Portfolio Contracts In Supply Chain Risk Management: Analysis of Procurement Strategy with System Dynamics Models

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▪ Abstract

This paper presents a simulation study on procurement contract management. The purpose of the study is to develop a general framework for supply contracts, which aims to drive costs down and reduce risks of inventory and price flexibility.

The first part of the paper emphasizes the important role of procurement strategy in the supply chain management and introduces the main supply contracts. On the basis of the reference modes, the research problems are articulated.

Then, system dynamics is used as the main research approach and fulfil three main tasks. Firstly, system dynamics models are developed to link the key variables and present the feedback structure of the supply chain system. The second task is to compare the influences of different contracts on the performance of the buyer and supplier. Last but not least, it shows the dynamics of the system and tests the scenarios, which is critical for the policy design.

The innovation of the study is to propose the portfolio contract. The computational simulation results are presented to illustrate the performance of optimal portfolio contracts and their sensitivity to the parameter selection.

The study helps to foster in-depth view on highly dynamic and complex problem, and thus contributes to a better understanding of procurement portfolio contracts and supply chain system. This paper indicates that portfolio contracts not only reduce the company's cost, increase the expected profit but also help to control the risks. The work would, hopefully, be a framework for supply contracts that could help the player in the supply chain to optimise their performances like reducing costs and controlling inventory and price risks.

Key Words: System Dynamics, Procurement Strategy, Portfolio Contract, Supply Chain Management

Chapter 1

Introduction

1.1 Context

The Procurement Strategy outlines the strategic approach to procuring goods, works and services, people's responsibilities, how we intend to manage and plan for managing procurement in the future. It is regarded as one component of supply chain management due to the fact that procurement directly impacts profitability and the financial success of both the supplier and buyer in the supply chain.

Purchasing contracts, which refer to contracts for common goods/services as well as reflect purchasing strategies the buyer/supplier takes, are the focus of this thesis. By simulating dynamic performance of the buyer with different contracts, a conceptual framework for purchasing strategy is set up.

This chapter reviews the concepts and background of purchasing strategy, supply contracts and supply chain management. Meanwhile, system dynamics, as a methodology for research, is proposed and introduced here.

1.1.1 Purchasing Strategy and Supply Chain Management

A supply chain refers to an integrated and sequentially interrelated value system of suppliers, manufacturers, subcontractors, distributors and retailers working together

with the prime purpose of creating value to the output for the ultimate end-users.

Supply chain management (SCM) is the oversight of materials, information, and finances as they move in a process from supplier to manufacturer to wholesaler to retailer to consumer. SCM involves coordinating and integrating these flows both within and among firms so that firms within a supply chain can achieve sustainable competitive advantages through developing much closer relationships with all companies, and they can significantly reduce time and costs depending on the appropriate management of the supply chain, while serving customer needs at the same time. Therefore, in a competitive environment, successful SCM is regarded as an effective way to offer the firms the opportunities to reduce inventories, shorten lead times and distances, plan operations better, remove uncertainties, and squeeze waste out of the supply chain and very helpful in strengthening the competitive edge of firms (Kumar, Vrat, & Shankar, 2004).

When we treasure the value of the SCM, we shouldn't ignore the difficulty and challenge of implementing SCM. It should be clear, theoretically, why it is that supply chain management is both the potentially most advantageous approach for a buyer but also the one that is the most difficult to implement in practice. Due to the high complexity of supply chain system, SCM covers many fields and many significant challenges remain; the search for extra value in the supply chain will continue for as long as there are supply chains.

For a company which plays the role of buyer in a supply chain, simply maintaining adequate sources of supply is not enough. Awareness of risks of inventory and profit is the basis of taking suitable procurement strategy and maximize the profit of the company itself. Well-managed purchasing strategies can recover considerable sums of money by curtailing off-contract spending and enhancing staff efficiency.

On the other hand, the recent research find that the procurement cost of raw material or components occupy a rather high percentage of the total production cost in a certain manufacturer. As the estimation of Bender (1985), the procurement cost of raw material may be as high as 60% of the sales. Since purchases represent the largest single element of cost to a company, it is quite natural where more attention and effort will be directed. Meanwhile, the ever-increasing trend in globalisation of business has also made the order planning and purchasing strategy more complex due to the fact that the markets are becoming progressively more unpredictable, fragmented, and dynamic. Also, uncertainty in supply and customer demand raises the question of whether to purchase supply now or wait for better market conditions in the future.

Based on the above statement and analysis, the procurement strategy would influence both the cost and the inventory, that is, simultaneously influencing the financial flow and material flow in supply chain. Thus, the study on the procurement

strategy is practical and important. Knowing the influence of the purchasing contracts on the inventory and cost in a dynamic way benefits us to find the in-depth reasons and design the policies to optimise the performance of the firms as well as the whole supply chain.

1.1.2   Main Supply Contracts

Procurement is defined as the acquisition of goods and/or services at the best possible total cost of ownership, in the right quantity and quality, at the right time, in the right place for the direct benefit or use of governments, corporations, or individuals, generally via a contract. Therefore, in order to research on the procurement strategy in an effective way, we focus on the supply contracts in this study.

In practice, there are two supply contracts most widely used in procurement management: long-term contract and option contract.

Long-term contract, also called forward or fixed commitment contract, is an agreement between two parties to buy or sell an asset (which can be of any kind) at a pre-agreed future point in time. Therefore, the trade date and delivery date are separated. This contract specifies a fixed amount of supply to be delivered at some point in the future; the supplier and the manufacturer/buyer agree on both the price and the quantity delivered to the manufacturer.

An option contract is defined as "a promise which meets the requirements for the formation of a contract and limits the promisor's power to revoke an offer." *[Restatement (Second) of Contracts § 25 (1981)].* The option contract requires buyer pre-pays a relatively small fraction of the product price up-front, in return for a commitment from the supplier to reserve capacity up to a certain level. The initial payment is typically referred to as reservation price or premium. If the buyer does not exercise the option, the initial payment is lost. The buyer can purchase any amount of supply up to the option level, by paying an additional price, agreed to at the time the contract is signed, for each unit purchased. This additional price is referred to as execution price or exercise price. The total price (reservation plus execution price) paid by the manufacturer for each purchased unit is typically higher than the price of a long-term contract.

1.2   Research Methodology

System dynamics is an approach that should help in important top-management problems…Very often the most important problems are but a bit more difficult to handle than the unimportant. Many people predetermine mediocre results by setting initial goals too low. The attitude must be one of enterprise design. The expectation

should be for major improvement…The goal should be to find management policies and organizational structures that lead to greater success.

---Jay W. Forrester (Industrial Dynamics, 1961, p.449)

This research is about the procurement strategies in the supply chain management.

Supply chains are complicated systems. They involve multiple chains of stocks and flows with the resulting time delays and often extend beyond the boundaries of a single organization and three features oscillation, amplification and phase lag are pervasive in it. Some research methods like operation research (OR) may suffer from the highly non-linearity of supply chain system so that they can't be used effectively to show the problems. Due to the fact the procurement strategies deal with the financial flow of the supply chain, our research needs to consider these three flows: material flow, information flow and financial flow in a supply chain simultaneously, which further increases the complexity of the models. In addition, the purpose of setting the models is to find the problems of current procurement strategies and try to propose the feasible solutions. It requires a tool to compare the discrepancy of the enterprises' performance when they carry out different purchasing strategies in a supply chain system. Also, it's important to point out that the supply chain is of high dynamics and the behaviour of the elements changes with time. Therefore we need a dynamic framework in which the elements of the system are able to work throughout the time period in such a way as they do in the real world.

The primary modelling and analysis tool used in my thesis is system dynamics (SD) methodology. System dynamics methodology includes both system thinking and System Dynamics modelling. System thinking can provide a larger scope of worldview to perceive issues in dynamic and systematic way while system dynamics modelling enhances our understanding of such pictures by eliciting underlying structures and visualizing dynamic behaviours. In this research, system dynamics thinking brings our cognition of the supply chain system to a more advanced level and interprets the causes of the procurement problems in a highly dynamic picture. On the other hand, system dynamics is an approach for analysing and solving complex problems. The computer-based models are constructed to show the capture of flows, the delays, the feedbacks and the non-linearity that exceed the human's capacity of mental thinking. Meanwhile, system dynamics, as a simulation modelling method, makes the laboratory experiments feasible. By simulations, we can test alternative scenarios and visualizes their outcomes. And the discrepancy of different purchasing contracts' effect on the performance of the supply chain can be exhibited. The policies, proposed to solve the problems in this

research, can be discussed whether they are effective or not by analysing the simulation results.

1.3 Organization of the paper

This chapter, as the beginning of the thesis gives a general but detailed introduction. The rest of the paper is organized as follows: Chapter 2 refers to Literature Review, introducing the studies on related fields. Meanwhile, the innovation and contribution of this study is illustrated. Chapter 3 is Problem Description, which introduces the research problems in details. Chapter 4 refers to Dynamic Hypothesis, formulated to account for the problematic behaviour. Chapter 5 introduces and develops the structure the System Dynamics models and Chapter 6 deals with model testing. In chapter 7, the behavioural pattern generated by the models are analysed and compared. Meanwhile, the problems in this research are shown. Chapter 8 raises discussion about policy and the implementation. Conclusions of this paper are drawn in Chapter 9. Appendix is included in the end as background information.

Chapter 2

Literature Review

2.1 Introduction

In this section, I review the streams of literature related to this thesis, illustrating these literature's importance and weakness. Meanwhile I delineate the innovation of this study and my contributions to the research field.

As mentioned in chapter 1, the nature of supply chain management (SCM) and procurement strategies is complex. Therefore, it has motivated a wide range of basic and applied research initiatives. These efforts have generated a great number of literatures, the most relevant portion of which is referred and summarized in this chapter. Meanwhile, researches done in the view-points of economics and System Dynamics are reviewed and commented.

This chapter shows that traditional economics models are unable to reveal and help understand the internal mechanism of the system. Their pitfalls significantly influence the quality of those researches, esp. when the researches propose some policies. Finally, it introduces the innovation of this paper in the research field of procurement strategy and supply chain management.

2.2 Research on Supply Chain Management

The concept of supply chain management (SCM) can be traced back to the 1960s. Increased study began in the 1980s, with a dramatic increase in the publication rate since 1990. In this managerial view-point, numerous descriptive or normative methods and models have been developed to address the problems in supply chain management (e.g., bullwhip effect, capacity control, planning, scheduling and so on). Most of these studies focus on theoretical analysis and mathematical models, which are quite different from the system dynamics methodology in this study.

2.2.1 Review of Basic Theory of SCM

SCM research can be classified into three categories:

(1) *Operational:* This area is concerned with the daily operation of a facility such as a plant or distribution centre to ensure that the most profitable way to fulfil customer order is executed. Examples include inventory management (Cachon and Zipkin,1997) and production, planning, and scheduling (Lederer and Li, 1997). The focus is to develop mathematical tools that aid in the efficient operation of the supply chain as a whole. Also included are the development of software and better manufacturing methods and technologies (Slats et al., 1995)

(2) *Design:* Design of the supply chain focuses on the location of decision spots and the objectives of the chain (Mourits and Evers,1995). Four categories of models are found in the literature: (1) deterministic analytical models (Cohen and Lee,1989),(2) stochastic analytical models (Lee et al., 1993), (3) economic models (Christy and Grout,1994), and (4)simulation models (Towill, 1991). A good design should integrate various elements of the supply chain and strive for optimization of the entire chain rather than individual entities. Information sharing and its control play a vital role in integration, which requires highly coordinated efforts of both engineers and managers (Lee et al.,1997)

(3) *Strategic:* Strategic decisions are made by business managers, which requires understanding the dynamics of a supply chain and development of objectives for the whole chain (Gopal,1992). This task also includes critical evaluation of alternative supply chain configurations and partnerships, and the determination of opportunities that can enhance the competitiveness of the firm as a part of the supply chain or the network of supply chains.

