finding the optimal solution of the original problem as illustrated in Figure 6.9 (Lee, L & Fan 2002). The former phase has a significant impact on the GA performance by selecting the convenient values for these parameters. The latter is considered as the normal optimisation by using the first phase for finding the optimal or near-optimal solution of the original problem.

The original problem in the second phase (Ph_2) can be shown as

$$\max_{x \in X} F(x) \qquad \textbf{(6-2)}$$

Where x is a feasible solution, X is the space that includes all possible solutions (xs), $F(x)$ is fitness function (performance measure) and represents the resultant objective function for each solution x.

The first phase (Ph_1) represents the selection of the basic parameters of the proposed GA to find the fastest algorithm that could achieve the optimal solution to the original problem. It can be seen as

$$\min_{\alpha \in A} t_\alpha \qquad \textbf{(6-3)}$$

Subject to $\quad t_\alpha(x^*) = t_\alpha(x^\#)$

Where x^* is the optimal solution of (Ph_2), α represents the GA with a particular selected values of the basic parameters, A represents the solutions space including all possible values of the GA parameters, $x^\#$ is the solution obtained by α and t_α is the expected time required for α to find the solution $x^\#$.

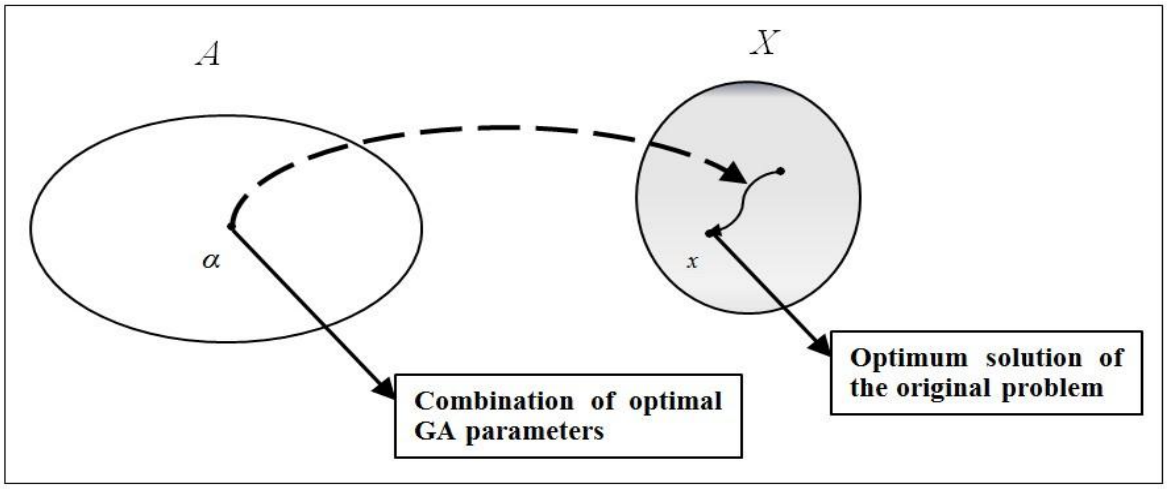


Figure 6.9 Two-phases of using GA for solving the SCRRJITS optimisation problem (Lee, L & Fan 2002)

6.5.2. *The Experimental Design of the Basic Parameters in the Proposed GA*

The GA basic parameters such as crossover rate (P_C), mutation rate (P_m), population size (N) and the maximum generations (G_{max}) generally play a significant role in solving problems. For this reason, computational experiments are carried out to determine the appropriate values for these parameters. The experiments are applied to determine the effects of the above GA basic parameters on finding the optimum solution to the given problem. To

determine the proper parameters used in the proposed GA, two levels of each parameter are carried out as shown in Table 6.2. By running the GA ten times for each level and parameter, the total GA running's number is 160 times shown in Table A.1 in Appendix A.

Table 6.2 The selected levels of the GA basic parameters

No.	Parameter	Level numbers	Setting
1	Crossover rate (P_C)	2	0.2, 0.8
2	Mutation rate (P_m)	2	0.2, 0.8
3	Population size (N)	2	100, 400
4	Maximum generations (G_{max})	2	1000, 5000

Table 6.3 illustrates the computational results of the average values of 10 runs for the basic parameters of the proposed GA using the illustrative example. The findings shown in Table 6.3 incorporate the parameters rates (P_C, P_m, N and G_{max}) for each experiment, the best and average fitness function ($F.F$ and $F.F_{(\text{Ave})}$), the minimum and average total cost (C_T and $C_{T(\text{Ave})}$), the average value of 10 runs of the maximum and average fitness function ($F.F$ and $F.F_{(\text{Ave})}$), the average value of 10 runs of the convergence generations ($C.G$) and the average value of the minimum and average total cost (C_T and $C_{T(\text{Ave})}$) respectively.

Table 6.3 Computational results of the average values of 10 runs for the GA basic parameters

Exp. No.	P_c	P_m	N	G_{max}	$F.F$	$F.F$ (Ave)	C_T	C_T (Ave)	Average of $F.F$	Average of $F.F$ (Ave)	Average of $C.G$	Average of C_T	Average of C_T (Ave)
1	0.2	0.8	100	1000	0.227014	0.226407	439.501312	440.681820	0.227009	0.221826	257.7	439.510635	450.631190
2	0.2	0.8	100	5000	0.227014	0.222639	439.501312	448.156817	0.227014	0.220049	335.2	439.501312	454.023380
3	0.2	0.8	400	1000	0.227014	0.226252	439.501312	440.984976	0.227014	0.221964	167.5	439.501312	450.133860
4	0.2	0.8	400	5000	0.227014	0.220396	439.501312	452.728150	0.227014	0.221705	208.9	439.501312	450.161859
5	0.2	0.2	100	1000	0.226966	0.221823	439.594549	449.809067	0.226995	0.222684	498.8	439.538877	448.246736
6	0.2	0.2	100	5000	0.227014	0.221863	439.501312	449.728922	0.227000	0.223319	395.3	439.529282	446.839893
7	0.2	0.2	400	1000	0.227014	0.225034	439.501312	443.376351	0.227014	0.221076	269.7	439.501312	451.980227
8	0.2	0.2	400	5000	0.227014	0.222330	439.501312	448.781381	0.227014	0.219976	263.6	439.501312	454.031836
9	0.8	0.8	100	1000	0.227014	0.226967	439.501312	439.592682	0.227004	0.225604	128.3	439.519959	442.368556
10	0.8	0.8	100	5000	0.227014	0.226931	439.501312	439.663327	0.227014	0.226374	429.8	439.501312	440.755500
11	0.8	0.8	400	1000	0.227014	0.220874	439.501312	451.746216	0.227014	0.224317	98.1	439.501312	444.937390
12	0.8	0.8	400	5000	0.227014	0.226912	439.501312	439.699812	0.227014	0.224597	95.5	439.501312	444.319897
13	0.8	0.2	100	1000	0.227014	0.225269	439.501312	442.913260	0.226990	0.226473	186.1	439.548019	440.556274
14	0.8	0.2	100	5000	0.227014	0.226659	439.501312	440.190429	0.227014	0.224001	631.1	439.501312	445.619253

15	0.8	0.2	400	1000	0.227014	0.225945	439.501312	441.585079	0.227014	0.226754	84	439.501312	440.007984
16	0.8	0.2	400	5000	0.227014	0.226838	439.501312	439.843684	0.227014	0.226780	69.9	439.501312	439.955742

It is evident from Table 6.3 that the proper rates of the basic parameters that can be used to find the optimal or near-optimal solution of this problem are P_C= 0.8, P_m= 0.2, N= 400 and G_{max}= 5000. These parameters' rate can also be very clearly seen as illustrated in Figure 6.10.

The analysis of variance (ANOVA) is used to determine the impacts of the basic parameters of the proposed GA on the objective function (minimum total cost) of the proposed model to find the optimum solution of the problem. According to the literature, ANOVA has been adopted as an analytical approach to define the significant probabilities (P-value) of each parameter. This value should be less than 0.05.

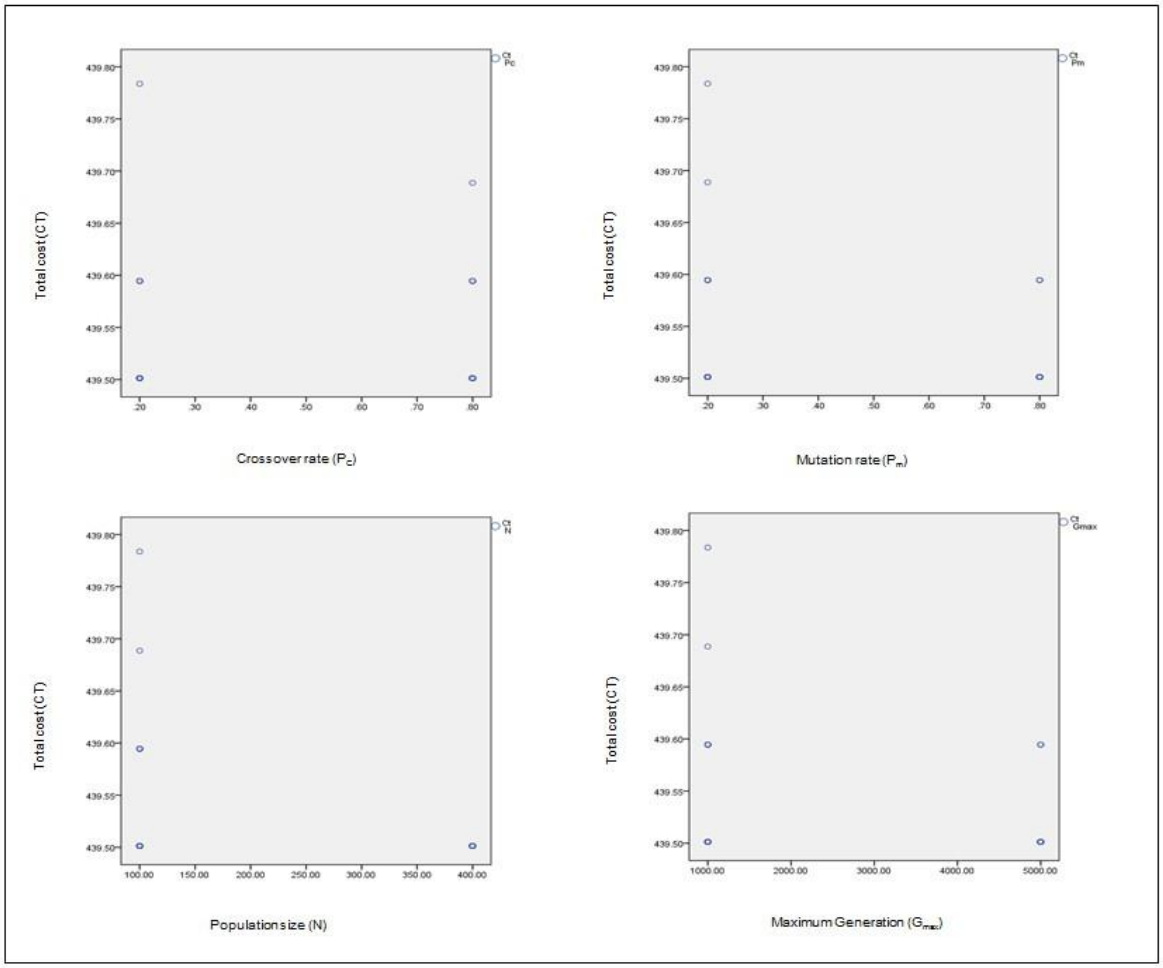


Figure 6.10 The main effects of the GA parameters on the total cost of the final product

Table 6.4 illustrates the effects of each parameter on the obtained results by applying the proposed GA in the illustrative example. It is clear that P_m, N and G_{max} have a significant

impact on the GA performance when their P-values are less or around 0.05. These P-values suggest that changing the values of the independent variables significantly affects the dependent variable. However, P_C has an insignificant impact on its performance. This may lead to a difficulty in finding the optimal solution for the proposed GA; and for improving its performance using the crossover rate (P_C), due to some chromosomes dominating the process after a limited number of generations.

Table 6.4 ANOVA factorial experiment of basic parameters

Parameter	Sum of Squares	*df*	Mean square	*F* value	*P*- value	Significance
Pc vs. C_T	0.000056	1	0.000056	0.047084	0.828496	**x**
Pm vs. C_T	0.004439	1	0.004439	3.789436	0.053351	√
N vs. C_T	0.012287	1	0.012287	10.954736	0.001157	√
Gmax vs. C_T	0.004439	1	0.004439	3.789529	0.053348	√
Pc & *Pm* vs. C_T	0.004495	2	0.002248	1.907255	0.151912	**x**
Pc & *N* vs. C_T	0.012344	2	0.006172	5.469451	0.005055	√
Pc & *Gmax* vs. C_T	0.004495	2	0.002248	1.907301	0.151905	**x**
Pm & *N* vs. C_T	0.016726	2	0.008363	7.599137	0.000708	√
Pm & *Gmax* vs. C_T	0.008877	2	0.004439	3.858030	0.023139	√
N & *Gmax* vs. C_T	0.016726	2	0.008363	7.599190	0.000708	√
Pc, *Pm* & *N* vs. C_T	2940.037208	3	980.012403	7.642881	0.000084	√
Pc, *Pm* & *Gmax* vs. C_T	2943.013220	3	981.004407	7.651756	0.000084	√
Pm, *N* & *Gmax* vs. C_T	119.270481	3	39.756827	0.271735	0.845713	**x**
Pc, *Pm*, *N* & *Gmax* vs. C_T	0.021221	4	0.005305	0.005305	0.000974	√

6.5.3. *Further Experimental Studies of the Proposed GA Basic Parameters*

The above analysis of ANOVA carried out in experiments on the basic parameters of the GA in the given example illustrated may be used as a general guideline. Therefore, it is necessary to run further experimental studies using different values for the basic parameters of the proposed GA to determine the best value of those parameters. This can be done by changing one parameter and fixing the others. To compare the obtained results of each case, the program has been run using the values of the basic parameters used in these experimental studies, which are: P_C= 0.8, P_m= 0.2, N= 400 and G_{max}= 5000. The detailed model analysis when applying different settings of each parameter is presented below.

6.5.3.1. Crossover operator experimentation

This experimentation examines how the GA model responds to different values of crossover rates. Five different crossover rate (P_C) values, and each of these rates, are used for this purpose. These values are 0.2, 0.4, 0.6, 0.8 and 0.9 and each is individually tested. For each crossover rate, the GA has been run by fixing the other parameters. For all crossover rate

values, the findings illustrate that the minimum total cost is the same. The GA finds the optimal solution after a different numbers of generations and different periods of time as shown in Figure 6.11. Using P_C= 0.2, the optimisation model converges to the minimum total cost of the final product (T_C), which is 439.5013(MU) after 232 generations. In the case P_C= 0.4, the model converges to the minimum cost after 127 generations. By using P_C= 0.6, the minimum total cost can be obtained after 115 generations. The model converges to the minimum cost of the final product after 88 generations using P_C= 0.8. Finally, the minimum total cost can be obtained by using P_C= 0.9 after 317 generations.

Table 6.5 shows a summary of the obtained results for different crossover rates including the number of generations, the minimum total cost and the average total cost. It is clear that the crossover rate of 0.8 outperforms the crossover rate of 0.2, 0.4, 0.6 and 0.9 in finding the optimal solution of this problem.

Table 6.5 The results obtained from the five different crossover rate values

Crossover rate (P_C)	Generations	Total minimum cost (C_T)	Total average cost ($C_{T(Ave)}$)
0.2	232	439.5013	442.6827
0.4	127	439.5013	440.0657
0.6	115	439.5013	440.2462
0.8	88	439.5013	439.6792
0.9	317	439.5013	439.5941

Figure 6.11 illustrates that the experiments with the lowest and highest crossover rates (i.e. 0.2 and 0.9 respectively) converge towards their point of maximum efficiency slower at the end of the iteration process. The crossover rate of 0.2, however, performs better than 0.9 in terms of convergence speed. It appears that the middle crossover rates of 0.6 and 0.8 produce faster initial convergences with a slightly improved convergence-speed crossover rate of 0.8, reaching a minimum total cost of the final product after 88 generations and in a limited period of time. The detailed results are listed in Table B.1 in Appendix B.

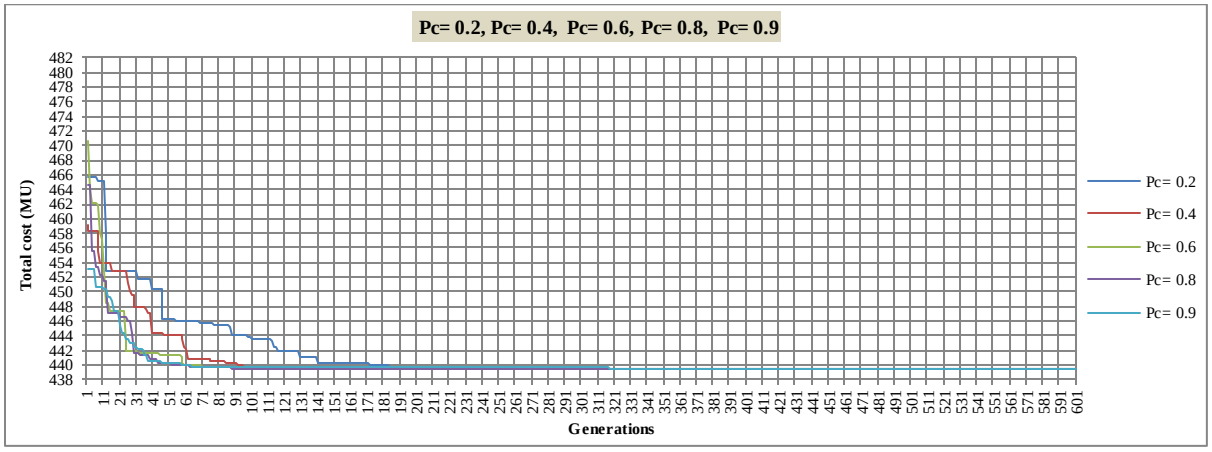


Figure 6.11 Comparison of the converging crossover rates to the minimum total cost of the final product

6.5.3.2. Mutation operator experimentation

Different values of the mutation rate (P_m) are used in this experimentation. These values are 0.1, 0.2, 0.4, 0.6 and 0.8 and also tested individually. Similar to the experimentation of the crossover rate, the proposed GA has been run for each value by fixing the other parameters to ascertain the best value that can be used for finding the optimal or near-optimal solution of the problem. Based on the results illustrated in Figure 6.12, the findings show that the minimum total cost of the final product is the same for all mutation rate values. However, the GA converges to the minimum total cost, which is 439.5013 (MU) after a different numbers of generations and different periods of time. While the GA procedure is run using P_m= 0.1, the optimal overall cost was obtained after 208 generations. The proposed GA converges to the minimum total cost after 60 generations using P_m= 0.2. The GA converges to the best fitness function after 94 generations using P_m= 0.4 and it converges to the minimum cost after 282 generations using P_m= 0.6. Finally, in case P_m= 0.8, the minimum cost is found after 403 generations.

In Table 6.6, a summary of the achieved results for the different mutation rates includes the number of generations, the minimum total cost and the average total cost. In this example, a mutation rate of 0.2 outperforms the mutation rate of 0.1, 0.4, 0.6 and 0.8.

Table 6.6 The results obtained from the five different mutation rate values

Mutation rate (P_m)	Generations	Total minimum cost (C_T)	Total minimum cost ($C_{T(Ave)}$)
0.1	208	439.5013	441.3799
0.2	60	439.5013	442.5519
0.4	94	439.5013	439.6863
0.6	282	439.5013	439.5941
0.8	403	439.5013	455.4879

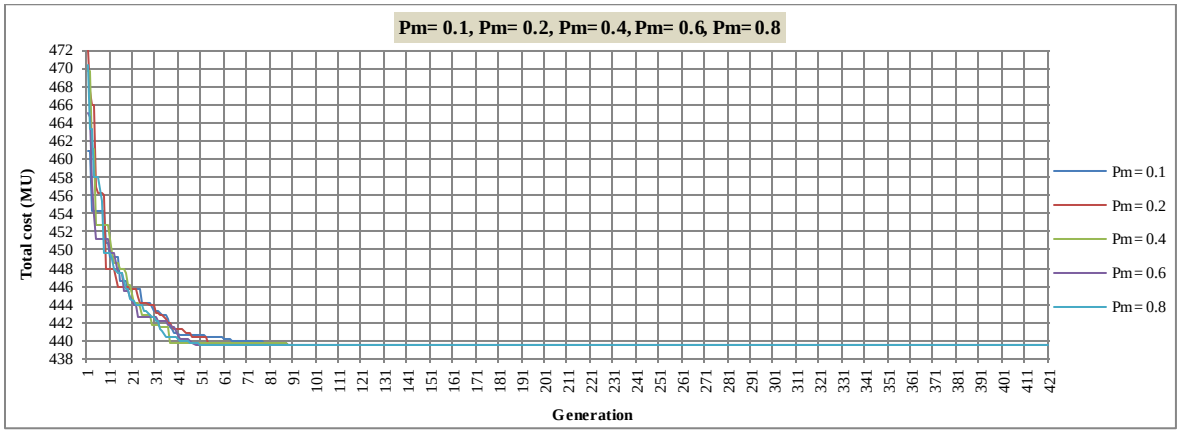


Figure 6.12 Comparison of the converging mutation rates to the minimum total cost of the final product

From the results depicted in Figure 6.12, it is clear that the mutation rate of 0.2 has the highest performance among the five alternatives in finding the minimum total cost of the final product after a limited number of generations. In this regard the higher value of P_m cannot always be sure of finding the optimal solution to the SCRRJITS optimisation problem. These findings can be very clearly seen in Table B.2 in Appendix B.

6.5.3.3. Population size experimentation

This experimentation examines different population sizes of 100, 200, 300, 400 and 500 individuals while the crossover rate (P_C), mutation rate (P_m) and maximum generations (G_{max}) are fixed at 0.8, 0.2 and 5000 respectively. The experimentation is undertaken to find the optimal population size in the case of the simultaneous cost-risk reduction in the production system using the JIT system.

Figure 6.13 depicts a comparison of the population size rates with their convergence to the minimum total cost of the final product. From Figure 6.13, it is clear that this cost, which is 439.5013 (MU) and obtained by all population size values, is the same. However, the proposed GA converges to the minimum total cost after a different numbers of generations and different periods of time. Using N= 100, the proposed GA converges to the minimum cost after 307 generations. The minimum total cost is also obtained after 189 generations using N= 200. The GA converges to the best fitness function after 97 generations by using N= 300. However, in the case N= 400, the optimal solution to the given problem is found after only 60 generations. Finally, the proposed optimisation model converges to the minimum total cost after 72 generations using N= 500.

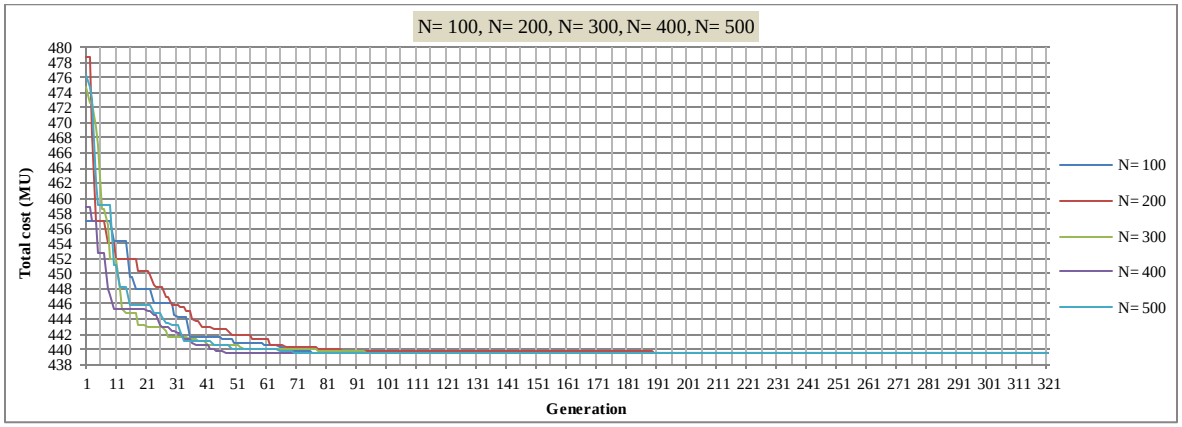


Figure 6.13 Comparison of the population size rates and the minimum total product cost

Table 6.7 illustrates a summary of the achieved results for different population sizes including the number of generations, the minimum total cost and the average total cost. It can be observed that a population size of 400 individuals outperforms population sizes of 100, 200, 300 and 500 individuals for finding the minimum optimal cost of the final product in the given example.

Table 6.7 The results obtained from the five different population size values

Population size (*N*)	Generations	Total minimum cost (C_T)	Total minimum cost ($C_{T(Ave)}$)
100	307	439.5013	443.5939
200	189	439.5013	439.7809
300	97	439.5013	439.8100
400	60	439.5013	441.0206
500	72	439.5013	440.0755

The detailed results listed in Table B.3 in Appendix B and summarised in Figure 6.13, demonstrates that the proper number of population size that can be used for finding the optimal solution of the given problem, is N= 400. This can be achieved after 60 generations.

6.5.3.4. Maximum generation experimentation

In the experiments above, the maximum generations (P_m) of 1000, 2000, 3000, 4000 and 5000 generations are used to determine the appropriate value for solving the simultaneous cost risk-reduction problem in JIT systems. The same steps applied in the last experiments are applied by using each value of this parameter and fixing the others, in order to determine the best value of G_{max} for finding the optimal solution of the given problem. Figure 6.14 illustrates a comparison of the maximum generation rates on their convergence to the minimum total cost of the final product. In case G_{max}= 1000, the proposed GA converges to the best fitness function after 109 generations. The minimum total cost can be found after 575

generations using G_{max}= 2000. Also, the best fitness function is obtained after 153 generations in the case of G_{max}= 3000. Additionally, the proposed GA converges to the minimum cost after 159 generations by using G_{max}= 4000. However, in case G_{max}= 5000, the minimum total cost of the final product is found only after 74 generations.

Table 6.8 demonstrates a summary of the attained results for different values of maximum generations including the number of generations, the minimum total cost and the average total cost. It can be noted that the maximum generation of 5000 generations, outperforms the maximum generations of 1000, 2000, 3000 and 4000 generations in finding the optimal solution of the given problem.

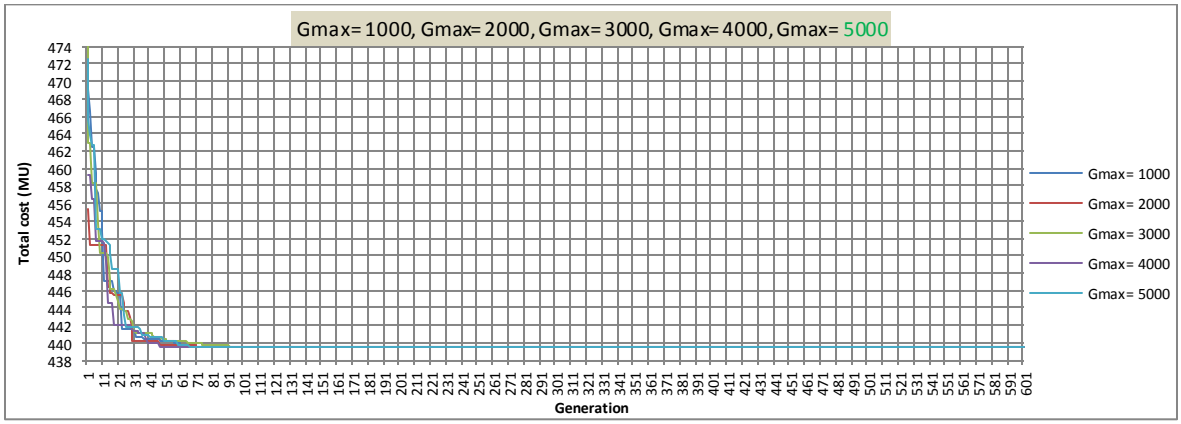


Figure 6.14 Comparison of the converging maximum generation rates to the minimum total cost of the final product

Table 6.8 The results obtained from the five different maximum generation values

Maximum generations (G_{max})	Generations	Total minimum cost (C_T)	Total minimum cost ($C_{T(Ave)}$)
1000	109	439.5013	441.4815
2000	575	439.5013	439.5941
3000	153	439.5013	465.8186
4000	159	439.5013	441.7231
5000	74	439.5013	439.8338

From the achieved results plotted in Figure 6.14 and listed in more detail in Table B.3 in Appendix B, it is clear that the time to reach the optimal solution is significantly lower for the maximum generation of 5000 generations compared with that of 1000, 2000, 3000 and 4000 generations. Therefore, it is essential that the maximum generations should be large enough to ensure the required genetic diversity.

A summary of the above experimentations illustrating the best combinations of the GA basic parameters, for the given illustrative example, are listed in Table 6.9. These values are

selected for optimising the simultaneous cost-risk reduction in JIT systems and also can be used for optimising the case study in Chapter 7.

Table 6.9 Input GA parameters

Parameter	Rate
Crossover rate (P_c)	0.8
Mutation rate (P_m)	0.2
Population size (N)	400
Maximum generations (G_{max})	5000
Generation stop (G_{max}_Stop)	30000

6.6. An Illustrative Example of the SCRRJITS optimisation

This section discusses the implementation of the developed mathematical model presented in Chapter 5 as an example illustrating the assembly of a simple electric motor with a hollow shaft. The purpose of this section is to determine the effectiveness of the proposed GA for optimising the simultaneous cost-risk reduction in the production system using the JIT approach. The production system uses multiple identical processes to assemble 25 individual parts into the finished product. The proposed GA is used to find the optimal or near-optimal solution to the given problem. It is assumed that the production system procures raw materials in a fixed lot size from eleven different regular external suppliers. It is also assumed that in case one or more of external suppliers suffering disruption, the production system can procure its raw materials from seven local backup suppliers at a higher cost, but at a lower risk. The details of the illustrative example are presented in Chapter 5.

6.7. Computational Results and Analysis of the SCRRJITS Optimisation

The proposed GA in this chapter is applied by using the best values of the basic parameters obtained from the previous experiments to solve the problem of the simultaneous cost-risk reduction optimisation by adopting a JIT approach.

6.7.1. *Determination of the most suitable selection method for the proposed GA*

The proposed GA tests the four selection methods (Roulette wheel, Binary tournament, Elitist and Replacement selection methods). It is run 10 times for each method to obtain the optimum solution for minimising the total cost of the final product and the risk effects in JIT systems in the short term. A comparison between the four selection methods is carried out to determine which method is more suitable than the others by using the GA parameters illustrated in Table 6.10. Iter is the number of iterations required to find the best solution.

This means that after this number the GA is unable to find a better solution than this. The results are listed in details as seen in Table C.1 in Appendix C.

Table 6.10 The GA outputs of the four selection methods

Method	Iter.	Time (S)	d_p	C_{pt}	C_R	$C_{T\text{-}max}$	$C_{T\text{-}ave}$	$F.F_{max}$	$F.F_{ave}$
RW	90	47.2	210	418.573	20.93	439.5013	446.8472	0.227014	0.223667
BT	122	47.0	210	418.573	20.93	439.5013	446.8472	0.227014	0.223667
ELIT	110	46.9	210	418.573	20.93	439.5013	442.1773	0.227014	0.225643
REP	227	47.1	210	418.573	20.93	439.5013	440.1363	0.227014	0.226687

Table 6.10 illustrates the average values of the best iterations, computation time, customer demand, product cost, risk cost, total cost (maximum and average) and fitness function (maximum and average) for each selection method. The findings demonstrate that the replacement selection method is more effective than the others as shown in Figure 6.15. By using this method, the proposed GA retains population diversity and effectively explores the search space. It follows that the replacement selection method demonstrates that the best chromosome always passes to the next generation.

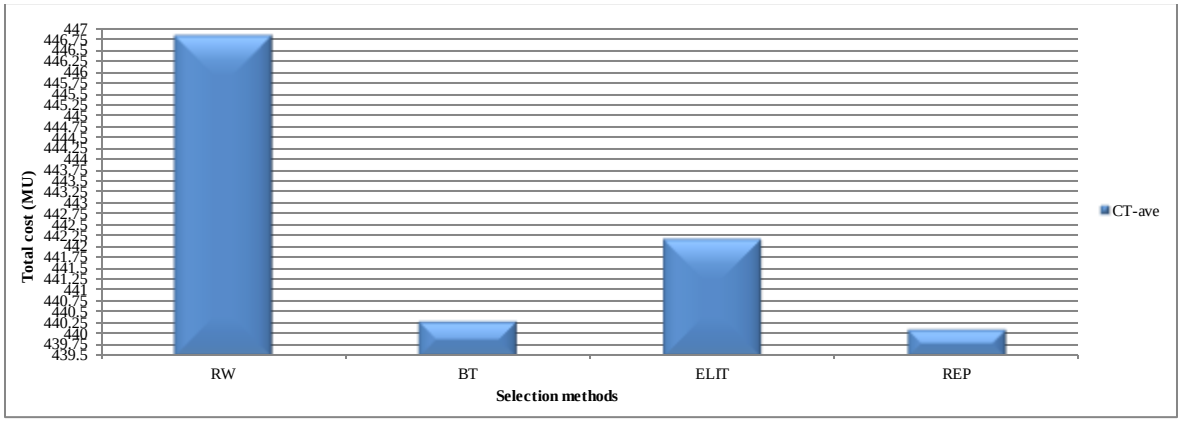


Figure 6.15 Comparison of the four selection methods and the average total cost

6.7.2. *The performance of the genetic operators in the proposed GA*

The effects of crossover and mutation operator rates on the proposed GA are discussed using different values to determine the most proper value for solving the issue. New chromosomes are produced by using crossover and mutation. The crossover produces new chromosomes equal to $N \times P_C$ offspring and the mutation produces $N \times P_m$ offspring for each generation. The values of both crossover rate (P_C) and mutation rate (P_m) used are: 0.2, 0.4, 0.6, 0.8 and 1.0. The proposed GA is run 10 times for each value to find the optimum solution for minimising the total cost of the final product and the risk effects in JIT systems within a limited time.

Figure 6.16 presents a comparison between the 10 runs of crossover rates and the average total cost. It is clear that the higher number of generations is obtained when PC = 0.8 and Pm= 0.2. In this case, the number of chromosomes in each generation is 400×0.8 = 320 offspring and the number of new chromosomes produced using the mutation rate of 0.2 is 400×0.2=80 offspring. By comparing the average value of 10 runs of the crossover rates and the average total cost, it is clear that the best average crossover rate that gives a minimum average total cost is 0.8 as seen in Figure 6.17.