2.2.2 Weakness

There exist several pitfalls in SCM research fields using traditional descriptive or normative methods and models.

Firstly, the mathematic models for the problems relevant to SCM are usually of high non-linearity due to the complex nature of supply chain. But the high non-linearity usually causes the difficulty for the mathematic tools e.g. operation research to get the numerical solution. In order to get the numerical solution rather than analytical solution, many presumptions are set, some of which may be contrast to the reality. It's hard to ensure all the presumptions are reasonable and the solutions are meaningful and instructive to the real industry.

Secondly, the traditional research methods are inadequate to show the dynamics of a supply chain. Because of the uncertainty of market demand and complex structure of the supply chain, demand amplification and bullwhip effect could easily be caused if improper decisions are made. Only by considering the changes and dynamics of more time periods could show these phenomena. But the traditional modelling methods like operation research (OR) fail to do so.

Thirdly, a large number of the researches related to SCM only focus on the theoretical innovation. Although the theory is important and instructive to practice, solutions to the practical problems are expected. Also, due to the high cost of failure, the proposed solutions and policies need to be proved effective.

Based on the above analysis, better research methods are expected to solve the issues related to SCM.

2.2.3 System Dynamics Methodology in SCM

As introduced above, System Dynamics has been applied in a wide range of problem domains. As to the application of System Dynamics methodology to Supply Chain Management, it can be traced to 1950s.

In 1958, Jay Forrester, the founder of System Dynamics (SD), first published work 'A major breakthrough for decision makers' in System Dynamics Modelling, which was related to supply chain management. In that paper, the Forrester Model --- a model of a production-distribution system is showed with six interacting flow sub-systems, that is, the flows of manpower, orders, information, materials, money and capital equipment. Based on the SD models and simulation results, many issues around SCM are analysed and explained. As early as in 1960s, Forrester has already pointed out many current research issues in supply chain management such as demand amplification, inventory swings, the effect of advertising policies on production

variations, de-centralised control and so on. After that, supply chain has been viewed as part of an industrial and researchers use system dynamics more frequently to do the research on supply chain management esp. in the field of such issues ranging from inventory management to integrated supply chains.

In order to prove that misperceptions of feedback account for poor performance in dynamic decision-making, Sterman (1989) uses the Beer Game to conduct an experiment on managing a simulated industrial production and distribution system. The biggest contribution of this paper is to present a generic model of a stock management system in the supply chain, which is widely referred to as the basic model structure when followers use system dynamics methodology to do the research in supply chain field.

Besides the most important literature stated above, there exist a large number of research about the application of System Dynamics Modelling to solve a problem in supply chain management. They range from inventory management and ordering policies design to supply chain integration.

Barlas and Aksogan (1997) use a case study in the apparel industry to develop a System Dynamics simulation model of a typical retail supply chain, where a three echelon chain composed of manufacturer, wholesaler, retailer and end customer. The purpose of their simulation exercise is to develop inventory policies that increase the retailer's revenue and at the same time reduce costs; another objective of the research is to study the implications of different diversification strategies.

Anderson, Fine and Parker (1997) use the machine tool industry as a case study to explore the implication of demand amplification on lead-time, inventory, production, productivity, and workforce. System Dynamics model is built to explain demand amplification along capital equipment supply chains, and to test various strategies that could improve the functioning of the industry. The System Dynamics Modelling methodology helps to incorporate typical features of the capital equipment industries, such as feedback loops, delays and non-linearity.

In addition, Hafeez et al. (1996) demonstrate the application of systems engineering. to supply chains and describe an integrated system dynamics framework, with the aim of giving an example to good total systems design. Akkermans (1995) proposes an approach labelled Participative Business Modelling (PBM) to address the technical and the organisational complexities inherent in the development of logistics strategies. Towill (1996b) do research on supply chain re-design. Akkermans's research is a typical example of work in the use of System Dynamics Modelling in international supply chain management (Akkermans et al. 1999).

In a word, the application of system dynamics modelling methods to supply chain management not only has long history but also prove to be effective in a wide research field.

2.3 Research on Procurement Strategies

This part of literature review is divided into two parts. One is about the procurement strategy and the other is to introduce the classical portfolio approach proposed by Kraljic in 1983.

2.3.1 Literature Review of Procurement Strategy

In this stream of literature, the academic literature is quite recent. For a review see Cachon (2002) or Lariviere (1999). As observed in Lariviere (1999), such literature can be further classified into two main categories. The first focuses on replenishment policies and detailed contract parameters for a given type of contract, covering Anupindi and Bassok (1999) for flexibility contracts, Brown and Lee (1997) for option contracts applied in the semiconductor industry setting, or Wu, Kleindorfer and Zhang(2002), Kleinknecht and Akella (2002), Spinlerm(2002) or Golovachkina (2002)for option contracts in the presence of a spot market. Typically, the objective in this category is to optimize the buyer's procurement strategy with very little regard to the impact of the decision on the seller. The second category focuses on optimizing the terms of the contract so as to improve supply chain coordination, which includes buy-back contracts, revenue sharing contracts, or option contracts. The objective is to characterize contracts that allow each party to optimize its own profit but lead to a globally optimized supply chain.

On the other hand, the nature of procurement strategy in supply chain has also motivated a wide range of applied research initiatives. These efforts generate a prolific number of papers, a substantial portion of which are referred and summarized as follows. Based on an extensive literature review, Olsen and Ellram (1997) concluded that normative research is needed on how to manage different types of buyer-supplier relationships. Also, they mentioned that current research does not reveal how purchasing professionals handle the problem of positioning commodities and suppliers into the portfolio, how they actually develop purchasing strategies, and what results. Billington C (2001) illustrates that, rather than attempt to address these procurement issues through some sort of simple process optimization, HP's procurement groups took the same strategy used by financial investors, namely, to use a "portfolio" approach that allowed them to diversify and spread the risk over a number of options.

2.3.2 Literature Review of Portfolio Contracts Model

In the stream of research relative to procurement portfolio contract model, the basis is the theoretical ones. In 1983, Kraljic introduced the first comprehensive portfolio approach for the determination of a set of differentiated purchasing strategies. Its general idea is to minimize supply risk and make the most of buying power. This explains the choice of dimensions: accounting for risk on the one hand, and using buying power on the other hand. Kraljic's approach includes the construction of a portfolio matrix that classifies products on the basis of two dimensions: profit impact and supply risk ("low" and "high"). The result is a 2x2 matrix and a classification in four categories: bottleneck, non-critical, leverage, and strategic items. Each category requires a distinctive approach toward suppliers. This model made a reasonable case for the usefulness of the portfolio approach by describing the experiences of some large industrial companies. Later on, the Kraljic matrix has become the standard in the field of purchasing portfolio models (Lamming and Harrison 2001[23]; Gelderman 2003 [16]).

After Kraljic's innovative matrix, other scholars (e.g. Bensaou, 1999; Elliott-Shircore & Steele, 1985; Lilliecreutz & Ydreskog, 1999; Olsen & Ellram, 1997; Syson, 1992; Van Weele, 2000) refined the original matrix and elaborated on the main tasks for bottleneck, non-critical and leverage items. In addition, they formulated strategic recommendations, resulting in one overall purchasing strategy for each cell/category.

2.3.3 Weakness

The researches stated above give an introduction of procurement strategies and supply contracts. However, they suffer from some weakness as follows.

The current literatures relevant to procurement strategies mainly consider the procurement issues independently but fail to show the effect of procurement contracts on the whole supply chain, especially the dynamic effect. In other words, the current literatures ignore the interrelationship between procurement strategies and supply chain. In addition, most current researches focus on the theory innovation but some of these procurement theories are not so practical. Some mathematical models built in these literatures are too complex to solve and therefore numerous presumptions are given.

As to the portfolio contracts model, it is a concept firstly proposed by Kraljic and later continuously updated by other researchers. In the past twenty years, Kraljic's models have been challenged for its simplicity, which is in contrast to the complexity of business decision. 'Its major weakness is that the methodology does not provide us with any proactive thinking about what can or should be done to change the existing reality of power.' (Cox, 1997) In addition, the measurement issues have been

highlighted as a key criticism of portfolio models. It is difficult to know whether or not the most appropriate variables dimensions, factors and weights are being used.

2.4 Innovation of this study

In order to avoid the pitfalls of the current research methods and models mentioned above, and to address the procurement issues in a more effective way, System Dynamics is applied in this study to help capture the dynamic complexities by providing insight into the underlying structural mechanism. A model focusing on the dynamic relationships among the choices of purchasing contracts, inventory level and cost of the enterprises in a supply chain is built and used.

The model is formulated to show different features of different purchasing strategies. The dynamics of supply chain is highlighted in the model. As is known, in a supply chain, there exist three flows---information flow, material flow and finance flow. It's important to point out that the model in this study takes these three flows into account at the same time. 'In fact, the most complex behaviours usually arise from the interactions (feedbacks) among the components of the system, not from the complexity of the components themselves' (Sterman, 1999). Similarly, feedbacks are formulated here to help understand the interactions between elements of the system.

This paper does the research on the purchasing contracts and the main innovations can be concluded into four points.

Firstly, system dynamics methodology is used to replace the normative methods or models. Such structure-oriented viewpoint helps us interpret the dynamic behaviours of the system based on its underlying structure.

Secondly, this study considers the three flows of the supply chain simultaneously, which is impossible for other research methods to take into account because of the high complexity of the supply chain system.

Thirdly, this paper not only introduces different purchasing contracts but also builds dynamics models to show and compare their effect on the performance of the enterprises in a supply chain.

Last but not least, decisions and policies are made on the basis of the simulation results, which could be instructive for the companies in reality.

On the other hand, based on the above literature reviews, several points are noticeable. Firstly, the procurement contracts problem has been realized and the theoretical and mathematical tools have been applied in this field of research. Meanwhile, the reviews point out that these tools are insufficient to show the

dynamics because of the high complexity of the problem and non-linearity of the supply chain system. Secondly, system dynamics is regarded as an effective method to do the research in SCM field. SD is good at revealing the feedback of the system and showing the dynamics of the problems. This part of review tells us that SD can reveal what other research methods can't. Thirdly, these researches set a good foundation and give the theoretical evidence and support for the modelling in this study.

Chapter 3

Problem Description

3.1 Introduction

Finding the problems is the premise for solving the problems. A procurement strategy for products has to focus on both driving costs down and reducing risks. This chapter is aimed to depict the problem dynamically and intuitively. We would firstly illustrate the problem background and problem focus. After that, possible policy instruments are to be proposed.

3.2 Problem Illustration

Procurement problems mainly refer to risk problems, including both inventory and price risks. By inventory risk we refer to inventory shortages or unsold products while price risk refers to the uncertainty of purchasing cost which may be directly influenced by the fluctuation of spot market price.

According to the definition and characteristics of the long-term contracts and option contracts introduced before, neither of them can simultaneously optimise the inventory and costs. The reasons are explained as follows.