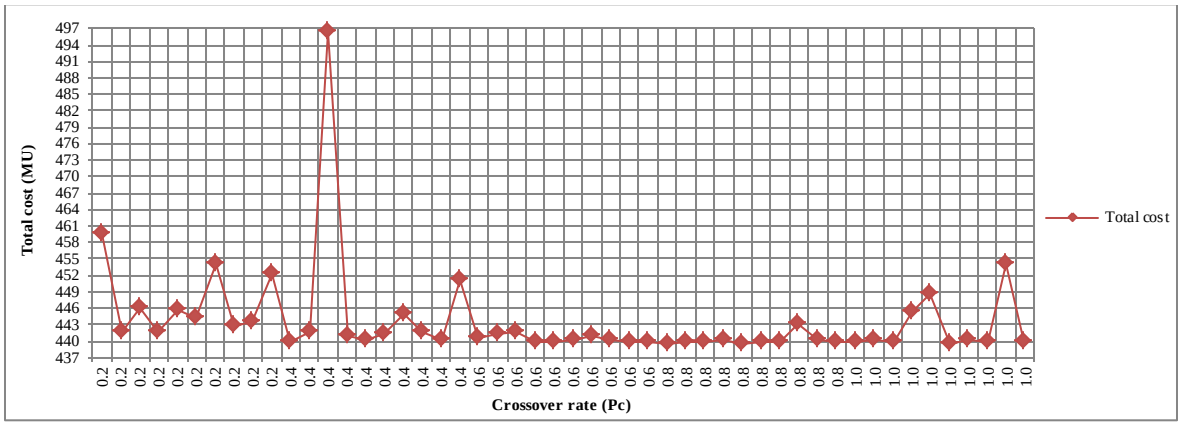


Figure 6.16 Comparison of the 10 generation runs of different crossover rates and the average total cost

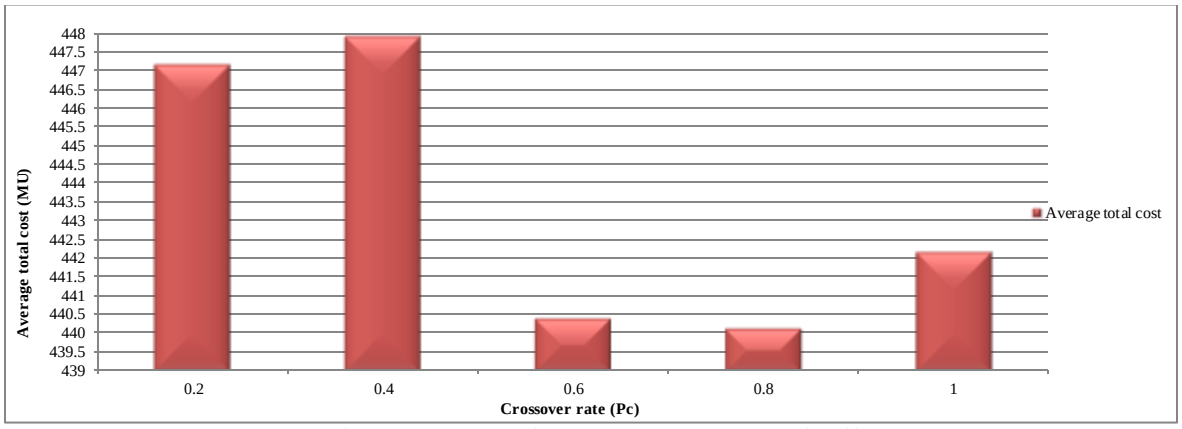


Figure 6.17 Comparison of the average of 10 generation runs of different crossover rates and the average total cost

As mentioned above, it is assumed that $P_C + P_m$= constant. Therefore, by using a low value of the crossover rate, the proposed GA will be contingent upon a mutation rate that will be a high value. This may lead to a limited search from the previous generations. By using a high crossover rate and a low mutation rate, however, the similarity of the offspring with their parents will be high and after a small number of iterations the proposed GA converges to the best fitness function. The details of all GA runs are listed in Table C.2 in Appendix C.

6.7.3. *Determination of the optimal solution in the proposed GA*

By using the GA parameters illustrated in Table 6.9, the proposed GA produces the optimum solution for minimising the total cost of the final product and the risk effects in JIT systems in the short term. The optimum solution is achieved after 252 generations. The best chromosome is shown in Table 5.11 and the findings for the proposed GA including the number of iterations, the required time, customer demand, and the cost types are listed in Table 6.12.

Table 6.11 The best chromosome obtained using a replacement selection method

X_1											X_2	X_3											X_4										
1	0	0	0	1	0	1	0	1	0	0	210	1	3	4	2	1	3	2	4	1	3	4	1	1	1	1	1	1	1	1	1	1

Table 6.12 The output GA obtained using a replacement selection method

Iter.	Time (S)	d_p	C_O	C_H	C_P	C_R	C_D	TP	C_W	C_U	C_{pt}	C_R	C_T
252	47.29	210	6.953	9.919	314.961	36.26	2.919	2.235	8.0	37.325	418.573	20.928	439.501

Figure 6.18 depicts the average and the best costs of all chromosomes according to iterations. It is clear that the fluctuation has been occurring as a result of population diversity caused by the adopted injection strategy. The crossover operator therefore will generate a new offspring that is able to move in other directions in the search space and enable the proposed GA to escape from local optimal areas. The detailed results of the optimal solution for solving the simultaneous cost-risk reduction problem using the JIT approach in the given illustrative example are provided in Table C.3 in Appendix C.

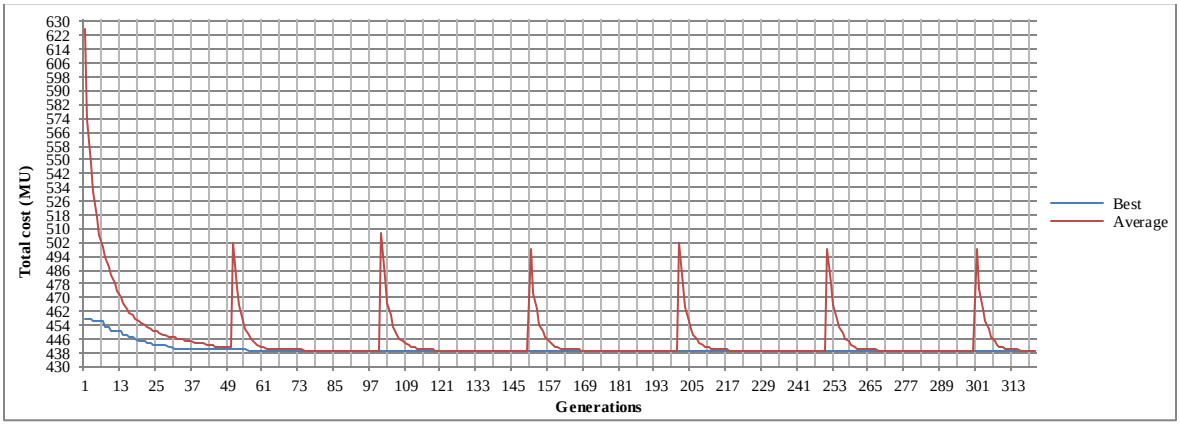


Figure 6.18 The best and average value of the total final product cost

6.8. Concluding Remarks

In this research, GA was selected as an appropriate optimisation technique useful in solving the problem of the simultaneous cost-risk reduction in JIT systems. The main components of the standard GA approach are chromosome representation, generation of initial population, reproduction operators (crossover and mutation), fitness function, selection operator and termination criterion. All these components of this algorithm are presented in detail in this chapter. The proposed GA was coded using JAVA language based on its simplicity and accuracy for finding the optimal solution of such problems.

A real-coded genetic algorithm (RCGA) was used in this research to solve the problem of a simultaneous cost-risk reduction in the production systems adopting a JIT approach. By using RCGA, the chromosome representation of the proposed GA was designed to produce only feasible solutions to minimise the computational time in each generation. Three crossover methods (one-cut point crossover, flat-crossover and extended-intermediate-crossover) were used in this research but only one of these methods is randomly selected in each generation to produce different offspring. Three methods of mutation were also used which were a simple random mutation, a random exchange mutation and random insertion mutation, and only one method is randomly selected in each generation to maintain the feasibility of mutated chromosomes. To select a part of the initial population, the following four selection methods, Roulette wheel, Binary tournament, Elitist and Replacement selection methods, were selected and tested, to determine the appropriate selection method for the developed GA approach.

The basic parameters of the proposed GA (P_C, P_m, N and G_{max}) were analysed using ANOVA to ascertain the effects of these parameters on the objective function of the developed model. Some experimental studies using different values for each parameter were applied by changing its value and fixing the other parameters to determine the proper value of these parameters for solving the simultaneous cost-risk reduction problem in JIT systems. The results achieved were analysed and discussed to illustrate the effectiveness of the proposed GA for finding the optimal solution to the given problem. In Chapter 7, the proposed model combined with the GA approach will be investigated by implementing it in a case study utilising the same parameters used in this chapter.

7. Performance Evaluation of the SCRRJITS Framework: An Industrial Case Study

7.1. Introduction

In the last two chapters, the first stage of the developed framework was undertaken towards the development of an optimisation model for simultaneously minimising the total cost of the finished products and the potential risks related to these benefits. A mathematical model was developed in Chapter 4 and a genetic algorithm method for solving these kinds of problems was proposed in Chapter 6. The second stage (validation) is discussed in this chapter, based on the analysis and application of the proposed optimisation model in an actual industrial case study. The case study discussed here has been taken from Fahimnia (2011) to evaluate the performance of the proposed approach. Both the benefits and limitations deriving from adopting the model and methodology are presented based on experimental studies, which will be described in this chapter.

The objectives of this chapter are as follows:

- To assess the effectiveness of the optimisation model proposed for simultaneously minimising the total cost of the final product and also minimising the potential risks in production systems, under the JIT environment;
- To demonstrate the capability of the optimisation approach developed to handle the complexity of a real industrial case study; and
- To compare the solution design obtained from the proposed approach with the results obtained from the real case study in Fahimnia (2011).

The remainder of this chapter is organised as follows: Section 7.2 presents a description of the company selected for this case; the methodology for conducting the company case is then described in Section 7.3; Section 7.4 presents the implementation of the developed optimisation model in the company case scenario; Section 7.5 analyses and compares the results obtained from the proposed model with the results from the company case in Fahimnia (2011); next, the results obtained by considering some risks arising from implementing the JIT approach are analysed in Section 7.6 to illustrate the effectiveness of the developed optimisation model for such problems; finally, a summary of this chapter is described in Section 7.7.

7.2. The Company Case

Pooladin Sazeh Persian (PSP) is a large manufacturer and exporter of motorcycle spare parts. It was founded in 1973 and headquarters were established in south Tehran (the capital city of Iran). It has four production systems spread over an area comprising 25,000 square meters in Iran's major cities (see Figure 7.1). Moreover, PSP has six large good-storages warehouses in several cities to ensure a prompt indirect delivery of its products from production systems to the geographically spread end-customer base.

PSP is a leading manufacturer of a wide range of metal and plastic motorcycle parts and accessories. These include front and rear mudguards, mud flaps, wheel rims, leg guards, side guards, front axles, chain covers, clutch cases and parts, break parts, handles and stands. Depending on the type of products manufactured, each production system is equipped with different machinery and quality control testing facilities to ensure effective processing, painting/coating, packing and delivering of goods (refer to Figure 7.1). Automatic and semi-automatic lathe machines, drill machines, milling machines, surface grinders, shaping machines, paint booths, plastic injection moulding machines and oven conveyors are the common production facilities in all PSP production systems. Some of these production systems producing a variety of products are also equipped with several CNC Machines. To meet the customised specifications of the end-customers, PSP uses high-degree precision components such as CAD/CAM facilities for design.

Mudguards are the most high-volume components produced by SPS. These are a valued product-line for the company because their high durability and performance put them in high-demand in the regions retail sectors. Specifically, Honda and Yamaha brand mudguards are the most produced and sought after. Mudguards (also known as a fender or splash guard) are used on motorbikes to protect riders against water and mud thrown up by the wheels during riding. They also protect the front and back of the bike from rock and road debris whilst enhancing the design of the motor bike. Steel, aluminium, plastic, fibreglass and carbon fibre are amongst the most common materials used for making mudguards. PSP uses high-grade raw materials in all its manufacturing processes procuring its supplies from reliable local and international vendors.



Fig 7.1 PSP production and storage facilities in Tehran, Esfahan, Tabriz and Mashhad (Fahimnia 2011)

PSP is an ISO 9001:2000 certified company. This means that in order to achieve a world class standard of motorbike spare parts it adheres to the quality assurance of recognised international standards at every production stage. To ensure this certification standard, each product is fully tested at every stage of manufacturing, picking, packing and dispatching before being delivered to retailers. PSP has a team of highly experienced professionals who have in-depth knowledge and experience in their fields. PSP is touted as a leading manufacturer employing highly qualified and experienced engineers, designers, quality personnel, research and marketing professionals, supervisors as well as skilled and semi-skilled labourers.

7.3. Methodology for Conducting the Case Company

This chapter investigates the optimisation of the SCRRJITS problem at PSP with Honda and Yamaha plastic motorcycle parts and accessories where diverse products are produced in numerous production systems including geographically diverse machine centres. The final products are then either directly distributed from production systems to geographically spread end-customers or indirectly through a number of distribution centres. It is necessary to collect the input data required to conduct experiments using the optimisation model proposed in Chapter 6. However, because the company produces a number of diverse products this chapter only discusses the Honda and Yamaha front and rear mudguard problem. Therefore, the required data related to these components will be collected for the purpose of optimising the proposed model in this case study.

This section outlines a methodology designed to perform a case study in a SCRRJITS optimisation. The methodology achieves this in three stages: data collection, experimentation and output data analysis. The following sub-sections outline details of these stages.

7.3.1. *Input Data Collection*

For any experiment, the first step is data collection. This is an important stage because inaccurate data may lead to imprecise conclusions. In this regard, the quality of input data highly affects the accuracy and reliability of the results achieved. For the case study under consideration, the designed methodology of data collection are categorised into five characteristics: facility location, product to be produced, demand data, cost and capacity features. The data given in this section is either measured or estimated based on the average value from the operations performed by the company PSP. However, not all data required for applying the model proposed in Chapter 4 is available in this case study. Therefore, this research assumes the missing data needed for this model is based on the literature review from the field of supply chain management. The above characteristics are described below.

7.3.1.1. Location of the facility characteristics

PSP owns four production facilities, six distribution centres and five end-customer outlets in different major cities in Iran. Table 7.1 illustrates the cities where the production systems, distribution centres and end-customer outlets are located. Figure 7.2 also depicts the configuration of the case company supply chain, which consists of the production systems, distribution centres and end-customers. Figure 7.2 shows that the final products can be

supplied by a number of production systems to the distribution centres and then to the end-customers.

Table 7.1 Location of PSP production systems, distribution centres and end-customers

Item	1	2	3	4	5	6
Production system (*P*)	Tehran	Esfahan	Tabriz	Shiraz	-	-
Distribution centre (*DC*)	Tehran	Karaj	Ghazvin	Esfahan	Tabriz	Mashhad
End- customer (*e*)	Tehran	Tehran	Mashhad	Bandar Abas	Rasht	-

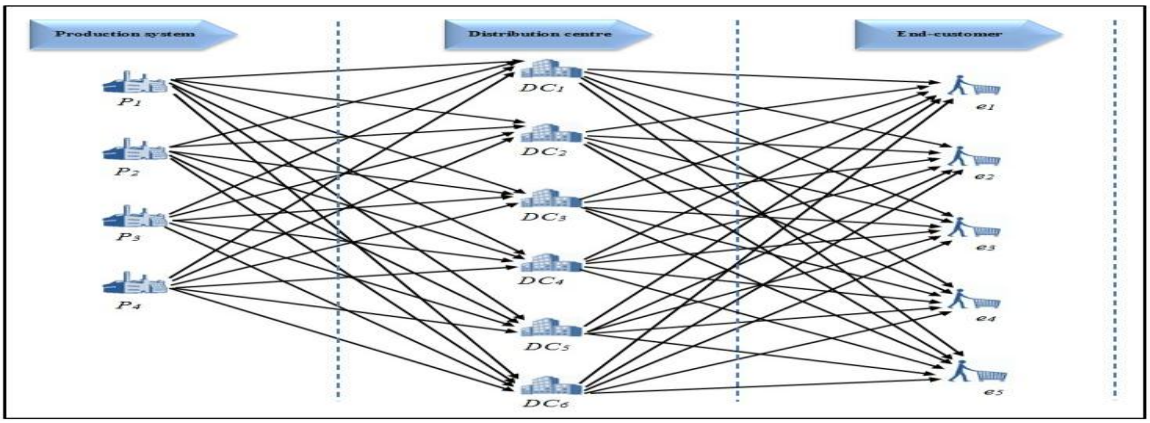


Fig. 7.2 The geographical location of PSP production systems, distribution centres and end-customers

7.3.1.2. Product characteristics

Data for the quantity and the type of products to be produced at each production system needs to be collected. Data for the number and the type of components which is drawn from the bill of material (BOM) is also required. PSP produces a wide range of metal and plastic motorcycle components. This chapter however, concerns four types of Honda and Yamaha mudguards ($i_1 - i_4$) respectively as shown in Figure 7.3 and Figure 7.4.

The four kinds of mudguards are listed as below:

i_1: Honda CG125 front mudguard

i_2: Honda CG125 rear mudguard

i_3: Yamaha IT200 front mudguard

i_4: Yamaha IT200 rear mudguard



Fig. 7.3 The Honda CG125 rear [a] and front mudguards [b] (Fahimnia 2011)



Fig. 7.4 The Yamaha IT200 front [a] and rear mudguards [b] (Fahimnia 2011)

Production facility 1 and 2 (P_1 and P_2) in Tehran and Esfahan respectively are able to produce all four types of products (i_1 - i_4). However, the production facility 3 (P_3) in Tabriz only produces i_1 and i_2 and the production facility 4 (P_4) in Shiraz produces i_1 and i_3. All four items must be manufactured by passing through four machine centres (m_1 - m_4). These centres are the press and milling shop, drill shop, assembly shop and paint shop.

7.3.1.3. Demand characteristic

Demand data is assumed to be known for the entire planning horizon for two weeks prior to sale. However, the demand varies from period to period. The production systems on average work eight hours a day for six days a week in regular time, unless over-time is required (i.e. planning horizon T = 12 days). The weekend in many middle-eastern countries is only one day which is Friday. The average demand for the four types of mudguards at five end-customers for all 12 days of the planning horizon is illustrated in Table 7.2.

Table 7.2 Daily forecasted demand of the final products for two weeks (unit)

Product	End-customer				
	e_1	e_2	e_3	e_4	e_5
i_1	590	572	580	594	590
i_2	500	466	450	450	490
i_3	470	482	448	464	448
i_4	304	320	318	300	300

Table 7.3 illustrates the production and distribution characteristics used in the company case study. In the SCRRJITS problem proposed in this chapter, four types of final products (i= 4) are produced in four production systems (P= 4) during a planning horizon of twelve days (T= 12). The final products are distributed to five distribution centres (DC= 4). Finally, six end-customers (e= 6) fill their demand from the above mentioned distribution centres.

Table 7.3 PSP production and distribution characteristics

Item	Symbol	Number
Planning horizon	T	12
Types of products	i	4
Production systems	P	4
Distribution centres	DC	6
End-customers	e	5

7.3.1.4. Cost characteristics

These characteristics cover all relevant cost data incurred in the case study supply chain. The relevant data includes the ordering cost (C_O), holding cost (C_H), which includes the work-in-process (WIP) holding cost (C_{WIPH}) in the production system, and the unit holding cost (C'_H) of the final product in the distribution system. The raw materials cost (C_{RM}) includes purchasing cost (C_P), and the duties cost (C_D) and transfer price cost (TP). The worker cost (C_W), transportation cost (C_{tr}), utilities cost (C_U) includes operating costs ($O_{P,DC}$) and overhead costs (α_i) and risk costs (C_R) which corporate outsourcing costs (OS_P) and shortage costs (SC_e). All these costs are illustrated in Table 7.4 to Table 7.17.

Table 7.4 Ordering cost (C_O) of raw materials for each product ($)

Product	P_1	P_2	P_3	P_4
i_1	0.5	0.5	0.4	0.6
i_2	0.5	0.5	0.4	-
i_3	0.5	0.5	-	0.6
i_4	0.5	0.5	-	-

Table 7.5 WIP holding cost (C_{WIPH}) of each product in production systems ($)

Product	P_1	P_2	P_3	P_4
i_1	0.4	0.3	0.3	0.3
i_2	0.4	0.3	0.3	-
i_3	0.4	0.3	-	0.3
i_4	0.5	0.4	-	-

Table 7.6 Holding cost (C'_H) of each product in distribution centres ($)

Product	DC_1	DC_2	DC_3	DC_4	DC_5	DC_6
i_1	0.4	0.3	0.3	0.2	0.3	0.25
i_2	0.4	0.25	0.3	0.2	0.25	0.2
i_3	0.4	0.2	0.25	0.2	0.2	0.2
i_4	0.5	0.4	0.4	0.25	0.3	0.3

Table 7.7 Purchasing cost (C_P) of raw materials for each product ($)

Product	P_1	P_2	P_3	P_4
i_1	5.5	5.5	5.6	5.4
i_2	7.5	7.5	7.6	-
i_3	4.5	4.5	-	4.4
i_4	9.5	9.5	-	-

Table 7.8 Transportation cost (C_{tr}) of the products from production systems to distribution centres ($)

Product	Production system	DC_1	DC_2	DC_3	DC_4	DC_5	DC_6
i_1	P_1	2	3	8.5	16	12	5
	P_2	8.5	8	1.8	19	17	10
	P_3	12	10	22	17	1.5	8
	P_4	11	11	5	23	20	14
i_2	P_1	1.8	2.8	8.2	5.6	11.6	4.7
	P_2	8.1	8.1	1.6	18.5	16.5	9.7
	P_3	11.7	9.7	21.2	16.3	1.2	7.7
	P_4	10.6	11.6	4.7	22.2	19.7	13.6
i_3	P_1	2	3	8.5	16	12	5
	P_2	8.5	8	1.8	19	17	10
	P_3	12	10	22	17	1.5	8

	P_4	11	11	5	23	20	14
i_4	P_1	2.2	3.2	9	17	13	5.5
	P_2	9.2	9	2.2	20	18	11
	P_3	13	10.7	23	18	16	8.7
	P_4	11.7	11.7	5.6	24	21	15

Table 7.9 Transportation cost (C_{tr}) of products from distribution centres to end-customers ($)

Product	Distribution centre	e_1	e_2	e_3	e_4	e_5
i_1	DC_1	2	2.1	16	19	9
	DC_2	3	3	17	18	8.7
	DC_3	8.5	8.5	19	10	16
	DC_4	16	16	1.3	28	24
	DC_5	12	12	25	31	9
	DC_6	5	5	19	22	15
i_2	DC_1	1.8	2	15	18	8
	DC_2	2.8	2.7	16	17	8
	DC_3	8	8	18	9.5	15
	DC_4	15	15	1	26.5	23
	DC_5	11.3	11	24	29.3	8.5
	DC_6	4.7	4.7	1.8	21	4.7
i_3	DC_1	2	2.1	16	19	9
	DC_2	3	3	17	18	8.7
	DC_3	8.5	8.5	19	10	16
	DC_4	16	16	1.3	28	24
	DC_5	12	12	25	31	9
	DC_6	5	5	19	22	5
i_4	DC_1	2.2	2.4	17	20.5	10
	DC_2	3.3	3.3	18	19	9.5
	DC_3	9	9	20	11	17.5
	DC_4	17	17	1.5	29.5	26
	DC_5	13	13	27	32.5	10
	DC_6	5.7	5.7	20	23.5	5.7

Table 7.10 Worker cost (C_W) of the product for regular-time production in production systems and distribution centres ($)

Product	P_1	P_2	P_3	P_4
i_1	0.65	0.6	0.55	0.5
i_2	0.55	0.5	0.45	-
i_3	0.3	0.3	-	0.25
i_4	0.45	0.4	-	-

Table 7.11 Worker cost (C_W) of the product for over-time production in production systems and distribution centres ($)

Product	P_1	P_2	P_3	P_4
i_1	0.9	0.84	0.77	0.7
i_2	0.78	0.7	0.63	-
i_3	0.42	0.42	-	0.35
i_4	0.63	0.56	-	-

Table 7.12 Production systems operating cost (O_P)/day for each product ($)

Production system	Operating Costs (O_P)
P_1	0.25
P_2	0.2
P_3	0.35
P_4	0.4

Table 7.13 Distribution centres operating cost (O_{DC})/day for each product ($)

No.	Operating Costs (O'_P)
DC_1	0.25
DC_2	0.25
DC_3	0.2
DC_4	0.15
DC_5	0.2
DC_6	0.2

Table 7.14 Production systems overhead cost (α_P) /day for regular-time production ($)

Product	P_1	P_2	P_3	P_4
i_1	0.75	0.7	0.7	0.7
i_2	0.7	0.65	0.65	-
i_3	0.6	0.55	-	0.55
i_4	0.65	0.6	-	-

Table 7.15 Production systems overhead cost ($ß_P$) /day for over-time production ($)

Product	P_1	P_2	P_3	P_4
i_1	1.05	1	1	1
i_2	1	0.95	0.95	-
i_3	0.85	0.8	-	0.8
i_4	0.9	0.85	-	-

Table 7.16 Outsourcing cost (OS_P) of the final product in production systems ($)

Product	P_1	P_2	P_3	P_4
i_1	65	56	50	52
i_2	59	50	45	-
i_3	36	33	-	30
i_4	50	45	-	-

Table 7.17 Shortage cost (SC_e) of the final product in distribution centres ($)

Product	e_1	e_2	e_3	e_4	e_5
i_1	8	8	5	5	6.5
i_2	7	7	4	4	5.5
i_3	7	7	4	4	5.5
i_4	7	7	4	4	5.5

7.3.1.5. Capacity characteristics

This comprises all data associated with the capacity of production systems, the capacity to house final products at the distribution centres and the maximum shortage allowed at the end-customer points. The developed mathematical model reflects the capacity data in the form of constraints which limit the search space of the optimisation problem. Table 7.18 depicts the production capacities of all production systems. Distribution capacities at distribution centres are shown in Table 7.19. Finally, Table 7.20 illustrates the backlogging capacity of products at each end-customer.

In the SCRRJITS problem, the capacity of supply chain members is limited. However, obtaining a precise data for each member in the supply chain may not be possible and estimation can be used for this kind of data. The transportation capacity is also limited and known. This capacity is different from one transporter to another and depends on the transportation mode and route used. In this regard, the proposed optimisation model uses four different transportation modes (t_m= 4) for transporting the final products from the production systems to the end-customers (Chapter 4).

Table 7.18 Distribution capacity of final products (unit) at production systems (γ_P)

Product	P_1	P_2	P_3	P_4
i_1	900	800	900	900
i_2	1050	1050	900	-
i_3	900	900	-	800
i_4	900	800	-	-

Table 7.19 Distribution capacity of final products (unit) at distribution centres ($£_{DC}$)

Product	DC_1	DC_2	DC_3	DC_4	DC_5	DC_6
i_1	600	900	600	900	600	900
i_2	600	900	600	900	600	900
i_3	600	600	600	600	600	600
i_4	600	600	600	600	600	600

Table 7.20 Maximum shortage permitted (unit) at end-customers (S^{max}_{e})

Product	e_1	e_2	e_3	e_4	e_5
i_1	100	120	80	100	110
i_2	70	100	50	70	80
i_3	70	100	50	70	80
i_4	50	80	30	50	60

Essentially, this chapter shows the variation in the collected data across different JIT supply chain parties even for the same product. The variability is because of the differences in geographic locations and the manufacturing circumstances such as labour costs and the differences in the manufacturing skills used in the production systems. This awareness justifies the existence of variability across the collected data.

7.3.2. *Implementation of the Developed SCRRJITS Approach*

In this chapter, the experiments apply carefully selected decision variables to evaluate the capability of the proposed framework approach (SCRRJITS) to address the given problem and to compare results. In Chapter 6, an optimisation approach (GA) was proposed to find the optimal solution of the mathematical model developed in Chapter 4. Table 7.21 lists the expected ranges of the decision variables used in the proposed optimisation model.

Table 7.21 Adjustable ranges of decision variables used in the proposed model

Item	Min	Max
LT	1	24
d_P	1	1000
t_m	1	4
Q_M	1	5

Figures 7.5 - 7.8 demonstrate the configuration of the studied supply chain of the four products (i_1, i_2, i_3 and i_4) respectively. Figure 7.5 illustrates that i_1 can be supplied by five

suppliers (DC_1, DC_2, DC_3, DC_4 and DC_5) to five end-customers (e_1, e_2, e_3, e_4 and e_5). DC_1 and DC_2 can supply i_1 produced in P_1 to e_1. e_2 procures its goods (i_1) produced in P_1 and P_2 from DC_2 and DC_3 as well. DC_3 and DC_4 can supply i_1 produced in P_2, P_3 and P_4 to e_3. Also, e_4 procures its goods (i_1) produced in P_2 from DC_2 and DC_3. Finally, DC_5 supplies its product (i_1) produced in P_3 and to e_5.

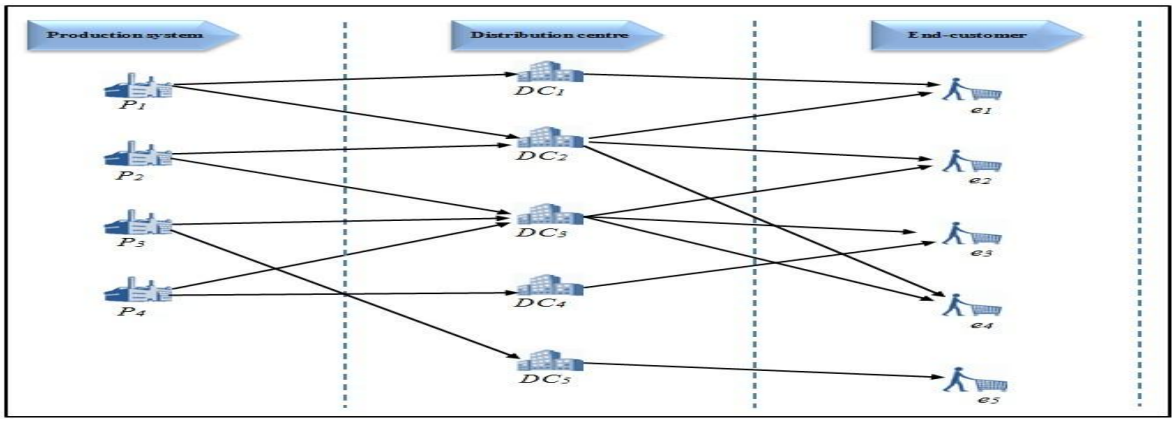


Figure 7.5 Supply chain of product 1 (i_1)

In Figure 7.6, DC_1, DC_2, DC_3, DC_5 and DC_6 supplies i_2 to the five end-customers. DC_1 supplies its product (i_1) produced in P_1 to e_1. DC_2 and DC_3 can supply i_2 produced in P_1 and P_2 to e_2. e_3 procures its goods (i_2) produced in P_2 and P_3 from DC_6. DC_3 can supply i_2 produced in P_2 to e_4. Finally, e_5 procures its goods (i_2) produced in P_3 from DC_5.

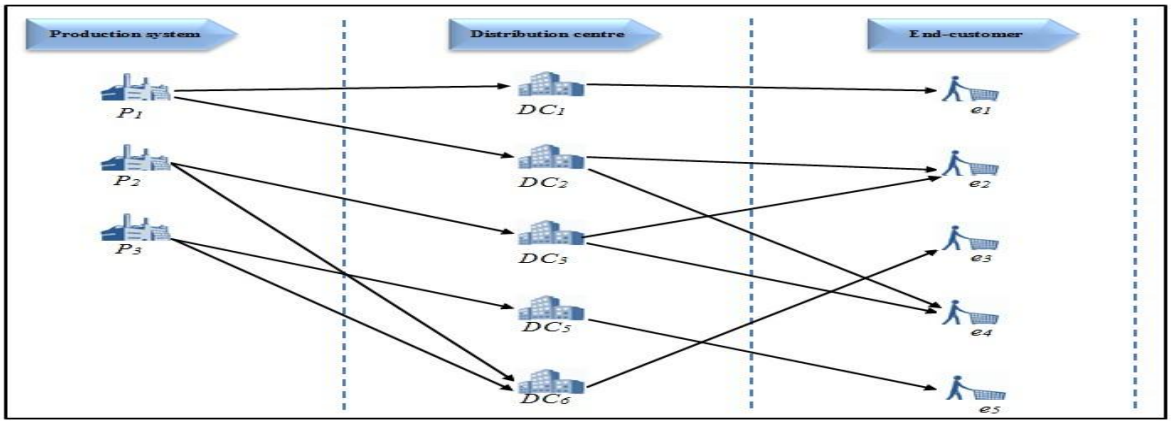


Figure 7.6 Supply chain of product 2 (i_2)

Figure 7.7 depicts the supply chain of product 3 (i_3) supplied by five suppliers (DC_1, DC_2, DC_3, DC_4 and DC_6) to the five end-customers. DC_1 supplies i_3 produced in P_1 to e_1. e_2 procures its goods (i_3) produced in P_2 from DC_2. DC_6 supplies i_3 produced in P_1 to e_3. Also,

e_4 procures its goods (i_3) produced in P_2 from DC_4. Finally, DC_3 supplies its product (i_3) produced in P_4 and to e_5.

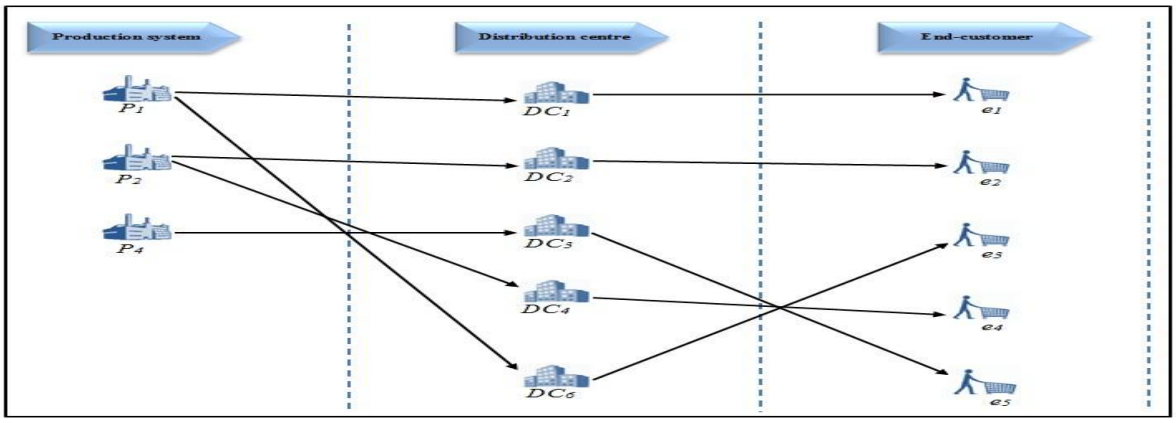


Figure 7.7 Supply chain of product 3 (i_3)

The supply chain of product 4 (i_4) is illustrated in Figure 7.8. The five end-customers procure their goods (i_4) from DC_1, DC_2, DC_4 and DC_6. DC_1 supplies its product (i_1) produced in P_1 to e_1. DC_1 and DC_2 supply i_4 produced in P_1 to e_2. e_3 procures its goods (i_4) produced in P_2 and P_1 from DC_6 and DC_4 respectively. DC_2 supplies i_4 produced in P_1 to e_4. Finally, e_5 procures its goods (i_4) produced in P_2 from DC_6.

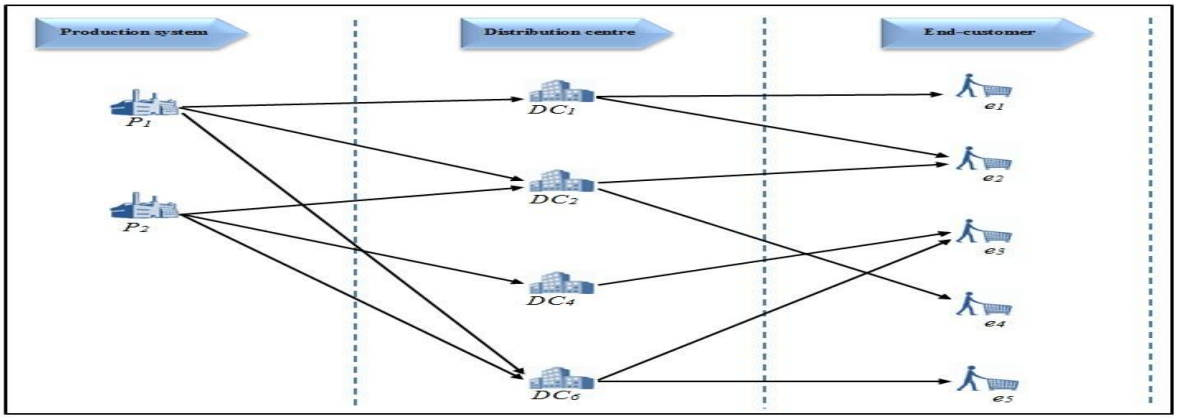


Figure 7.8 Supply chain of product 4 (i_4)

The end-customers order their goods based on their average daily demand during the planning horizon as shown in Table 7.2. They procure their goods produced in P_1, P_2, P_3 and P_4 from DC_1, DC_2, DC_3, DC_4, DC_5 and DC_6 as regular external suppliers (S_E). Each order depends on the lead time up to 24 hours from each supplier. These order quantities can meet customer needs during a fixed interval of normal time. However, in cases where there are demand interruptions, the external suppliers may not be able to meet the suppliers' demand due to delayed supply of products to the end-customers within the planned time. This may

create physical, social, legal, operational, economic and political risk factors and these factors can affect and disrupt the entire supply chain.

7.3.2.1. Local Backup Suppliers used to Supply End-customers' Goods in Case External Suppliers have Disruption

In this Sub-section, it is assumed that five local backup suppliers (S_{LB1}, S_{LB2}, S_{LB3}, S_{LB4} and S_{LB5}) are accessible to provide the end-customers with their daily demand. These suppliers had been selected using different criteria. Although the cost of procurement is a significant factor to most of the organisations, other factors such as product quality, reliability and supplier responsiveness may be of greater significance to organisations due to the high level of competition faced in today's global marketplace.

Figure 7.9 depicts the supply chain of the five local suppliers who supply their goods (i_1, i_2, i_3 and i_4) to the five end-customers. S_{LB1} supplies its goods to e_1. e_2 procures its goods from S_{LB4}. S_{LB5} supplies to e_3. Also, e_4 obtains its goods from S_{LB2}. Finally, S_{LB3} supplies its goods to e_5.

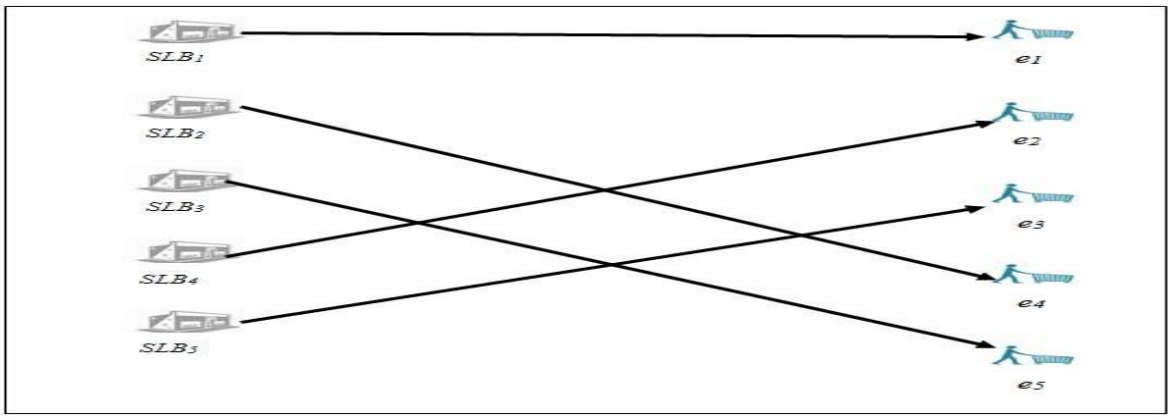


Figure 7.9 Supply chain of local backup suppliers and their end-customers

Table 7.22 lists the external suppliers who normally supply the required products under regular circumstances and the local suppliers who can fill the end-customers demand if one or more external supplier experiences some kind of disruption. For any higher quantity of products procured from both of external and local suppliers, it is assumed that discounts are offered to the end-customers as shown in Tables 7.23 and 7.24.

Table 7.22 External and local backup suppliers who are able to supply products to end-customers in the regular situation and in the disruption time

Case No.	External supplier (S_E)						Local backup supplier (S_{LB})				
	1	2	3	4	5	6	1	2	3	4	5
1	0	1	1	1	1	1	1	0	0	1	0
2	1	0	1	1	1	1	1	1	0	1	0
3	1	1	0	1	1	1	0	1	1	1	1
4	1	1	1	0	1	1	0	1	0	0	1
5	1	1	1	1	0	1	0	0	1	0	0
6	1	1	1	1	1	0	0	0	1	0	1

Table 7.23 Discounts offered by external suppliers for purchasing extra products

External supplier	Discounts rate (%)				
	Q_{M1}	Q_{M2}	Q_{M3}	Q_{M4}	Q_{M5}
1	95	90	85	80	75
2	93	88	85	82	80
3	95	90	85	80	75
4	90	88	86	84	82
5	95	92	90	88	85
6	95	90	85	80	75

Table 7.24 Discounts offered by local backup suppliers for purchasing extra products

Local backup supplier	Discounts rate (%)				
	Q_{M1}	Q_{M2}	Q_{M3}	Q_{M4}	Q_{M5}
1	95	90	85	80	75
2	93	88	85	82	80
3	95	90	85	80	75
4	90	88	86	84	82
5	96	92	90	88	86

The total cost of the goods supplied to the end-customers is based on the number of experimental studies. Table 7.25 - Table 7.28 list all costs incurred by the local backup suppliers including C_O, C_H, C_P, C_{tr}, C_W, C_U, C_{pt}, C_R and C_T providing end-customers with their required demands for the four products during the disruption time.

Table 7.25 Costs incurred in local suppliers for providing end-customers with product 1 (i_1)

Local backup supplier	Costs incurred ($)/unit								
	C_O	C_H	C_P	C_{tr}	C_W	C_U	C_{pt}	C_R	C_T
1	0.4	0.65	25.5	1.5	0.3	0.5	28.85	4.3275	33.1775
2	0.55	0.5	24.5	1.75	0.4	0.55	28.25	4.2375	32.4875
3	0.5	0.6	25	2	0.3	0.5	28.9	4.335	33.235
4	0.45	0.55	26	1.25	0.3	0.6	29.15	4.3725	33.5225
5	0.6	0.65	25.5	1.5	0.4	0.55	29.2	4.38	33.58

Table 7.26 Costs incurred in local suppliers for providing end-customers with product 2 (i_2)

Local backup supplier	Costs incurred ($)/unit								
	C_O	C_H	C_P	C_{tr}	C_W	C_U	C_{pt}	C_R	C_T
1	0.4	0.65	29.5	1.5	0.3	0.5	32.85	4.9275	37.7775
2	0.55	0.5	29	1.75	0.4	0.55	32.75	4.9125	37.6625
3	0.5	0.6	28.5	2	0.3	0.5	32.4	4.86	37.26
4	0.45	0.55	29.5	1.25	0.3	0.6	32.65	4.8975	37.5475
5	0.6	0.65	29	1.5	0.4	0.55	32.7	4.905	37.605

Table 7.27 Costs incurred in local suppliers for providing end-customers with product 3 (i_3)

Local backup supplier	Costs incurred ($)/unit								
	C_O	C_H	C_P	C_{tr}	C_W	C_U	C_{pt}	C_R	C_T
6	0.5	0.65	22.5	1.75	0.3	0.4	26.1	3.915	30.015
7	0.45	0.55	23	2	0.4	0.55	26.95	4.0425	30.9925
8	0.5	0.65	24.5	1.25	0.45	0.6	27.95	4.1925	32.1425
9	0.55	0.6	25	1.75	0.3	0.6	28.8	4.32	33.12
10	0.5	0.65	25.5	1.3	0.4	0.55	28.9	4.335	33.235

Table 7.28 Costs incurred in local suppliers for providing end-customers with product 4 (i_4)

Local backup supplier	Costs incurred ($)/unit								
	C_O	C_H	C_P	C_{tr}	C_W	C_U	C_{pt}	C_R	C_T
6	0.5	0.65	32.5	1.75	0.3	0.4	36.1	5.415	41.515
7	0.45	0.55	31.5	2	0.4	0.55	35.45	5.3175	40.7675
8	0.5	0.65	33	1.25	0.45	0.6	36.45	5.4675	41.9175
9	0.55	0.6	32.5	1.75	0.3	0.6	36.3	5.445	41.745
10	0.5	0.65	33.5	1.3	0.4	0.55	36.9	5.535	42.435

7.3.2.2. Risk Assessment in the Supply Chain

The following section identifies the supply chain risks facing the production systems and distribution centres. There are many approaches that have been developed for risk assessment such as the fault tree analysis (FTA), the failure modes and effect analysis (FMEA), the Markov method, the network reduction method and the decomposition method (Musa 2012). The potential risks in this research were assessed using the FMEA approach. Table 7.29 shows the main supply chain risks and their impacts within the supply chain that potentially negatively influences the production and marketing of these products. Potential risks were identified by examining the effect of disruption and demand changes within the production systems and their distribution centres. This may also be approached by investigating all possible root causes of supply chain issues.

Table 7.29 Risk assessment of the supply chain system

Risk Symbol	Risk	End-customer Effect	Likelihood (1 - 10)	Impact (1 - 10)	% Total Risk Score
H_1	Supplier 1 cannot supply raw materials on the scheduled time or is destroyed by disasters.	1 & 2	6	5	$\frac{30}{100} = 30\%$
H_2	Supplier 2 cannot supply raw materials on the scheduled time or is destroyed by disasters.	1, 2 & 4	4	7	$\frac{28}{100} = 28\%$
H_3	Supplier 3 cannot supply raw materials on the scheduled time or is destroyed by disasters.	2, 3, 4 & 5	4	7	$\frac{28}{100} = 28\%$
H_4	Supplier 4 cannot supply raw materials on the scheduled time or is destroyed by disasters.	3 & 4	6.6	5.5	$\frac{31}{100} = 31\%$
H_5	Supplier 5 cannot supply raw materials on the scheduled time or is destroyed by disasters.	5	7	4	$\frac{28}{100} = 28\%$
H_6	Supplier 6 cannot supply raw materials on the scheduled time or is destroyed by disasters.	3 & 5	5.4	5.4	$\frac{29}{100} = 29\%$
H_7	End-customer demand is higher than forecasted demand.	All product	5	9	$\frac{45}{100} = 20\%$
H_8	End-customer demand is lower than forecasted demand.	All product	5	9	$\frac{45}{100} = 20\%$

The risks H_1, H_2, H_3, H_4, H_5 and H_6 in Table 7.29 might result from increasing the lead time of the products supplied by external suppliers S_{E1}, S_{E2}, S_{E3}, S_{E4}, S_{E5} and S_{E6} respectively to arrive at the end-customer at the planned time. Such risks may be realised in the eventuality of and resulting from unforseen factors such as natural and man-made disasters or economic crises such as currency crashes and strikes. The risk H_7 may occur from a shortfall in the actual quantity of products ordered and delivered from external suppliers by the end-customers. This may have arisen due to factors such as unexpected increases in customer demand and inventory elimination arising from implementing a JIT system within the production systems and distribution centres. The likelihood of its occurrence is low but its impact on the production system would be mostly high. Finally, H_8 may result from the lack of customer demand in the marketplace which incurs a holding cost for the production systems and distribution centres by keeping the final products within their stores until required. The likelihood of its occurrence is also quite low but its impact on the production system will be high.

Any of the risks listed in Table 7.29 might disrupt the production systems and the distribution centres and at the same time affect the end-customers. However, their impact is reduced by using local suppliers even if the total costs of the products relatively increase. This strategy

can dramatically improve the supply chain's efficiency and responsiveness making it capable of meeting the customer's demand throughout the duration of the disruption whilst ensuring that the firms' reputation in the marketplace remains high.

7.3.2.3. The proposed GA used in the Case Company

As mentioned above, the case study under examination has a large number of possible solutions. These are represented by combinations of the parameters and decision variables used. It takes a long calculation time to evaluate all these combinations. Consequently, the mathematical model itself developed in Chapter 4 is not able to solve the case study problem. However, combining the developed model with an optimisation approach such as GA, an optimal or near-optimal solution may be found in a shorter time. The proposed GA (presented in detail in Chapter 6) is used to solve the SCRRJITS problem in this case study. The application of the proposed GA starts with a population of random chromosomes representing decision variables used in the developed model. Table 7.30 illustrates a random chromosome in the proposed GA for the purpose of optimisation values for decision variables. As detailed in Chapter 6, each integer is represented by a corresponding real coded bit on the chromosome generated by the proposed algorithm.

Table 7.30 The chromosome construction of the proposed GA

X_1						X_2	X_3						X_4					
1	0	1	0	1	0	450	1	4	2	3	2	1	1	3	2	5	4	1

Based on the expected ranges of the decision variables used in the proposed optimisation model illustrated in Table 7.21, the number of possible solution spaces can be calculated as $2^6 \times 1000 \times 4^6 \times 5^6 = 4.1 \times 10^{12}$ solutions.

7.3.3. *Experimental Results and Discussion*

This section presents the results obtained by implementing the proposed optimisation model in the case study concerned. The findings of this chapter are organised into three sections. Sub-section 7.3.3.1 presents the results achieved from the optimisation model implementation in the case where all external suppliers can supply their products to the end-customers. Sub-section 7.3.3.2 compares the achieved results with the results of the case study which demonstrates the significance of the JIT implementation in production systems. Finally, Sub-section 7.3.3.3 highlights the total cost of products supplied to the end-customers in case one

or more external supplier experiences disruption. The local backup suppliers have been used for this purpose.

7.3.3.1. The Optimised Model Results in the Case where all External Suppliers are Able to Supply their Products to the End-customers

This sub-section analyses the total cost of the products required by end-customers using external suppliers under a JIT adoption. The GA parameters such as initial population (N), maximum generations (G_{max}), crossover rate (P_C) and mutation rate (P_m) were determined experimentally as shown in Table 7.31. Based on the experiments carried out for the four selection methods (Roulette wheel, Binary tournament, Elitist and Replacement selection methods) in Chapter 6 the replacement selection method is also used in this chapter to select only the best chromosomes from the parents and offspring pools.

Table 7.31 Input GA parameters used in the case study

Parameter	Rate
Crossover rate (P_c)	0.8
Mutation rate (P_m)	0.2
Population size (N)	400
Maximum generations (G_{max})	5000
Generation stop (G_{max}_Stop)	30000

By using these parameters, the proposed GA is run to produce the optimal solution for minimising the total cost of the products and the risk effects adopting the JIT approach for managing their processes. Table 7.32 illustrates the best chromosome and the findings for the proposed GA are depicted in Table 7.33 including the number of iterations, the required time, the customer demand and the cost types of the final products.

Table 7.32 The best chromosome obtained using a replacement selection method

X_1						X_2	X_3						X_4					
1	1	1	1	1	0	1000	3	3	1	1	2	1	2	2	5	3	4	5

The average and best costs of the four products are shown in Figure 7.10 according to the number of iterations. It can be observed from Figure 7.10 that the proposed GA can achieve the optimal solution after 154 generations. The detailed results of the optimal solution for solving the simultaneous cost-risk reduction problem using the JIT approach in the concerned case study are provided in Table D.1 in Appendix D.

Table 7.33 The output GA obtained using a replacement selection method

Iter.	d_p	C_O ($)	C_H ($)	C_P ($)	C_w ($)	C_D ($)	TP ($)	C_W ($)	C_U ($)	C_{pt} ($)	C_R ($)	C_T ($)
465	1000	2.254	4.802	27.7	85.25	4.309	3.134	1.96	12.745	142.153	28.431	170.584

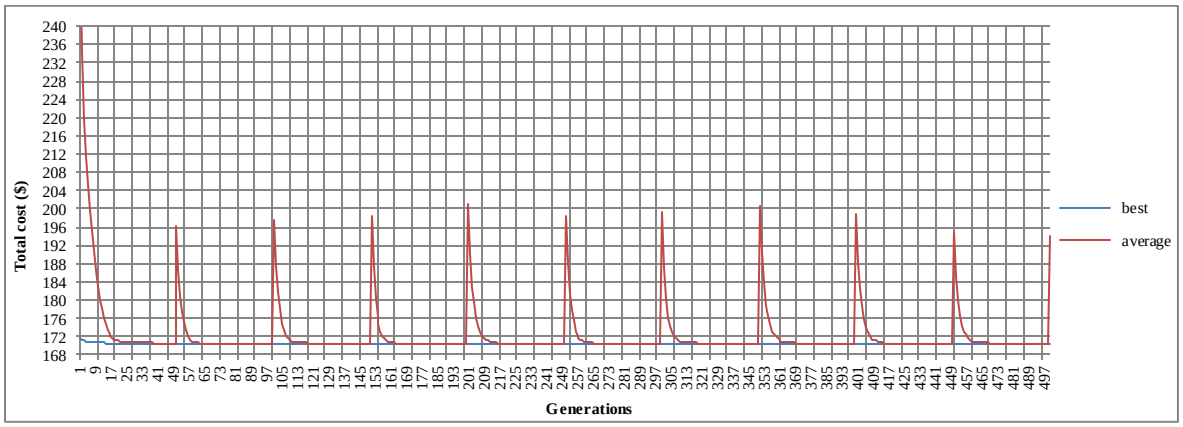


Figure 7.10 The best and average value of the total final product cost

7.3.3.2. Comparison of the Obtained Results and the Results of the Original Case Study

This sub-section presents a comparison between the results obtained by using a JIT approach in this chapter and the results of the original company case using inventory management. This comparison is to demonstrate the effectiveness of the JIT approach which can minimise the total cost of products in the supply chain. Figure 7.11 shows that the total cost of the four products required to meet the end-customers' approval during the planning horizon using the JIT approach is less than the total cost using the inventory management approach.

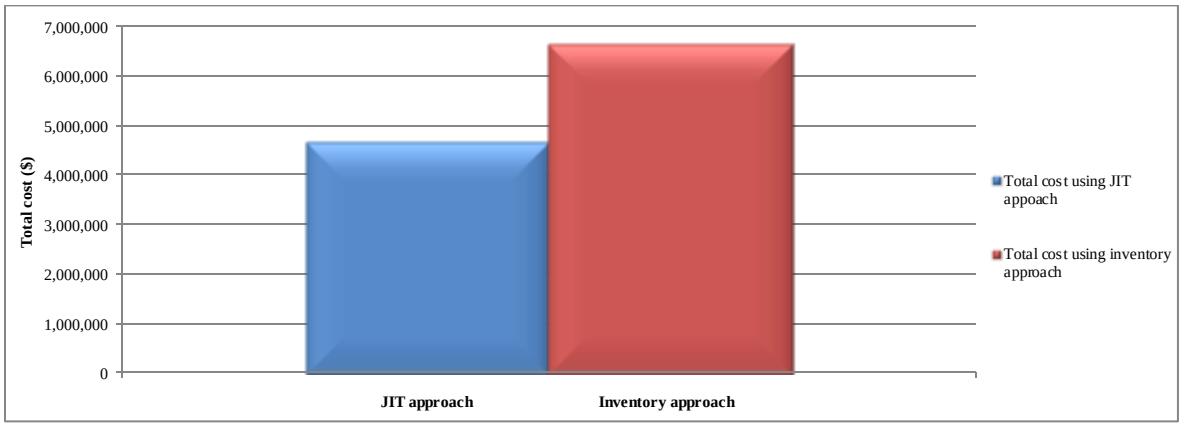


Fig. 7.11 Comparison between the total cost using the JIT approach and the inventory management approach

Figure 7.11 indicates that the proposed SCRRJITS model converges to maintain an optimal consistency with a reduction of 29.6% in the overall cost using the inventory management approach. Using the SCRRJITS model, the total cost of the four products is $4,678,123 compared to the company case value of $6,647,984. This reduction in the total cost is mainly gained through inventory elimination within the production systems and distribution centres.

It is achieved due to the use of multiple suppliers (rather than using only a single supplier) which supply products to the end-customers at lower costs.

7.3.3.3. Model Results Analysis in the Case where some or all of External Suppliers have a Disruption to the Supply of their Products to the End-customers

Three scenarios have been developed to measure and quantify the effects of decision variables in the case where all or some external suppliers experience disruption to their supply of products to the end-customer base. Scenario I presents the achieved results in the case where some external suppliers are able to supply their products to their customer and the others are not. Scenario II shows the total cost of products supplied to the end-customers in the event where the external suppliers of Scenario I reverse their positions. Scenario III highlights the results achieved from the optimisation model implementation in the case where none of the external suppliers are able to supply their products to the end-customers.

Scenario I:

This scenario analyses the effects of the decision variables in the event of some disruption occurrences for the external suppliers (S_{E1}=1, S_{E2}=0, S_{E3}=1, S_{E4}=0, S_{E5}=1, S_{E6}=0). In this case, the local backup suppliers will replace the disrupted external suppliers to provide the end-customers with their order-requirements for the duration of the disruption. The findings for the proposed GA are illustrated in Table 7.34 including the number of iterations, the required time, the customer demand and the cost types of the final products.

Table 7.34 The output GA obtained from Scenario I

Iter.	d_p	C_O ($)	C_H ($)	C_P ($)	C_w ($)	C_D ($)	TP ($)	C_W ($)	C_U ($)	C_{pt} ($)	C_R ($)	C_T ($)
57	1000	1.702	4.634	85.86	66.08	2.627	1.985	1.96	16.289	181.137	36.227	217.364

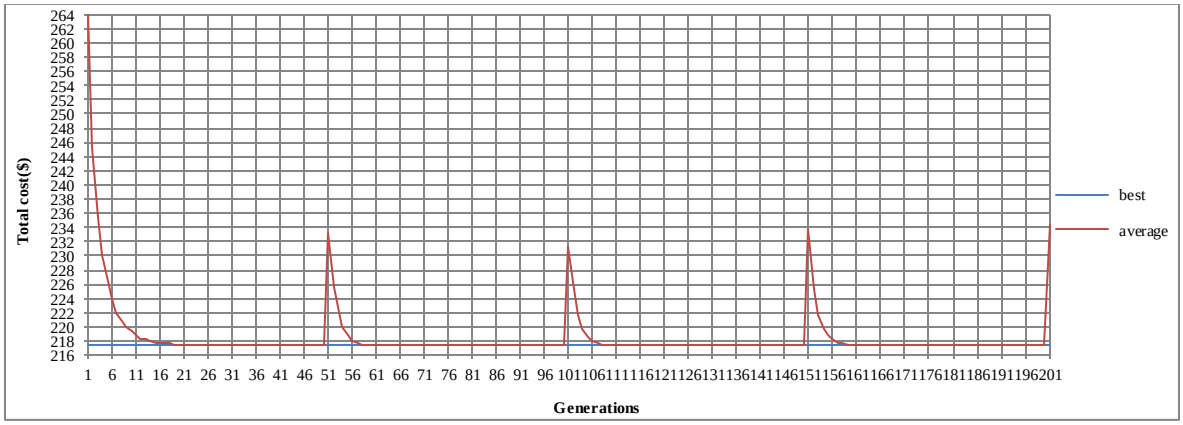


Figure 7.12 The best and average value of the total final product cost in Scenario I

Figure 7.12 depicts the average and best costs of the four products based on the number of iterations. It can be observed from Figure 7.12 that the proposed GA can achieve the optimal solution after 57 generations. Table D.2 in Appendix D lists the detailed results of the optimal solution for solving the simultaneous cost-risk reduction problem using the JIT approach in the concerned case study.

Scenario II:

The second scenario presents the total cost of products supplied to the end-customers in the case of reversing the external supplier status in Scenario I (S_{E1}=0, S_{E2}=1, S_{E3}=0, S_{E4}=1, S_{E5}=0, S_{E6}=1). Table 7.35 illustrates the findings of the proposed GA comprising the number of iterations, the required time, the customer demand and the cost types of the final products. Figure 7.13 shows the graph of the best and average cost curve for each generation for a total of 500 generations. From this figure, it is obvious that the proposed GA converges to the optimal or near-optimal solution after 219 generations.

The detailed results of the optimal solution for the simultaneous cost-risk reduction under a JIT adoption in the concerned case study are provided in Table D.3 in Appendix D.

Table 7.35 The output GA obtained from Scenario II

Iter.	d_p	C_O ($)	C_H ($)	C_P ($)	C_w ($)	C_D ($)	TP ($)	C_W ($)	C_U ($)	C_{pt} ($)	C_R ($)	C_T ($)
219	1000	1.354	4.468	115.025	44.17	1.682	1.148	1.96	16.785	186.591	37.318	223.909

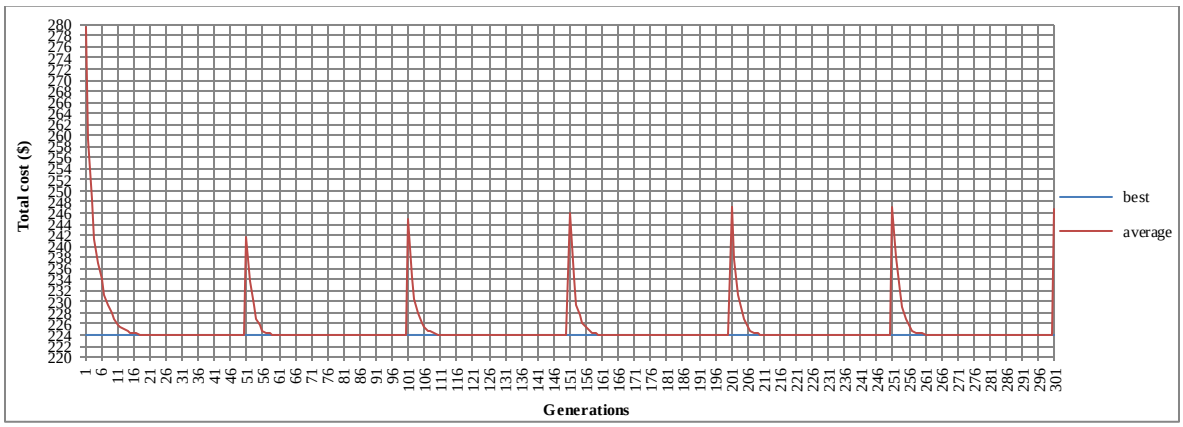


Figure 7.13 The best and average value of the total final product cost in Scenario II

Scenario III:

This scenario highlights the analysis of model results where all external suppliers are disrupted (S_{E1}=0, S_{E2}=0, S_{E3}=0, S_{E4}=0, S_{E5}=0, S_{E6}=0). This means that for the duration of the disruption all the external suppliers are replaced by local backup suppliers to supply the required goods to the end-customers. The number of iterations, the required time, the

customer demand and the cost types of the final products are demonstrated in Table 7.36. In Figure 7.14, the average and minimum costs of the four kinds of the required goods are illustrated. Figure 7.14 shows that the proposed GA can converge to the best solution after 27 generations. Table D.4 in Appendix D lists in detail the results obtained from this scenario.

Table 7.36 The output GA obtained from Scenario III

Iter.	d_p	C_O ($)	C_H ($)	C_P ($)	C_w ($)	C_D ($)	TP ($)	C_W ($)	C_U ($)	C_{pt} ($)	C_R ($)	C_T ($)
27	1000	0.802	4.3	173.185	16	0	0	1.96	19.429	215.674	43.135	258.809

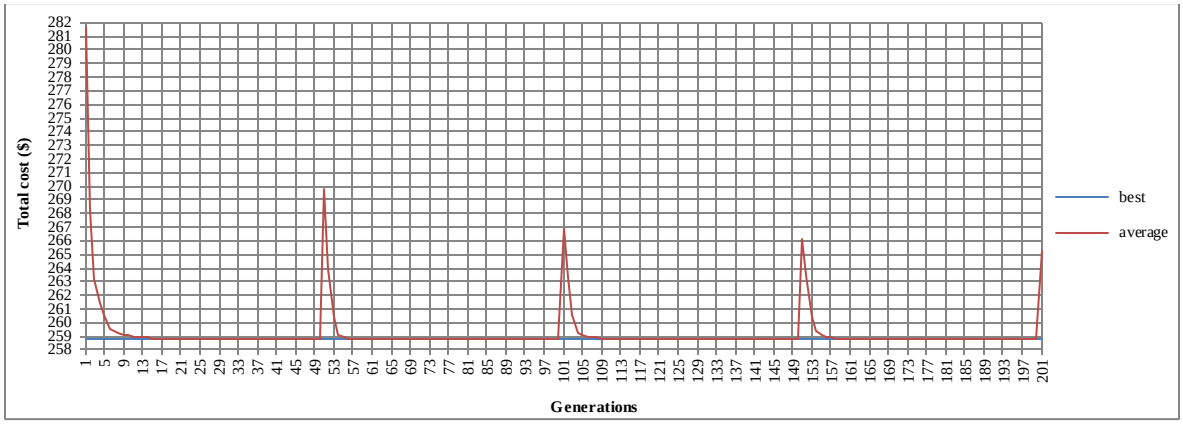


Figure 7.14 The best and average value of the total final product cost in Scenario III

7.4. Sensitivity Analysis and Testing of the Developed SCRRJITS Optimisation Model

Sensitivity analysis is considered as a useful tool in model building and evaluation to identify the model response by changing the value of its parameters (Lee, Y-S et al. 2013). It is defined as the investigation of these potential changes and errors, and their impacts on the conclusions drawn from the model (Baird 1989). Sensitivity analysis can be useful for the identification and the prioritisation of key sources of uncertainty, for the identification of critical limits of controllable inputs and model refinements and for the verification and validation (Mokhtari & Frey 2005). Performing an extensive sensitivity analysis creates an inclusive set of predictions that show the effects of any changes in the model parameters on its outputs (Lee, Y-S et al. 2013).

This section highlights the conduct of the sensitivity analysis of decision variables along with some interesting insights. In this research Chapter 4 presents four decision variables. These are the number of suppliers used for supplying raw materials to the production system (X_1), customer demand (X_2), transportation modes used for shipping the required raw materials from suppliers to the production facility (X_3) and the quantity of raw materials ordered in each patch required to produce the final product per unit of time (X_4). Experimental studies

are carried out using these decision variables to determine the effects of each variable. This can be achieved by changing the levels of each variable while the other variables are fixed. The sensitivity analysis of the four decision variables is performed as described below.

7.4.1. *The Effects of External Suppliers on the Model Costs*

This sub-section analyses the various numbers of the external suppliers used to supply their products to end-customers. Seven different external suppliers are used (S_E= 0, 1, 2, 3, 4, 5 and 6) to determine the effects of external suppliers on the objective function of the developed model. The results obtained from the proposed GA are analysed by ANOVA using the normality test. Table 7.37 illustrates the overall significance of the number of external suppliers' effect on the costs which are C_P, C_{tr}, C_{pt}, C_R and C_T (p-value< 0.05).

Table 7.37 ANOVA factorial experiments of the model cost due to changing the number of external suppliers

Cost type	Sum of Squares	*df*	Mean square	*F* value	*P*- value
Purchasing cost (C_P)	16.824445	1	16.824445	99.618525	0.000565
Transportation cost (C_{tr})	15.654343	1	15.654343	33.926874	0.004327
Product cost (C_{pt})	15.446713	1	15.446713	30.091674	0.005379
Risk cost (C_R)	15.446098	1	15.446098	30.081476	0.005382
Total cost (C_T)	15.446610	1	15.446610	30.089974	0.005379

Figure 7.15 depicts the normality test in the form of a probability plot and histogram for the total cost of the four goods. The impact of this variable (S_E) on these costs can be clearly seen in Figure 7.16. This figure illustrates that the costs C_P and C_R are decreased which lead to the costs C_{pt} and C_T being minimised. However, the transportation cost (C_{tr}) will increase as a result of increasing the number of the external suppliers used for supplying their goods to the end-customers.

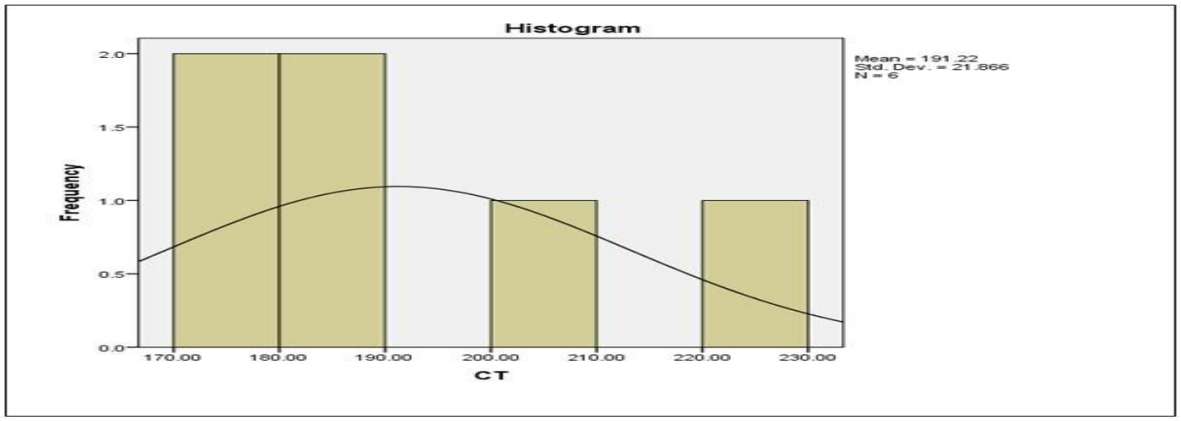


Figure 7.15 The histogram with normal curve of the overall cost and the external suppliers

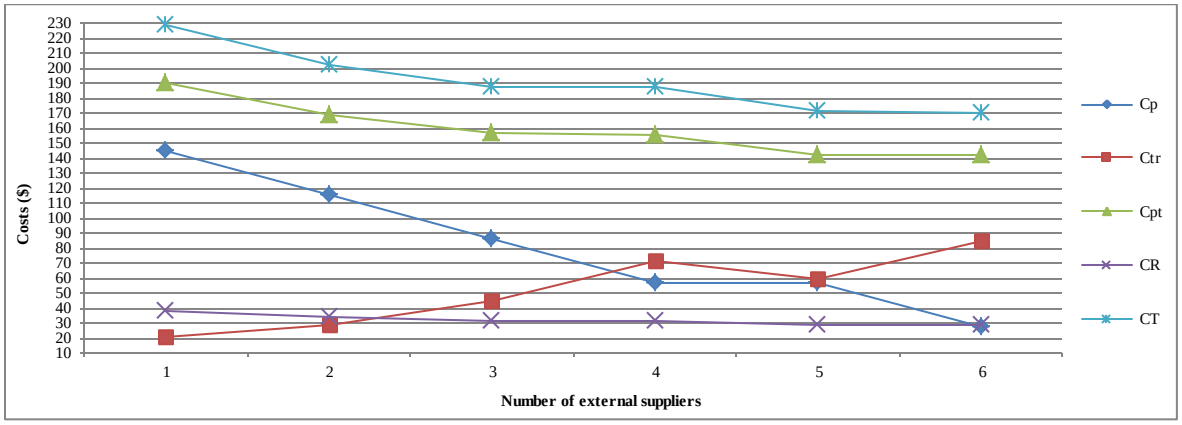


Figure 7.16 The effects of external suppliers on the model costs

7.4.2. *The Effects of Customer Demand on the Model Costs*

In this analysis, five different quantities of the daily customer demand are used (d_P= 200, 400, 600, 800 and 1000) to investigate the impact of customer demand on the model costs. Table 7.38 lists the analysis of variance of the model costs using different rates of the daily customer demand. These analyses present the significance of the customer demand effect on the model costs. By running the proposed optimisation model, Figure 7.17 shows that an increase in customer demand means that costs C_O and C_H are minimised. It follows that costs C_{pt} and C_T are also minimised. The risk cost (C_R) however is a fixed cost.