Long-term contract helps to reduce price risks but may increase more instability of the inventory level. For instance, the inventory level oscillates seriously. In long-term contract, the supplier and the manufacturer/buyer agree on both the price and the quantity delivered to the manufacturer and the fixed amount of supply would be delivered at some time point. If a procurement strategy hopes to eliminate price risk or control commodity prices (e.g. oil price), it would choose long-term contract. In this case, the manufacturer/buyer bears no price risk while taking huge inventory risk due to uncertainty in demand and the inability to adjust order quantities.

In contrast, option contracts perform better in controlling buyer's inventory but the price risk is relatively high. The option contracts provide the manufacturer/buyer with flexibility to adjust order quantities depending on realized demand and hence these contracts reduce inventory risk because the buyer only needs to pre-pay a relatively small fraction of the product price (reservation price) up-front, in return for a commitment from the supplier to reserve capacity up to a certain level. For the buyers, they can execute the option according to the real demand in each time period. However, no matter whether the buyer executes the option, the pre-paid money can't be withdrawn. In addition, the execution price is in the same trend of the spot market price, which is expected to grow in the long run. Therefore, the option contract bears more price risks.

After knowing the problems, we concern about how these problems influence the supply chain. We would expect to make it clear that 1) how procurement strategies influence the performance of the firms as well as the whole supply chain; 2) and how the firm chooses a suitable contract to maximize its profit while controlling the risks.

There are three main reasons why we focus on the above two points.

1. Firstly, just as the problem background sector introduces, procurement problems are very common in practice. On the one hand, the successful implementation of the strategy can create added value, which is a great motivation for its wide-scale application in the business. On the other hand, the complexity of the problems makes the firms feel difficult to carry out suitable procurement strategies.

2. Secondly, the current research in this field mainly focuses on the theoretical analysis but lack of enough evidences or proofs. The problem is of high dynamics. It deals with three flows of the supply chain simultaneously. The current research tells that the procurement contracts would influence the cost and inventory level of the firms, but conclusions are mainly based on the theoretical analysis. Some researchers hope to use mathematical models to prove but due to the high linearity

of the system, they have to set a lot of assumptions, which cause the results be far away from the reality and become meaningless to some extent.

3. The third reason refers to the weakness of the traditional purchasing/supply contracts. For the buyers, they hope to reduce the procurement costs but control the risks of inventory and price. In reality, these two purposes often conflict with each other. As described in chapter 1.1.2, two kinds of contracts are most frequently used by manufacturers when the manufacturers play the role of buyers in the supply chain to purchase the raw material or outsource non-strategic products from the upstream suppliers.

3.3   Reference Mode

System dynamics modeler seeks to characterize the problems in a dynamic picture. The reference mode, as a pattern of behavior, is used here for the purposes of showing how the problems arise and how they might evolve in the future. It describes the problems through graphs of the key variables over a certain time period.

In this study, the time unit is 'month' and the time horizon is set to be 72 months, equal to six years. Setting such a long time period is aimed to show the problems in the long run and hope to study the equilibrium statues if possible. Each contract lasts for *12 months*, which means at the beginning of the pre-agreed contract period, the contract is signed and every month the supplier delivers the raw material/components to the manufacturer according to the contract.

Considering the purpose of this study, two key variables that can reflect the problems are chosen as follows: 1) Average Unit Procurement Cost <$/Unit>; 2) Raw Material Inventory <Unit>. The 'Average Unit Procurement Cost' is defined as the total procurement cost in a certain contract period (e.g. 12 months) divided by the total purchased quantity in the same time period.

The reference modes of these two variables are shown in figure 1.1 and figure 1.2. In each graph, there exist two curves: the dashed curves reflect the situations in option contracts while the other ones in long-term contracts. The curves presented in these figures are a hypothetical sketch of what may happen when the demand randomly fluctuates around the average value and the spot market price changes as the figure 3.2 showed. In order to simplify the problem, we assume that the spot market price is in the upper trend in the long run. In reality, such assumption is reasonable because the potential energy crisis has caused the increase in the prices of almost all the industrial raw material as well as products these years.

Since the spot market price influences reservation price and execution price directly or indirectly, the variable 'Average Unit Procurement Cost' has the relationship with the spot market price to some extent. As we can see from figure 3.2,

the behavior of 'Average Unit Procurement Cost' presents the similar trend as the spot market price goes. However, the procurement cost with option contract is high than that with long-term contract.

Besides, we focus on the inventory level and compare the behavior of *Raw Material Inventory* in the conditions of different contracts (see Figure 3.1). Here it is assumed that the raw material is what the buyer/manufacturer purchases from the upper-stream supplier and the raw material could be the components (e.g. automotive parts) or energy (e.g. petroleum).

The variable 'Inventory' is an accumulation of material flows. As the key variable, it also reflects the effect of procurement contracts on the material flow. Take the behavior of 'Desired Inventory' as the benchmark, we can see from figure 3.1, with the long-term contract, the *Raw Material Inventory* shows more oscillation than that in option contract although their behavior pattern appears similar.
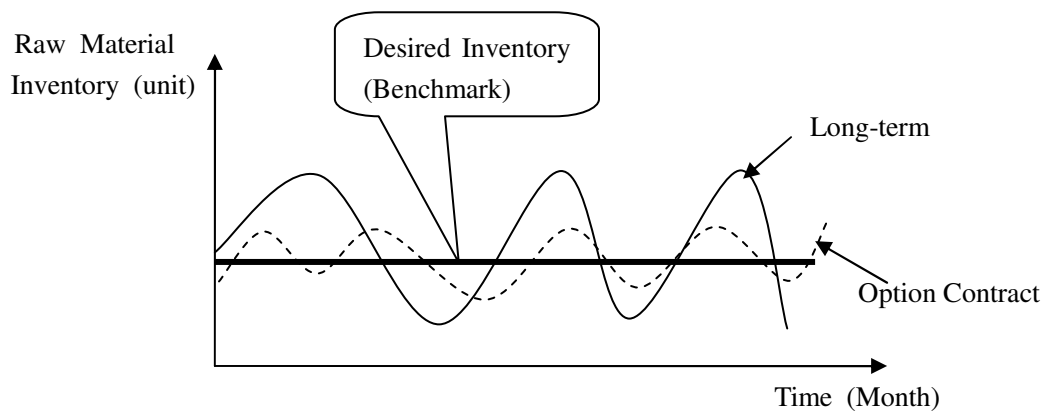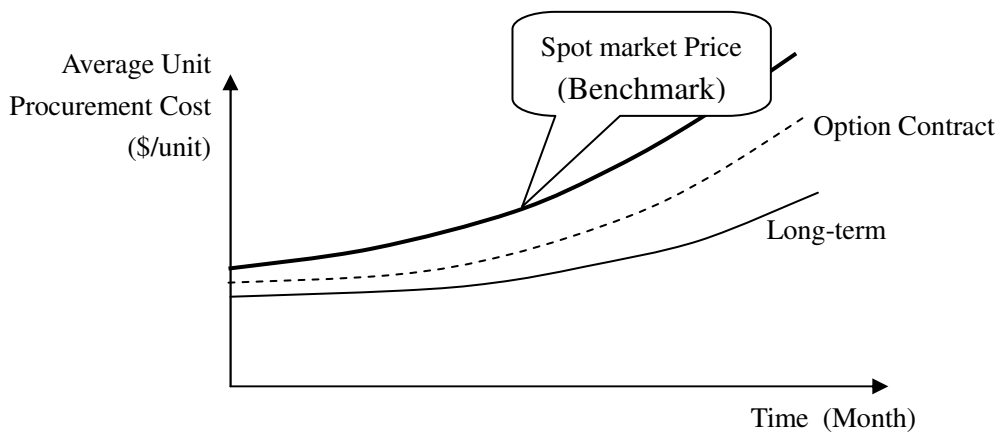

Figure 3.1: Inventory Reference Mode

Figure 3.2: Procurement Cost Reference Mode

It is necessary to point out that the spot market price also influence the procurement quantity. In this paper, we assume that the spot market price is in the upper trend. When the spot market price is lower than the expectation, the manufacturer would like to order a bit more, which indirectly influence the inventory level. And larger demand would increase the price to some extent. The dynamic process is formed, linking the financial flow with inventory flow.

Chapter 4

Dynamic Hypothesis

4.1 Background

In Chapter 3, the research problem in this study has been illustrated and characterized in the reference mode. In this chapter, dynamic hypothesis would be formulated to account for the problematic behaviour. We use the Causal Loop Diagram (CLD) to depict the dynamic hypothesis. Causal Loop Diagrams (CLDs) are an important tool for representing the feedback structure of system. One of CLDs' features is that they are excellent for quickly capturing the hypotheses about the causes of dynamics.

A causal diagram consists of variables connected by arrows denoting the causal influences among the variables. The important feedback loops are also identified in the diagram.

4.2 Hypothesis

The hypothesis to be tested in this research is as follows. Shown in Figure 4.1, it is a simplified Causal Loop Diagram (CLD) presenting the main interrelationships of the key variables of the manufacturer sub-system. From it, we can see how the components are purchased and delivered as well as find the different effect of the option contract and long-term contract on the inventory level.

In CLDs, variables are related by causal links, shown by arrows. Each causal link is assigned a polarity, either positive (+) or negative (-) to indicate how the dependent variable changes when the independent variable changes. A positive link labelled '+' means that if the cause increases, the effect increases above what it would otherwise have been, and if the cause decreases, the effect decreases below what it could otherwise have been. In contrast, a negative link labelled '-'means that if the cause increases, the effect decreases below what it would otherwise have been. (Sterman, 2000)

In figure 4.1, we would see that the loops are highlighted by a loop identifier which shows whether the loop is a positive (reinforcing) labelled 'R' or negative (balancing) feedback labelled 'B'. The fast way to tell if a loop is positive or negative is to count the number of negative links in the loop. If the number of negative links is even, the loop is positive; otherwise, the loop is negative.

Figure 4.1 depicts the material inflows in the manufacturer part as well as how the purchasing contracts effect on the inventory level of raw materials, work-in-process products and finished products in the manufacturer. As we can see from the figures, there mainly exist three balancing loops. Among them, loop B1 and B3 are the loops existing in both the long-term contract and option contract. Loop B2, highlighted in blue, represents the extra part causal structure if the manufacturer chooses the option contract to purchase the components from the supplier. See figure 4.1, with option contract, there exist a balancing loop (B2) that helps to adjust the raw material inventory level. When the inventory is higher than the desired level, fewer raw materials are desired to purchase and thus the amount of the actual purchased raw material (execution rate) is lower. All these three flows influence the *Raw Material Inventory*, but in option contract, the balancing loop B2 further adjusts and controls the *Raw Material Inventory* which explains why the option contract structure would perform better in controlling inventory risks.
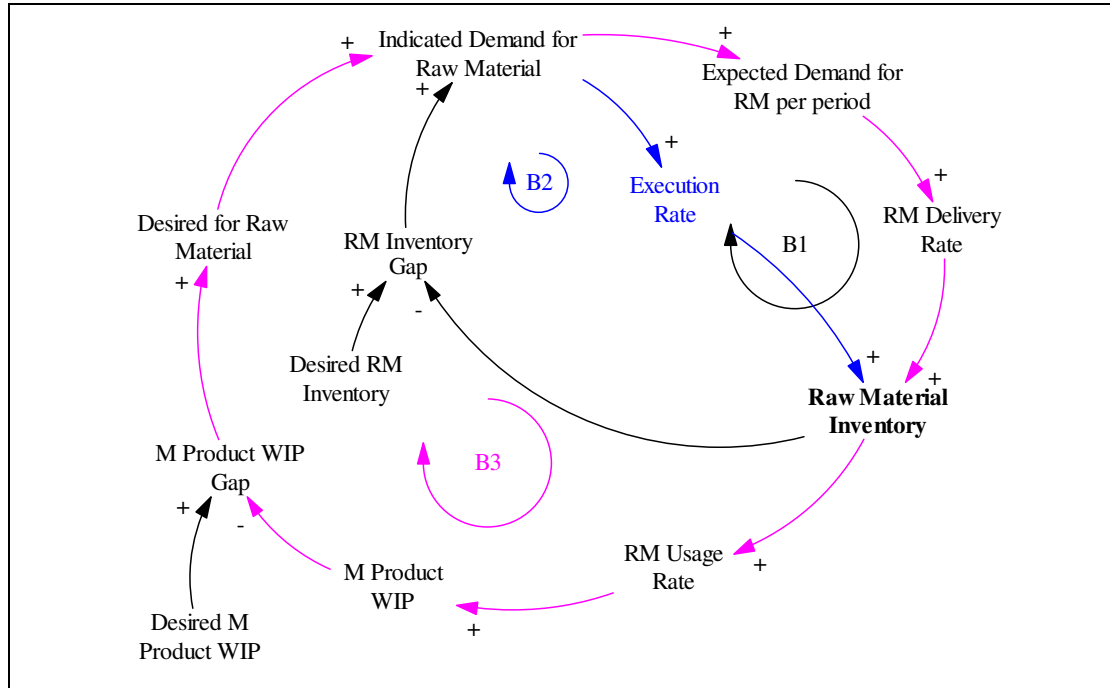
Figure 4.1: CLD for the Effect of Contracts on Material Flow