Table 7.38 ANOVA factorial experiments of the model cost due to changing the daily customer demand

Cost type	Sum of Squares	*df*	Mean square	*F* value	*P*- value
Ordering cost (C_O)	16.824445	1	16.824445	99.618525	0.000565
Holding cost (C_H)	15.654343	1	15.654343	33.926874	0.004327
Product cost (C_{pt})	15.446713	1	15.446713	30.091674	0.005379
Risk cost (C_R)	15.446098	1	15.446098	30.081476	0.005382
Total cost (C_T)	15.446610	1	15.446610	30.089974	0.005379

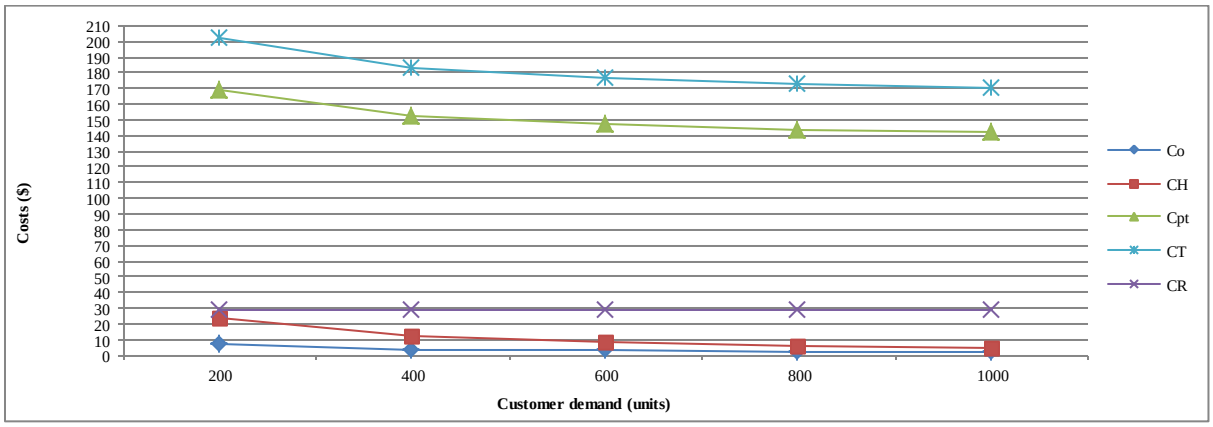


Figure 7.17 The effects of customer demand on the model costs

7.4.3. *The Effects of Transportation Mode on the Model Costs*

This sub-section presents various numbers of the transportation modes used for transporting the goods from their suppliers to the end-customers. Four different transportation modes are used to ascertain the effects of this decision variable on the objective function of the developed model: waterways, railways, roadway and airways (t_m= 1, 2, 3 and 4). Table 7.39 lists the significance of the transportation modes' impact on the model costs using ANOVA. The impact of the transportation modes is on C_P, C_{tr}, C_{pt} and C_T.

Table 7.39 ANOVA factorial experiments of the model cost due to changing the number of external suppliers

Cost type	Sum of Squares	*df*	Mean square	*F* value	*P*- value
Purchasing cost (C_P)	16.824445	1	16.824445	99.618525	0.000565
Transportation cost (C_{tr})	15.654343	1	15.654343	33.926874	0.004327
Product cost (C_{pt})	15.446713	1	15.446713	30.091674	0.005379
Risk cost (C_R)	15.446098	1	15.446098	30.081476	0.005382
Total cost (C_T)	15.446610	1	15.446610	30.089974	0.005379

Figure 7.18 illustrates the decision variable effects on the model costs. Based on Figure 7.18 and using the results of ANOVA listed in Table 7.39, it is clear that the costs C_{tr} and C_U are increased by using the different transportation modes. This increase will lead to an increase in C_{pt} and C_T. However, the other costs are the same rates using the different levels of transportation modes.

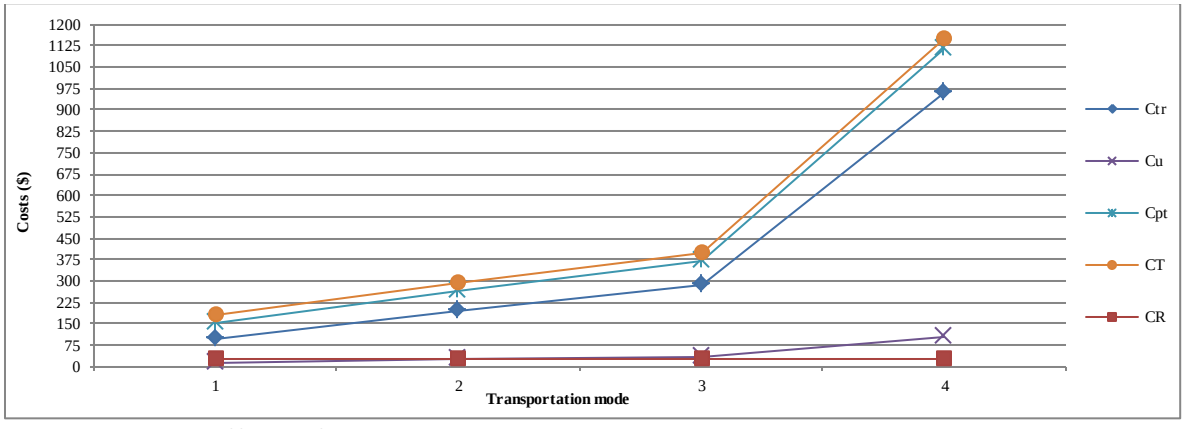


Figure 7.18 The effects of transportation mode on the model costs

7.4.4. *The Effects of Raw Materials Quantity on the Model Costs*

The last decision variable is analysed in this sub-section to define its effect on the objective function of the developed model. Five different quantities of the required goods are used in this analysis (Q_m= 400, 500, 600, 700 and 800). The results of ANOVA in Table 7.40

indicate the significance of the quantity of the goods' impact on the objective function of the developed model. The impact of this decision variable is on C_P, C_U, C_{pt} and C_T.

Table 7.40 ANOVA factorial experiments of the model cost due to changing the number of external suppliers

Cost type	Sum of Squares	*df*	Mean square	*F* value	*P*- value
Purchasing cost (C_P)	16.824445	1	16.824445	99.618525	0.000565
Transportation cost (C_U)	15.654343	1	15.654343	33.926874	0.004327
Product cost (C_{pt})	15.446713	1	15.446713	30.091674	0.005379
Risk cost (C_R)	15.446098	1	15.446098	30.081476	0.005382
Total cost (C_T)	15.446610	1	15.446610	30.089974	0.005379

Figure 7.19 depicts the normal probability plots of the impacts of the quantities of the goods on the model costs. It is obvious that the costs C_P and C_U have a slight decrease using the different quantities of goods procured from their suppliers. This reduction minimises the costs C_{pt} and C_T. Nevertheless, the other costs have no effect using the different levels of this decision variable.

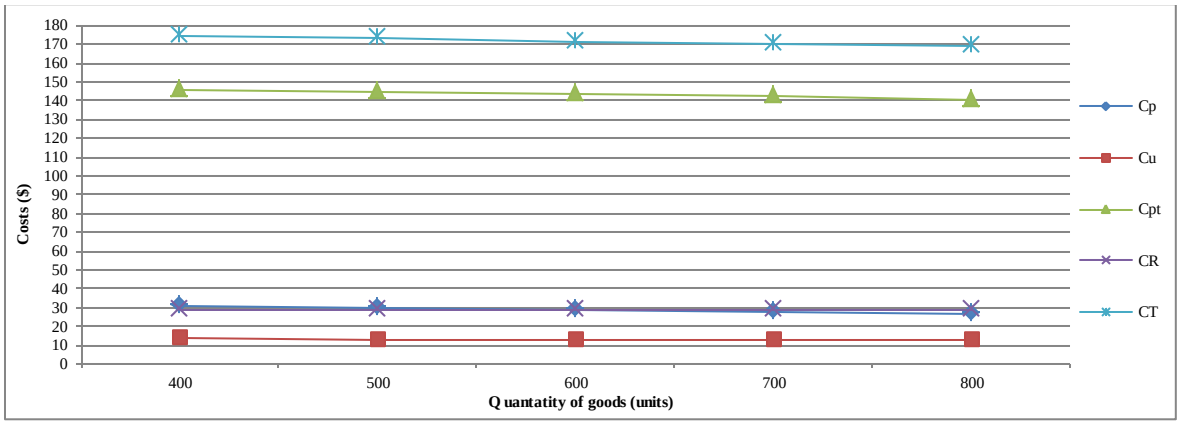


Figure 7.19 The effects of the quantity of goods on the model costs

The aforementioned sensitivity analysis indicated that the selection of an appropriate combination of the decision variables (as discussed in Chapter 6) is essential for the implementation of the SCRRJITS optimisation approach. The results illustrated the effectiveness of this approach for solving such problems.

7.5. Concluding Remarks

This chapter presented an analysis and an application of the developed SCRRJITS optimisation model in an industrial case study which had been taken from Fahimnia (2011). The case study involved the Pooladin Sazeh Persian (PSP) Company which is the largest

Iranian manufacturer and exporter of various motorcycle spare parts. The supply chain includes a three echelon supply chain. The first echelon consists of four production systems producing two final products of Honda and Yamaha front and rear mudguard parts. The second echelon includes five suppliers who normally supply these two products to their end-customers under regular circumstances. The third echelon evolves six end-customers receiving their goods from their suppliers. In the case where one or more regular supplier experiences some kind of disruption, five local backup suppliers can fill the end-customers demand.

The company case was first described and the input data used for this study was illustrated. Experimental studies of the SCRRJITS problem were carried out to evaluate the performance and effectiveness of the proposed optimisation model in achieving its objective function. The results obtained from this research study illustrated that the proposed optimised SCRRJITS model converges to be optimality consistent with a reduction of 29.6% in the overall cost using the inventory management approach. Three different scenarios were also examined in the case where some or all of external suppliers were not able to supply their products to the end-customers.

In addition, sensitivity analyses were performed to ascertain the influence of each variable on the overall cost of the final product in the production system under a JIT environment. This was achieved by changing its levels while the other variables remained fixed. The results of the statistical analyses conducted using ANOVA confirmed that these variables have a significant impact on the design objectives. The objective of applying these scenarios and sensitivity analysis was to measure and quantify the decision variables' impact on the objective function of the proposed optimisation model.

8. Conclusion, Research Scientific Contributions and Suggestions for Future Work

8.1. Introduction

Ensuring that products are delivered in the required quantities and to the right place in a timely and cost effective manner is an increasing challenge for the supply chain management of contemporary global enterprises (Christopher & Lee 2004). Consequently, organisations in the supply chain have eliminated most non-value adding activities and run leaner by using lean manufacturing tools such as Just-in-Time (JIT). The lack of sufficient inventory however makes logistical processes vulnerable to disruption (Vlajic, van der Vorst & Haijema 2012). Additionally, outsourcing as a key strategy for improving costs and competitiveness has created new kinds of risks arising from the implementation of modern management approaches within organisations such as JIT. That is because of the limited time for organisations to find appropriate response solutions (such as stop-gap supplies) to handle these risks. Two recent examples of this issue are the earthquake and tsunami in Japan and serious flooding in Thailand. These natural disasters have disabled many local production plants in both countries, and negatively impacted on their entire global supply chain (Revilla & Sáenz 2013).

Such supply chain disruptions with their associated risks currently receive considerable attention from researchers because these interruptions are costly to industry. One solution is to adopt lean manufacturing techniques such as a JIT system to manage their process. This research grasps the opportunity to resolve this issue by developing a robust SCRRJITS optimisation framework.

The remainder of this chapter is organised in the following way: Section 8.2 concludes the progress outlined in the last six chapters; Section 8.3 presents the significant contributions of the extensive research detailed in previous chapters; Section 8.4 outlines the opportunities of future work; finally Section 8.5 summarises this chapter.

8.2. Conclusion

Organisations operate in uncertain environments and employ various strategies of risk management to guard their interests against adverse situations arising from the move to new manufacturing practices such as JIT (Pochard 2003). As a result of the market responsiveness

that has caused supply chains to be more dynamically inter-related than before, organisations are frequently required to manage and integrate their process in order to promote coordination among the supply chain members (Iannone, Miranda & Riemma 2007). Although risk management is not the first priority of organisations, it is essential that such a concern be at the forefront of supply chain management (Pochard 2003). This research developed one such system to address the problem of SCRRJITS in supply chain systems.

An extensive literature review on supply chain cost and risk models and different optimisation approaches was conducted. A review of this is presented in Chapter 2 along with various motivating examples from different industries. This was achieved by a detailed classification of the cost-risks arising from product cost reduction while highlighting the key features required to avoid potential risks in the production systems and the whole supply chain. The review of the available literature on the JIT approach shows that there is a lack of an adequate coverage of models developed for the purpose of achieving cost reduction while simultaneously ensuring a lower risk level arising from implementing a JIT regimen.

To address the potential limitations, the main objective of this research was to develop an optimisation model required to incorporate both cost and risk reduction in production systems using a JIT approach for managing their process. Specifically, the objective function of this approach was to find the optimal design of SCRRJITS which is characterised by simultaneously reducing both the cost of products in production facilities and the potential risks arising from this reduction. The developed optimisation approach includes two stages: a modelling and an optimisation stage. The first stage is to develop a mathematical model to map the input parameters and decision variables with its objective functions. The developed model considers four decision variables: the number of suppliers used for supplying raw materials to the production system; customer demand; transportation modes used for shipping the required raw materials from suppliers to the production facility; and finally the quantity of raw materials ordered in each batch required to produce the final product per unit of time (see Chapter 4).

Owing to the complexity of the SCRRJITS design problem, the proposed model is not able to solve the problems that have large design spaces. This has led to the adoption of a meta-heuristic technique as an optimisation approach. In the second stage of the SCRRJITS approach, GA was selected as the effective optimisation technique followed by a detailed analysis and evaluation using an illustrated example (refer to Chapter 6). A novel GA was

proposed for eliciting the optimal or near-optimal solution of such problems using three kinds of crossover and mutation operators. The proposed GA tested four selection methods to determine an effective method to be used for selecting only the best chromosomes from the parents and offspring pools.

The proposed optimisation approach was validated in a real case study (Pooladin Sazeh Persian) which has been taken from Fahimnia (2011). The performance and effectiveness of the proposed optimisation approach was illustrated in Chapter 7 through computational experiments and a comparative study between the results obtained using the JIT approach and the outcomes of Fahimnia's original case study using the inventory management approach. The findings of this research study illustrated that the proposed optimised SCRRJITS model converges to be optimality consistent with a reduction of 29.6% in the overall cost using the inventory management approach. The findings also showed the efficacy of the proposed optimisation model in solving the SCRRJITS optimisation problems.

8.3. Research Contributions

This chapter highlights the contributions of this research by successfully developing an efficient optimisation system using a GA approach in order to solve the problem of SCRRJITS optimisation in production systems. The key contributions of the research work are linked with the respective publications and chapters as shown in Table 8.1 and are summarised as follows.

C_1: The development of a robust framework that can be utilised for simultaneously minimising the cost of products within production systems under a JIT adoption and the risks arising from this reduction. The justification of the developed framework has been demonstrated by implementing the proposed GA approach in a case study presented in Chapter 6;

C_2: The development of a mathematical model used for the purpose of simultaneously reducing the cost in production systems under a JIT regimen to manage their processes and the risks arising from these benefits. The proposed model is created using an objective function based on the minimum overall cost of the final product as presented in detail in Chapter 4;

C_3: The use of a robust optimisation meta-heuristic technique for solving the SCRRJITS optimisation problem in production systems. This research has proposed an optimisation approach (GA). The superiority of the proposed GA has been demonstrated by the experimental studies shown in details in Chapter 6; and

C_4: The success in solving a three-echelon supply chain using the proposed GA. This can be seen by implementing the developed optimisation model in a real case study to validate it as presented in Chapter 7. The success of this research further highlights the robustness of the proposed GA approach in solving such problems.

This research is also expected to contribute to the current international research focus on the areas of operations management and supply chain modelling and optimisation. It was done by introducing a system that views quality as the single most important factor for becoming competitive in the global market. This thesis could potentially contribute to alleviating the paucity of knowledge about JIT adoptions and implementations in the batch process industry where a developed framework has been applied in a case study to validate the proposed optimisation model. Table 8.1 illustrates the publications and chapters in which those contributions are presented.

Table 8.1 The scientific contributions in the publications and in the chapters

Publications / Chapters		**Contributions**			
		C_1	**C_2**	**C_3**	**C_4**
Publications	**P_1**	√	√		
	P_2	√	√		
	P_3	√	√		
	P_4	√	√		
	P_5	√	√		√
	P_6	√	√		√
	P_7	√		√	√
	P_8	√		√	√
	P_9	√		√	√
	P_{10}	√	√	√	√
Chapters	**Chapter 3**	√			
	Chapter 4	√	√		√
	Chapter 6	√		√	√
	Chapter 7	√	√	√	√

8.4. Future Work Suggestions

The lack of research studies that addresses the risks arising from utilising a JIT approach within organisations in order to minimise the overall cost of their products illustrates the research gap presented in Chapter 1. In this regard, this research grasps the opportunity to develop a robust optimisation SCRRJITS framework to solve this issue. In spite of this study, making some contributions in this new research area there are still some major opportunities requiring further attention and offering new directions for further research. This section highlights key aspects of future work suggestions outlined in the following sub-sections.

8.4.1. *Extending the Developed SCRRJITS Framework*

The SCRRJITS framework developed in this thesis is considered as a unique framework, which has been developed to simultaneously minimise the total cost of the final product in production systems. This includes the risk cost arising from adopting a JIT approach to manage production systems' processes which are used to combine the pre-disruption and post-disruption management processes. The key objective of a SCRRJITS framework is the inter-relations between supply chain members and how they support each other in the whole process of management disruption.

It is recommended that an optimisation model be developed for solving the SCRRJITS problem. It is envisaged that such a model be adopted so that organisations in the supply chain can evaluate their performance in different stages of risk quantifications; and can also be used in comparison with similar organisations. As a consequence, the strengths and deficiencies in the process of disruption management can be recognised and plans for improvement can be defined.

8.4.2. *Incorporating the Model Uncertainty*

In this thesis, a developed model was built to address the significant characteristics of disruption management in production systems under a JIT adoption. The input parameters such as lead-time, demand and production capacity used in this research were assumed to be deterministic. However, some of these parameters are uncertain due to the volatile and changeable nature of the global marketplace. A consideration of stochastic demand and lead time in the developed model would be an interesting direction for further research.

8.4.3. *Simultaneous Optimisation of Multi-objective Functions*

In this study, the developed SCRRJITS model simultaneously minimises the total cost of the final product in production systems including the cost of the product and the risks arising from this reduction. The adoption of multi-objective models is recommended as a future work direction. These can simultaneously optimise different objective functions such as the total cost, service level, supplier selection and quality. Such models may provide more managerial understanding for decision-makers in deciding whether or not to include more flexibility in their supply chain management.

8.4.4. *Solving the model using other heuristics*

As mentioned above, the model developed in this research used GA as an optimisation approach for finding the optimal solution of the SCRRJITS problem. The research work may be further extended by solving the problem of the proposed model using other heuristic approaches such as tabu search (TS), simulated annealing (SA) and particle swarm optimisation (PSO) and then comparing the performance of the proposed GA approach with these heuristic approaches. This is one of the limitations in this research and offers a direction for future work.

The above suggestions for future work may accelerate the implementation of a SCRRJITS optimisation model in supply chain systems. This suggested future research could additionally be used to modify the proposed optimisation model to extend its validity.

8.5. Concluding Remarks

In recent years, supply chain risk management has received increasing attention from researchers and practitioners over the impact of the risks associated with cost minimisation in the supply chain (Tang, C 2006). These risks are as a result of implementing modern management approaches such as JIT in organisations to achieve their goals. A supply chain disruption is an event that occurs in one tier in the supply chain but may also negatively impact the performance of one or more elements located in other different tiers (Melnyk, Rodrigues & Ragatz 2009). This research was motivated by a requirement to develop a robust framework for the SCRRJITS optimisation in supply chain systems.

The robust framework in this thesis includes two main stages: development and validation. The former stage, which is the development stage, includes two parts: modelling and optimisation of the SCRRJITS in production systems. In this part, a mathematical model for

calculating the overall cost of the final product in the production system was developed. This cost includes the cost of the product and the risk cost that arises from the use of the JIT approach in these facilities to manage their process. The second part was to propose an optimisation approach for solving the SCRRJITS problem in the production systems under the JIT adoption. A GA as a stochastic optimisation technique was selected for this purpose. The second stage is the validation of the developed optimisation model. This stage was to justify the robustness of the developed optimisation model by implementing it in a real case study and designing some experiments on different case scenarios. The findings illustrated the effectiveness of the proposed approach for solving such problems.

Despite the success of this research study in developing a SCRRJITS optimisation model, it would be interesting to extend this study to the area of supply chain management. The following four suggestions are made for possible future study. Firstly, researches could work towards extending the SCRRJITS framework. This could be achieved by developing appropriate models to solve this issue in all tiers of the supply chain in different stages of risk assessment compared with similar organisations. Secondly, future studies could be undertaken to incorporate the model uncertainty through consideration of certain input parameters such as stochastic instead of deterministic data. Thirdly, further study could be undertaken towards simultaneously optimising models with multi-objective functions. Finally, it is suggested that future research could resolve the problem of the optimisation model using other heuristics such as tabu search (TS), simulated annealing (SA) and particle swarm optimisation (PSO) and then comparing the performance of the proposed modified GA approach with these heuristic approaches.

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Appendix A. Computational results for combinations of the GA basic parameters

Table A.1 Computational results for combinations of the GA basic parameters

S.N	Exp. No.	GA operators				F.F	$F.F_{(Ave)}$	C.G	C_T	$C_{T(Ave)}$	Average F.F	Average $F.F_{(Ave)}$	Average C.G	Average C_T	Average $C_{T(Ave)}$
		P_c	P_m	N	G_{max}										
1	1	0.2	0.8	100	1000	0.227014	0.226407	390	439.501312	440.681820	0.227009	0.221826	257.7	439.510635	450.631190
2	2	0.2	0.8	100	1000	0.226966	0.221642	666	439.594547	450.178565					
3	3	0.2	0.8	100	1000	0.227014	0.195173	250	439.501312	511.366590					
4	4	0.2	0.8	100	1000	0.227014	0.223952	175	439.501312	445.523344					
5	5	0.2	0.8	100	1000	0.227014	0.226308	192	439.501312	440.875560					
6	6	0.2	0.8	100	1000	0.227014	0.225672	184	439.501312	442.121254					
7	7	0.2	0.8	100	1000	0.227014	0.225892	190	439.501312	441.689303					
8	8	0.2	0.8	100	1000	0.227014	0.224962	177	439.501312	443.518991					
9	9	0.2	0.8	100	1000	0.227014	0.224842	227	439.501312	443.756781					
10	10	0.2	0.8	100	1000	0.227014	0.223414	126	439.501312	446.599687					
11	1	0.2	0.8	100	5000	0.227014	0.222639	217	439.501312	448.156817	0.227014	0.220049	335.2	439.501312	454.023380
12	2	0.2	0.8	100	5000	0.227014	0.223780	224	439.501312	445.867466					
13	3	0.2	0.8	100	5000	0.227014	0.224759	172	439.501312	443.920131					
14	4	0.2	0.8	100	5000	0.227014	0.214997	156	439.501312	464.122291					
15	5	0.2	0.8	100	5000	0.227014	0.225494	187	439.501312	442.471712					
16	6	0.2	0.8	100	5000	0.227014	0.226190	933	439.501312	441.106357					
17	7	0.2	0.8	100	5000	0.227014	0.225950	240	439.501312	441.575589					
18	8	0.2	0.8	100	5000	0.227014	0.217539	259	439.501312	458.687177					
19	9	0.2	0.8	100	5000	0.227014	0.219147	214	439.501312	455.315347					
20	10	0.2	0.8	100	5000	0.227014	0.199996	750	439.501312	499.010913					
21	1	0.2	0.8	400	1000	0.227014	0.226252	192	439.501312	440.984976	0.227014	0.221964	167.5	439.501312	450.133860
22	2	0.2	0.8	400	1000	0.227014	0.224446	173	439.501312	444.541264					
23	3	0.2	0.8	400	1000	0.227014	0.225790	140	439.501312	441.890317					
24	4	0.2	0.8	400	1000	0.227014	0.199113	150	439.501312	501.226276					
25	5	0.2	0.8	400	1000	0.227014	0.223011	170	439.501312	447.408527					
26	6	0.2	0.8	400	1000	0.227014	0.225899	144	439.501312	441.676117					
27	7	0.2	0.8	400	1000	0.227014	0.226443	194	439.501312	440.612570					
28	8	0.2	0.8	400	1000	0.227014	0.220600	213	439.501312	452.308880					
29	9	0.2	0.8	400	1000	0.227014	0.224896	129	439.501312	443.649458					
30	10	0.2	0.8	400	1000	0.227014	0.223194	170	439.501312	447.040219					
31	1	0.2	0.8	400	5000	0.227014	0.220396	161	439.501312	452.728150	0.227014	0.221705	208.9	439.501312	450.161859
32	2	0.2	0.8	400	5000	0.227014	0.225483	274	439.501312	442.492014					
33	3	0.2	0.8	400	5000	0.227014	0.222317	166	439.501312	448.807553					
34	4	0.2	0.8	400	5000	0.227014	0.226536	197	439.501312	440.431482					
35	5	0.2	0.8	400	5000	0.227014	0.225242	134	439.501312	442.967439					
36	6	0.2	0.8	400	5000	0.227014	0.220977	464	439.501312	451.536805					
37	7	0.2	0.8	400	5000	0.227014	0.218837	160	439.501312	455.960569					
38	8	0.2	0.8	400	5000	0.227014	0.220141	162	439.501312	453.255253					
39	9	0.2	0.8	400	5000	0.227014	0.214273	155	439.501312	465.694466					
40	10	0.2	0.8	400	5000	0.227014	0.222844	216	439.501312	447.744858					
41	1	0.2	0.2	100	1000	0.226966	0.221823	420	439.594549	449.809067	0.226995	0.222684	498.8	439.538877	448.246736
42	2	0.2	0.2	100	1000	0.227014	0.223071	421	439.501312	447.287752					
43	3	0.2	0.2	100	1000	0.226869	0.226232	439	439.783730	441.024512					
44	4	0.2	0.2	100	1000	0.227014	0.226439	748	439.501312	440.619953					
45	5	0.2	0.2	100	1000	0.227014	0.219380	463	439.501312	454.830557					
46	6	0.2	0.2	100	1000	0.227014	0.226306	990	439.501312	440.878803					
47	7	0.2	0.2	100	1000	0.227014	0.214108	809	439.501312	466.054760					
48	8	0.2	0.2	100	1000	0.227014	0.226378	292	439.501312	440.738682					
49	9	0.2	0.2	100	1000	0.227014	0.226713	197	439.501312	440.087100					
50	10	0.2	0.2	100	1000	0.227014	0.216386	209	439.501312	461.136177					
51	1	0.2	0.2	100	5000	0.227014	0.221863	815	439.501312	449.728922	0.227000	0.223319	395.3	439.529282	446.839893
52	2	0.2	0.2	100	5000	0.226966	0.223121	272	439.594547	447.188075					
53	3	0.2	0.2	100	5000	0.227014	0.226528	647	439.501307	440.445588					

54	4	0.2	0.2	100	5000	0.226966	0.224370	276	439.594547	444.692054					
55	5	0.2	0.2	100	5000	0.227014	0.226511	398	439.501312	440.479120					
56	6	0.2	0.2	100	5000	0.227014	0.224276	325	439.501312	444.879755					
57	7	0.2	0.2	100	5000	0.226966	0.223149	267	439.594547	447.130615					
58	8	0.2	0.2	100	5000	0.227014	0.223700	323	439.501312	446.026586					
59	9	0.2	0.2	100	5000	0.227014	0.218182	263	439.501312	457.332809					
60	10	0.2	0.2	100	5000	0.227014	0.221486	367	439.501312	450.495401					
61	1	0.2	0.2	400	1000	0.227014	0.225034	231	439.501312	443.376351	0.227014	0.221076	269.7	439.501312	451.980227
62	2	0.2	0.2	400	1000	0.227014	0.224626	328	439.501312	444.185424					
63	3	0.2	0.2	400	1000	0.227014	0.226002	196	439.501312	441.473315					
64	4	0.2	0.2	400	1000	0.227014	0.197984	450	439.501312	504.091202					
65	5	0.2	0.2	400	1000	0.227014	0.219661	262	439.501312	454.246793					
66	6	0.2	0.2	400	1000	0.227014	0.226425	244	439.501312	440.647391					
67	7	0.2	0.2	400	1000	0.227014	0.223681	222	439.501312	446.065715					
68	8	0.2	0.2	400	1000	0.227014	0.221765	316	439.501312	449.926850					
69	9	0.2	0.2	400	1000	0.227014	0.225048	185	439.501312	443.349231					
70	10	0.2	0.2	400	1000	0.227014	0.220536	263	439.501312	452.440000					
71	1	0.2	0.2	400	5000	0.227014	0.222330	219	439.501312	448.781381	0.227014	0.219976	263.6	439.501312	454.031836
72	2	0.2	0.2	400	5000	0.227014	0.219042	214	439.501312	455.533805					
73	3	0.2	0.2	400	5000	0.227014	0.206499	252	439.501312	483.264719					
74	4	0.2	0.2	400	5000	0.227014	0.221102	215	439.501312	451.280827					
75	5	0.2	0.2	400	5000	0.227014	0.226199	239	439.501312	441.088095					
76	6	0.2	0.2	400	5000	0.227014	0.211600	555	439.501312	471.588835					
77	7	0.2	0.2	400	5000	0.227014	0.214083	207	439.501312	466.108199					
78	8	0.2	0.2	400	5000	0.227014	0.226239	287	439.501312	441.011205					
79	9	0.2	0.2	400	5000	0.227014	0.226119	199	439.501312	441.244194					
80	10	0.2	0.2	400	5000	0.227014	0.226543	249	439.501312	440.417097					
81	1	0.8	0.8	100	1000	0.227014	0.226967	472	439.501312	439.592682	0.227004	0.225604	128.3	439.519959	442.368556
82	2	0.8	0.8	100	1000	0.227014	0.215041	52	439.501312	464.026916					
83	3	0.8	0.8	100	1000	0.227014	0.226907	82	439.501312	439.708293					
84	4	0.8	0.8	100	1000	0.227014	0.226698	85	439.501312	440.116203					
85	5	0.8	0.8	100	1000	0.227014	0.226957	87	439.501312	439.612382					
86	6	0.8	0.8	100	1000	0.227014	0.226771	61	439.501312	439.974219					
87	7	0.8	0.8	100	1000	0.227014	0.226200	62	439.501312	441.086602					
88	8	0.8	0.8	100	1000	0.226966	0.226918	224	439.594547	439.687964					
89	9	0.8	0.8	100	1000	0.226966	0.226796	74	439.594547	439.924532					
90	10	0.8	0.8	100	1000	0.227014	0.226780	84	439.501312	439.955765					
91	1	0.8	0.8	100	5000	0.227014	0.226931	91	439.501312	439.663327	0.227014	0.226374	429.8	439.501312	440.755500
92	2	0.8	0.8	100	5000	0.227014	0.226872	786	439.501312	439.778078					
93	3	0.8	0.8	100	5000	0.227014	0.226839	76	439.501312	439.840792					
94	4	0.8	0.8	100	5000	0.227014	0.223845	1257	439.501312	445.738204					
95	5	0.8	0.8	100	5000	0.227014	0.226538	46	439.501312	440.426452					
96	6	0.8	0.8	100	5000	0.227014	0.226967	723	439.501312	439.592682					
97	7	0.8	0.8	100	5000	0.227014	0.226967	528	439.501312	439.592682					
98	8	0.8	0.8	100	5000	0.227014	0.226885	663	439.501312	439.751961					
99	9	0.8	0.8	100	5000	0.227014	0.225046	59	439.501312	443.352663					
100	10	0.8	0.8	100	5000	0.227014	0.226851	69	439.501312	439.818155					
101	1	0.8	0.8	400	1000	0.227014	0.220874	304	439.501312	451.746216	0.227014	0.224317	98.1	439.501312	444.937390
102	2	0.8	0.8	400	1000	0.227014	0.223882	57	439.501312	445.663569					
103	3	0.8	0.8	400	1000	0.227014	0.225734	59	439.501312	441.999170					
104	4	0.8	0.8	400	1000	0.227014	0.226111	60	439.501312	441.259935					
105	5	0.8	0.8	400	1000	0.227014	0.213866	52	439.501312	466.582501					
106	6	0.8	0.8	400	1000	0.227014	0.226273	49	439.501312	440.943183					
107	7	0.8	0.8	400	1000	0.227014	0.225758	60	439.501312	441.952476					
108	8	0.8	0.8	400	1000	0.227014	0.226885	74	439.501312	439.751230					
109	9	0.8	0.8	400	1000	0.227014	0.226818	67	439.501312	439.881541					
110	10	0.8	0.8	400	1000	0.227014	0.226966	199	439.501312	439.594081					
111	1	0.8	0.8	400	5000	0.227014	0.226912	74	439.501312	439.699812	0.227014	0.224597	95.5	439.501312	444.319897

112	2	0.8	0.8	400	5000	0.227014	0.226845	369	439.501312	439.828891					
113	3	0.8	0.8	400	5000	0.227014	0.218399	53	439.501312	456.878265					
114	4	0.8	0.8	400	5000	0.227014	0.226642	63	439.501312	440.224234					
115	5	0.8	0.8	400	5000	0.227014	0.221354	55	439.501312	450.764742					
116	6	0.8	0.8	400	5000	0.227014	0.226818	73	439.501312	439.881219					
117	7	0.8	0.8	400	5000	0.227014	0.221276	104	439.501312	450.924658					
118	8	0.8	0.8	400	5000	0.227014	0.226567	43	439.501312	440.369766					
119	9	0.8	0.8	400	5000	0.227014	0.224878	59	439.501312	443.686216					
120	10	0.8	0.8	400	5000	0.227014	0.226274	62	439.501312	440.941163					
121	1	0.8	0.2	100	1000	0.227014	0.225269	158	439.501312	442.913260	0.226990	0.226473	186.1	439.548019	440.556274
122	2	0.8	0.2	100	1000	0.227014	0.226956	95	439.501312	439.614617					
123	3	0.8	0.2	100	1000	0.227014	0.226793	916	439.501312	439.931545					
124	4	0.8	0.2	100	1000	0.227014	0.226911	117	439.501312	439.701301					
125	5	0.8	0.2	100	1000	0.226966	0.226713	84	439.594547	440.087054					
126	6	0.8	0.2	100	1000	0.226966	0.225978	60	439.594547	441.520074					
127	7	0.8	0.2	100	1000	0.226966	0.226824	92	439.594547	439.870110					
128	8	0.8	0.2	100	1000	0.227014	0.226867	183	439.501312	439.786055					
129	9	0.8	0.2	100	1000	0.226918	0.225547	60	439.688684	442.367402					
130	10	0.8	0.2	100	1000	0.227014	0.226875	96	439.501312	439.771323					
131	1	0.8	0.2	100	5000	0.227014	0.226659	173	439.501312	440.190429	0.227014	0.224001	631.1	439.501312	445.619253
132	2	0.8	0.2	100	5000	0.227014	0.226138	761	439.501312	441.207147					
133	3	0.8	0.2	100	5000	0.227014	0.225092	157	439.501312	443.261876					
134	4	0.8	0.2	100	5000	0.227014	0.224882	1607	439.501312	443.677435					
135	5	0.8	0.2	100	5000	0.227014	0.224791	207	439.501312	443.858187					
136	6	0.8	0.2	100	5000	0.227014	0.219805	205	439.501312	453.947746					
137	7	0.8	0.2	100	5000	0.227014	0.226967	230	439.501312	439.592682					
138	8	0.8	0.2	100	5000	0.227014	0.226967	1786	439.501312	439.592682					
139	9	0.8	0.2	100	5000	0.227014	0.226967	133	439.501312	439.592682					
140	10	0.8	0.2	100	5000	0.227014	0.211743	1052	439.501312	471.271666					
141	1	0.8	0.2	400	1000	0.227014	0.225945	110	439.501312	441.585079	0.227014	0.226754	84	439.501312	440.007984
142	2	0.8	0.2	400	1000	0.227014	0.226938	91	439.501312	439.649706					
1443	3	0.8	0.2	400	1000	0.227014	0.226918	77	439.501312	439.688761					
144	4	0.8	0.2	400	1000	0.227014	0.226874	83	439.501312	439.772694					
145	5	0.8	0.2	400	1000	0.227014	0.226905	116	439.501312	439.713854					
146	6	0.8	0.2	400	1000	0.227014	0.226869	70	439.501312	439.782540					
147	7	0.8	0.2	400	1000	0.227014	0.226401	62	439.501312	440.693497					
148	8	0.8	0.2	400	1000	0.227014	0.226939	71	439.501312	439.647553					
149	9	0.8	0.2	400	1000	0.227014	0.226868	82	439.501312	439.784235					
150	10	0.8	0.2	400	1000	0.227014	0.226880	78	439.501312	439.761925					
151	1	0.8	0.2	400	5000	0.227014	0.226838	77	439.501312	439.843684	0.227014	0.226780	69.9	439.501312	439.955742
152	2	0.8	0.2	400	5000	0.227014	0.226645	66	439.501312	440.218523					
153	3	0.8	0.2	400	5000	0.227014	0.226903	69	439.501312	439.717442					
154	4	0.8	0.2	400	5000	0.227014	0.226863	71	439.501312	439.794091					
155	5	0.8	0.2	400	5000	0.227014	0.226848	83	439.501312	439.824596					
156	6	0.8	0.2	400	5000	0.227014	0.226701	69	439.501312	440.108786					
157	7	0.8	0.2	400	5000	0.227014	0.226839	68	439.501312	439.842105					
158	8	0.8	0.2	400	5000	0.227014	0.226843	68	439.501312	439.833207					
159	9	0.8	0.2	400	5000	0.227014	0.226641	63	439.501312	440.226108					
160	10	0.8	0.2	400	5000	0.227014	0.226681	65	439.501312	440.148879					

Appendix B. Experimental design of the GA operators

Table B.1 Genetic search results for optimising the SCRRJITS model under changing the value of crossover rate

Generation	Pc= 0.2	Pc= 0.4	Pc= 0.6	Pc= 0.8	Pc= 0.9
0	465.5731	459.1763	470.6408	464.7278	453.0969
1	465.5731	458.3361	470.6408	464.7278	453.0969
2	465.5731	458.3361	464.0299	464.7278	453.0969
3	465.5731	458.3361	462.0589	455.7009	453.0969
4	465.5731	458.3361	462.0589	455.7009	453.0969
5	465.5731	458.3361	462.0589	453.3014	450.5906
6	465.1523	458.3361	461.8717	453.3014	450.5906
7	465.1523	455.567	461.8717	453.3014	450.5906
8	465.1523	453.9846	458.1508	452.3817	450.5906
9	465.1523	453.9846	457.2603	452.3817	450.5906
10	465.1523	453.9846	452.858	451.54	450.4982
11	457.9754	453.9846	448.5268	451.54	450.4982
12	452.9223	453.9846	448.5268	450.5034	450.4982
13	452.9223	453.9846	448.5268	447.0761	449.1577
14	452.9223	453.9846	447.2665	447.0761	449.1577
15	452.9223	452.8581	447.2665	447.0761	448.686
16	452.9223	452.8581	447.2665	447.0761	447.4147
17	452.9223	452.8581	447.2665	447.0761	447.4147
18	452.9223	452.8581	447.2665	447.0761	447.4147
19	452.9223	452.8581	447.2665	447.0095	447.3161
20	452.9223	452.8581	447.2665	446.5312	445.4278
21	452.9223	452.8581	447.2665	446.5312	444.2731
22	452.9078	452.8581	447.2665	446.4235	444.2731
23	452.9078	452.8581	443.1258	446.4235	443.5975
24	452.9078	452.8581	441.965	446.4235	443.5975
25	452.8585	451.1585	441.965	445.8547	443.5975
26	452.8585	450.0778	441.965	445.8547	442.9932
27	452.8585	449.535	441.965	444.4512	442.9932
28	452.8585	449.4167	441.965	441.6543	442.9932
29	452.8585	447.871	441.965	441.6543	442.292
30	452.8585	447.871	441.965	441.6543	442.292
31	451.6749	447.871	441.6815	441.6543	442.1245
32	451.6749	447.871	441.6815	441.2744	442.1245
33	451.6749	447.871	441.6815	441.2744	442.1245
34	451.6749	447.871	441.6815	441.2744	441.7722
35	451.6749	447.871	441.6815	441.2038	441.3535
36	451.6749	447.7539	441.6815	441.2038	441.3535
37	451.6749	447.1475	441.6815	441.2038	440.5681
38	451.6749	447.1475	441.6815	440.7447	440.5681
39	450.3235	444.3108	441.6815	440.7447	440.5681
40	450.3235	444.3108	441.6815	440.7447	440.5681
41	450.3235	444.3108	441.6815	440.7447	440.5681
42	450.3235	444.3108	441.6815	440.7447	440.5681
43	450.3235	444.3108	441.6815	440.3648	440.5681
44	450.3235	444.3108	441.4026	440.2942	440.5681
45	450.3235	444.3108	441.4026	440.2942	440.3429
46	446.2364	444.3108	441.4026	440.2942	440.3429
47	446.2364	444.0798	441.1964	440.2942	440.3429
48	446.2364	444.0798	441.1964	440.2942	440.3429
49	446.2364	444.0798	441.1964	440.2942	440.3429
50	446.2364	444.0798	441.1964	440.2942	440.3429
51	446.2364	444.0798	441.1964	439.9143	440.3429
52	446.2364	444.0798	441.1964	439.9143	440.3429
53	446.2364	444.0798	441.1964	439.9143	440.3429
54	445.8725	444.0798	441.1964	439.9143	440.3429
55	445.8725	444.0798	441.1964	439.9143	440.3429
56	445.8725	444.0798	441.1964	439.9143	440.3429
57	445.8725	444.0798	441.0677	439.9143	440.0657
58	445.8725	443.4561	440.1979	439.9143	440.0657
59	445.8725	442.5386	440.008	439.9143	440.0657
60	445.8725	442.0325	440.008	439.9143	439.8405
61	445.8725	440.8977	440.008	439.9143	439.8405
62	445.8725	440.8977	440.008	439.7844	439.8405
63	445.8725	440.8977	440.008	439.7844	439.8405
64	445.8725	440.8977	439.9143	439.7844	439.7245
65	445.8725	440.8977	439.9143	439.7844	439.7245
66	445.8725	440.8977	439.9143	439.7844	439.7245
67	445.8725	440.8977	439.9143	439.7469	439.7245
68	445.7425	440.8977	439.9143	439.7469	439.7245
69	445.7425	440.8977	439.9143	439.7469	439.7245
70	445.7425	440.8977	439.7844	439.7469	439.7245
71	445.7425	440.8977	439.7844	439.7469	439.7245
72	445.7425	440.8977	439.7844	439.7469	439.7105
73	445.7425	440.8977	439.7844	439.7469	439.7105
74	445.7425	440.7806	439.7844	439.7469	439.7105
75	445.7425	440.5674	439.7844	439.6169	439.5945
76	445.7425	440.5674	439.7844	439.6169	439.5945
77	445.3375	440.5674	439.7844	439.6169	439.5945
78	445.3375	440.451	439.7844	439.6169	439.5945
79	445.3375	440.4168	439.7844	439.6169	439.5945
80	445.3375	440.4168	439.7844	439.6169	439.5945
81	445.3375	440.4168	439.7844	439.6169	439.5945
82	445.3375	440.4168	439.7844	439.6169	439.5945
83	445.3375	440.4168	439.7844	439.6169	439.5945
84	445.3375	440.1602	439.7844	439.6169	439.5945
85	445.3375	440.1602	439.7844	439.6169	439.5945
86	445.3375	440.1602	439.7844	439.6169	439.5945
87	445.1362	440.1602	439.7844	439.6169	439.5945
88	443.9432	440.1602	439.7844	439.5013	439.5945
89	443.9432	440.1602	439.7844	439.5013	439.5945

90	443.9432	440.1602	439.7844	439.5013	439.5945
91	443.9432	440.0303	439.7469	439.5013	439.5945
92	443.9432	440.0303	439.7469	439.5013	439.5945
93	443.9432	440.0303	439.7469	439.5013	439.5945
94	443.9432	440.0096	439.7469	439.5013	439.5945
95	443.9432	439.8186	439.7469	439.5013	439.5945
96	443.9432	439.8186	439.7469	439.5013	439.5945
97	443.9432	439.8186	439.7469	439.5013	439.5945
98	443.7815	439.8186	439.7469	439.5013	439.5945
99	443.7815	439.8186	439.6169	439.5013	439.5945
100	443.4614	439.8186	439.6169	439.5013	439.5945
101	443.4614	439.8186	439.6169	439.5013	439.5945
102	443.4614	439.8186	439.6169	439.5013	439.5945
103	443.4614	439.8186	439.6169	439.5013	439.5945
104	443.4614	439.8186	439.6169	439.5013	439.5945
105	443.4614	439.8186	439.6169	439.5013	439.5945
106	443.4614	439.8186	439.6169	439.5013	439.5945
107	443.4614	439.8186	439.6169	439.5013	439.5945
108	443.4614	439.8186	439.6169	439.5013	439.5945
109	443.4614	439.8186	439.6169	439.5013	439.5945
110	443.4614	439.8186	439.6169	439.5013	439.5945
111	443.4614	439.8186	439.6169	439.5013	439.5945
112	443.2997	439.8051	439.6169	439.5013	439.5945
113	442.4669	439.8051	439.6169	439.5013	439.5945
114	442.4669	439.8051	439.6169	439.5013	439.5945
115	442.4669	439.6887	439.5013	439.5013	439.5945
116	441.8432	439.6887	439.5013	439.5013	439.5945
117	441.8432	439.6887	439.5013	439.5013	439.5945
118	441.8432	439.6887	439.5013	439.5013	439.5945
119	441.8432	439.6887	439.5013	439.5013	439.5945
120	441.8432	439.6887	439.5013	439.5013	439.5945
121	441.8432	439.6887	439.5013	439.5013	439.5945
122	441.8432	439.6887	439.5013	439.5013	439.5945
123	441.8432	439.6887	439.5013	439.5013	439.5945
124	441.8432	439.6169	439.5013	439.5013	439.5945
125	441.8208	439.6169	439.5013	439.5013	439.5945
126	441.8208	439.6169	439.5013	439.5013	439.5945
127	441.8208	439.5013	439.5013	439.5013	439.5945
128	441.8208	439.5013	439.5013	439.5013	439.5945
129	441.1572	439.5013	439.5013	439.5013	439.5945
130	441.1572	439.5013	439.5013	439.5013	439.5945
131	441.1572	439.5013	439.5013	439.5013	439.5945
132	441.1572	439.5013	439.5013	439.5013	439.5945
133	441.1572	439.5013	439.5013	439.5013	439.5945
134	441.0289	439.5013	439.5013	439.5013	439.5945
135	441.0289	439.5013	439.5013	439.5013	439.5945
136	441.0289	439.5013	439.5013	439.5013	439.5945
137	441.0289	439.5013	439.5013	439.5013	439.5945
138	441.0289	439.5013	439.5013	439.5013	439.5945
139	441.0289	439.5013	439.5013	439.5013	439.5945
140	440.359	439.5013	439.5013	439.5013	439.5945
141	440.359	439.5013	439.5013	439.5013	439.5945
142	440.359	439.5013	439.5013	439.5013	439.5945
143	440.359	439.5013	439.5013	439.5013	439.5945
144	440.359	439.5013	439.5013	439.5013	439.5945
145	440.359	439.5013	439.5013	439.5013	439.5945
146	440.359	439.5013	439.5013	439.5013	439.5945
147	440.359	439.5013	439.5013	439.5013	439.5945
148	440.359	439.5013	439.5013	439.5013	439.5945
149	440.359	439.5013	439.5013	439.5013	439.5945
150	440.359	439.5013	439.5013	439.5013	439.5945
151	440.359	439.5013	439.5013	439.5013	439.5945
152	440.359	439.5013	439.5013	439.5013	439.5945
153	440.359	439.5013	439.5013	439.5013	439.5945
154	440.359	439.5013	439.5013	439.5013	439.5945
155	440.359	439.5013	439.5013	439.5013	439.5945
156	440.359	439.5013	439.5013	439.5013	439.5945
157	440.359	439.5013	439.5013	439.5013	439.5945
158	440.359	439.5013	439.5013	439.5013	439.5945
159	440.359	439.5013	439.5013	439.5013	439.5945
160	440.359	439.5013	439.5013	439.5013	439.5945
161	440.359	439.5013	439.5013	439.5013	439.5945
162	440.359	439.5013	439.5013	439.5013	439.5945
163	440.359	439.5013	439.5013	439.5013	439.5945
164	440.359	439.5013	439.5013	439.5013	439.5945
165	440.359	439.5013	439.5013	439.5013	439.5945
166	440.359	439.5013	439.5013	439.5013	439.5945
167	440.359	439.5013	439.5013	439.5013	439.5945
168	440.359	439.5013	439.5013	439.5013	439.5945
169	440.359	439.5013	439.5013	439.5013	439.5945
170	440.359	439.5013	439.5013	439.5013	439.5945
171	440.2493	439.5013	439.5013	439.5013	439.5945
172	439.8422	439.5013	439.5013	439.5013	439.5945
173	439.8422	439.5013	439.5013	439.5013	439.5945
174	439.8422	439.5013	439.5013	439.5013	439.5945
175	439.8422	439.5013	439.5013	439.5013	439.5945
176	439.8422	439.5013	439.5013	439.5013	439.5945
177	439.8422	439.5013	439.5013	439.5013	439.5945
178	439.8422	439.5013	439.5013	439.5013	439.5945
179	439.8422	439.5013	439.5013	439.5013	439.5945
180	439.8422	439.5013	439.5013	439.5013	439.5945
181	439.8422	439.5013	439.5013	439.5013	439.5945
182	439.8422	439.5013	439.5013	439.5013	439.5945
183	439.8422	439.5013	439.5013	439.5013	439.5945
184	439.8198	439.5013	439.5013	439.5013	439.5945
185	439.8198	439.5013	439.5013	439.5013	439.5945
186	439.8198	439.5013	439.5013	439.5013	439.5945
187	439.8198	439.5013	439.5013	439.5013	439.5945
188	439.8198	439.5013	439.5013	439.5013	439.5945

189	439.8198	439.5013	439.5013	439.5013	439.5945
190	439.8198	439.5013	439.5013	439.5013	439.5945
191	439.8198	439.5013	439.5013	439.5013	439.5945
192	439.7265	439.5013	439.5013	439.5013	439.5945
193	439.7265	439.5013	439.5013	439.5013	439.5945
194	439.7265	439.5013	439.5013	439.5013	439.5945
195	439.7265	439.5013	439.5013	439.5013	439.5945
196	439.7265	439.5013	439.5013	439.5013	439.5945
197	439.7265	439.5013	439.5013	439.5013	439.5945
198	439.7265	439.5013	439.5013	439.5013	439.5945
199	439.7265	439.5013	439.5013	439.5013	439.5945
200	439.7265	439.5013	439.5013	439.5013	439.5945
201	439.7265	439.5013	439.5013	439.5013	439.5945
202	439.7265	439.5013	439.5013	439.5013	439.5945
203	439.7265	439.5013	439.5013	439.5013	439.5945
204	439.7265	439.5013	439.5013	439.5013	439.5945
205	439.7265	439.5013	439.5013	439.5013	439.5945
206	439.7265	439.5013	439.5013	439.5013	439.5945
207	439.7265	439.5013	439.5013	439.5013	439.5945
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499	439.5013	439.5013	439.5013	439.5013	439.5013
500	439.5013	439.5013	439.5013	439.5013	439.5013
501	439.5013	439.5013	439.5013	439.5013	439.5013
502	439.5013	439.5013	439.5013	439.5013	439.5013
503	439.5013	439.5013	439.5013	439.5013	439.5013
504	439.5013	439.5013	439.5013	439.5013	439.5013
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506	439.5013	439.5013	439.5013	439.5013	439.5013
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508	439.5013	439.5013	439.5013	439.5013	439.5013
509	439.5013	439.5013	439.5013	439.5013	439.5013
510	439.5013	439.5013	439.5013	439.5013	439.5013
511	439.5013	439.5013	439.5013	439.5013	439.5013
512	439.5013	439.5013	439.5013	439.5013	439.5013
513	439.5013	439.5013	439.5013	439.5013	439.5013
514	439.5013	439.5013	439.5013	439.5013	439.5013
515	439.5013	439.5013	439.5013	439.5013	439.5013
516	439.5013	439.5013	439.5013	439.5013	439.5013
517	439.5013	439.5013	439.5013	439.5013	439.5013
518	439.5013	439.5013	439.5013	439.5013	439.5013
519	439.5013	439.5013	439.5013	439.5013	439.5013
520	439.5013	439.5013	439.5013	439.5013	439.5013
521	439.5013	439.5013	439.5013	439.5013	439.5013
522	439.5013	439.5013	439.5013	439.5013	439.5013
523	439.5013	439.5013	439.5013	439.5013	439.5013
524	439.5013	439.5013	439.5013	439.5013	439.5013
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526	439.5013	439.5013	439.5013	439.5013	439.5013
527	439.5013	439.5013	439.5013	439.5013	439.5013
528	439.5013	439.5013	439.5013	439.5013	439.5013
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530	439.5013	439.5013	439.5013	439.5013	439.5013
531	439.5013	439.5013	439.5013	439.5013	439.5013
532	439.5013	439.5013	439.5013	439.5013	439.5013
533	439.5013	439.5013	439.5013	439.5013	439.5013
534	439.5013	439.5013	439.5013	439.5013	439.5013
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537	439.5013	439.5013	439.5013	439.5013	439.5013
538	439.5013	439.5013	439.5013	439.5013	439.5013
539	439.5013	439.5013	439.5013	439.5013	439.5013
540	439.5013	439.5013	439.5013	439.5013	439.5013
541	439.5013	439.5013	439.5013	439.5013	439.5013
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543	439.5013	439.5013	439.5013	439.5013	439.5013
544	439.5013	439.5013	439.5013	439.5013	439.5013
545	439.5013	439.5013	439.5013	439.5013	439.5013
546	439.5013	439.5013	439.5013	439.5013	439.5013
547	439.5013	439.5013	439.5013	439.5013	439.5013
548	439.5013	439.5013	439.5013	439.5013	439.5013
549	439.5013	439.5013	439.5013	439.5013	439.5013
550	439.5013	439.5013	439.5013	439.5013	439.5013
551	439.5013	439.5013	439.5013	439.5013	439.5013
552	439.5013	439.5013	439.5013	439.5013	439.5013
553	439.5013	439.5013	439.5013	439.5013	439.5013
554	439.5013	439.5013	439.5013	439.5013	439.5013
555	439.5013	439.5013	439.5013	439.5013	439.5013
556	439.5013	439.5013	439.5013	439.5013	439.5013
557	439.5013	439.5013	439.5013	439.5013	439.5013
558	439.5013	439.5013	439.5013	439.5013	439.5013
559	439.5013	439.5013	439.5013	439.5013	439.5013
560	439.5013	439.5013	439.5013	439.5013	439.5013
561	439.5013	439.5013	439.5013	439.5013	439.5013
562	439.5013	439.5013	439.5013	439.5013	439.5013
563	439.5013	439.5013	439.5013	439.5013	439.5013
564	439.5013	439.5013	439.5013	439.5013	439.5013
565	439.5013	439.5013	439.5013	439.5013	439.5013
566	439.5013	439.5013	439.5013	439.5013	439.5013
567	439.5013	439.5013	439.5013	439.5013	439.5013
568	439.5013	439.5013	439.5013	439.5013	439.5013
569	439.5013	439.5013	439.5013	439.5013	439.5013
570	439.5013	439.5013	439.5013	439.5013	439.5013
571	439.5013	439.5013	439.5013	439.5013	439.5013
572	439.5013	439.5013	439.5013	439.5013	439.5013
573	439.5013	439.5013	439.5013	439.5013	439.5013
574	439.5013	439.5013	439.5013	439.5013	439.5013
575	439.5013	439.5013	439.5013	439.5013	439.5013
576	439.5013	439.5013	439.5013	439.5013	439.5013
577	439.5013	439.5013	439.5013	439.5013	439.5013
578	439.5013	439.5013	439.5013	439.5013	439.5013
579	439.5013	439.5013	439.5013	439.5013	439.5013
580	439.5013	439.5013	439.5013	439.5013	439.5013
581	439.5013	439.5013	439.5013	439.5013	439.5013
582	439.5013	439.5013	439.5013	439.5013	439.5013
583	439.5013	439.5013	439.5013	439.5013	439.5013
584	439.5013	439.5013	439.5013	439.5013	439.5013

585	439.5013	439.5013	439.5013	439.5013	439.5013
586	439.5013	439.5013	439.5013	439.5013	439.5013
587	439.5013	439.5013	439.5013	439.5013	439.5013
588	439.5013	439.5013	439.5013	439.5013	439.5013
589	439.5013	439.5013	439.5013	439.5013	439.5013
590	439.5013	439.5013	439.5013	439.5013	439.5013
591	439.5013	439.5013	439.5013	439.5013	439.5013
592	439.5013	439.5013	439.5013	439.5013	439.5013
593	439.5013	439.5013	439.5013	439.5013	439.5013
594	439.5013	439.5013	439.5013	439.5013	439.5013
595	439.5013	439.5013	439.5013	439.5013	439.5013
596	439.5013	439.5013	439.5013	439.5013	439.5013
597	439.5013	439.5013	439.5013	439.5013	439.5013
598	439.5013	439.5013	439.5013	439.5013	439.5013
599	439.5013	439.5013	439.5013	439.5013	439.5013
600	439.5013	439.5013	439.5013	439.5013	439.5013

Table B.2 Genetic search results for optimising the SCRRJITS model under changing the value of mutation rate

Generation	Pm= 0.1	Pm= 0.2	Pm= 0.4	Pm= 0.6	Pm= 08
0	460.8645	472.0808	469.641	465.0018	470.3981
1	460.8645	467.4009	469.641	464.6159	463.3731
2	454.3095	465.9571	461.047	457.2817	463.3731
3	454.3095	465.9571	461.047	453.9351	458.0805
4	454.3095	456.9156	452.7901	451.1284	458.0805
5	454.3095	456.2375	452.7901	451.1284	458.0805
6	454.3095	456.2375	452.7901	451.1284	455.4729
7	454.3095	456.1343	452.7901	451.1284	449.6517
8	450.8445	447.8759	452.7901	451.1284	449.6517
9	450.8445	447.8759	452.7901	451.1284	449.6517
10	449.1493	447.8759	451.1616	449.5663	449.6517
11	449.1493	447.8759	449.7294	449.5663	448.9839
12	449.1493	447.8759	448.6022	449.5663	447.9192
13	449.1493	445.8922	448.6022	447.519	447.564
14	446.5109	445.8922	447.9911	447.519	447.564
15	446.5109	445.8922	447.8747	447.519	447.564
16	446.5109	445.8922	447.8267	445.4977	446.4755
17	446.5109	445.8922	447.4195	445.4977	445.794
18	445.713	445.8142	446.1756	445.4977	445.794
19	445.713	445.7989	446.1756	444.8278	444.6164
20	445.713	445.7989	444.1774	443.9314	444.3626
21	445.713	445.7989	444.1774	443.9314	443.868
22	445.713	444.8381	444.1774	442.5281	443.868
23	445.713	444.1877	443.8014	442.5281	443.868
24	444.0846	444.1877	442.7936	442.5281	443.868
25	444.0846	444.1877	442.7936	442.5281	443.3748
26	444.0846	444.1877	442.7936	442.5281	443.2588
27	444.0846	443.8419	442.7936	442.5281	442.7655
28	443.6606	443.8419	441.7281	442.5281	442.6417
29	443.3544	443.8419	441.7281	442.5281	442.6417
30	443.3544	442.9497	441.7281	442.5281	442.1216
31	443.3544	442.9497	441.7281	442.2349	442.1216
32	443.12	442.8171	441.5982	442.2349	441.2092
33	442.9301	442.8171	441.5982	442.2349	441.0932
34	442.9301	442.3064	441.5838	442.2349	440.4728
35	442.4306	441.9281	441.5838	441.8468	440.4728
36	441.619	441.8605	439.8051	441.8468	440.4728
37	441.2576	441.5696	439.8051	441.4337	440.4728
38	440.8505	441.3637	439.8051	441.4337	440.4728
39	440.8505	441.3637	439.8051	441.1103	440.3568
40	440.6605	441.3637	439.8051	440.1949	439.9497
41	440.6605	441.3637	439.8051	440.1949	439.9497
42	440.6605	440.9926	439.8051	440.1949	439.9497
43	440.6605	440.9372	439.8051	440.1949	439.9497
44	440.6605	440.9372	439.8051	440.1949	439.9497
45	440.6605	440.899	439.8051	439.9704	439.8405
46	440.6605	440.4751	439.8051	439.7105	439.7245
47	440.6605	440.4751	439.6887	439.5945	439.7245
48	440.6605	440.4751	439.6887	439.5945	439.7245
49	440.6605	440.4751	439.6887	439.5945	439.5945
50	440.6605	440.3762	439.6887	439.5945	439.5945
51	440.6605	440.3762	439.6887	439.5945	439.5945
52	440.5155	440.3762	439.6887	439.5945	439.5945
53	440.5155	439.7265	439.6887	439.5945	439.5945
54	440.5155	439.7265	439.6887	439.5945	439.5945
55	440.3988	439.7265	439.6887	439.5945	439.5945
56	440.3256	439.7265	439.6887	439.5945	439.5945
57	440.3256	439.7265	439.6887	439.5945	439.5945
58	440.3256	439.7265	439.6887	439.5945	439.5945
59	440.3256	439.7265	439.6887	439.5945	439.5945
60	440.2096	439.5013	439.6887	439.5945	439.5945
61	440.2096	439.5013	439.6887	439.5945	439.5945
62	440.1956	439.5013	439.6887	439.5945	439.5945
63	439.9358	439.5013	439.6887	439.5945	439.5945
64	439.9358	439.5013	439.6887	439.5945	439.5945
65	439.9358	439.5013	439.6887	439.5945	439.5945
66	439.9358	439.5013	439.6887	439.5945	439.5945
67	439.9358	439.5013	439.6887	439.5945	439.5945
68	439.9358	439.5013	439.6887	439.5945	439.5945
69	439.9358	439.5013	439.6887	439.5945	439.5945
70	439.9358	439.5013	439.6887	439.5945	439.5945
71	439.9358	439.5013	439.6887	439.5945	439.5945
72	439.9358	439.5013	439.6887	439.5945	439.5945
73	439.9358	439.5013	439.6887	439.5945	439.5945
74	439.9358	439.5013	439.6887	439.5945	439.5945
75	439.9358	439.5013	439.6887	439.5945	439.5945

76	439.9358	439.5013	439.6887	439.5945	439.5945
77	439.8198	439.5013	439.6887	439.5945	439.5945
78	439.8198	439.5013	439.6887	439.5945	439.5945
79	439.8198	439.5013	439.6887	439.5945	439.5945
80	439.8198	439.5013	439.6887	439.5945	439.5945
81	439.8198	439.5013	439.6887	439.5945	439.5945
82	439.7105	439.5013	439.6887	439.5945	439.5945
83	439.7105	439.5013	439.6887	439.5945	439.5945
84	439.7105	439.5013	439.6887	439.5945	439.5945
85	439.7105	439.5013	439.6887	439.5945	439.5945
86	439.7105	439.5013	439.6887	439.5945	439.5945
87	439.7105	439.5013	439.6887	439.5945	439.5945
88	439.5945	439.5013	439.6169	439.5945	439.5945
89	439.5945	439.5013	439.6169	439.5945	439.5945
90	439.5945	439.5013	439.6169	439.5945	439.5945
91	439.5945	439.5013	439.6169	439.5945	439.5945
92	439.5945	439.5013	439.6169	439.5945	439.5945
93	439.5945	439.5013	439.6169	439.5945	439.5945
94	439.5945	439.5013	439.5013	439.5945	439.5945
95	439.5945	439.5013	439.5013	439.5945	439.5945
96	439.5945	439.5013	439.5013	439.5945	439.5945
97	439.5945	439.5013	439.5013	439.5945	439.5945
98	439.5945	439.5013	439.5013	439.5945	439.5945
99	439.5945	439.5013	439.5013	439.5945	439.5945
100	439.5945	439.5013	439.5013	439.5945	439.5945
101	439.5945	439.5013	439.5013	439.5945	439.5945
102	439.5945	439.5013	439.5013	439.5945	439.5945
103	439.5945	439.5013	439.5013	439.5945	439.5945
104	439.5945	439.5013	439.5013	439.5945	439.5945
105	439.5945	439.5013	439.5013	439.5945	439.5945
106	439.5945	439.5013	439.5013	439.5945	439.5945
107	439.5945	439.5013	439.5013	439.5945	439.5945
108	439.5945	439.5013	439.5013	439.5945	439.5945
109	439.5945	439.5013	439.5013	439.5945	439.5945
110	439.5945	439.5013	439.5013	439.5945	439.5945
111	439.5945	439.5013	439.5013	439.5945	439.5945
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113	439.5945	439.5013	439.5013	439.5945	439.5945
114	439.5945	439.5013	439.5013	439.5945	439.5945
115	439.5945	439.5013	439.5013	439.5945	439.5945
116	439.5945	439.5013	439.5013	439.5945	439.5945
117	439.5945	439.5013	439.5013	439.5945	439.5945
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119	439.5945	439.5013	439.5013	439.5945	439.5945
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121	439.5945	439.5013	439.5013	439.5945	439.5945
122	439.5945	439.5013	439.5013	439.5945	439.5945
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127	439.5945	439.5013	439.5013	439.5945	439.5945
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133	439.5945	439.5013	439.5013	439.5945	439.5945
134	439.5945	439.5013	439.5013	439.5945	439.5945
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153	439.5945	439.5013	439.5013	439.5945	439.5945
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155	439.5945	439.5013	439.5013	439.5945	439.5945
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162	439.5945	439.5013	439.5013	439.5945	439.5945
163	439.5945	439.5013	439.5013	439.5945	439.5945
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165	439.5945	439.5013	439.5013	439.5945	439.5945
166	439.5945	439.5013	439.5013	439.5945	439.5945
167	439.5945	439.5013	439.5013	439.5945	439.5945
168	439.5945	439.5013	439.5013	439.5945	439.5945
169	439.5945	439.5013	439.5013	439.5945	439.5945
170	439.5945	439.5013	439.5013	439.5945	439.5945
171	439.5945	439.5013	439.5013	439.5945	439.5945
172	439.5945	439.5013	439.5013	439.5945	439.5945
173	439.5945	439.5013	439.5013	439.5945	439.5945
174	439.5945	439.5013	439.5013	439.5945	439.5945
175	439.5945	439.5013	439.5013	439.5945	439.5945

176	439.5945	439.5013	439.5013	439.5945	439.5945
177	439.5945	439.5013	439.5013	439.5945	439.5945
178	439.5945	439.5013	439.5013	439.5945	439.5945
179	439.5945	439.5013	439.5013	439.5945	439.5945
180	439.5945	439.5013	439.5013	439.5945	439.5945
181	439.5945	439.5013	439.5013	439.5945	439.5945
182	439.5945	439.5013	439.5013	439.5945	439.5945
183	439.5945	439.5013	439.5013	439.5945	439.5945
184	439.5945	439.5013	439.5013	439.5945	439.5945
185	439.5945	439.5013	439.5013	439.5945	439.5945
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358	439.5013	439.5013	439.5013	439.5013	439.5945
359	439.5013	439.5013	439.5013	439.5013	439.5945
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373	439.5013	439.5013	439.5013	439.5013	439.5945
374	439.5013	439.5013	439.5013	439.5013	439.5945
375	439.5013	439.5013	439.5013	439.5013	439.5945

376	439.5013	439.5013	439.5013	439.5013	439.5945
377	439.5013	439.5013	439.5013	439.5013	439.5945
378	439.5013	439.5013	439.5013	439.5013	439.5945
379	439.5013	439.5013	439.5013	439.5013	439.5945
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385	439.5013	439.5013	439.5013	439.5013	439.5945
386	439.5013	439.5013	439.5013	439.5013	439.5945
387	439.5013	439.5013	439.5013	439.5013	439.5945
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394	439.5013	439.5013	439.5013	439.5013	439.5945
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397	439.5013	439.5013	439.5013	439.5013	439.5945
398	439.5013	439.5013	439.5013	439.5013	439.5945
399	439.5013	439.5013	439.5013	439.5013	439.5945
400	439.5013	439.5013	439.5013	439.5013	439.5945
401	439.5013	439.5013	439.5013	439.5013	439.5945
402	439.5013	439.5013	439.5013	439.5013	439.5945
403	439.5013	439.5013	439.5013	439.5013	439.5013
404	439.5013	439.5013	439.5013	439.5013	439.5013
405	439.5013	439.5013	439.5013	439.5013	439.5013
406	439.5013	439.5013	439.5013	439.5013	439.5013
407	439.5013	439.5013	439.5013	439.5013	439.5013
408	439.5013	439.5013	439.5013	439.5013	439.5013
409	439.5013	439.5013	439.5013	439.5013	439.5013
410	439.5013	439.5013	439.5013	439.5013	439.5013
411	439.5013	439.5013	439.5013	439.5013	439.5013
412	439.5013	439.5013	439.5013	439.5013	439.5013
413	439.5013	439.5013	439.5013	439.5013	439.5013
414	439.5013	439.5013	439.5013	439.5013	439.5013
415	439.5013	439.5013	439.5013	439.5013	439.5013
416	439.5013	439.5013	439.5013	439.5013	439.5013
417	439.5013	439.5013	439.5013	439.5013	439.5013
418	439.5013	439.5013	439.5013	439.5013	439.5013
419	439.5013	439.5013	439.5013	439.5013	439.5013
420	439.5013	439.5013	439.5013	439.5013	439.5013

Table B.3 Genetic search results for optimising the SCRRJITS model under changing the population size value