The Average Unit Procurement Cost measures the price risk in this study. It equals to the pre-paid price (PP) in long-term contract. Through option contracts, Average Unit Procurement Cost (AUPC) is the Weighted Average of execution price and reservation price. The equation is as follows:

$$AUPC = \frac{RR \times RP + ER \times EP}{ER}$$

(1)

Where,

RR: Reservation Rate

RP: Reservation Price

ER: Execution Rate

EP: Execution Price

In our model, we assume that the sum of reservation price and execution price in option contract is higher than the spot market price. Meanwhile, the purchasing price, which is equal to the AUPC in long-term contract, is lower than spot market price. Besides, the execution rate is no more than the reservation rate. Therefore, the AUPC in option contract is lower than that in long-term contract.

Based on the above analysis, we put forward the major hypothesis as follows: If we can properly combine long-term contract and option contract, the performance of the buyer/manufacturer can be improved compared with the single procurement contracts.

In order to show this hypothesis in a dynamic way, a simplified Causal Loop Diagram (CLD) is drawn as figure 4.2 shows. As depicted in figure 4.2, there mainly exist two reinforcing loops (R1) and two balancing loop (B1,B2). Note that these three loops all involve *Share from Option Contract*. In loop B1, the *Ratio of Raw Material Inventory* equals to the *Raw Material Inventory* divided by *Desired RM Inventory*. The higher ratio it is, the higher *Share from Option Contract* and more purchased from option contract. Correspondingly, the Raw Material Inventory increases and Ratio is reduced. Then the balancing loop is closed. As to B2, it deals with the *Average Unit Procurement Cost (AUPC)*. Since the AUPC in long-term contract is determined mainly by spot price and can be regarded as the exogenous in this part of CLDs, the Ratio of AUPC is influenced by the changes of AUPC in option contract, which makes a positive effect on the *share from option contract*. B2 illustrates the relationship between AUPC and the share of option contract. The reinforcing loop R1 is highlighted in pink, which shows how the shares from different contract influence the *Raw Material Inventory*.

By describing how the portfolio contract forms and works, it also tells the advantages of the portfolio contracts in balancing the risks of inventory and cost.
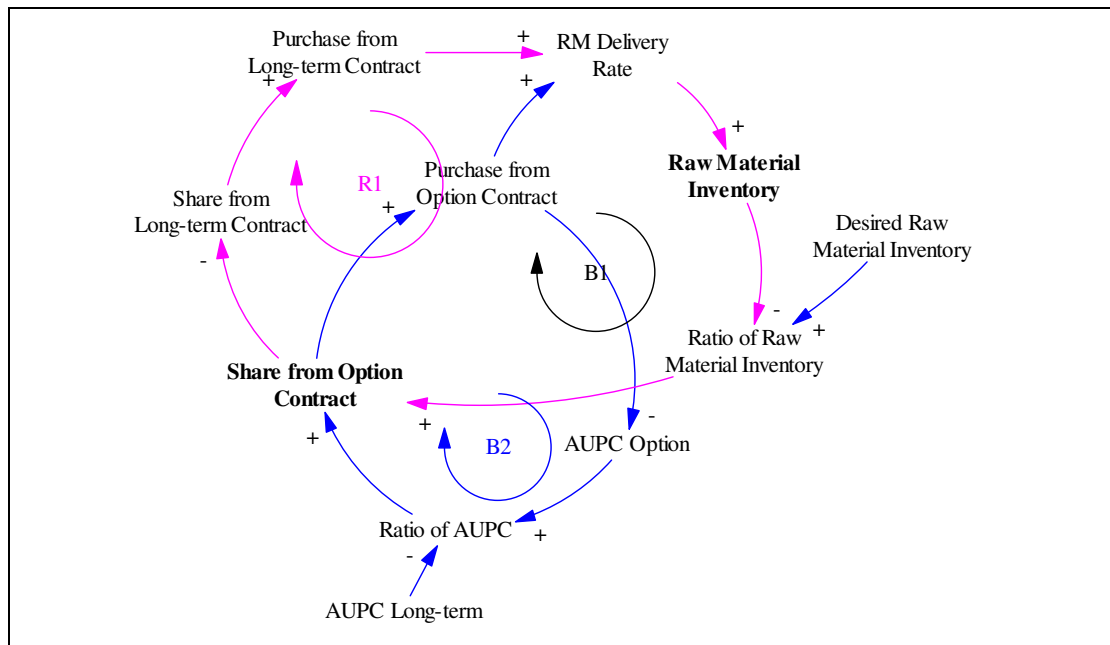

Figure 4.2: Simplified CLD of Portfolio Contract

Chapter 5

Model Description

5.1 Introduction

To show the dynamics of procurement strategies' influence on the cost and inventory level of the manufacturer in a typical supply chain system, a System Dynamics model is developed to provide insights into the underlying structural mechanism and further test various supply contracts and their influences. I will introduce the structure and variables of the model step by step.

This chapter starts with a model overview including the assumptions, the model boundary and so on. Illustration of sub-system diagrams, and outline major feedback loops by Causal Loop Diagram are followed. Then, I present the formal Vensim model in detail in sector documentation by identifying key variables and describing the associated stock and flow diagrams. Finally, a brief summary is given. The complete list of model equations can be found in the Appendix.

5.2 Model Overview

In the last four chapters, the background and the purpose of this study are introduced in details, which set a good foundation for the introduction of system dynamics model here. The model, which is the main part and focus of the thesis, is described by words and graphs here in the purpose of telling how model is organized and oriented. Meanwhile, by outlining the model's main characteristics—boundary, subsystem and main causal loop diagram, this section is intended to help us recognize the architecture of the model, and offer us a well-founded starting point to explore the details of model in sector 5.3.

5.2.1 Major Model Assumptions

For the sake of simplifying the model and better understanding of the dynamic system, some assumptions are set here.

1. The supply chain system studied here is assumed to be composed of supplier, manufacturer, distributor and customer. Manufacturer plays the core role in the system. It purchases the components from the up-stream supplier, processes the components into the products and delivers to the down-stream distributor.

2. This study only focuses on the procurement of non-strategic components. According to the Kraljic's Matrix Theory (1983), manufacturers often take different approach for purchasing strategic components and non-strategic components. For the non-strategic components, they can be purchased from a variety of suppliers and flexibility to market conditions is perceived as more important than a permanent relationship with the suppliers. Usually, non-strategic components are commodity products like steel or computer memory and they are typically available from a large number of suppliers and can be purchased in spot markets. Because these are highly standard products, switching from one supplier to another is not considered as a major problem.

3. Assuming a high level of market competition so that no single player can affect prices. And the spot market price is exogenous but it would influence execution price and reservation price. In addition, the demand and price have some cause-result relationship.

4. The order rate is triggered by the demand for components/products and adjusted by the inventory level of the manufacturer/distributor. The demand is uncertain and the demand information is delivered from one to the upper one but not shared among all the players in the supply chain.

5. The level of procurement cost is measured by the 'Average Unit Procurement Cost', which is defined to be the total procurement cost in a certain contract period (e.g. 12 months) divided by the total purchased quantity in the same time period. The

inventory of the component is the accumulation of arriving rate minus the loss rate in a certain time period.

6. Assuming one component is required to produce a unit of finished goods.

7. The spot market price is higher than the pre-paid price in long-term contract. And, the total of reservation price and execution price in option contract is also higher than that in long-term contract. This assumption is set on the basis of Victor's research [36].

8. The spot market price is in the trend of increase in the long run. Nowadays, the whole world is faced with the potential energy crisis and the oil price keeps soaring in the past several years and is expected in such trend for a long time. The increased energy price is the main reason for the increase in the prices of almost all the industrial raw material as well as products these years.

9. In this model, there is no backlog of unfilled order/demand, and those that not immediately filled are lost as customers seek alternate suppliers.

5.2.2 Model Boundary

Since system dynamics seeks endogenous explanations for phenomena, the focus of the system is endogenous variables. And the exogenous variables in this model are expected to be small and each candidate for an exogenous input must be carefully scrutinized to consider whether there are in fact any important feedbacks from the endogenous elements to the candidate. However, it doesn't mean exogenous variables should be excluded. But the clear division of endogenous and exogenous ones is important for further discussion and modelling.

System dynamics includes a variety of tools to presents the boundary of the model as well as the causal structure such as model boundary diagrams, subsystem diagrams, causal loop diagrams, and stock and flow maps. Here, I firstly use a model boundary chart to summarize the scope of the model by listing which key variables are included endogenously, which are exogenous and which are excluded from the model. Such a chart helps us form an overview of the model content and the level of aggregation chosen.

Figure 5.1 shows a model boundary diagram for the model designed in this study. The purpose of the model is to explore the internal mechanism of purchasing strategies' influence on the supply chain's performance and to see how different purchasing contracts help to reach the optimization.

Endogenous	Exogenous	Excluded
• Execution Price	• Spot Market Price	• Production capacity
• Execution Rate	• Reservation Price	• Fund restriction for Purchasing
• Shipment Rate	• Contract period	• Types of components or products
• Reservation Rate	• Customer demand	
• Share from option contract	• Delivery time	
• Avg. unit Procurement cost	• Adjustment time	
• M_ Raw Material INV	• Safety Stock Coverage	

Figure 5.1: Model Boundary Chart

Meanwhile, we find the model excludes some factors that we consider irrelevant to this research for our purpose. Reasons are listed here to show the reasonability of eliminating some effects from the model.

1. Production Capacity

Here, the production capacity is assumed to be sufficient enough to meet the requirements. Sometimes, the lack of capacity appears in some manufacturers but this situation is not common and it may be because of such accidence like sudden increase in demand and so on. Usually, the manufacturers accept the order based on own production capacity. If the demand exceeds the capacity, they can either decline or increase the capacity if possible. Otherwise, they have to pay a great deal of money for disobeying contract. Therefore, assuming enough manufacturing capacity conforms to the reality and the benefit of the manufacturer.