Generation	N= 100	N= 200	N= 300	N= 400	N= 500
0	456.8733	478.672	474.8434	458.7723	476.202
1	456.8733	478.672	472.6546	458.7723	474.8094
2	456.8733	468.6908	472.6546	456.9147	473.0503
3	456.8733	457.0405	469.334	456.9147	462.173
4	456.8733	457.0405	467.068	452.6546	458.9723
5	456.8733	457.0405	458.4835	452.6546	458.9723
6	456.8733	457.0405	458.4835	452.6546	458.9723
7	456.8733	453.9415	456.3958	448.0779	458.9723
8	456.8733	453.9415	452.0252	447.177	458.9723
9	454.3409	453.9415	452.0252	445.4185	451.0851
10	454.3409	452.0009	452.0252	445.4185	451.0851
11	454.3409	452.0009	448.0772	445.4185	448.1057
12	454.3409	452.0009	445.2407	445.4185	448.1057
13	454.3409	451.8565	444.7707	445.4185	448.1057
14	449.5823	451.8565	444.7707	445.4185	445.9401
15	449.5823	451.8565	444.7707	445.4185	445.9401
16	447.8417	451.8565	444.7707	445.4185	445.9401
17	447.8417	450.469	443.074	445.4185	445.9401
18	447.8417	450.3707	443.074	445.2286	445.9401
19	447.8417	450.3707	443.074	445.2286	445.9401
20	447.8417	450.3707	442.8804	445.0114	445.9401
21	447.8417	449.9134	442.8804	445.0114	445.8457
22	446.1029	448.5065	442.8804	444.5147	444.8697
23	446.1029	448.3467	442.8804	444.5147	444.8697
24	446.1029	448.3467	442.8804	443.1281	444.8697
25	446.1029	448.2629	442.8532	443.0097	444.1998
26	446.1029	446.796	442.3611	443.0097	443.5637
27	446.1029	446.796	441.7284	443.0097	443.5637
28	446.1029	445.8374	441.7284	442.4617	443.1748
29	444.4568	445.8374	441.7284	442.4617	443.1748
30	444.3623	445.8374	441.7284	442.1781	443.1748
31	444.3623	445.5284	441.5348	442.0072	442.4376
32	444.3623	445.5284	441.5348	441.3125	441.1824
33	444.2208	445.0895	441.5348	441.3125	441.1824
34	441.5816	445.0895	441.2513	441.3125	441.1824
35	441.5816	443.891	441.2513	440.7154	441.066
36	441.5816	443.6688	441.2513	440.6218	441.066
37	441.5816	443.6688	441.0066	440.6218	441.066
38	441.5816	442.8315	441.0066	440.5842	441.066
39	441.5816	442.8315	441.0066	440.4543	441.066
40	441.5816	442.8315	440.5294	440.4543	441.066
41	441.5816	442.8315	440.5294	440.1194	441.066
42	441.5816	442.6378	440.5294	440.1194	440.6762
43	441.5816	442.6378	440.5294	439.8422	440.6762
44	441.5816	442.6378	440.5294	439.8422	440.6156
45	441.212	442.6378	440.4231	439.8422	440.4856
46	441.212	442.6378	440.4231	439.6169	440.4721

47	441.212	442.4214	440.4231	439.6169	440.4721
48	441.212	442.0026	440.4231	439.6169	440.0958
49	440.9117	442.0026	440.4231	439.6169	440.0958
50	440.9117	441.9391	440.4231	439.6169	440.0958
51	440.9117	441.9391	440.2695	439.6169	440.0958
52	440.9117	441.9391	440.1396	439.6169	440.0958
53	440.9117	441.9391	440.1396	439.6169	440.0958
54	440.9117	441.9391	440.1396	439.6169	440.0958
55	440.9117	441.4108	440.1396	439.6169	440.0958
56	440.9117	441.4108	440.1396	439.6169	440.0958
57	440.9117	441.4108	440.1396	439.6169	440.0785
58	440.9117	441.4108	440.1396	439.6169	440.0785
59	440.5768	441.4108	440.1396	439.6169	440.0785
60	440.5768	441.2172	440.1396	439.5013	440.0785
61	440.4526	440.5446	440.1396	439.5013	440.0241
62	440.4526	440.5446	440.1396	439.5013	439.9084
63	440.4526	440.5446	439.9721	439.5013	439.9084
64	440.2707	440.5446	439.9721	439.5013	439.8051
65	440.2707	440.5446	439.9721	439.5013	439.6887
66	440.0455	440.3509	439.9721	439.5013	439.6887
67	439.7105	440.3509	439.9721	439.5013	439.6887
68	439.7105	440.3509	439.9721	439.5013	439.6887
69	439.7105	440.3509	439.9721	439.5013	439.6169
70	439.7105	440.3509	439.9721	439.5013	439.6169
71	439.7105	440.3509	439.9721	439.5013	439.6169
72	439.7105	440.3509	439.9721	439.5013	439.5013
73	439.7105	440.3509	439.9721	439.5013	439.5013
74	439.7105	440.3509	439.9721	439.5013	439.5013
75	439.5945	440.3509	439.9721	439.5013	439.5013
76	439.5945	440.3509	439.9721	439.5013	439.5013
77	439.5945	440.1257	439.8565	439.5013	439.5013
78	439.5945	440.0941	439.8565	439.5013	439.5013
79	439.5945	440.0941	439.8422	439.5013	439.5013
80	439.5945	439.9005	439.8422	439.5013	439.5013
81	439.5945	439.9005	439.8422	439.5013	439.5013
82	439.5945	439.9005	439.8422	439.5013	439.5013
83	439.5945	439.9005	439.8422	439.5013	439.5013
84	439.5945	439.9005	439.8422	439.5013	439.5013
85	439.5945	439.7837	439.8422	439.5013	439.5013
86	439.5945	439.7837	439.7265	439.5013	439.5013
87	439.5945	439.7837	439.7265	439.5013	439.5013
88	439.5945	439.7837	439.7265	439.5013	439.5013
89	439.5945	439.7837	439.7265	439.5013	439.5013
90	439.5945	439.7837	439.7265	439.5013	439.5013
91	439.5945	439.7837	439.7265	439.5013	439.5013
92	439.5945	439.7837	439.6312	439.5013	439.5013
93	439.5945	439.7837	439.6169	439.5013	439.5013
94	439.5945	439.7837	439.6169	439.5013	439.5013
95	439.5945	439.7837	439.6169	439.5013	439.5013
96	439.5945	439.7837	439.6169	439.5013	439.5013
97	439.5945	439.7837	439.5013	439.5013	439.5013
98	439.5945	439.7837	439.5013	439.5013	439.5013
99	439.5945	439.7837	439.5013	439.5013	439.5013
100	439.5945	439.7837	439.5013	439.5013	439.5013
101	439.5945	439.7837	439.5013	439.5013	439.5013
102	439.5945	439.7837	439.5013	439.5013	439.5013
103	439.5945	439.7837	439.5013	439.5013	439.5013
104	439.5945	439.7837	439.5013	439.5013	439.5013
105	439.5945	439.7837	439.5013	439.5013	439.5013
106	439.5945	439.7837	439.5013	439.5013	439.5013
107	439.5945	439.7837	439.5013	439.5013	439.5013
108	439.5945	439.7837	439.5013	439.5013	439.5013
109	439.5945	439.7837	439.5013	439.5013	439.5013
110	439.5945	439.7837	439.5013	439.5013	439.5013
111	439.5945	439.7837	439.5013	439.5013	439.5013
112	439.5945	439.7837	439.5013	439.5013	439.5013
113	439.5945	439.7837	439.5013	439.5013	439.5013
114	439.5945	439.7837	439.5013	439.5013	439.5013
115	439.5945	439.7837	439.5013	439.5013	439.5013
116	439.5945	439.7837	439.5013	439.5013	439.5013
117	439.5945	439.7837	439.5013	439.5013	439.5013
118	439.5945	439.7837	439.5013	439.5013	439.5013
119	439.5945	439.7837	439.5013	439.5013	439.5013
120	439.5945	439.7837	439.5013	439.5013	439.5013
121	439.5945	439.7837	439.5013	439.5013	439.5013
122	439.5945	439.7837	439.5013	439.5013	439.5013
123	439.5945	439.7837	439.5013	439.5013	439.5013
124	439.5945	439.7837	439.5013	439.5013	439.5013
125	439.5945	439.7837	439.5013	439.5013	439.5013
126	439.5945	439.7837	439.5013	439.5013	439.5013
127	439.5945	439.7837	439.5013	439.5013	439.5013
128	439.5945	439.7837	439.5013	439.5013	439.5013
129	439.5945	439.7837	439.5013	439.5013	439.5013
130	439.5945	439.7837	439.5013	439.5013	439.5013
131	439.5945	439.7837	439.5013	439.5013	439.5013
132	439.5945	439.7837	439.5013	439.5013	439.5013
133	439.5945	439.7837	439.5013	439.5013	439.5013
134	439.5945	439.7837	439.5013	439.5013	439.5013
135	439.5945	439.7837	439.5013	439.5013	439.5013
136	439.5945	439.7837	439.5013	439.5013	439.5013
137	439.5945	439.7837	439.5013	439.5013	439.5013
138	439.5945	439.7837	439.5013	439.5013	439.5013
139	439.5945	439.7837	439.5013	439.5013	439.5013
140	439.5945	439.7837	439.5013	439.5013	439.5013
141	439.5945	439.7837	439.5013	439.5013	439.5013
142	439.5945	439.7837	439.5013	439.5013	439.5013
143	439.5945	439.7837	439.5013	439.5013	439.5013
144	439.5945	439.7837	439.5013	439.5013	439.5013
145	439.5945	439.7837	439.5013	439.5013	439.5013
146	439.5945	439.7837	439.5013	439.5013	439.5013

147	439.5945	439.7837	439.5013	439.5013	439.5013
148	439.5945	439.7837	439.5013	439.5013	439.5013
149	439.5945	439.7837	439.5013	439.5013	439.5013
150	439.5945	439.7837	439.5013	439.5013	439.5013
151	439.5945	439.7837	439.5013	439.5013	439.5013
152	439.5945	439.7837	439.5013	439.5013	439.5013
153	439.5945	439.7837	439.5013	439.5013	439.5013
154	439.5945	439.7837	439.5013	439.5013	439.5013
155	439.5945	439.7837	439.5013	439.5013	439.5013
156	439.5945	439.7837	439.5013	439.5013	439.5013
157	439.5945	439.7837	439.5013	439.5013	439.5013
158	439.5945	439.7837	439.5013	439.5013	439.5013
159	439.5945	439.7837	439.5013	439.5013	439.5013
160	439.5945	439.7837	439.5013	439.5013	439.5013
161	439.5945	439.7837	439.5013	439.5013	439.5013
162	439.5945	439.7837	439.5013	439.5013	439.5013
163	439.5945	439.7837	439.5013	439.5013	439.5013
164	439.5945	439.7837	439.5013	439.5013	439.5013
165	439.5945	439.7837	439.5013	439.5013	439.5013
166	439.5945	439.7837	439.5013	439.5013	439.5013
167	439.5945	439.7837	439.5013	439.5013	439.5013
168	439.5945	439.7837	439.5013	439.5013	439.5013
169	439.5945	439.7837	439.5013	439.5013	439.5013
170	439.5945	439.7837	439.5013	439.5013	439.5013
171	439.5945	439.7837	439.5013	439.5013	439.5013
172	439.5945	439.7837	439.5013	439.5013	439.5013
173	439.5945	439.7837	439.5013	439.5013	439.5013
174	439.5945	439.7837	439.5013	439.5013	439.5013
175	439.5945	439.7837	439.5013	439.5013	439.5013
176	439.5945	439.7837	439.5013	439.5013	439.5013
177	439.5945	439.7837	439.5013	439.5013	439.5013
178	439.5945	439.7837	439.5013	439.5013	439.5013
179	439.5945	439.7837	439.5013	439.5013	439.5013
180	439.5945	439.7837	439.5013	439.5013	439.5013
181	439.5945	439.7837	439.5013	439.5013	439.5013
182	439.5945	439.7837	439.5013	439.5013	439.5013
183	439.5945	439.7837	439.5013	439.5013	439.5013
184	439.5945	439.7837	439.5013	439.5013	439.5013
185	439.5945	439.7837	439.5013	439.5013	439.5013
186	439.5945	439.7837	439.5013	439.5013	439.5013
187	439.5945	439.7837	439.5013	439.5013	439.5013
188	439.5945	439.7837	439.5013	439.5013	439.5013
189	439.5945	439.5013	439.5013	439.5013	439.5013
190	439.5945	439.5013	439.5013	439.5013	439.5013
191	439.5945	439.5013	439.5013	439.5013	439.5013
192	439.5945	439.5013	439.5013	439.5013	439.5013
193	439.5945	439.5013	439.5013	439.5013	439.5013
194	439.5945	439.5013	439.5013	439.5013	439.5013
195	439.5945	439.5013	439.5013	439.5013	439.5013
196	439.5945	439.5013	439.5013	439.5013	439.5013
197	439.5945	439.5013	439.5013	439.5013	439.5013
198	439.5945	439.5013	439.5013	439.5013	439.5013
199	439.5945	439.5013	439.5013	439.5013	439.5013
200	439.5945	439.5013	439.5013	439.5013	439.5013
201	439.5945	439.5013	439.5013	439.5013	439.5013
202	439.5945	439.5013	439.5013	439.5013	439.5013
203	439.5945	439.5013	439.5013	439.5013	439.5013
204	439.5945	439.5013	439.5013	439.5013	439.5013
205	439.5945	439.5013	439.5013	439.5013	439.5013
206	439.5945	439.5013	439.5013	439.5013	439.5013
207	439.5945	439.5013	439.5013	439.5013	439.5013
208	439.5945	439.5013	439.5013	439.5013	439.5013
209	439.5945	439.5013	439.5013	439.5013	439.5013
210	439.5945	439.5013	439.5013	439.5013	439.5013
211	439.5945	439.5013	439.5013	439.5013	439.5013
212	439.5945	439.5013	439.5013	439.5013	439.5013
213	439.5945	439.5013	439.5013	439.5013	439.5013
214	439.5945	439.5013	439.5013	439.5013	439.5013
215	439.5945	439.5013	439.5013	439.5013	439.5013
216	439.5945	439.5013	439.5013	439.5013	439.5013
217	439.5945	439.5013	439.5013	439.5013	439.5013
218	439.5945	439.5013	439.5013	439.5013	439.5013
219	439.5945	439.5013	439.5013	439.5013	439.5013
220	439.5945	439.5013	439.5013	439.5013	439.5013
221	439.5945	439.5013	439.5013	439.5013	439.5013
222	439.5945	439.5013	439.5013	439.5013	439.5013
223	439.5945	439.5013	439.5013	439.5013	439.5013
224	439.5945	439.5013	439.5013	439.5013	439.5013
225	439.5945	439.5013	439.5013	439.5013	439.5013
226	439.5945	439.5013	439.5013	439.5013	439.5013
227	439.5945	439.5013	439.5013	439.5013	439.5013
228	439.5945	439.5013	439.5013	439.5013	439.5013
229	439.5945	439.5013	439.5013	439.5013	439.5013
230	439.5945	439.5013	439.5013	439.5013	439.5013
231	439.5945	439.5013	439.5013	439.5013	439.5013
232	439.5945	439.5013	439.5013	439.5013	439.5013
233	439.5945	439.5013	439.5013	439.5013	439.5013
234	439.5945	439.5013	439.5013	439.5013	439.5013
235	439.5945	439.5013	439.5013	439.5013	439.5013
236	439.5945	439.5013	439.5013	439.5013	439.5013
237	439.5945	439.5013	439.5013	439.5013	439.5013
238	439.5945	439.5013	439.5013	439.5013	439.5013
239	439.5945	439.5013	439.5013	439.5013	439.5013
240	439.5945	439.5013	439.5013	439.5013	439.5013
241	439.5945	439.5013	439.5013	439.5013	439.5013
242	439.5945	439.5013	439.5013	439.5013	439.5013
243	439.5945	439.5013	439.5013	439.5013	439.5013
244	439.5945	439.5013	439.5013	439.5013	439.5013
245	439.5945	439.5013	439.5013	439.5013	439.5013
246	439.5945	439.5013	439.5013	439.5013	439.5013

247	439.5945	439.5013	439.5013	439.5013	439.5013
248	439.5945	439.5013	439.5013	439.5013	439.5013
249	439.5945	439.5013	439.5013	439.5013	439.5013
250	439.5945	439.5013	439.5013	439.5013	439.5013
251	439.5945	439.5013	439.5013	439.5013	439.5013
252	439.5945	439.5013	439.5013	439.5013	439.5013
253	439.5945	439.5013	439.5013	439.5013	439.5013
254	439.5945	439.5013	439.5013	439.5013	439.5013
255	439.5945	439.5013	439.5013	439.5013	439.5013
256	439.5945	439.5013	439.5013	439.5013	439.5013
257	439.5945	439.5013	439.5013	439.5013	439.5013
258	439.5945	439.5013	439.5013	439.5013	439.5013
259	439.5945	439.5013	439.5013	439.5013	439.5013
260	439.5945	439.5013	439.5013	439.5013	439.5013
261	439.5945	439.5013	439.5013	439.5013	439.5013
262	439.5945	439.5013	439.5013	439.5013	439.5013
263	439.5945	439.5013	439.5013	439.5013	439.5013
264	439.5945	439.5013	439.5013	439.5013	439.5013
265	439.5945	439.5013	439.5013	439.5013	439.5013
266	439.5945	439.5013	439.5013	439.5013	439.5013
267	439.5945	439.5013	439.5013	439.5013	439.5013
268	439.5945	439.5013	439.5013	439.5013	439.5013
269	439.5945	439.5013	439.5013	439.5013	439.5013
270	439.5945	439.5013	439.5013	439.5013	439.5013
271	439.5945	439.5013	439.5013	439.5013	439.5013
272	439.5945	439.5013	439.5013	439.5013	439.5013
273	439.5945	439.5013	439.5013	439.5013	439.5013
274	439.5945	439.5013	439.5013	439.5013	439.5013
275	439.5945	439.5013	439.5013	439.5013	439.5013
276	439.5945	439.5013	439.5013	439.5013	439.5013
277	439.5945	439.5013	439.5013	439.5013	439.5013
278	439.5945	439.5013	439.5013	439.5013	439.5013
279	439.5945	439.5013	439.5013	439.5013	439.5013
280	439.5945	439.5013	439.5013	439.5013	439.5013
281	439.5945	439.5013	439.5013	439.5013	439.5013
282	439.5945	439.5013	439.5013	439.5013	439.5013
283	439.5945	439.5013	439.5013	439.5013	439.5013
284	439.5945	439.5013	439.5013	439.5013	439.5013
285	439.5945	439.5013	439.5013	439.5013	439.5013
286	439.5945	439.5013	439.5013	439.5013	439.5013
287	439.5945	439.5013	439.5013	439.5013	439.5013
288	439.5945	439.5013	439.5013	439.5013	439.5013
289	439.5945	439.5013	439.5013	439.5013	439.5013
290	439.5945	439.5013	439.5013	439.5013	439.5013
291	439.5945	439.5013	439.5013	439.5013	439.5013
292	439.5945	439.5013	439.5013	439.5013	439.5013
293	439.5945	439.5013	439.5013	439.5013	439.5013
294	439.5945	439.5013	439.5013	439.5013	439.5013
295	439.5945	439.5013	439.5013	439.5013	439.5013
296	439.5945	439.5013	439.5013	439.5013	439.5013
297	439.5945	439.5013	439.5013	439.5013	439.5013
298	439.5945	439.5013	439.5013	439.5013	439.5013
299	439.5945	439.5013	439.5013	439.5013	439.5013
300	439.5945	439.5013	439.5013	439.5013	439.5013
301	439.5945	439.5013	439.5013	439.5013	439.5013
302	439.5945	439.5013	439.5013	439.5013	439.5013
303	439.5945	439.5013	439.5013	439.5013	439.5013
304	439.5945	439.5013	439.5013	439.5013	439.5013
305	439.5945	439.5013	439.5013	439.5013	439.5013
306	439.5945	439.5013	439.5013	439.5013	439.5013
307	439.5013	439.5013	439.5013	439.5013	439.5013
308	439.5013	439.5013	439.5013	439.5013	439.5013
309	439.5013	439.5013	439.5013	439.5013	439.5013
310	439.5013	439.5013	439.5013	439.5013	439.5013
311	439.5013	439.5013	439.5013	439.5013	439.5013
312	439.5013	439.5013	439.5013	439.5013	439.5013
313	439.5013	439.5013	439.5013	439.5013	439.5013
314	439.5013	439.5013	439.5013	439.5013	439.5013
315	439.5013	439.5013	439.5013	439.5013	439.5013
316	439.5013	439.5013	439.5013	439.5013	439.5013
317	439.5013	439.5013	439.5013	439.5013	439.5013
318	439.5013	439.5013	439.5013	439.5013	439.5013
319	439.5013	439.5013	439.5013	439.5013	439.5013
320	439.5013	439.5013	439.5013	439.5013	439.5013

Table B.4 Genetic search results for optimising the SCRRJITS model under changing the value of maximum generations

Generation	Gmax= 1000	Gmax= 2000	Gmax= 3000	Gmax= 4000	Gmax= 5000
0	470.6096872	455.44553	480.032952	459.291521	472.504043
1	469.1292675	455.44553	462.8495	459.291521	465.723794
2	466.6332261	451.174261	462.8495	459.291521	463.939319
3	462.5069886	451.174261	458.3219	456.504586	462.691919
4	462.5069886	451.174261	458.3219	456.504586	462.691919
5	459.3711575	451.174261	458.3219	451.59838	453.115331
6	457.6126761	451.174261	458.3219	451.59838	453.115331
7	457.283495	451.174261	453.758295	451.59838	453.115331
8	455.1496386	451.174261	450.208718	451.59838	453.115331
9	455.1496386	451.174261	450.208718	451.59838	451.795971
10	452.8688872	451.174261	450.208718	451.59838	451.795971
11	447.1857207	451.174261	450.208718	451.4211	451.795971
12	447.1857207	451.174261	450.208718	449.306705	451.594228
13	447.1857207	446.510426	449.876296	444.457593	451.461403
14	447.1857207	446.510426	447.429498	444.457593	451.126453
15	447.1857207	445.760523	446.148893	444.457593	450.352221
16	447.1857207	445.760523	446.148893	444.457593	448.39199
17	445.8286996	445.433503	446.148893	442.014768	448.39199

18	445.8286996	445.433503	445.502032	442.014768	448.39199
19	445.7103121	445.433503	445.502032	442.014768	448.39199
20	445.7103121	445.433503	444.849518	442.014768	448.39199
21	445.4451177	445.433503	443.99193	442.014768	445.634918
22	441.6682677	445.433503	443.99193	442.014768	445.634918
23	441.6682677	444.544153	443.628105	442.014768	443.107865
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551	439.5013069	439.594547	439.501307	439.501307	439.501307
552	439.5013069	439.594547	439.501307	439.501307	439.501307
553	439.5013069	439.594547	439.501307	439.501307	439.501307
554	439.5013069	439.594547	439.501307	439.501307	439.501307
555	439.5013069	439.594547	439.501307	439.501307	439.501307
556	439.5013069	439.594547	439.501307	439.501307	439.501307
557	439.5013069	439.594547	439.501307	439.501307	439.501307
558	439.5013069	439.594547	439.501307	439.501307	439.501307
559	439.5013069	439.594547	439.501307	439.501307	439.501307
560	439.5013069	439.594547	439.501307	439.501307	439.501307
561	439.5013069	439.594547	439.501307	439.501307	439.501307
562	439.5013069	439.594547	439.501307	439.501307	439.501307
563	439.5013069	439.594547	439.501307	439.501307	439.501307
564	439.5013069	439.594547	439.501307	439.501307	439.501307
565	439.5013069	439.594547	439.501307	439.501307	439.501307
566	439.5013069	439.594547	439.501307	439.501307	439.501307
567	439.5013069	439.594547	439.501307	439.501307	439.501307
568	439.5013069	439.594547	439.501307	439.501307	439.501307
569	439.5013069	439.594547	439.501307	439.501307	439.501307
570	439.5013069	439.594547	439.501307	439.501307	439.501307
571	439.5013069	439.594547	439.501307	439.501307	439.501307
572	439.5013069	439.594547	439.501307	439.501307	439.501307
573	439.5013069	439.594547	439.501307	439.501307	439.501307
574	439.5013069	439.594547	439.501307	439.501307	439.501307
575	439.5013069	439.501307	439.501307	439.501307	439.501307
576	439.5013069	439.501307	439.501307	439.501307	439.501307
577	439.5013069	439.501307	439.501307	439.501307	439.501307
578	439.5013069	439.501307	439.501307	439.501307	439.501307
579	439.5013069	439.501307	439.501307	439.501307	439.501307
580	439.5013069	439.501307	439.501307	439.501307	439.501307
581	439.5013069	439.501307	439.501307	439.501307	439.501307
582	439.5013069	439.501307	439.501307	439.501307	439.501307
583	439.5013069	439.501307	439.501307	439.501307	439.501307
584	439.5013069	439.501307	439.501307	439.501307	439.501307
585	439.5013069	439.501307	439.501307	439.501307	439.501307
586	439.5013069	439.501307	439.501307	439.501307	439.501307
587	439.5013069	439.501307	439.501307	439.501307	439.501307
588	439.5013069	439.501307	439.501307	439.501307	439.501307
589	439.5013069	439.501307	439.501307	439.501307	439.501307
590	439.5013069	439.501307	439.501307	439.501307	439.501307
591	439.5013069	439.501307	439.501307	439.501307	439.501307
592	439.5013069	439.501307	439.501307	439.501307	439.501307
593	439.5013069	439.501307	439.501307	439.501307	439.501307
594	439.5013069	439.501307	439.501307	439.501307	439.501307
595	439.5013069	439.501307	439.501307	439.501307	439.501307
596	439.5013069	439.501307	439.501307	439.501307	439.501307
597	439.5013069	439.501307	439.501307	439.501307	439.501307
598	439.5013069	439.501307	439.501307	439.501307	439.501307
599	439.5013069	439.501307	439.501307	439.501307	439.501307
600	439.5013069	439.501307	439.501307	439.501307	439.501307

Appendix C. Determination of the most suitable selection method for the proposed GA

Table C.1 Comparison between the four selection methods (RW, BT, ELIT and REP)

Generation	RW	BT	ELIT	REP
0	467.3022	472.9857	461.2443	463.5252
1	467.3022	472.9857	461.2443	463.5252
2	467.3022	465.8334	461.2443	463.5252
3	463.3463	465.8334	461.2443	457.6077
4	460.7401	461.9165	457.2332	457.6077
5	457.8388	461.7216	457.2332	447.8624
6	451.7231	460.3211	457.2332	447.8624
7	451.7231	459.9523	456.4596	447.8624
8	451.7231	458.5778	447.3589	447.8624
9	451.7231	452.0138	447.3589	447.8624
10	451.7231	448.0933	447.3589	447.8624
11	451.7231	448.0933	447.3589	447.8624
12	450.5346	448.0933	447.3589	446.7363
13	450.5346	448.0933	447.3589	446.7363
14	450.0012	447.9901	447.3589	446.7363
15	448.1623	447.9901	447.3589	446.7363
16	446.9664	447.9901	447.3589	446.7363
17	446.9664	447.9901	445.9556	446.7363
18	446.9664	445.9482	445.9556	446.6191
19	445.4337	445.9482	445.9556	446.6191
20	444.564	443.7815	445.9556	446.6191
21	444.3046	443.4325	445.9556	446.6191
22	443.1203	443.4325	445.3266	445.9566
23	443.1203	442.1616	445.3266	443.4792
24	443.1203	442.1616	445.2177	443.4792
25	443.1203	442.1616	445.0374	443.4792
26	443.1203	442.1616	445.0374	443.4792
27	443.1203	442.1616	444.4165	442.6042
28	443.1203	442.1616	444.4165	442.6042
29	442.7132	442.1616	444.3655	442.6042
30	442.7132	442.1616	444.0469	442.6042
31	442.7132	442.1616	444.0469	442.6042
32	442.165	442.1616	444.0469	442.6042
33	442.165	442.0372	443.4001	442.1191
34	442.1175	442.0372	442.9497	442.1191
35	442.1175	442.0372	442.9497	442.1191
36	442.1175	441.5812	442.8804	442.1191
37	441.2954	441.5812	442.3953	442.0989
38	441.2954	441.5812	442.3173	442.0989
39	441.2954	440.8593	442.3173	442.0989
40	441.2954	440.8593	441.1306	441.8952
41	441.0035	440.8593	441.1306	441.8952
42	441.0035	440.8593	441.1306	441.8188
43	441.0035	440.8593	441.1306	441.4043
44	441.0035	440.8593	441.1306	441.4043
45	441.0035	440.7294	441.1306	441.4043
46	441.0035	440.3458	441.1306	441.1877
47	441.0035	440.3458	441.1306	441.1877
48	441.0035	440.3458	441.0179	441.1877
49	441.0035	440.3458	441.0179	441.1877
50	441.0035	440.3458	441.0179	441.1877
51	441.0035	440.3458	441.0179	440.8198
52	441.0035	440.3458	441.0179	440.8198
53	441.0035	440.3458	441.0006	440.8198
54	441.0035	440.3458	440.8505	440.7979
55	440.3598	440.3458	440.8505	440.5945
56	440.3598	439.878	440.8505	440.5945
57	440.3598	439.878	440.8505	440.5945
58	440.3598	439.878	440.7205	440.5674
59	440.068	439.878	440.7205	440.451
60	440.068	439.878	440.6628	440.352
61	440.068	439.878	440.6628	440.2349
62	440.068	439.878	440.6628	440.0303
63	440.068	439.878	440.6281	440.0303
64	440.068	439.878	440.1604	440.0303
65	440.068	439.878	440.1604	439.9139
66	440.068	439.878	440.1604	439.9139
67	440.068	439.878	440.1604	439.9139
68	440.068	439.878	440.1604	439.9139
69	440.068	439.878	440.1604	439.9139
70	439.878	439.878	440.1604	439.9139
71	439.878	439.878	440.1604	439.9139
72	439.878	439.878	440.1604	439.9139
73	439.878	439.878	440.1604	439.9139
74	439.878	439.878	440.1604	439.8051
75	439.878	439.8405	440.1604	439.8051
76	439.878	439.7105	440.1604	439.8051
77	439.878	439.7105	440.1604	439.8051
78	439.878	439.7105	440.1604	439.8051
79	439.878	439.7105	440.1604	439.8051
80	439.878	439.7105	440.0304	439.6887
81	439.878	439.7105	439.9005	439.6887
82	439.7105	439.7105	439.9005	439.6887
83	439.7105	439.7105	439.9005	439.6887
84	439.7105	439.7105	439.9005	439.6887
85	439.5945	439.7105	439.9005	439.6887
86	439.5945	439.7105	439.9005	439.6887
87	439.5945	439.7105	439.9005	439.6887
88	439.5945	439.5945	439.9005	439.6887
89	439.5945	439.5945	439.7837	439.6887
90	439.5945	439.5945	439.7837	439.6887

91	439.5945	439.5945	439.7837	439.6887
92	439.5945	439.5945	439.7837	439.6887
93	439.5945	439.5945	439.7837	439.6887
94	439.5945	439.5945	439.7837	439.6887
95	439.5945	439.5945	439.7837	439.6887
96	439.5945	439.5945	439.7837	439.6887
97	439.5945	439.5945	439.7837	439.6887
98	439.5945	439.5945	439.7837	439.6887
99	439.5945	439.5945	439.7837	439.6887
100	439.5945	439.5945	439.7837	439.6887
101	439.5945	439.5945	439.7837	439.6887
102	439.5945	439.5945	439.7837	439.6887
103	439.5945	439.5945	439.7837	439.6887
104	439.5945	439.5945	439.7837	439.6887
105	439.5945	439.5945	439.6887	439.6887
106	439.5945	439.5945	439.6887	439.5945
107	439.5945	439.5945	439.5945	439.5945
108	439.5945	439.5945	439.5945	439.5945
109	439.5945	439.5945	439.5945	439.5945
110	439.5945	439.5945	439.5945	439.5945
111	439.5945	439.5945	439.5945	439.5945
112	439.5945	439.5945	439.5945	439.5945
113	439.5945	439.5945	439.5945	439.5945
114	439.5945	439.5945	439.5945	439.5945
115	439.5945	439.5945	439.5945	439.5945
116	439.5945	439.5945	439.5945	439.5945
117	439.5945	439.5945	439.5945	439.5945
118	439.5945	439.5945	439.5945	439.5945
119	439.5945	439.5945	439.5945	439.5945
120	439.5945	439.5945	439.5945	439.5945
121	439.5945	439.5945	439.5945	439.5945
122	439.5945	439.5945	439.5945	439.5945
123	439.5945	439.5945	439.5945	439.5945
124	439.5945	439.5945	439.5945	439.5945
125	439.5945	439.5945	439.5945	439.5945
126	439.5945	439.5945	439.5945	439.5945
127	439.5945	439.5945	439.5945	439.5945
128	439.5945	439.5945	439.5945	439.5945
129	439.5945	439.5945	439.5945	439.5945
130	439.5945	439.5945	439.5945	439.5945
131	439.5945	439.5945	439.5945	439.5945
132	439.5945	439.5945	439.5945	439.5945
133	439.5945	439.5945	439.5945	439.5945
134	439.5945	439.5945	439.5945	439.5945
135	439.5945	439.5945	439.5945	439.5945
136	439.5945	439.5945	439.5945	439.5945
137	439.5945	439.5945	439.5945	439.5945
138	439.5945	439.5945	439.5945	439.5945
139	439.5945	439.5945	439.5945	439.5945
140	439.5945	439.5945	439.5945	439.5945
141	439.5945	439.5945	439.5945	439.5945
142	439.5945	439.5945	439.5945	439.5945
143	439.5945	439.5945	439.5945	439.5945
144	439.5945	439.5945	439.5945	439.5945
145	439.5945	439.5945	439.5945	439.5945
146	439.5945	439.5945	439.5945	439.5945
147	439.5945	439.5945	439.5945	439.5945
148	439.5945	439.5945	439.5945	439.5945
149	439.5945	439.5945	439.5945	439.5945
150	439.5945	439.5945	439.5945	439.5945
151	439.5945	439.5945	439.5945	439.5945
152	439.5945	439.5945	439.5945	439.5945
153	439.5945	439.5945	439.5945	439.5945
154	439.5945	439.5945	439.5945	439.5945
155	439.5945	439.5945	439.5945	439.5945
156	439.5945	439.5945	439.5945	439.5945
157	439.5945	439.5945	439.5945	439.5945
158	439.5945	439.5945	439.5945	439.5945
159	439.5945	439.5945	439.5945	439.5945
160	439.5945	439.5945	439.5945	439.5945
161	439.5945	439.5945	439.5945	439.5945
162	439.5945	439.5945	439.5945	439.5945
163	439.5945	439.5945	439.5945	439.5945
164	439.5945	439.5945	439.5945	439.5945
165	439.5945	439.5945	439.5945	439.5945
166	439.5945	439.5945	439.5945	439.5945
167	439.5945	439.5945	439.5945	439.5945
168	439.5945	439.5945	439.5945	439.5945
169	439.5945	439.5945	439.5945	439.5945
170	439.5945	439.5945	439.5945	439.5945
171	439.5945	439.5945	439.5945	439.5945
172	439.5945	439.5945	439.5945	439.5945
173	439.5945	439.5945	439.5945	439.5945
174	439.5945	439.5945	439.5945	439.5945
175	439.5945	439.5945	439.5945	439.5945
176	439.5945	439.5945	439.5945	439.5945
177	439.5945	439.5945	439.5945	439.5945
178	439.5945	439.5945	439.5945	439.5945
179	439.5945	439.5945	439.5945	439.5945
180	439.5945	439.5945	439.5945	439.5945
181	439.5945	439.5945	439.5945	439.5945
182	439.5945	439.5945	439.5945	439.5945
183	439.5945	439.5945	439.5945	439.5945
184	439.5945	439.5945	439.5945	439.5945
185	439.5945	439.5945	439.5945	439.5945
186	439.5945	439.5945	439.5945	439.5945
187	439.5945	439.5945	439.5945	439.5945
188	439.5945	439.5945	439.5945	439.5945
189	439.5945	439.5945	439.5945	439.5945
190	439.5945	439.5945	439.5945	439.5945

191	439.5945	439.5945	439.5945	439.5945
192	439.5945	439.5945	439.5945	439.5945
193	439.5945	439.5945	439.5945	439.5945
194	439.5945	439.5945	439.5945	439.5945
195	439.5945	439.5945	439.5945	439.5945
196	439.5945	439.5945	439.5945	439.5945
197	439.5945	439.5945	439.5945	439.5945
198	439.5945	439.5945	439.5945	439.5945
199	439.5945	439.5945	439.5945	439.5945
200	439.5945	439.5945	439.5945	439.5945
201	439.5945	439.5945	439.5945	439.5945
202	439.5945	439.5945	439.5945	439.5945
203	439.5945	439.5945	439.5945	439.5945
204	439.5945	439.5945	439.5945	439.5945
205	439.5945	439.5945	439.5945	439.5945
206	439.5945	439.5945	439.5945	439.5945
207	439.5945	439.5945	439.5945	439.5945
208	439.5945	439.5945	439.5945	439.5945
209	439.5945	439.5945	439.5945	439.5945
210	439.5945	439.5945	439.5945	439.5945
211	439.5945	439.5945	439.5945	439.5945
212	439.5945	439.5945	439.5945	439.5945
213	439.5945	439.5945	439.5945	439.5945
214	439.5945	439.5945	439.5945	439.5945
215	439.5945	439.5945	439.5945	439.5945
216	439.5945	439.5945	439.5945	439.5945
217	439.5945	439.5945	439.5945	439.5945
218	439.5945	439.5945	439.5945	439.5945
219	439.5945	439.5945	439.5945	439.5945
220	439.5945	439.5945	439.5945	439.5945
221	439.5945	439.5945	439.5945	439.5945
222	439.5945	439.5945	439.5945	439.5945
223	439.5945	439.5945	439.5945	439.5945
224	439.5945	439.5945	439.5945	439.5945
225	439.5945	439.5945	439.5945	439.5013
226	439.5945	439.5945	439.5945	439.5013
227	439.5945	439.5945	439.5945	439.5013
228	439.5945	439.5945	439.5945	439.5013
229	439.5945	439.5945	439.5945	439.5013
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231	439.5945	439.5945	439.5945	439.5013
232	439.5945	439.5945	439.5945	439.5013
233	439.5945	439.5945	439.5945	439.5013
234	439.5945	439.5945	439.5945	439.5013
235	439.5945	439.5945	439.5945	439.5013
236	439.5945	439.5945	439.5945	439.5013
237	439.5945	439.5945	439.5945	439.5013
238	439.5945	439.5945	439.5945	439.5013
239	439.5945	439.5945	439.5945	439.5013
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242	439.5945	439.5945	439.5945	439.5013
243	439.5945	439.5945	439.5945	439.5013
244	439.5945	439.5945	439.5945	439.5013
245	439.5945	439.5945	439.5945	439.5013
246	439.5945	439.5945	439.5945	439.5013
247	439.5945	439.5945	439.5945	439.5013
248	439.5945	439.5945	439.5945	439.5013
249	439.5945	439.5945	439.5945	439.5013
250	439.5945	439.5945	439.5945	439.5013
251	439.5945	439.5945	439.5945	439.5013
252	439.5945	439.5945	439.5945	439.5013
253	439.5945	439.5945	439.5945	439.5013
254	439.5945	439.5945	439.5945	439.5013
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256	439.5945	439.5945	439.5945	439.5013
257	439.5945	439.5945	439.5945	439.5013
258	439.5013	439.5945	439.5945	439.5013
259	439.5013	439.5945	439.5945	439.5013
260	439.5013	439.5945	439.5945	439.5013
261	439.5013	439.5945	439.5945	439.5013
262	439.5013	439.5013	439.5945	439.5013
263	439.5013	439.5013	439.5945	439.5013
264	439.5013	439.5013	439.5945	439.5013
265	439.5013	439.5013	439.5945	439.5013
266	439.5013	439.5013	439.5945	439.5013
267	439.5013	439.5013	439.5945	439.5013
268	439.5013	439.5013	439.5945	439.5013
269	439.5013	439.5013	439.5945	439.5013
270	439.5013	439.5013	439.5945	439.5013
271	439.5013	439.5013	439.5945	439.5013
272	439.5013	439.5013	439.5945	439.5013
273	439.5013	439.5013	439.5945	439.5013
274	439.5013	439.5013	439.5945	439.5013
275	439.5013	439.5013	439.5945	439.5013
276	439.5013	439.5013	439.5945	439.5013
277	439.5013	439.5013	439.5945	439.5013
278	439.5013	439.5013	439.5945	439.5013
279	439.5013	439.5013	439.5945	439.5013
280	439.5013	439.5013	439.5945	439.5013
281	439.5013	439.5013	439.5945	439.5013
282	439.5013	439.5013	439.5945	439.5013
283	439.5013	439.5013	439.5945	439.5013
284	439.5013	439.5013	439.5945	439.5013
285	439.5013	439.5013	439.5945	439.5013
286	439.5013	439.5013	439.5945	439.5013
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642	439.5013	439.5013	439.5013	439.5013
643	439.5013	439.5013	439.5013	439.5013
644	439.5013	439.5013	439.5013	439.5013
645	439.5013	439.5013	439.5013	439.5013
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647	439.5013	439.5013	439.5013	439.5013
648	439.5013	439.5013	439.5013	439.5013
649	439.5013	439.5013	439.5013	439.5013
650	439.5013	439.5013	439.5013	439.5013
651	439.5013	439.5013	439.5013	439.5013
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653	439.5013	439.5013	439.5013	439.5013
654	439.5013	439.5013	439.5013	439.5013
655	439.5013	439.5013	439.5013	439.5013
656	439.5013	439.5013	439.5013	439.5013
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671	439.5013	439.5013	439.5013	439.5013
672	439.5013	439.5013	439.5013	439.5013
673	439.5013	439.5013	439.5013	439.5013
674	439.5013	439.5013	439.5013	439.5013
675	439.5013	439.5013	439.5013	439.5013
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678	439.5013	439.5013	439.5013	439.5013
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701	439.5013	439.5013	439.5013	439.5013
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714	439.5013	439.5013	439.5013	439.5013
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721	439.5013	439.5013	439.5013	439.5013
722	439.5013	439.5013	439.5013	439.5013
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727	439.5013	439.5013	439.5013	439.5013
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730	439.5013	439.5013	439.5013	439.5013
731	439.5013	439.5013	439.5013	439.5013
732	439.5013	439.5013	439.5013	439.5013
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734	439.5013	439.5013	439.5013	439.5013
735	439.5013	439.5013	439.5013	439.5013
736	439.5013	439.5013	439.5013	439.5013
737	439.5013	439.5013	439.5013	439.5013
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785	439.5013	439.5013	439.5013	439.5013
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788	439.5013	439.5013	439.5013	439.5013
789	439.5013	439.5013	439.5013	439.5013
790	439.5013	439.5013	439.5013	439.5013

791	439.5013	439.5013	439.5013	439.5013
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793	439.5013	439.5013	439.5013	439.5013
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796	439.5013	439.5013	439.5013	439.5013
797	439.5013	439.5013	439.5013	439.5013
798	439.5013	439.5013	439.5013	439.5013
799	439.5013	439.5013	439.5013	439.5013
800	439.5013	439.5013	439.5013	439.5013
801	439.5013	439.5013	439.5013	439.5013
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808	439.5013	439.5013	439.5013	439.5013
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813	439.5013	439.5013	439.5013	439.5013
814	439.5013	439.5013	439.5013	439.5013
815	439.5013	439.5013	439.5013	439.5013
816	439.5013	439.5013	439.5013	439.5013
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818	439.5013	439.5013	439.5013	439.5013
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821	439.5013	439.5013	439.5013	439.5013
822	439.5013	439.5013	439.5013	439.5013
823	439.5013	439.5013	439.5013	439.5013
824	439.5013	439.5013	439.5013	439.5013
825	439.5013	439.5013	439.5013	439.5013
826	439.5013	439.5013	439.5013	439.5013
827	439.5013	439.5013	439.5013	439.5013
828	439.5013	439.5013	439.5013	439.5013
829	439.5013	439.5013	439.5013	439.5013
830	439.5013	439.5013	439.5013	439.5013
831	439.5013	439.5013	439.5013	439.5013
832	439.5013	439.5013	439.5013	439.5013
833	439.5013	439.5013	439.5013	439.5013
834	439.5013	439.5013	439.5013	439.5013
835	439.5013	439.5013	439.5013	439.5013
836	439.5013	439.5013	439.5013	439.5013
837	439.5013	439.5013	439.5013	439.5013
838	439.5013	439.5013	439.5013	439.5013
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843	439.5013	439.5013	439.5013	439.5013
844	439.5013	439.5013	439.5013	439.5013
845	439.5013	439.5013	439.5013	439.5013
846	439.5013	439.5013	439.5013	439.5013
847	439.5013	439.5013	439.5013	439.5013
848	439.5013	439.5013	439.5013	439.5013
849	439.5013	439.5013	439.5013	439.5013
850	439.5013	439.5013	439.5013	439.5013
851	439.5013	439.5013	439.5013	439.5013
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853	439.5013	439.5013	439.5013	439.5013
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855	439.5013	439.5013	439.5013	439.5013
856	439.5013	439.5013	439.5013	439.5013
857	439.5013	439.5013	439.5013	439.5013
858	439.5013	439.5013	439.5013	439.5013
859	439.5013	439.5013	439.5013	439.5013
860	439.5013	439.5013	439.5013	439.5013
861	439.5013	439.5013	439.5013	439.5013
862	439.5013	439.5013	439.5013	439.5013
863	439.5013	439.5013	439.5013	439.5013
864	439.5013	439.5013	439.5013	439.5013
865	439.5013	439.5013	439.5013	439.5013
866	439.5013	439.5013	439.5013	439.5013
867	439.5013	439.5013	439.5013	439.5013
868	439.5013	439.5013	439.5013	439.5013
869	439.5013	439.5013	439.5013	439.5013
870	439.5013	439.5013	439.5013	439.5013
871	439.5013	439.5013	439.5013	439.5013
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875	439.5013	439.5013	439.5013	439.5013
876	439.5013	439.5013	439.5013	439.5013
877	439.5013	439.5013	439.5013	439.5013
878	439.5013	439.5013	439.5013	439.5013
879	439.5013	439.5013	439.5013	439.5013
880	439.5013	439.5013	439.5013	439.5013
881	439.5013	439.5013	439.5013	439.5013
882	439.5013	439.5013	439.5013	439.5013
883	439.5013	439.5013	439.5013	439.5013
884	439.5013	439.5013	439.5013	439.5013
885	439.5013	439.5013	439.5013	439.5013
886	439.5013	439.5013	439.5013	439.5013
887	439.5013	439.5013	439.5013	439.5013
888	439.5013	439.5013	439.5013	439.5013
889	439.5013	439.5013	439.5013	439.5013
890	439.5013	439.5013	439.5013	439.5013

891	439.5013	439.5013	439.5013	439.5013
892	439.5013	439.5013	439.5013	439.5013
893	439.5013	439.5013	439.5013	439.5013
894	439.5013	439.5013	439.5013	439.5013
895	439.5013	439.5013	439.5013	439.5013
896	439.5013	439.5013	439.5013	439.5013
897	439.5013	439.5013	439.5013	439.5013
898	439.5013	439.5013	439.5013	439.5013
899	439.5013	439.5013	439.5013	439.5013
900	439.5013	439.5013	439.5013	439.5013
901	439.5013	439.5013	439.5013	439.5013
902	439.5013	439.5013	439.5013	439.5013
903	439.5013	439.5013	439.5013	439.5013
904	439.5013	439.5013	439.5013	439.5013
905	439.5013	439.5013	439.5013	439.5013
906	439.5013	439.5013	439.5013	439.5013
907	439.5013	439.5013	439.5013	439.5013
908	439.5013	439.5013	439.5013	439.5013
909	439.5013	439.5013	439.5013	439.5013
910	439.5013	439.5013	439.5013	439.5013
911	439.5013	439.5013	439.5013	439.5013
912	439.5013	439.5013	439.5013	439.5013
913	439.5013	439.5013	439.5013	439.5013
914	439.5013	439.5013	439.5013	439.5013
915	439.5013	439.5013	439.5013	439.5013
916	439.5013	439.5013	439.5013	439.5013
917	439.5013	439.5013	439.5013	439.5013
918	439.5013	439.5013	439.5013	439.5013
919	439.5013	439.5013	439.5013	439.5013
920	439.5013	439.5013	439.5013	439.5013

Table C.2 The performance of the genetic operators in the proposed GA

S.N	P_c	P_m	C.G.	d_p	Time (S)	C_o	C_H	C_U	C_{pt}	C_R	$C_{T\text{-}ave}$	$C_{T\text{-}min}$	F.F-$_{ave}$	F.F-$_{max}$
1	0.2	0.8	158	210	50	6.953	9.9191	37.3248	418.5727	20.9286	459.3755	439.5013	0.2172	0.2270
2	0.2	0.8	146	210	49	6.953	9.9191	37.3248	418.5727	20.9286	441.8561	439.5013	0.2258	0.2270
3	0.2	0.8	171	210	49	6.953	9.9191	37.3248	418.5727	20.9286	446.0632	439.5013	0.2237	0.2270
4	0.2	0.8	183	210	49	6.953	9.9191	37.3248	418.5727	20.9286	441.7541	439.5013	0.2259	0.2270
5	0.2	0.8	171	210	49	6.953	9.9191	37.3248	418.5727	20.9286	445.6399	439.5013	0.2239	0.2270
6	0.2	0.8	175	210	49	6.953	9.9191	37.3248	418.5727	20.9286	444.2142	439.5013	0.2246	0.2270
7	0.2	0.8	114	210	49	6.953	9.9191	37.3248	418.5727	20.9286	454.2242	439.5013	0.2197	0.2270
8	0.2	0.8	132	210	48	6.953	9.9191	37.3248	418.5727	20.9286	442.7069	439.5013	0.2254	0.2270
9	0.2	0.8	176	210	49	6.953	9.9191	37.3248	418.5727	20.9286	443.4010	439.5013	0.2250	0.2270
10	0.2	0.8	162	210	49	6.953	9.9191	37.3248	418.5727	20.9286	452.1674	439.5013	0.2207	0.2270
Average values			**159**		**49**						**447.1403**	**439.5013**	**0.2232**	**0.2270**
11	0.4	0.6	131	210	48	6.953	9.9191	37.3248	418.5727	20.9286	439.8394	439.5013	0.2268	0.2270
12	0.4	0.6	78	210	48	6.953	9.9191	37.3248	418.5727	20.9286	441.7914	439.5013	0.2258	0.2270
13	0.4	0.6	100	210	48	6.953	9.9191	37.3248	418.5727	20.9286	496.3368	439.5013	0.2011	0.2270
14	0.4	0.6	91	210	49	6.953	9.9191	37.3248	418.5727	20.9286	441.0046	439.5013	0.2262	0.2270
15	0.4	0.6	87	210	49	6.953	9.9191	37.3248	418.5727	20.9286	440.2712	439.5013	0.2266	0.2270
16	0.4	0.6	92	210	48	6.953	9.9191	37.3248	418.5727	20.9286	441.4191	439.5013	0.2260	0.2270
17	0.4	0.6	162	210	48	6.953	9.9191	37.3248	418.5727	20.9286	444.9150	439.5013	0.2243	0.2270
18	0.4	0.6	118	210	48	6.953	9.9191	37.3248	418.5727	20.9286	441.7384	439.5013	0.2259	0.2270
19	0.4	0.6	99	210	49	6.953	9.9191	37.3248	418.5727	20.9286	440.3822	439.5013	0.2266	0.2270
20	0.4	0.6	107	210	48	6.953	9.9191	37.3248	418.5727	20.9286	451.3229	439.5013	0.2211	0.2270
Average values			**107**		**48.3**						**447.9021**	**439.5013**	**0.2228**	**0.2270**
21	0.6	0.4	66	210	48	6.953	9.9191	37.3248	418.5727	20.9286	440.5089	439.5013	0.2265	0.2270
22	0.6	0.4	68	210	48	6.953	9.9191	37.3248	418.5727	20.9286	441.2959	439.5013	0.2261	0.2270
23	0.6	0.4	65	210	48	6.953	9.9191	37.3248	418.5727	20.9286	441.5934	439.5013	0.2259	0.2270
24	0.6	0.4	77	210	48	6.953	9.9191	37.3248	418.5727	20.9286	439.9852	439.5013	0.2268	0.2270
25	0.6	0.4	87	210	47	6.953	9.9191	37.3248	418.5727	20.9286	439.6917	439.5013	0.2269	0.2270
26	0.6	0.4	83	210	49	6.953	9.9191	37.3248	418.5727	20.9286	440.1466	439.5013	0.2267	0.2270
27	0.6	0.4	114	210	48	6.953	9.9191	37.3248	418.5727	20.9286	440.8347	439.5013	0.2263	0.2270
28	0.6	0.4	73	210	48	6.953	9.9191	37.3248	418.5727	20.9286	440.2634	439.5013	0.2266	0.2270
29	0.6	0.4	119	210	48	6.953	9.9191	37.3248	418.5727	20.9286	439.7772	439.5013	0.2269	0.2270
30	0.6	0.4	88	210	48	6.953	9.9191	37.3248	418.5727	20.9286	440.0066	439.5013	0.2268	0.2270
Average values			**84**	**210**	**48**	**6.953**	**9.9191**	**37.3248**	**418.5727**	**20.9286**	**440.4104**	**439.5013**	**0.2265**	**0.2270**
31	0.8	0.2	77	210	47	6.953	9.9191	37.3248	418.5727	20.9286	439.6393	439.5013	0.2269	0.2270
32	0.8	0.2	83	210	47	6.953	9.9191	37.3248	418.5727	20.9286	439.7500	439.5013	0.2269	0.2270
33	0.8	0.2	264	210	47	6.953	9.9191	37.3248	418.5727	20.9286	439.8296	439.5013	0.2268	0.2270
34	0.8	0.2	70	210	47	6.953	9.9191	37.3248	418.5727	20.9286	440.1719	439.5013	0.2267	0.2270
35	0.8	0.2	118	210	48	6.953	9.9191	37.3248	418.5727	20.9286	439.6024	439.5013	0.2270	0.2270
36	0.8	0.2	514	210	47	6.953	9.9191	37.3248	418.5727	20.9286	439.7927	439.5013	0.2269	0.2270
37	0.8	0.2	83	210	47	6.953	9.9191	37.3248	418.5727	20.9286	439.7442	439.5013	0.2269	0.2270
38	0.8	0.2	907	210	47	6.953	9.9191	37.3248	418.5727	20.9286	442.9768	439.5013	0.2252	0.2270
39	0.8	0.2	95	210	47	6.953	9.9191	37.3248	418.5727	20.9286	440.0474	439.5013	0.2267	0.2270
40	0.8	0.2	92	210	47	6.953	9.9191	37.3248	418.5727	20.9286	439.7034	439.5013	0.2269	0.2270
Average values			**231**	**210**	**47.1**	**6.953**	**9.9191**	**37.3248**	**418.5727**	**20.9286**	**440.1258**	**439.5013**	**0.2267**	**0.2270**

41	1.0	0	63	210	47	6.953	9.9191	37.3248	418.5727	20.9286	439.8024	439.5013	0.2269	0.2270
42	1.0	0	62	210	46	6.953	9.9191	37.3248	418.5727	20.9286	440.1427	439.5013	0.2267	0.2270
43	1.0	0	416	210	51	6.953	9.9191	37.3248	418.5727	20.9286	439.7247	439.5013	0.2269	0.2270
44	1.0	0	455	210	47	6.953	9.9191	37.3248	418.5727	20.9286	445.3947	439.5013	0.2240	0.2270
45	1.0	0	54	210	47	6.953	9.9191	37.3248	418.5727	20.9286	448.7778	439.5013	0.2223	0.2270
46	1.0	0	83	210	47	6.953	9.9191	37.3248	418.5727	20.9286	439.6781	439.5013	0.2269	0.2270
47	1.0	0	46	210	47	6.953	9.9191	37.3248	418.5727	20.9286	440.2167	439.5013	0.2266	0.2270
48	1.0	0	96	210	46	6.953	9.9191	37.3248	418.5727	20.9286	439.7247	439.5013	0.2269	0.2270
49	1.0	0	103	210	47	6.953	9.9191	37.3248	418.5727	20.9286	453.9073	439.5013	0.2198	0.2270
50	1.0	0	277	210	47	6.953	9.9191	37.3248	418.5727	20.9286	439.7461	439.5013	0.2269	0.2270
Average values			**166**	**210**	**47.2**	**6.953**	**9.9191**	**37.3248**	**418.5727**	**20.9286**	**442.1698**	**442.7115**	**0.2256**	**0.2256**

Table C.3 Determination of the optimal solution in the proposed GA

Generation	Best	Worst	Average
0	458.2262	#DIV/0!	626.2985
1	458.2262	6881.706	574.2558
2	458.2262	5573.635	547.8369
3	456.5977	5573.635	531.585
4	456.5977	2222.488	516.8989
5	455.9745	696.6834	506.129
6	455.9745	591.526	499.818
7	453.1785	586.5902	493.0866
8	452.5681	573.7755	488.3772
9	450.709	573.7755	482.9697
10	450.709	572.0681	478.5003
11	450.2436	524.0524	474.0728
12	450.2436	523.763	470.14
13	448.9151	523.763	466.7022
14	448.7938	521.4039	463.7222
15	446.9199	519.5439	461.5912
16	446.9199	519.4603	459.7583
17	446.245	519.4543	457.8467
18	445.3837	494.755	456.4151
19	445.3837	484.2253	455.2846
20	445.3837	483.1977	453.9137
21	444.0002	480.7893	452.8847
22	444.0002	480.7893	451.8894
23	443.1401	480.7893	451.0388
24	443.1401	480.7893	450.3392
25	443.1401	480.7893	449.6314
26	443.0162	465.3797	448.8825
27	443.0162	461.7388	448.2253
28	441.5895	457.2545	447.6024
29	441.1102	455.1082	447.196
30	440.7753	455.1082	446.7939
31	440.7753	455.1082	446.3997
32	440.7753	455.1082	446.0391
33	440.7753	453.2593	445.6093
34	440.6589	453.2593	445.2618
35	440.6589	453.2593	444.8547
36	440.1004	452.1794	444.4399
37	440.1004	452.1794	444.1026
38	440.1004	452.1794	443.7762
39	440.1004	452.1794	443.4989
40	440.1004	450.5913	443.1875
41	440.1004	447.9204	442.8921
42	439.9844	447.9204	442.5809
43	439.9844	447.9204	442.2749
44	439.9844	447.9204	442.0196
45	439.9844	447.9204	441.8484
46	439.9844	446.2127	441.6241
47	439.9844	445.8702	441.398
48	439.9486	445.2673	441.1725
49	439.9486	445.2673	441.0038
50	439.9486	6142.083	502.1025
51	439.9486	3028.206	476.5966
52	439.9486	754.7123	465.541
53	439.9486	644.0992	456.9085
54	439.9486	624.9596	451.7047
55	439.6887	581.8235	448.0808
56	439.6887	567.4858	446.1369
57	439.6887	556.9606	443.9832
58	439.6887	556.9606	442.7121
59	439.6887	520.3192	441.5863
60	439.6887	490.3991	441.0874
61	439.6887	467.2486	440.5275
62	439.5945	467.2486	440.2968
63	439.5945	449.5454	440.1177
64	439.5945	449.5454	440.0775
65	439.5945	449.5454	440.0424
66	439.5945	440.8419	439.9597
67	439.5945	440.6807	439.9237
68	439.5945	440.6807	439.8889
69	439.5945	440.6807	439.8637
70	439.5945	440.5647	439.8337
71	439.5945	440.1143	439.7933
72	439.5945	440.1143	439.7609
73	439.5945	440.1143	439.7311
74	439.5945	440.1143	439.6979
75	439.5945	440.1143	439.6803
76	439.5945	439.9844	439.656
77	439.5945	439.9844	439.633

78	439.5945	439.9844	439.62
79	439.5945	439.9844	439.6129
80	439.5945	439.9844	439.6062
81	439.5945	439.9844	439.6042
82	439.5945	439.9844	439.6018
83	439.5945	439.9844	439.5979
84	439.5945	439.8544	439.5964
85	439.5945	439.8544	439.5961
86	439.5945	439.8544	439.5955
87	439.5945	439.8544	439.5955
88	439.5945	439.8544	439.5952
89	439.5945	439.5945	439.5945
90	439.5945	439.5945	439.5945
91	439.5945	439.5945	439.5945
92	439.5945	439.5945	439.5945
93	439.5945	439.5945	439.5945
94	439.5945	439.5945	439.5945
95	439.5945	439.5945	439.5945
96	439.5945	439.5945	439.5945
97	439.5945	439.5945	439.5945
98	439.5945	439.5945	439.5945
99	439.5945	439.5945	439.5945
100	439.5945	#DIV/0!	507.7737
101	439.5945	#DIV/0!	481.5492
102	439.5945	1476	467.3478
103	439.5945	669.8624	459.7007
104	439.5945	626.38	453.621
105	439.5945	579.3017	448.975
106	439.5945	562.1758	445.9549
107	439.5945	562.1758	444.4116
108	439.5945	562.1758	443.1877
109	439.5945	524.4876	442.4357
110	439.5945	501.3766	441.4835
111	439.5945	501.3766	441.0111
112	439.5945	498.7055	440.5556
113	439.5945	497.8744	440.4402
114	439.5945	497.8744	440.2815
115	439.5945	497.8744	440.0962
116	439.5945	473.2903	439.7704
117	439.5945	473.2903	439.7137
118	439.5945	473.2903	439.6875
119	439.5945	473.2903	439.6823
120	439.5945	457.1794	439.6463
121	439.5945	457.1794	439.6374
122	439.5945	457.1794	439.6374
123	439.5945	439.5945	439.5945
124	439.5945	439.5945	439.5945
125	439.5945	439.5945	439.5945
126	439.5945	439.5945	439.5945
127	439.5945	439.5945	439.5945
128	439.5945	439.5945	439.5945
129	439.5945	439.5945	439.5945
130	439.5945	439.5945	439.5945
131	439.5945	439.5945	439.5945
132	439.5945	439.5945	439.5945
133	439.5945	439.5945	439.5945
134	439.5945	439.5945	439.5945
135	439.5945	439.5945	439.5945
136	439.5945	439.5945	439.5945
137	439.5945	439.5945	439.5945
138	439.5945	439.5945	439.5945
139	439.5945	439.5945	439.5945
140	439.5945	439.5945	439.5945
141	439.5945	439.5945	439.5945
142	439.5945	439.5945	439.5945
143	439.5945	439.5945	439.5945
144	439.5945	439.5945	439.5945
145	439.5945	439.5945	439.5945
146	439.5945	439.5945	439.5945
147	439.5945	439.5945	439.5945
148	439.5945	439.5945	439.5945
149	439.5945	439.5945	439.5945
150	439.5945	3492.088	497.7932
151	439.5945	1247.517	473.2331
152	439.5945	1247.517	463.8768
153	439.5945	748.487	454.6016
154	439.5945	604.2307	450.6631
155	439.5945	604.2307	447.3723
156	439.5945	604.2307	444.8712
157	439.5945	563.716	443.245
158	439.5945	545.1742	442.0108
159	439.5945	545.1742	441.1125
160	439.5945	545.1742	440.7618
161	439.5945	516.2873	440.4989
162	439.5945	509.8995	440.3741
163	439.5945	509.8995	440.1177
164	439.5945	466.7313	439.8484
165	439.5945	466.7313	439.8379
166	439.5945	463.4973	439.7098
167	439.5945	448.6902	439.637
168	439.5945	448.6902	439.6189
169	439.5945	448.6902	439.6189
170	439.5945	448.6902	439.6189
171	439.5945	440.3164	439.5963
172	439.5945	440.3164	439.5963
173	439.5945	440.3164	439.5963
174	439.5945	440.3164	439.5963
175	439.5945	440.3164	439.5963
176	439.5945	440.3164	439.5963
177	439.5945	440.3164	439.5963

178	439.5945	439.5945	439.5945
179	439.5945	439.5945	439.5945
180	439.5945	439.5945	439.5945
181	439.5945	439.5945	439.5945
182	439.5945	439.5945	439.5945
183	439.5945	439.5945	439.5945
184	439.5945	439.5945	439.5945
185	439.5945	439.5945	439.5945
186	439.5945	439.5945	439.5945
187	439.5945	439.5945	439.5945
188	439.5945	439.5945	439.5945
189	439.5945	439.5945	439.5945
190	439.5945	439.5945	439.5945
191	439.5945	439.5945	439.5945
192	439.5945	439.5945	439.5945
193	439.5945	439.5945	439.5945
194	439.5945	439.5945	439.5945
195	439.5945	439.5945	439.5945
196	439.5945	439.5945	439.5945
197	439.5945	439.5945	439.5945
198	439.5945	439.5945	439.5945
199	439.5945	439.5945	439.5945
200	439.5945	8138.008	501.2162
201	439.5945	2084.69	477.3192
202	439.5945	2084.69	464.6856
203	439.5945	655.8497	456.2566
204	439.5945	591.1049	451.406
205	439.5945	591.1049	447.9753
206	439.5945	591.1049	446.1328
207	439.5945	591.1049	443.9765
208	439.5945	549.0903	442.5664
209	439.5945	549.0903	441.8383
210	439.5945	549.0903	441.3884
211	439.5945	549.0903	440.8395
212	439.5945	549.0903	440.492
213	439.5945	549.0903	440.1743
214	439.5945	535.1221	439.9649
215	439.5945	472.08	439.7375
216	439.5945	472.08	439.7111
217	439.5945	451.442	439.6237
218	439.5945	439.7105	439.5948
219	439.5945	439.7105	439.5948
220	439.5945	439.7105	439.5948
221	439.5945	439.7105	439.5948
222	439.5945	439.7105	439.5948
223	439.5945	439.7105	439.5948
224	439.5945	439.5945	439.5945
225	439.5945	439.5945	439.5945
226	439.5945	439.5945	439.5945
227	439.5945	439.5945	439.5945
228	439.5945	439.5945	439.5945
229	439.5945	439.5945	439.5945
230	439.5945	439.5945	439.5945
231	439.5945	439.5945	439.5945
232	439.5945	439.5945	439.5945
233	439.5945	439.5945	439.5945
234	439.5945	439.5945	439.5945
235	439.5945	439.5945	439.5945
236	439.5945	439.5945	439.5945
237	439.5945	439.5945	439.5945
238	439.5945	439.5945	439.5945
239	439.5945	439.5945	439.5945
240	439.5945	439.5945	439.5945
241	439.5945	439.5945	439.5945
242	439.5945	439.5945	439.5945
243	439.5945	439.5945	439.5945
244	439.5945	439.5945	439.5945
245	439.5945	439.5945	439.5945
246	439.5945	439.5945	439.5945
247	439.5945	439.5945	439.5945
248	439.5945	439.5945	439.5945
249	439.5945	439.5945	439.5945
250	439.5945	7547.104	498.3292
251	439.5945	1023.615	478.5364
252	439.5013	781.818	466.3076
253	439.5013	776.7004	458.0319
254	439.5013	642.9004	453.1787
255	439.5013	642.9004	449.1246
256	439.5013	579.1158	446.2682
257	439.5013	579.1158	444.6325
258	439.5013	549.0751	442.7328
259	439.5013	549.0751	441.6019
260	439.5013	498.4549	440.8171
261	439.5013	497.522	440.6235
262	439.5013	497.522	440.3262
263	439.5013	497.522	440.0571
264	439.5013	467.0854	439.8983
265	439.5013	467.0854	439.754
266	439.5013	467.0854	439.7102
267	439.5013	467.0854	439.6639
268	439.5013	467.0854	439.6585
269	439.5013	461.2642	439.638
270	439.5013	461.2642	439.6301
271	439.5013	461.2642	439.6228
272	439.5013	448.4329	439.5705
273	439.5013	440.2809	439.5324
274	439.5013	440.2809	439.524
275	439.5013	439.5945	439.5155
276	439.5013	439.5945	439.5111
277	439.5013	439.5945	439.5083

278	439.5013	439.5945	439.5057
279	439.5013	439.5945	439.5041
280	439.5013	439.5945	439.5032
281	439.5013	439.5945	439.5029
282	439.5013	439.5945	439.5018
283	439.5013	439.5945	439.5015
284	439.5013	439.5013	439.5013
285	439.5013	439.5013	439.5013
286	439.5013	439.5013	439.5013
287	439.5013	439.5013	439.5013
288	439.5013	439.5013	439.5013
289	439.5013	439.5013	439.5013
290	439.5013	439.5013	439.5013
291	439.5013	439.5013	439.5013
292	439.5013	439.5013	439.5013
293	439.5013	439.5013	439.5013
294	439.5013	439.5013	439.5013
295	439.5013	439.5013	439.5013
296	439.5013	439.5013	439.5013
297	439.5013	439.5013	439.5013
298	439.5013	439.5013	439.5013
299	439.5013	439.5013	439.5013
300	439.5013	#DIV/0!	498.396
301	439.5013	5965.259	475.096
302	439.5013	1016.641	462.941
303	439.5013	1016.641	456.2709
304	439.5013	1016.641	451.3426
305	439.5013	926.7938	447.6184
306	439.5013	623.4838	444.7196
307	439.5013	577.0288	442.9902
308	439.5013	577.0288	441.813
309	439.5013	577.0288	441.0648
310	439.5013	503.9166	440.4227
311	439.5013	503.9166	440.3019
312	439.5013	503.9166	440.1166
313	439.5013	488.3243	439.9643
314	439.5013	480.5369	439.7354
315	439.5013	480.5369	439.6304
316	439.5013	480.5369	439.6196
317	439.5013	440.2809	439.5033
318	439.5013	440.2809	439.5033
319	439.5013	439.5013	439.5013

Appendix D. The experimental results for the SCRRJITS optimisation design in the case study