2. Fund Restriction for Purchasing

Xu & Birge (2004) think financial constraints play an important role in determining the manufacturer's production decisions or purchasing decision because the internal cash position of the constrained company may not be able to support its desired output level or desired ordering level. It is truth! An important issue in supply chain management is the effective coordination of material flows, information flows, and financial flows. And in this paper, the model also considers and includes the structure to show these three flows at the same time.

However, I exclude the fund restriction from the model. My focus and research purpose is to find suitable purchasing strategies. On the one hand, the consideration of fund restriction may interfere with decision-makings; on the other hand, fund restriction of the buyer (eg., manufacturer) in the real world is not common. Even though it happens, the manufacturer can solve it by borrowing from banks or delay

payment in the short term. Given the purpose of the model and the above reasons, we don't take the fund restriction into account in this paper.

3. Types of Components or Products

According to the introduction and assumptions before, this study focuses on the procurement of the non-strategic components of the manufacturer and it is assumed one unit of component is needed to produce one product. Since the model is set as a framework, the types of components or products are not necessary to consider. So it is entirely reasonable to exclude the detailed types.

5.2.3 Subsystem Diagram

A subsystem diagram shows the overall architecture of a model. Each major subsystem is shown along with the flows of material, money, goods, information and soon coupling the subsystems to one another. The following subsystem diagram in Figure 5.2 helps to understand the major sectors and their interactions of the procurement portfolio model.

According to the model assumptions, the studied supply chain is composed of several parts: supplier, manufacturer, distributor and final customers. Besides, material flow, financial flow and information flow are considered simultaneously. Figure 5.3 depicts how three flows go through different parts of the supply chain system. From it, we can also see how the raw material is delivered and processed as well as how the contracts make effect on the whole system. Here, the manufacturer is regarded as the core part and this study focuses on how it carries out the purchasing strategy to buy the components from the supplier. Firstly, the manufacturer chooses one purchasing strategy to buy the components from the supplier according to the anticipation of the demand. Then, after the components arrive at the manufacturer at the beginning of each time period, the manufacturer processes or assembles the components into the products and the finished products are delivered to the downstream companies.

In this research, three models are to be constructed: option contract model, long-term contract model and the portfolio contract model. According to the basic conceptions introduced before, the portfolio contract is a combination of the long-term contract and option contract. Thus, the model is constructed on the basis of option contract model and long-term contract model. Note that the portfolio contract is proposed as the policy to optimize the performance of the companies in the supply chain system. The detailed sensitivity tests and behaviour analysis of portfolio contract would be done in the policy development.
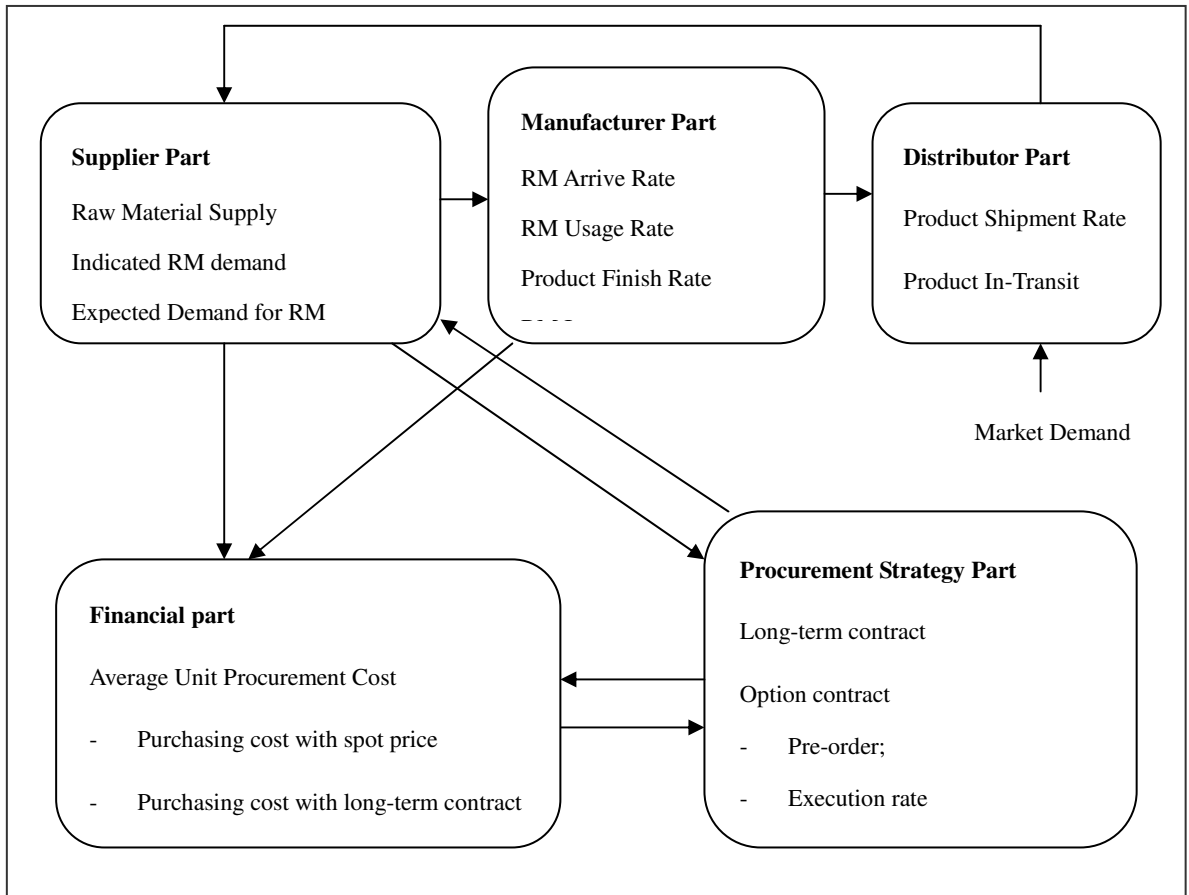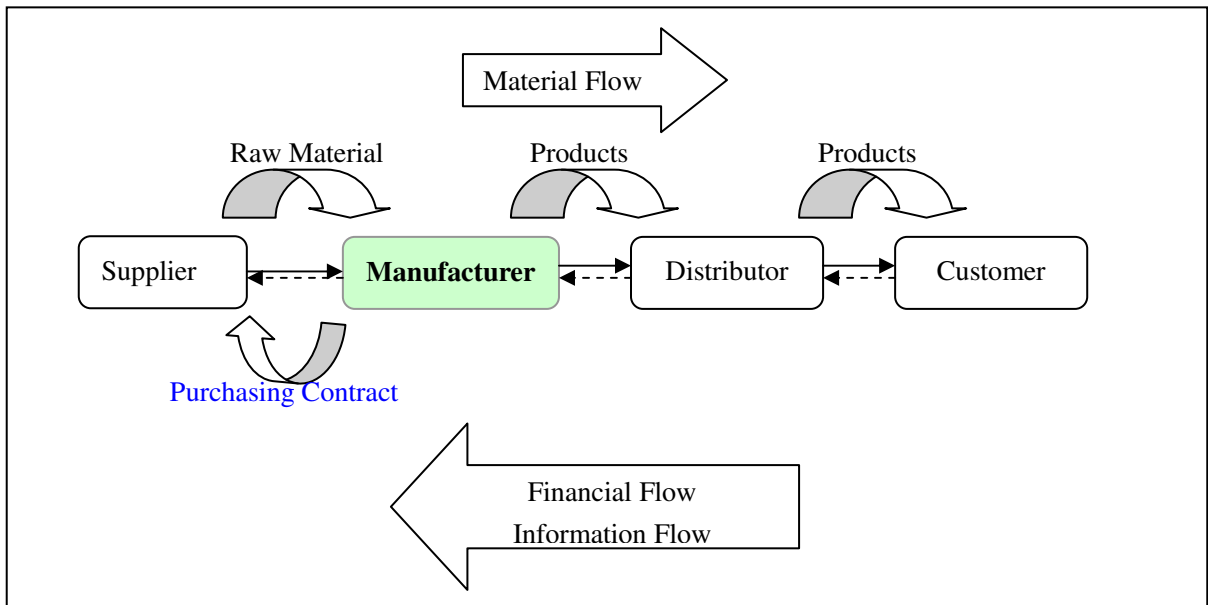
Figure 5.2: Subsystem Diagram

Figure 5.3: Three Flows in Supply Chain System

In this chapter, we would describe the models in details. As we can see in figure 5.2, the model can be divided into five parts and the subsystem diagrams are depicted to show the relationship between them. Arrows bridging subsystems (and the sub-domains within each) indicate dynamic interdependency.

Figure 5.2 depicts five subsystems, namely, 'Supplier Part', 'Manufacturer Part', 'Distributor Part', 'Procurement Strategy Part' and 'Financial Part'. And 'Demand for products' is taken exogenously and is thus out of the model boundary.

The details of this subsystem diagram are described as follows.

Firstly, the choice of purchasing/supply contracts is the decision-making point. In procurement strategy subsystem, three kinds of contracts are included. How to choose contract is determined by component inventory level as well as the procurement cost level. Meanwhile, the choice of contracts directly influences the 'Financial Part' as well as the components purchase & supply.

Secondly, 'Supplier Part', 'Manufacturer Part' and 'Distributor Part' constitute the main structure of the model. From these subsystems, we know how the demand information is transferred and how the components are purchased, delivered and processed. In addition, the actual amount of components purchased from the supplier determines the manufacturer's procurement cost and inventory level. Therefore, these three parts also influence the 'Financial Part'. When the inventory level is much higher than the desired level, the procurement strategy would be adjusted. Because of this, 'Procurement Strategy Part' is also linked with these parts.

Thirdly, the 'Financial Part' describes the procurement cost with different contracts. It is the reflection and measurement of the price risks. The cost is not only decided by the spot market price but also influenced by the procurement strategy the manufacturer chooses. Therefore, this part can be connected with the 'Procurement Strategy Part' and 'Supplier Part'.