Table D.1 the detailed results of the optimal solution of the SCRRJITS problem

Generation	Best	Worst	Average
0	171.7632	18844.61	259.9375
1	171.1108	9877.928	234.994
2	171.1108	343.7318	219.9929
3	170.7609	290.8987	211.5158
4	170.7609	290.8987	205.5709
5	170.7609	277.1727	199.7825
6	170.7609	277.1727	195.5862
7	170.7609	246.6612	190.7853
8	170.7609	237.9659	186.8324
9	170.7609	237.9659	183.1273
10	170.7609	236.9506	180.1302
11	170.7609	236.9506	178.3742
12	170.7609	217.5273	176.242
13	170.617	209.5755	174.7747
14	170.617	209.5755	173.3402
15	170.617	206.9447	172.6303
16	170.617	206.9447	172.1268
17	170.617	200.8094	171.7077
18	170.617	188.5767	171.2443
19	170.617	188.5767	171.1649
20	170.617	188.5767	171.0724
21	170.617	188.5767	171.0048
22	170.617	188.5767	170.9298
23	170.617	188.5767	170.9031
24	170.617	188.5767	170.8471
25	170.617	188.5767	170.8188
26	170.617	171.8944	170.7494
27	170.617	171.8944	170.7339
28	170.617	171.7632	170.7146
29	170.617	171.7632	170.6954
30	170.617	171.7632	170.6834
31	170.617	171.7632	170.6701
32	170.617	171.7632	170.6597
33	170.617	171.3017	170.6468
34	170.617	171.3017	170.6397
35	170.617	171.3017	170.6349
36	170.617	171.3017	170.6317
37	170.617	171.3017	170.6284
38	170.617	171.3017	170.6259
39	170.617	171.3017	170.623
40	170.617	170.7609	170.6188
41	170.617	170.7609	170.6185
42	170.617	170.7609	170.6177
43	170.617	170.7609	170.6177
44	170.617	170.7609	170.6174
45	170.617	170.7609	170.6174
46	170.617	170.7609	170.6174
47	170.617	170.617	170.617
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49	170.617	170.617	170.617
50	170.617	6998.916	196.2626
51	170.617	796.6771	186.6157
52	170.617	360.1656	180.897
53	170.617	326.9213	177.3168
54	170.617	262.1557	175.3578
55	170.617	262.1557	173.3416
56	170.617	230.7806	172.0597
57	170.617	221.4027	171.2611
58	170.617	206.1332	171.0611
59	170.617	196.7191	170.9173
60	170.617	196.7191	170.8209
61	170.617	189.1844	170.6693
62	170.617	171.0643	170.6181
63	170.617	170.617	170.617
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101	170.617	732.7327	187.3895
102	170.617	387.1269	181.8122
103	170.617	331.5792	178.2537
104	170.617	282.8601	174.8174
105	170.617	254.899	173.4145
106	170.617	254.899	172.3029
107	170.617	254.899	171.8288
108	170.617	242.7372	171.164
109	170.617	235.5275	171.0201
110	170.617	208.3598	170.9019
111	170.617	208.3598	170.8224
112	170.617	208.3598	170.746
113	170.617	208.3598	170.6944
114	170.617	208.3598	170.6944
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148	170.617	170.617	170.617
149	170.617	170.617	170.617
150	170.617	19062.35	198.6336
151	170.617	19062.35	187.4653
152	170.617	1371.198	180.3237
153	170.617	509.7922	176.6167
154	170.617	509.7922	174.634
155	170.617	246.3589	172.8737
156	170.617	226.5145	171.9989
157	170.617	214.7527	171.5846
158	170.617	214.7169	171.2466
159	170.617	207.7855	170.9457
160	170.617	202.6	170.7635
161	170.617	187.1281	170.6547
162	170.617	187.1281	170.6547
163	170.617	170.617	170.617
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195	170.617	170.617	170.617
196	170.5921	170.617	170.6169
197	170.5921	170.617	170.6167
198	170.5921	170.617	170.6166
199	170.5921	170.617	170.6162
200	170.5921	21378.32	201.0079
201	170.5921	6998.916	190.244
202	170.5921	363.1591	182.7019
203	170.5921	363.1591	179.493
204	170.5921	282.0036	176.1167
205	170.5921	262.1918	174.5313
206	170.5921	235.4348	173.1047
207	170.5921	222.7709	172.0789
208	170.5921	222.7709	171.8648
209	170.5921	222.7709	171.4511
210	170.5921	222.0286	171.2115
211	170.5921	209.7973	170.9406
212	170.5921	209.7973	170.8783
213	170.5921	204.248	170.7856
214	170.5921	204.248	170.6749
215	170.5921	170.617	170.6003
216	170.5921	170.617	170.5986
217	170.5921	170.617	170.597
218	170.5921	170.617	170.5957
219	170.5921	170.617	170.5946
220	170.5921	170.617	170.5939
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223	170.5921	170.617	170.5929

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248	170.5921	170.5921	170.5921
249	170.5921	170.5921	170.5921
250	170.5921	3055.419	198.4884
251	170.5921	1819.82	188.1683
252	170.5921	576.6505	181.4188
253	170.5921	308.3716	177.9152
254	170.5921	263.9826	175.6795
255	170.5921	250.3876	173.0588
256	170.5921	250.3876	172.1059
257	170.5921	223.3084	171.5937
258	170.5921	217.0758	171.3092
259	170.5921	217.0758	171.1561
260	170.5921	217.0758	170.9891
261	170.5921	217.0758	170.9743
262	170.5921	217.0758	170.7655
263	170.5921	187.0803	170.6739
264	170.5921	187.0803	170.6301
265	170.5921	170.7352	170.5925
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298	170.5921	170.5921	170.5921
299	170.5921	170.5921	170.5921
300	170.5921	9856.083	199.4423

301	170.5921	9856.083	186.9239
302	170.5921	593.5466	180.3538
303	170.5921	259.2179	176.3113
304	170.5921	259.2179	174.1618
305	170.5921	259.2179	173.0581
306	170.5921	251.8484	172.244
307	170.5921	251.8484	171.6553
308	170.5921	251.8484	171.2116
309	170.5921	251.8484	170.9681
310	170.5921	223.8757	170.9094
311	170.5921	223.8757	170.8729
312	170.5921	223.8757	170.7331
313	170.5921	203.826	170.701
314	170.5921	203.826	170.701
315	170.5921	203.826	170.6618
316	170.5921	203.826	170.6618
317	170.5921	203.826	170.6618
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347	170.5921	170.5921	170.5921
348	170.5921	170.5921	170.5921
349	170.5921	170.5921	170.5921
350	170.5921	2943.753	200.5377
351	170.5921	2127.59	190.7157
352	170.5921	784.4061	183.8521
353	170.5921	262.6838	178.6286
354	170.5921	262.553	176.5628
355	170.5921	259.3563	174.6169
356	170.5921	235.7841	173.2173
357	170.5921	235.7841	172.6405
358	170.5921	235.7841	172.099
359	170.5921	224.2505	171.605
360	170.5921	219.3228	171.1374
361	170.5921	219.3228	171.029
362	170.5921	219.3228	170.9862
363	170.5921	219.3228	170.8773
364	170.5921	219.3228	170.8129
365	170.5921	189.4382	170.6796
366	170.5921	189.4382	170.6765
367	170.5921	189.4382	170.6379
368	170.5921	189.4382	170.6379
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399	170.5921	170.5921	170.5921
400	170.5921	4379.314	198.7927
401	170.5921	1274.308	188.3435
402	170.5921	634.1538	182.666
403	170.5921	368.554	178.6579
404	170.5921	271.8123	175.8136
405	170.5921	271.8123	173.9709
406	170.5921	235.5418	172.825
407	170.5921	230.8931	172.078
408	170.5921	218.542	171.3943
409	170.5921	210.2254	171.2984
410	170.5921	210.2254	171.1034
411	170.5921	207.7624	171.0384
412	170.5921	198.0409	170.7923
413	170.5921	189.4382	170.7352
414	170.5921	176.6608	170.6235
415	170.5921	176.6608	170.6176
416	170.5921	174.3784	170.6075
417	170.5921	174.3784	170.6075
418	170.5921	174.3784	170.6014
419	170.5921	170.5921	170.5921
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421	170.5921	170.5921	170.5921
422	170.5921	170.5921	170.5921
423	170.5921	170.5921	170.5921
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447	170.5921	170.5921	170.5921
448	170.5921	170.5921	170.5921
449	170.5921	170.5921	170.5921
450	170.5921	2286.209	194.9332
451	170.5921	2286.209	185.3856
452	170.5921	582.5215	180.238
453	170.5921	582.5215	176.4942
454	170.5921	582.5215	174.4413
455	170.5921	266.4988	173.1888
456	170.5921	230.0618	172.3993
457	170.5921	222.3159	171.5915

458	170.5921	214.0303	171.1337
459	170.5921	214.0303	170.9406
460	170.5921	213.1226	170.8982
461	170.5921	206.7533	170.7843
462	170.5921	206.7533	170.7843
463	170.5921	206.7533	170.6683
464	170.5921	206.7533	170.6668
465	170.5839	206.7533	170.6668
466	170.5839	206.7533	170.6668
467	170.5839	206.7533	170.6668
468	170.5839	206.7533	170.6667
469	170.5839	170.5921	170.592
470	170.5839	170.5921	170.592
471	170.5839	170.5921	170.5919
472	170.5839	170.5921	170.5918
473	170.5839	170.5921	170.5918
474	170.5839	170.5921	170.5916
475	170.5839	170.5921	170.5914
476	170.5839	170.5921	170.5913
477	170.5839	170.5921	170.5909
478	170.5839	170.5921	170.5906
479	170.5839	170.5921	170.5903
480	170.5839	170.5921	170.5898
481	170.5839	170.5921	170.5891
482	170.5839	170.5921	170.5885
483	170.5839	170.5921	170.5877
484	170.5839	170.5921	170.5871
485	170.5839	170.5921	170.5864
486	170.5839	170.5921	170.5857
487	170.5839	170.5921	170.5851
488	170.5839	170.5921	170.5848
489	170.5839	170.5921	170.5844
490	170.5839	170.5921	170.5842
491	170.5839	170.5921	170.5841
492	170.5839	170.5921	170.584
493	170.5839	170.5921	170.5839
494	170.5839	170.5921	170.5839
495	170.5839	170.5921	170.5839
496	170.5839	170.5921	170.5839
497	170.5839	170.5921	170.5839
498	170.5839	170.5921	170.5839
499	170.5839	170.5921	170.5839
500	170.5839	816.3996	193.9604

Table D.2 the detailed results of the optimal solution of the SCRRJITS problem in Scenario I

Generation	Best	Worst	Average
0	217.4903	4898.946	264.1895
1	217.4527	2103.903	245.2988
2	217.4081	512.6121	235.5706
3	217.4081	512.6121	230.2528
4	217.4081	512.6121	226.332
5	217.386	512.6121	223.971
6	217.386	512.6121	222.0576
7	217.386	260.0597	220.8217
8	217.386	247.9629	220.0624
9	217.386	247.9629	219.2669
10	217.386	236.2321	218.7463
11	217.386	229.9666	218.3976
12	217.3786	229.9666	218.1992
13	217.3786	228.6934	217.9922
14	217.3786	228.4545	217.836
15	217.3786	228.4545	217.7357
16	217.3786	228.4545	217.6409
17	217.3786	228.4545	217.586
18	217.3786	220.5072	217.5158
19	217.3786	220.5072	217.4744
20	217.3786	220.5072	217.4505
21	217.3786	220.5072	217.434
22	217.3786	220.5072	217.4273
23	217.3786	220.5072	217.4119
24	217.3786	217.9927	217.3959
25	217.3786	217.9927	217.3923
26	217.3786	217.9927	217.3872
27	217.3786	217.9858	217.384
28	217.3786	217.5436	217.3813
29	217.3786	217.5436	217.3808
30	217.3786	217.5436	217.3801

31	217.3786	217.5436	217.3797
32	217.3786	217.4081	217.3792
33	217.3786	217.4081	217.3789
34	217.3786	217.4081	217.3788
35	217.3786	217.4081	217.3788
36	217.3786	217.4081	217.3787
37	217.3786	217.386	217.3786
38	217.3786	217.386	217.3786
39	217.3786	217.386	217.3786
40	217.3786	217.386	217.3786
41	217.3786	217.386	217.3786
42	217.3786	217.3786	217.3786
43	217.3786	217.3786	217.3786
44	217.3786	217.3786	217.3786
45	217.3786	217.3786	217.3786
46	217.3786	217.3786	217.3786
47	217.3786	217.3786	217.3786
48	217.3786	217.3786	217.3786
49	217.3786	217.3786	217.3786
50	217.3786	1068.127	233.077
51	217.3786	802.1892	225.742
52	217.3786	802.1892	222.7918
53	217.3786	718.3259	219.965
54	217.3786	718.3259	218.9466
55	217.3786	251.0994	218.0919
56	217.3786	251.0994	217.678
57	217.364	242.5143	217.5278
58	217.364	242.5143	217.51
59	217.364	242.5143	217.4739
60	217.364	242.5143	217.4465
61	217.364	232.9592	217.423
62	217.364	232.9592	217.4227
63	217.364	232.9592	217.4189
64	217.364	218.3133	217.3823
65	217.364	217.9858	217.3785
66	217.364	217.9858	217.3774
67	217.364	217.9858	217.3761
68	217.364	217.3786	217.3729
69	217.364	217.3786	217.3713
70	217.364	217.3786	217.3696
71	217.364	217.3786	217.3682
72	217.364	217.3786	217.367
73	217.364	217.3786	217.3661
74	217.364	217.3786	217.3653
75	217.364	217.3786	217.3647
76	217.364	217.3786	217.3644
77	217.364	217.3786	217.3642
78	217.364	217.3786	217.3642
79	217.364	217.3713	217.3641
80	217.364	217.3713	217.364
81	217.364	217.3713	217.364
82	217.364	217.3713	217.364
83	217.364	217.3713	217.364
84	217.364	217.3713	217.364
85	217.364	217.3713	217.364
86	217.364	217.3713	217.364
87	217.364	217.3713	217.364
88	217.364	217.364	217.364
89	217.364	217.364	217.364
90	217.364	217.364	217.364
91	217.364	217.364	217.364
92	217.364	217.364	217.364
93	217.364	217.364	217.364
94	217.364	217.364	217.364
95	217.364	217.364	217.364
96	217.364	217.364	217.364
97	217.364	217.364	217.364
98	217.364	217.364	217.364
99	217.364	217.364	217.364
100	217.364	2904.12	231.2427
101	217.364	2904.12	225.2509
102	217.364	518.6545	221.6881
103	217.364	518.6545	219.6312
104	217.364	261.7637	218.5069
105	217.364	249.2697	217.9157
106	217.364	234.6921	217.7088
107	217.364	234.6921	217.5111

108	217.364	234.6921	217.4679
109	217.364	226.3924	217.4082
110	217.364	226.2926	217.389
111	217.364	218.1851	217.366
112	217.364	218.1851	217.366
113	217.364	218.1851	217.366
114	217.364	217.364	217.364
115	217.364	217.364	217.364
116	217.364	217.364	217.364
117	217.364	217.364	217.364
118	217.364	217.364	217.364
119	217.364	217.364	217.364
120	217.364	217.364	217.364
121	217.364	217.364	217.364
122	217.364	217.364	217.364
123	217.364	217.364	217.364
124	217.364	217.364	217.364
125	217.364	217.364	217.364
126	217.364	217.364	217.364
127	217.364	217.364	217.364
128	217.364	217.364	217.364
129	217.364	217.364	217.364
130	217.364	217.364	217.364
131	217.364	217.364	217.364
132	217.364	217.364	217.364
133	217.364	217.364	217.364
134	217.364	217.364	217.364
135	217.364	217.364	217.364
136	217.364	217.364	217.364
137	217.364	217.364	217.364
138	217.364	217.364	217.364
139	217.364	217.364	217.364
140	217.364	217.364	217.364
141	217.364	217.364	217.364
142	217.364	217.364	217.364
143	217.364	217.364	217.364
144	217.364	217.364	217.364
145	217.364	217.364	217.364
146	217.364	217.364	217.364
147	217.364	217.364	217.364
148	217.364	217.364	217.364
149	217.364	217.364	217.364
150	217.364	9636.715	233.8224
151	217.364	909.2775	225.4596
152	217.364	317.3179	221.6649
153	217.364	278.5861	219.5998
154	217.364	278.5861	218.7103
155	217.364	258.4378	218.1327
156	217.364	258.4378	217.7946
157	217.364	240.1871	217.6408
158	217.364	240.1871	217.5625
159	217.364	228.6561	217.4753
160	217.364	228.6561	217.4272
161	217.364	222.2305	217.3924
162	217.364	222.2305	217.3811
163	217.364	222.2305	217.3776
164	217.364	222.2305	217.3776
165	217.364	222.2305	217.3759
166	217.364	222.2305	217.3759
167	217.364	221.8795	217.375
168	217.364	217.364	217.364
169	217.364	217.364	217.364
170	217.364	217.364	217.364
171	217.364	217.364	217.364
172	217.364	217.364	217.364
173	217.364	217.364	217.364
174	217.364	217.364	217.364
175	217.364	217.364	217.364
176	217.364	217.364	217.364
177	217.364	217.364	217.364
178	217.364	217.364	217.364
179	217.364	217.364	217.364
180	217.364	217.364	217.364
181	217.364	217.364	217.364
182	217.364	217.364	217.364
183	217.364	217.364	217.364
184	217.364	217.364	217.364

185	217.364	217.364	217.364
186	217.364	217.364	217.364
187	217.364	217.364	217.364
188	217.364	217.364	217.364
189	217.364	217.364	217.364
190	217.364	217.364	217.364
191	217.364	217.364	217.364
192	217.364	217.364	217.364
193	217.364	217.364	217.364
194	217.364	217.364	217.364
195	217.364	217.364	217.364
196	217.364	217.364	217.364
197	217.364	217.364	217.364
198	217.364	217.364	217.364
199	217.364	217.364	217.364
200	217.364	4923.899	234.3456

Table D.3 the detailed results of the optimal solution of the SCRRJITS problem in Scenario II

Generation	Best	Worst	Average
0	224.0653	18058.19	279.6267
1	224.0171	9412.953	259.1997
2	223.9763	3658.586	248.3607
3	223.9763	715.1338	241.403
4	223.9226	302.4897	237.0768
5	223.916	292.8639	234.0119
6	223.916	292.8445	231.0406
7	223.916	262.9027	229.2713
8	223.916	262.9027	227.9759
9	223.916	261.1004	226.7197
10	223.916	261.1004	225.9138
11	223.916	261.1004	225.3999
12	223.916	248.4968	224.9316
13	223.916	247.4799	224.6947
14	223.916	247.4799	224.5164
15	223.916	247.4799	224.3432
16	223.916	247.4799	224.2042
17	223.916	229.5765	224.0976
18	223.916	229.5765	224.0463
19	223.916	229.5765	224.0126
20	223.916	229.5765	223.9847
21	223.916	229.5765	223.965
22	223.916	225.811	223.9428
23	223.916	224.9435	223.9287
24	223.916	224.2508	223.9204
25	223.916	224.2508	223.9189
26	223.916	224.2508	223.9188
27	223.916	224.1568	223.9178
28	223.916	224.1568	223.9174
29	223.916	223.9966	223.9165
30	223.916	223.9966	223.9164
31	223.916	223.9966	223.9162
32	223.916	223.9966	223.9162
33	223.916	223.916	223.916
34	223.916	223.916	223.916
35	223.916	223.916	223.916
36	223.916	223.916	223.916
37	223.916	223.916	223.916
38	223.916	223.916	223.916
39	223.916	223.916	223.916
40	223.916	223.916	223.916
41	223.916	223.916	223.916
42	223.916	223.916	223.916
43	223.916	223.916	223.916
44	223.916	223.916	223.916
45	223.916	223.916	223.916
46	223.916	223.916	223.916
47	223.916	223.916	223.916
48	223.916	223.916	223.916
49	223.916	223.916	223.916
50	223.916	1034.722	241.6598
51	223.916	1034.722	233.9121
52	223.916	539.8367	229.2505
53	223.916	364.9025	227.0238
54	223.916	281.9531	225.618
55	223.916	271.0611	224.7204

56	223.916	267.1479	224.3994
57	223.916	267.1479	224.1828
58	223.916	235.7841	224.0109
59	223.916	233.725	223.9582
60	223.916	233.725	223.9579
61	223.916	230.1244	223.9344
62	223.916	224.7116	223.918
63	223.916	224.7116	223.918
64	223.916	223.916	223.916
65	223.916	223.916	223.916
66	223.916	223.916	223.916
67	223.916	223.916	223.916
68	223.916	223.916	223.916
69	223.916	223.916	223.916
70	223.916	223.916	223.916
71	223.916	223.916	223.916
72	223.916	223.916	223.916
73	223.916	223.916	223.916
74	223.916	223.916	223.916
75	223.916	223.916	223.916
76	223.916	223.916	223.916
77	223.916	223.916	223.916
78	223.916	223.916	223.916
79	223.916	223.916	223.916
80	223.916	223.916	223.916
81	223.916	223.916	223.916
82	223.916	223.916	223.916
83	223.916	223.916	223.916
84	223.916	223.916	223.916
85	223.916	223.916	223.916
86	223.916	223.916	223.916
87	223.916	223.916	223.916
88	223.916	223.916	223.916
89	223.916	223.916	223.916
90	223.916	223.916	223.916
91	223.916	223.916	223.916
92	223.916	223.916	223.916
93	223.916	223.916	223.916
94	223.916	223.916	223.916
95	223.916	223.916	223.916
96	223.916	223.916	223.916
97	223.916	223.916	223.916
98	223.916	223.916	223.916
99	223.916	223.916	223.916
100	223.916	9186.302	245.0418
101	223.916	1491.717	234.5858
102	223.916	1491.717	230.6034
103	223.916	291.9317	227.8768
104	223.916	291.9317	226.2878
105	223.916	269.7782	225.4573
106	223.916	261.1004	224.8349
107	223.916	261.1004	224.6318
108	223.916	261.1004	224.2175
109	223.916	235.7841	224.0712
110	223.916	235.7841	224.039
111	223.916	235.7841	224.0141
112	223.916	235.7841	224.0039
113	223.916	235.7841	223.9804
114	223.916	235.7841	223.9522
115	223.916	235.7841	223.945
116	223.916	224.2288	223.9168
117	223.916	223.916	223.916
118	223.916	223.916	223.916
119	223.916	223.916	223.916
120	223.916	223.916	223.916
121	223.916	223.916	223.916
122	223.916	223.916	223.916
123	223.916	223.916	223.916
124	223.916	223.916	223.916
125	223.916	223.916	223.916
126	223.916	223.916	223.916
127	223.916	223.916	223.916
128	223.916	223.916	223.916
129	223.916	223.916	223.916
130	223.916	223.916	223.916
131	223.916	223.916	223.916
132	223.916	223.916	223.916

133	223.916	223.916	223.916
134	223.916	223.916	223.916
135	223.916	223.916	223.916
136	223.916	223.916	223.916
137	223.916	223.916	223.916
138	223.916	223.916	223.916
139	223.916	223.916	223.916
140	223.916	223.916	223.916
141	223.916	223.916	223.916
142	223.916	223.916	223.916
143	223.916	223.916	223.916
144	223.916	223.916	223.916
145	223.916	223.916	223.916
146	223.916	223.916	223.916
147	223.916	223.916	223.916
148	223.916	223.916	223.916
149	223.916	223.916	223.916
150	223.916	2101.043	246.0253
151	223.916	1016.085	234.4508
152	223.916	1016.085	229.489
153	223.916	326.5271	227.5374
154	223.916	281.5162	226.2259
155	223.916	268.4753	225.3571
156	223.916	260.7522	224.7727
157	223.916	260.7522	224.4611
158	223.916	260.7522	224.2116
159	223.916	236.7813	224.0054
160	223.916	236.7813	223.9829
161	223.916	236.0119	223.9509
162	223.916	226.1535	223.9215
163	223.916	223.916	223.916
164	223.916	223.916	223.916
165	223.916	223.916	223.916
166	223.916	223.916	223.916
167	223.916	223.916	223.916
168	223.916	223.916	223.916
169	223.916	223.916	223.916
170	223.916	223.916	223.916
171	223.916	223.916	223.916
172	223.916	223.916	223.916
173	223.916	223.916	223.916
174	223.916	223.916	223.916
175	223.916	223.916	223.916
176	223.916	223.916	223.916
177	223.916	223.916	223.916
178	223.916	223.916	223.916
179	223.916	223.916	223.916
180	223.916	223.916	223.916
181	223.916	223.916	223.916
182	223.916	223.916	223.916
183	223.916	223.916	223.916
184	223.916	223.916	223.916
185	223.916	223.916	223.916
186	223.916	223.916	223.916
187	223.916	223.916	223.916
188	223.916	223.916	223.916
189	223.916	223.916	223.916
190	223.916	223.916	223.916
191	223.916	223.916	223.916
192	223.916	223.916	223.916
193	223.916	223.916	223.916
194	223.916	223.916	223.916
195	223.916	223.916	223.916
196	223.916	223.916	223.916
197	223.916	223.916	223.916
198	223.916	223.916	223.916
199	223.916	223.916	223.916
200	223.916	#DIV/0!	246.9637
201	223.916	1447.322	237.6169
202	223.916	1194.629	231.319
203	223.916	306.0559	228.2835
204	223.916	306.0559	226.777
205	223.916	306.0559	225.4391
206	223.916	253.2523	224.886
207	223.916	249.5515	224.3458
208	223.916	249.5515	224.2255
209	223.916	246.947	224.1147

210	223.916	246.947	224.111
211	223.916	236.7228	224.0266
212	223.916	236.5132	223.9562
213	223.916	236.5132	223.9537
214	223.916	236.5132	223.9458
215	223.916	236.5132	223.9458
216	223.916	236.5132	223.9458
217	223.916	223.916	223.916
218	223.916	223.916	223.916
219	223.9094	223.916	223.916
220	223.9094	223.916	223.9159
221	223.9094	223.916	223.9158
222	223.9094	223.916	223.9157
223	223.9094	223.916	223.9155
224	223.9094	223.916	223.9154
225	223.9094	223.916	223.9152
226	223.9094	223.916	223.9149
227	223.9094	223.916	223.9147
228	223.9094	223.916	223.9143
229	223.9094	223.916	223.9137
230	223.9094	223.916	223.9133
231	223.9094	223.916	223.9127
232	223.9094	223.916	223.9121
233	223.9094	223.916	223.9115
234	223.9094	223.916	223.9108
235	223.9094	223.916	223.9105
236	223.9094	223.916	223.9103
237	223.9094	223.916	223.91
238	223.9094	223.916	223.9099
239	223.9094	223.916	223.9098
240	223.9094	223.916	223.9096
241	223.9094	223.916	223.9095
242	223.9094	223.916	223.9095
243	223.9094	223.916	223.9095
244	223.9094	223.916	223.9094
245	223.9094	223.916	223.9094
246	223.9094	223.916	223.9094
247	223.9094	223.916	223.9094
248	223.9094	223.916	223.9094
249	223.9094	223.9094	223.9094
250	223.9094	4624.442	247.2614
251	223.9094	4624.442	238.2253
252	223.9094	585.6927	231.9989
253	223.9094	304.6932	228.9258
254	223.9094	304.6932	226.9331
255	223.9094	296.3388	225.5739
256	223.9094	283.6905	224.8059
257	223.9094	265.0326	224.3967
258	223.9094	248.7229	224.2378
259	223.9094	248.7229	224.2078
260	223.9094	248.7229	224.118
261	223.9094	248.7229	224.0207
262	223.9094	246.941	224.016
263	223.9094	237.9233	223.9743
264	223.9094	235.7779	223.9695
265	223.9094	235.7779	223.9657
266	223.9094	235.7779	223.9375
267	223.9094	223.9094	223.9094
268	223.9094	223.9094	223.9094
269	223.9094	223.9094	223.9094
270	223.9094	223.9094	223.9094
271	223.9094	223.9094	223.9094
272	223.9094	223.9094	223.9094
273	223.9094	223.9094	223.9094
274	223.9094	223.9094	223.9094
275	223.9094	223.9094	223.9094
276	223.9094	223.9094	223.9094
277	223.9094	223.9094	223.9094
278	223.9094	223.9094	223.9094
279	223.9094	223.9094	223.9094
280	223.9094	223.9094	223.9094
281	223.9094	223.9094	223.9094
282	223.9094	223.9094	223.9094
283	223.9094	223.9094	223.9094
284	223.9094	223.9094	223.9094
285	223.9094	223.9094	223.9094
286	223.9094	223.9094	223.9094

287	223.9094	223.9094	223.9094
288	223.9094	223.9094	223.9094
289	223.9094	223.9094	223.9094
290	223.9094	223.9094	223.9094
291	223.9094	223.9094	223.9094
292	223.9094	223.9094	223.9094
293	223.9094	223.9094	223.9094
294	223.9094	223.9094	223.9094
295	223.9094	223.9094	223.9094
296	223.9094	223.9094	223.9094
297	223.9094	223.9094	223.9094
298	223.9094	223.9094	223.9094
299	223.9094	223.9094	223.9094
300	223.9094	1957.96	246.6324

Table D.3 the detailed results of the optimal solution of the SCRRJITS problem in Scenario III

Generation	Best	Worst	Average
0	258.8323	17280.39	281.7051
1	258.8266	17280.39	268.379
2	258.8152	8766.764	263.1659
3	258.8152	8766.764	261.3636
4	258.8152	8766.764	260.5264
5	258.8152	271.0383	259.5617
6	258.8152	267.9917	259.3564
7	258.8152	264.7169	259.2049
8	258.8152	263.5479	259.1305
9	258.8152	263.5479	259.0532
10	258.8152	263.5479	258.9957
11	258.8152	263.5479	258.9466
12	258.8152	260.7318	258.9047
13	258.8152	260.5337	258.8833
14	258.8152	259.7565	258.8609
15	258.8152	259.7565	258.8496
16	258.8152	259.7565	258.8401
17	258.8152	259.7565	258.8344
18	258.8152	259.7565	258.8308
19	258.8152	259.7565	258.8265
20	258.8152	259.0831	258.8209
21	258.8152	259.0153	258.819
22	258.8152	259.0153	258.818
23	258.8152	258.949	258.8166
24	258.8152	258.949	258.8164
25	258.8152	258.949	258.8162
26	258.8152	258.949	258.8161
27	258.8095	258.949	258.8159
28	258.8095	258.949	258.8155
29	258.8095	258.949	258.8155
30	258.8095	258.949	258.8154
31	258.8095	258.949	258.8154
32	258.8095	258.8152	258.815
33	258.8095	258.8152	258.815
34	258.8095	258.8152	258.8148
35	258.8095	258.8152	258.8147
36	258.8095	258.8152	258.8145
37	258.8095	258.8152	258.8143
38	258.8095	258.8152	258.814
39	258.8095	258.8152	258.8138
40	258.8095	258.8152	258.8133
41	258.8095	258.8152	258.8129
42	258.8095	258.8152	258.8124
43	258.8095	258.8152	258.8119
44	258.8095	258.8152	258.8113
45	258.8095	258.8152	258.811
46	258.8095	258.8152	258.8106
47	258.8095	258.8152	258.8101
48	258.8095	258.8152	258.81
49	258.8095	258.8152	258.8098
50	258.8095	5928.887	269.8675
51	258.8095	5928.887	263.9741
52	258.8095	658.5447	260.4315
53	258.8095	274.6328	259.0897
54	258.8095	274.6328	258.9588
55	258.8095	261.7464	258.8633
56	258.8095	261.7464	258.8455
57	258.8095	260.1408	258.8228

58	258.8095	259.7565	258.8179
59	258.8095	259.4753	258.8131
60	258.8095	259.4753	258.813
61	258.8095	258.8095	258.8095
62	258.8095	258.8095	258.8095
63	258.8095	258.8095	258.8095
64	258.8095	258.8095	258.8095
65	258.8095	258.8095	258.8095
66	258.8095	258.8095	258.8095
67	258.8095	258.8095	258.8095
68	258.8095	258.8095	258.8095
69	258.8095	258.8095	258.8095
70	258.8095	258.8095	258.8095
71	258.8095	258.8095	258.8095
72	258.8095	258.8095	258.8095
73	258.8095	258.8095	258.8095
74	258.8095	258.8095	258.8095
75	258.8095	258.8095	258.8095
76	258.8095	258.8095	258.8095
77	258.8095	258.8095	258.8095
78	258.8095	258.8095	258.8095
79	258.8095	258.8095	258.8095
80	258.8095	258.8095	258.8095
81	258.8095	258.8095	258.8095
82	258.8095	258.8095	258.8095
83	258.8095	258.8095	258.8095
84	258.8095	258.8095	258.8095
85	258.8095	258.8095	258.8095
86	258.8095	258.8095	258.8095
87	258.8095	258.8095	258.8095
88	258.8095	258.8095	258.8095
89	258.8095	258.8095	258.8095
90	258.8095	258.8095	258.8095
91	258.8095	258.8095	258.8095
92	258.8095	258.8095	258.8095
93	258.8095	258.8095	258.8095
94	258.8095	258.8095	258.8095
95	258.8095	258.8095	258.8095
96	258.8095	258.8095	258.8095
97	258.8095	258.8095	258.8095
98	258.8095	258.8095	258.8095
99	258.8095	258.8095	258.8095
100	258.8095	5928.887	266.8948
101	258.8095	5928.887	263.3588
102	258.8095	2685.6	260.5772
103	258.8095	275.6566	259.2049
104	258.8095	275.6566	259.0302
105	258.8095	275.6566	258.9492
106	258.8095	275.6566	258.8919
107	258.8095	275.6566	258.8751
108	258.8095	260.0723	258.8222
109	258.8095	260.0723	258.8169
110	258.8095	259.2697	258.8129
111	258.8095	259.2697	258.8128
112	258.8095	259.2301	258.8116
113	258.8095	258.8152	258.8095
114	258.8095	258.8152	258.8095
115	258.8095	258.8095	258.8095
116	258.8095	258.8095	258.8095
117	258.8095	258.8095	258.8095
118	258.8095	258.8095	258.8095
119	258.8095	258.8095	258.8095
120	258.8095	258.8095	258.8095
121	258.8095	258.8095	258.8095
122	258.8095	258.8095	258.8095
123	258.8095	258.8095	258.8095
124	258.8095	258.8095	258.8095
125	258.8095	258.8095	258.8095
126	258.8095	258.8095	258.8095
127	258.8095	258.8095	258.8095
128	258.8095	258.8095	258.8095
129	258.8095	258.8095	258.8095
130	258.8095	258.8095	258.8095
131	258.8095	258.8095	258.8095
132	258.8095	258.8095	258.8095
133	258.8095	258.8095	258.8095
134	258.8095	258.8095	258.8095

135	258.8095	258.8095	258.8095
136	258.8095	258.8095	258.8095
137	258.8095	258.8095	258.8095
138	258.8095	258.8095	258.8095
139	258.8095	258.8095	258.8095
140	258.8095	258.8095	258.8095
141	258.8095	258.8095	258.8095
142	258.8095	258.8095	258.8095
143	258.8095	258.8095	258.8095
144	258.8095	258.8095	258.8095
145	258.8095	258.8095	258.8095
146	258.8095	258.8095	258.8095
147	258.8095	258.8095	258.8095
148	258.8095	258.8095	258.8095
149	258.8095	258.8095	258.8095
150	258.8095	#DIV/0!	266.0923
151	258.8095	#DIV/0!	263.4537
152	258.8095	3091.011	260.4486
153	258.8095	293.1038	259.4479
154	258.8095	276.395	259.0735
155	258.8095	276.395	258.9845
156	258.8095	276.395	258.8744
157	258.8095	259.2564	258.8158
158	258.8095	259.0337	258.812
159	258.8095	258.9971	258.8107
160	258.8095	258.949	258.8103
161	258.8095	258.8726	258.8097
162	258.8095	258.8208	258.8095
163	258.8095	258.8095	258.8095
164	258.8095	258.8095	258.8095
165	258.8095	258.8095	258.8095
166	258.8095	258.8095	258.8095
167	258.8095	258.8095	258.8095
168	258.8095	258.8095	258.8095
169	258.8095	258.8095	258.8095
170	258.8095	258.8095	258.8095
171	258.8095	258.8095	258.8095
172	258.8095	258.8095	258.8095
173	258.8095	258.8095	258.8095
174	258.8095	258.8095	258.8095
175	258.8095	258.8095	258.8095
176	258.8095	258.8095	258.8095
177	258.8095	258.8095	258.8095
178	258.8095	258.8095	258.8095
179	258.8095	258.8095	258.8095
180	258.8095	258.8095	258.8095
181	258.8095	258.8095	258.8095
182	258.8095	258.8095	258.8095
183	258.8095	258.8095	258.8095
184	258.8095	258.8095	258.8095
185	258.8095	258.8095	258.8095
186	258.8095	258.8095	258.8095
187	258.8095	258.8095	258.8095
188	258.8095	258.8095	258.8095
189	258.8095	258.8095	258.8095
190	258.8095	258.8095	258.8095
191	258.8095	258.8095	258.8095
192	258.8095	258.8095	258.8095
193	258.8095	258.8095	258.8095
194	258.8095	258.8095	258.8095
195	258.8095	258.8095	258.8095
196	258.8095	258.8095	258.8095
197	258.8095	258.8095	258.8095
198	258.8095	258.8095	258.8095
199	258.8095	258.8095	258.8095
200	258.8095	1199.093	265.1927