In a word, like most System Dynamics models, different sectors in this portfolio contract model work together to provide an integrated representation of the system. And the information generated in each of the sectors is available during each time step of the simulation as needed in the remaining sectors.
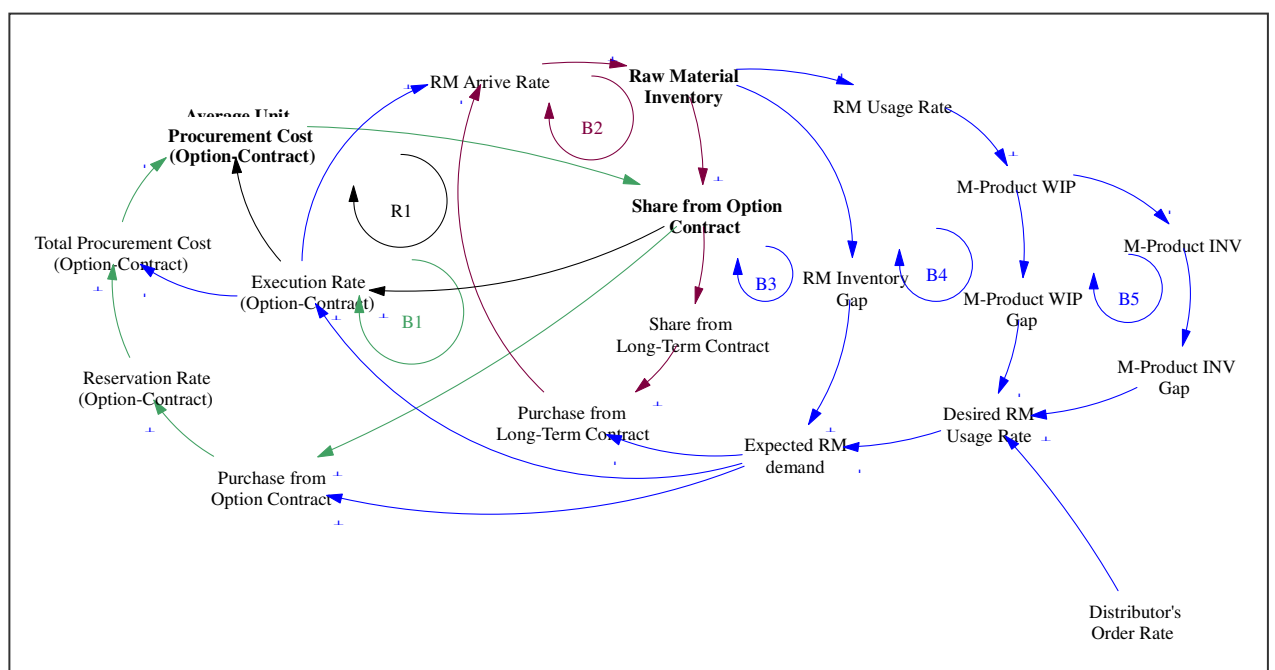
5.2.4 Major Causal Loop Diagrams (CLDs)

The overarching objective of System Dynamics methodology is to discover, or uncover a set of relations that describe the decision processes that lead to the problematic outcomes. Feedback is one of the core concepts of system dynamics and causal loop diagrams (CLDs) are an important tool for representing the feedback

structure of systems. Sterman [business dynamics, 2000] describes CLDs to be excellent for quickly capturing the hypotheses about the causes of dynamics; eliciting and capturing the mental models of individuals or teams; communicating the important feedbacks which are thought to be believed to be responsible for a problem. All dynamics arise from the interactions of two types of feedback loops: reinforcing loop that amplifies whatever is happening in the system and balancing loop that counteract or oppose changes. All the CLDs in this paper are derived from the stock-flow diagrams, which would be described in details, and depict the feedback structure in a clearer way. Here in our CLDs, reinforcing loops are labelled as R and balancing loops are labelled as B.

Before the detailed descriptions of the major CLDs, several notes would be pointed out.

1. The causal loop diagrams depicted in figure 5.4 is mainly related to the manufacturer's material flow, information flow and financial flow. For simplicity, the distributor part is not considered because it has little influence on the decision-making of the procurement strategy.

2. Almost all the processes include delays. These delays may be caused by the material delivery or production or information transmission.

3. The CLDs only include the key variables but neglect many others. And the CLDs depicted in figure 5.4 are just the most important ones in the model, but not all.

4. Figure 5.4 tells how the portfolio contracts are formed. In this system, the 'share from option contract' represents the percentage of purchased quantity with the option contract while the 'share from long-term contract' is that with long-term contract.

Figure 5.4: Major Causal Loop Diagram

There are five balancing loops and one reinforcing loop as it shows in figure 5.4. In order to explain the main CLDs more clearly, we would decompose and describe them one by one as follows.

1. Reinforcing Loops (R)

R1: The Increase of Average Unit Procurement Cost

Loop R1 is not a dominating loop in the whole system. It is comprised of three variables related with the option contract. The growing Average Unit Procurement Cost creates incentives to reduce the share from option contract because the option contract features higher cost compared to the long-term contract. Also this lower share results in lower execution rate. Therefore, this loop, together with the following loop B1, tells us how the Average Unit Procurement Cost in option contract influences and is influenced by the 'share from Option Contract'.

Average Unit Procurement Cost (Option-Contract) -

R1

Share from Option Contract -

Execution Rate (Option-Contract) +
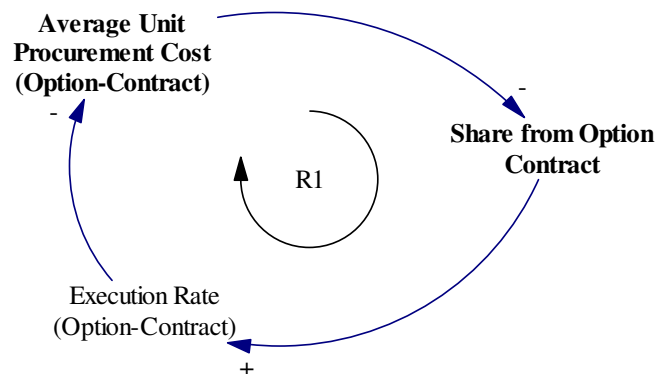
2. Balancing Loops (B)

B1: The Balancing Effect of Procurement Strategy on the Procurement Cost

Loop B1 reveals the dynamics resulting from setting the ratio of taking Option Contract. Higher share from option contract leads to a higher purchasing quantity from the option contracts and further more money paid for the reservation, leading to higher average unit procurement cost. The increase of the procurement cost creates the incentive to reduce the ratio of option contracts. In this process, the procurement cost is controlled. This loop also illustrates the relationship between reservation rate and average unit procurement cost in the option contract.
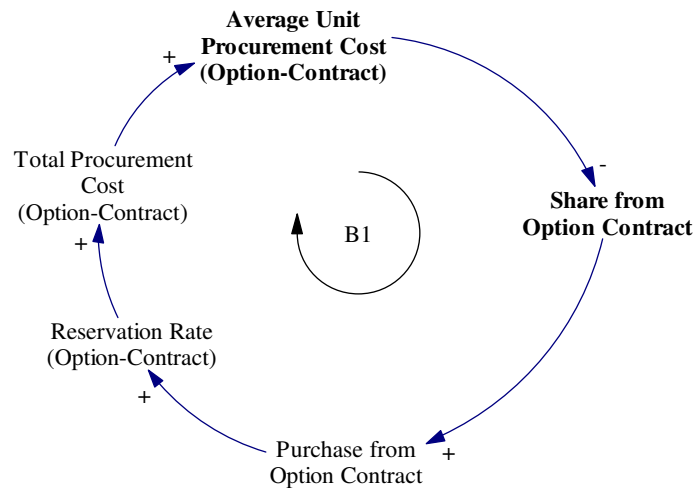
B2: The Interaction of Inventory Level and Procurement Strategy

Loop B2 illustrates how the Raw Material Inventory influences the choice of purchasing contracts and how their dynamic relations are formed. Optimal portfolio contracts are expected to control the inventory in a proper level. According to the former analysis, the share from option contract is directly determined by the Raw Material Inventory. The effect of inventory level on the ratio of the option contract is positive, that is, more inventory, more share from option contract.

In addition, the increased ratio of option contract reduces the ratio of long-term contract and therefore, the purchasing quantity from long-term contract is relatively lower. Fewer purchased, lower inventory level is. Thus, the balancing loop is closed.
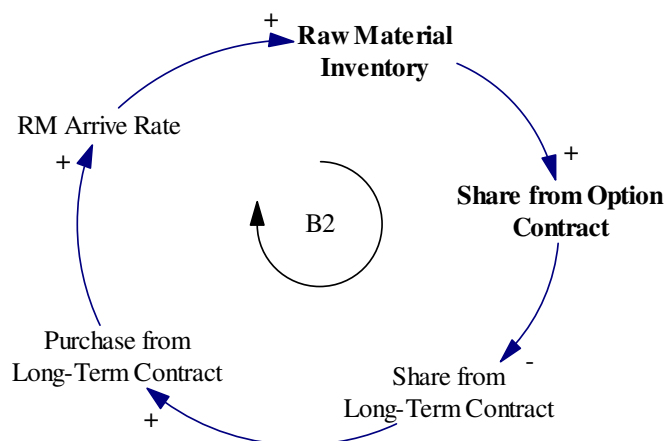

B3: Self-adjustment of Raw Material Inventory

Loop B3 mainly discusses how the raw material inventory is controlled by the adjustment of the input. When the inventory level is higher than the desired one, the

desired RM demand would be reduced so that the inflow to the inventory stock could be less. Through this process, the raw material inventory would be kept in a proper level.
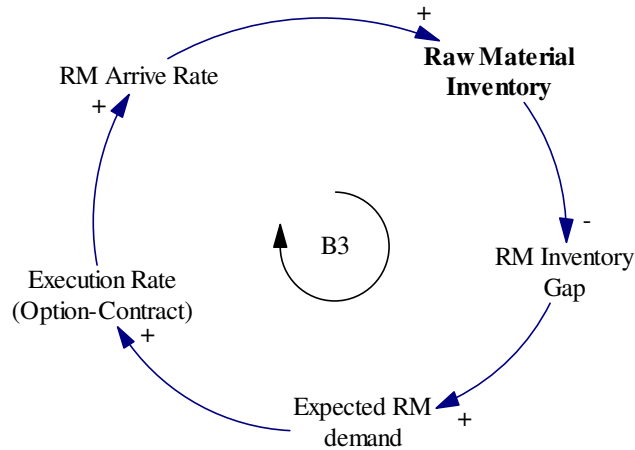
B4: The Effect of Product WIP (Working In Process) on the Raw Material Inventory

The raw material, purchased by the manufacturer from the supplier, is used for producing the products to meet the demand of the market. More raw materials are used for production, more products are in process. If the WIP products are beyond the expectation, the demand for raw materials are correspondingly decreased, which leads to the lower of the raw material inventory and fewer could be used for production. Therefore, this closed loop reveals the effect of the adjustment of WIP products on the raw material inventory.
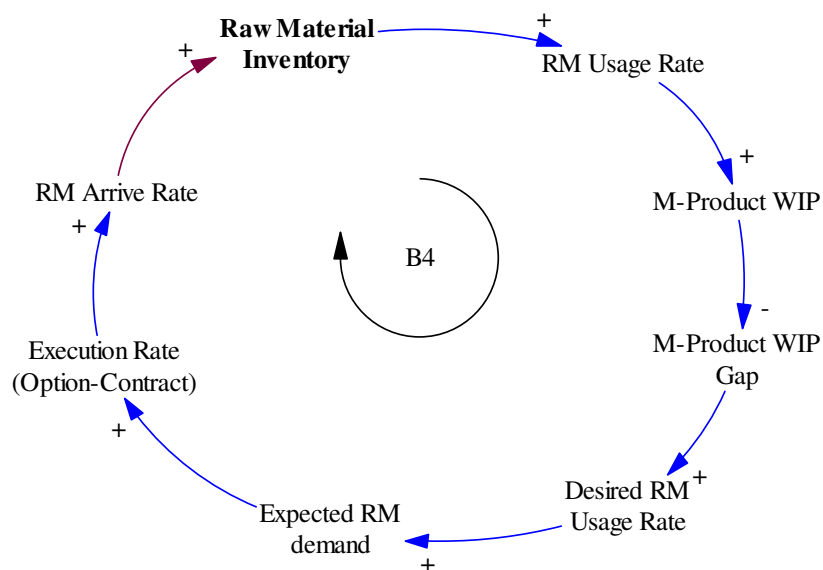
B5: The relationship between Product Inventory and Raw Material Inventory

Similar to loop B4, loop B5 also illustrates the material flow in this supply chain system. Once the finished products inventory is higher, then the demand for production is lower. Correspondingly, the consumption of raw materials is reduced. Fewer raw materials arrive, lower inventory level and fewer are used for production. The above description tells us how a balancing loop is formed and works.

In a word, the causal loop diagrams are not built for dynamic optimisation, but it allows an enhanced understanding on the influencing elements, the behaviours they cause and furthermore tests on policies.
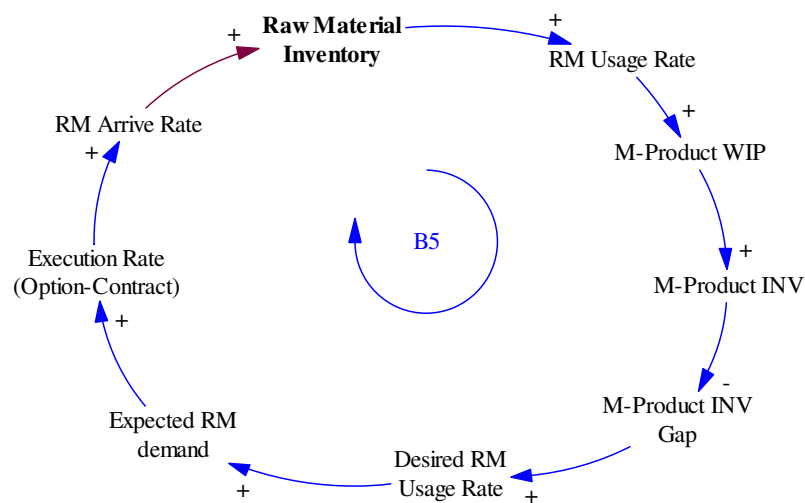

5.3 Sector Documentation

Causal loop diagrams are useful in many situations. They are well suited to represent interdependencies and feedback processes in complicated systems. They are used effectively in the early stage of a modeling project to capture the basic structure. However, they have certain limitations. They fail to distinguish between stocks and flows and some loops could be specified in more details (Sterman, 2000).

On the other hand, causal loop diagrams are built on the basis of the stock and flow diagrams （SFD）, which emphasize the underlying physical structure and present the conceptual and mathematical definitions of stocks and flows. Therefore, in this sector, the SFD of the model in this chapter will be introduced step by step.

In this study, the model is built with the modelling software Vensim. Below is the detailed description of the formal stock and flow structure in Vensim. To clarify the nature of the dynamic interactions, the model is constructed by several sub-sectors as follows.

5.3.1 Material Flow Sub-Sectors

An effective supply chain models must represent different actors and organizations including suppliers, the firm, distribution channels, and customers [Sterman]. In my model, three actors--supplier, manufacturer and distributor, are included and the study is focus on the manufacturer. Based on the purchasing contracts agreed by the supplier and manufacturer, upper-stream supplier delivers raw material to manufacturer in a certain way. The manufacturer holds the raw material inventory and then uses available raw material to start the production according to the forecast of the distributor's demand for products. Finally, manufacturer delivers the finished products to distributor so that the distributor sells them to meet the market demand. In this process (figure 5.5), the material flows go through the whole supply chain system.

| Supplier | Raw Material → | Manufacturer | Components → | Distributor |
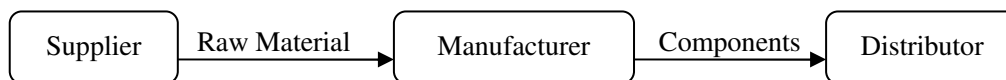
Figure 5.5: Material Flows Structure

Since material flows sub-model tells how the raw materials/products are processed, produced, delivered and so on, which sets the basis of the extended models, it is necessary to introduce its stock & flow diagram and formula of the key variables in details.

1. Supplier Part

In this part, three figures are depicted to show how the raw materials are purchased and delivered with different types of contracts. Figure 5.6 represent the situation with option contract and figure 5.7 is with long-term contract. Based on the sub model sector in figure 5.6 and 5.7, the supplier sub-model with portfolio contract is built as figure 5.7 shows.

Through option contract, the manufacturer firstly pays the reservation price to order a certain amount of raw materials from the supplier within a pre-agreed contract period. Then in each month, according to the monthly forecast, manufacturer executes part of the contract. However, it needs to be pointed out that the accumulated execution rate within the contract period can't exceed the reserved raw material quantity.

At the beginning of each contract period, the *Reservation Rate* is set and as the inflow to the Stock '*Raw Material Supply (Option)*'. Its initial value is zero. This variable tells how much raw materials option is left in that contract period that could

be executed. The outflow of it is the *Execution Rate*.

- *Raw Material* = $\int_0^{Contract\_Period}$ (Reservation Rate - Execution Rate)*dt* + *Initial Raw Material*

Since the *Reservation Rate* is determined at the beginning of each period, the equation is set as the IF function.

- *Reservation Rate* = If then else [Remainder (Time/Contract Period) = 0, Expected Demand for Raw Material, 0]

The *Indicated Raw Material Demand* determines how much option is to be executed in that month. So the *Execution Rate* is assumed to equal to the *Indicated Raw Material Demand.*

- *Execution Rate* = Indicated Raw Material Demand

Based on the *Indicated RM Demand,* here we use the SMOOTH Function to forecast the demand for raw material, which plays a key role in determining the Reservation Rate in the option contract.

- *Expected Demand for Raw Material* = SMOOTH (Indicated RM Demand, 6)

And the parameter **Contract Period** pictures how long each contract lasts for. It is an exogenous variable and the unit is set to be 'Month'.
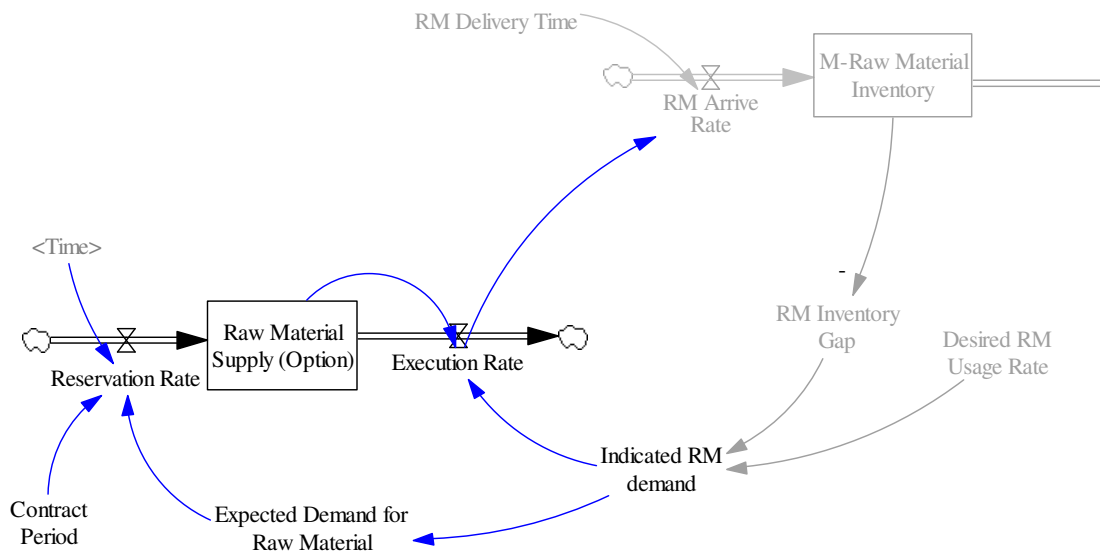
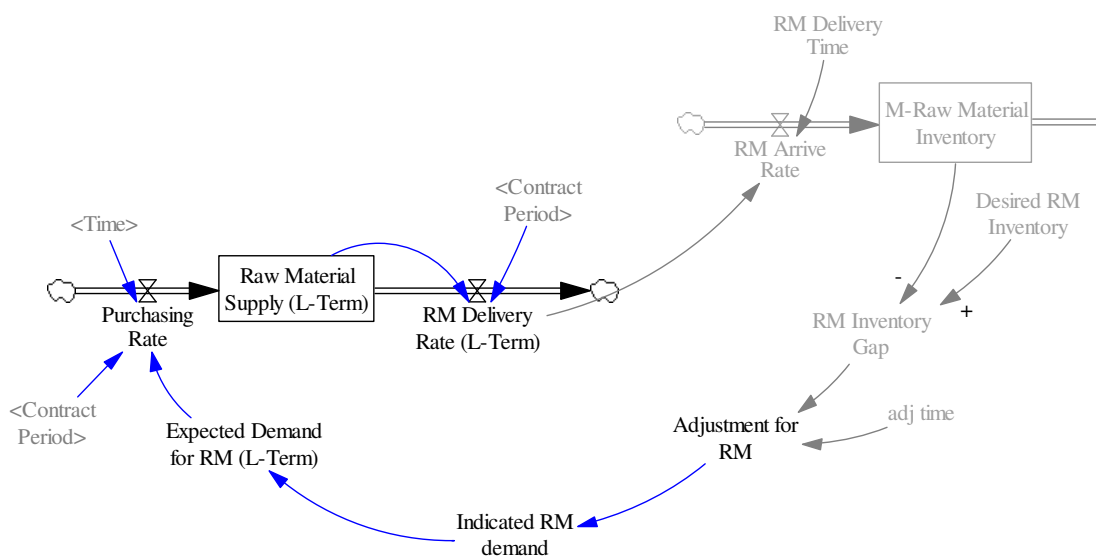**Figure 5.6: Supplier Sub-model Structure with Option Contract**

Figure 5.7 shows the model structure of the supplier part with the long-term contract. Look close at this structure, we would easily find its main difference from the structure with option contract.

In long-term contract, the outflow *Raw Material Delivery Rate* refers to the actual raw material quantity delivered from the supplier to the manufacturer each month. Different from the *Execution Rate* in long-term contract, this variable is not determined by the manufacturer but the supplier accoring to the pre-agreed contract. In other word, during the contract period, the delivery rate is equal to the pre-ordered quantity divided by the contract period and therefore, within each contract period, the delivery rate keeps the same.

$$\blacksquare \quad \textit{RM Delivery Rate} = \frac{\text{Raw Material Supply \_Long\_Term}}{\text{Contract Period}}$$

The *Purchasing Rate* is the quantity of raw materials that the manufacturer pre-paid and purchased from the supplier based on the forecast of the demand throughout that contract period. This variable is quite similar with the Reservation Rate in the option contract.

■ *Purchasing Rate* = If then else [Remainder (Time/Contract Period) = 0, Expected Demand for Raw Material, 0]

Figure 5.7:   Supplier Sub-model Structure with Long-Term Contract

2. Manufacturer Part

The purpose of this study is to help manufacturer choose an optimal contract to reduce the cost and control the risks. Therefore, this sub-model is the key part of the system.

Figure 5.8 shows the structure of the sub-model, describing the stocks and flows in details. Three stocks are included, that is, *M_Raw Material Inventory*, *M_Product WIP* and *M_Product Inventory*.

The *M_Raw Material Inventory* refers to the manufacturer's holding of raw materials, which is the accumulation of *Arrive Rate* minus *Usage Rate*. Therefore, the stock of raw materials is increased by the arrive rate and decreased by the material usage rate.

$$\text{M\_ Raw Material Inventory} = \int_0^t (\text{RM Arrive Rate - RM Usage Rate}) + \text{Initial M\_Raw Material Inventory}$$

We define *M_Product WIP* the accumulation of work_in_process products in a certain time point. When the process is finished, the number of the WIP Products is decreased. Meanwhile, the raw materials are taken from the inventory and used for production.

$$\text{M\_Product WIP} = \int_0^t (\text{RM Usage Rate - Finish Rate}) + \text{Initial M\_Product WIP}$$

Similar to *M_Raw Material Inventory*, M_Product Inventory accumulates the changes of finished products of manufacturer. When the WIP Products finish the production, they would be sent to the inventory. When the down-stream distributor orders the products, they would be shipped out of the inventory. From the above illustration, it's easy to understand that the stock of products is increased by the product finish rate but decreased by the shipping rate.

$$\text{M\_Product Inventory} = \int_0^t (\text{Product Finish Rate - Shipping Rate}) \, dt + \text{Initial M\_Product Inventory}$$

After introduction of the stocks, our attention comes to the inflows and outflows in this sub-model. As we can see from figure 5.8, *RM Arrive Rate, RM Usage Rate, Prodcut Finish Rate* and *Shipping Rate* would be illustrated as follows.

1. The *Raw Material Arrive Rate* is the inflow to Raw Material Inventory. In the option contract model (in reference with figure 5.6), it is determined by the sum of the delivery rate in long-term contract and the execution rate in option contract. Because it takes time to transport the raw material from the supplier to the manufacturer, a one-order delay is used to model the *Raw Material Arrive Rate:*

$$\text{Raw Material Arrive Rate} = \text{DELAY}(\text{RM delivery Rate} + \text{Execution Rate}, \text{RM delivery Time})$$

2. The *Raw Material Usage Rate* tells how many raw materials are used for production within a certain time period. The actual raw material usage rate is the desired raw material usage rate unless the stock of raw material inventory is inadequante, in which case usage falls below the desired rate.

$$\text{Raw Material Usage Rate} = Min\left(\text{M\_Raw Material Inventory}, \text{Desired RM Usage Rate}\right)$$

Note that the *Desired RM Usage Rate* equals to the sum of the *Adjustment for WIP Product* and the *Desired Production Start Rate* multiplied by the *Raw Material Usage Per Product*.

$$\text{Desired RM Usage Rate} = \left(\text{Adjustment for WIP Product} + \text{Desired Production Start Rate}\right) * \text{Raw Material Usage Per Product}$$

In this formula, the *Adjustment for WIP Product* modifies production starts to keep the WIP inventory in line with the desired level. Desired WIP is set to provide a level of work in process sufficient to yield the desired rate of production given the current manufacturing cycle time:

$$\text{Adjustment for WIP Product} = \frac{\text{(Desired WIP Product – M\_WIP Inventory)}}{\text{WIP Adj. Time}}$$

To facilitate analysis of the model, and without loss of generality, the simulations below assume *Raw Material Usage Per Product =1*, which means producing one unit costs one piece of the raw material.

As to the *Desired Production Start Rate*, it is determined by *Adjustment for Product Inventory* and the *Shipment Rate* and it is constrained to be nonnegative.

$$\text{Desired Production Start Rate} = MAX\left(\text{Adjustment for Product Inventory} + \text{Shipment Rate}, 0\right)$$

3. The *Product Finish Rate* is defined as the rate of finishing the production. This variable works as the inflow to the Stock M-Product Inventory and the outflow from the Stock M-Product WIP at the same time.
The third-order delay is used to model the production process:

■   *Product Finish Rate* = DELAY3 (*RM Usage Rate*, *Manufacturing Cycle Time*)
Here, the *Manufacturing Cycle Time* represents the average transit time for all items aggregated together in the model.

4. As to the *Shipment Rate*, it is analogous to the *Raw Material Usage Rate* and plays the role as the outflow of Product Inventory Stock. Normally, the shipment rate equals

the desired shipment rate, but if inventory is inadequate, some of the requested products will be out of stock, so it is also constrained by the *Max Shipment Rate*.

$$\text{Shipment Rate} = \text{MIN} \left(\frac{\text{Desired Shipment}}{\text{Rate}}, \frac{\text{Max Shipment}}{\text{Rate}} \right)$$

The *Max Shipment Rate* depends on the manufacturer's current raw material inventory level and the *Minimum Processing Time*.

$$\blacksquare \quad \frac{\text{Max Shipment}}{\text{Rate}} = \frac{\text{Raw Material Inventory}}{\text{Min Processing Time}}$$

The variables *Desired Shipment Rate* will be explained in the following Distributor Part. It needs to point out that the values of the exogenous, such as the adjustment time, safety stock coverage and so on, will be set for the model simulation. The details are listed in the appendix.
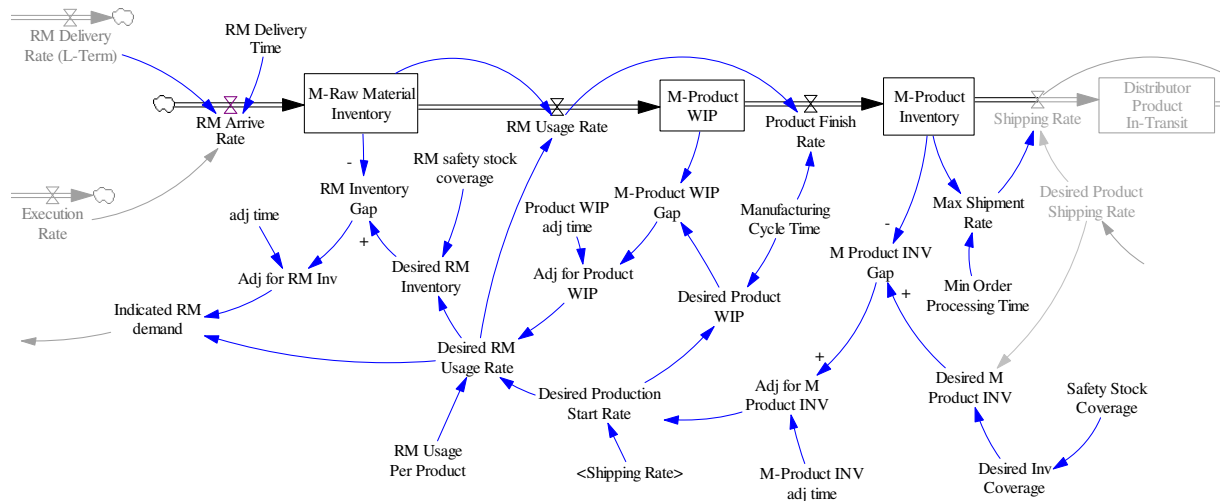
Figure 5.8: Manufacturer Sub-model Structure

3. Distributor Part

The distributor is also an important part in the supply chain model. It sets the bridge between the manufacturer and the customer. However, due to the existence of the distributor, the delivery of the products and information may meet some problems caused by the time delay. On the other hand, this part deals with the demand forecasting, which is the critical information for all parts in the system.

Figure 5.9 depicts the sub-model structure of the distributor. From it, we can see this part includes two stocks: *Distributor In_Transit Products* and *Distributor Product Inventory.*

Distributor In_Transit Products refers to the accumulation of the products in transportation and *Distributor Product Inventory* represents the inventory level of the distributor.

$$\text{Distributor Product In\_Transit} = \int_0^t (\text{Shipment Rate - Arrive Rate})dt + \text{Initial Distributor Product In\_Transit}$$

$$\text{Distributor Product Inventory} = \int_0^t (\text{Arrive Rate - Sales Rate})\,dt + \text{Initial Distributor Product Inventory}$$

The inflow---Shipment Rate has been introduced in the last sector, where it is regarded as the outflow to the product inventory. As to the *Desired Shipment* Rate, it represents the demand for products from the distributor, which is determined by the forecasted customer demand and the adjustment of the inventory level. The formula is constructed:

$$\text{Desired Shipment Rate} = \text{Adjustment for Product In\_Transit} + \text{Desired Product Demand}$$

Where, the *Desired Product Demand* is defined as the sum of *Adjustment for Product Inventory* and the *Forecasted Customer Demand*.

Another flow, the S*ales Rate*, the outflow of the stock-Product Inventory, is analogous to RM Usage Rate in figure 5.8. This output variable tells how many products will be sold to the customers within a certain time period. The S*ales Rate* is equal to the actual customer demand for the product but it is constrained by the available products that can be supplied. The formula is constructed:

$$\text{Sales Rate} = Min\left(\text{Customer demand for product}, \text{Distributor Product INV}\right)$$

There comes to the demand forecasting. Here the *Customer Demand for Product* is assumed to be the exogenous. And the forecasted demand is using the first-order exponential smoothing of the actual customer demand.

$$\text{Forecasted Customer Demand for Product} = \text{SMOOTH}\left(\text{Customer demand for product}, 6\right)$$

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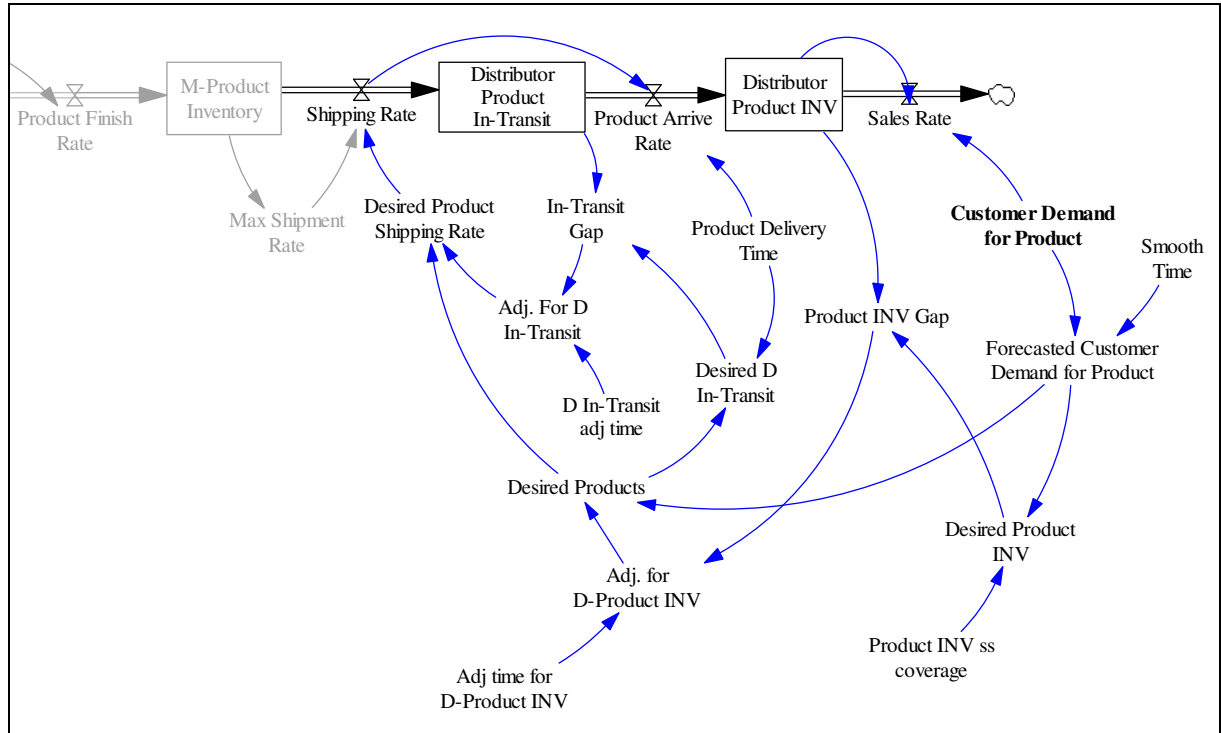
Figure 5.9: Distributor Sub-model Structure

5.3.2 Finance Flow Sub-Sector

Finance flow, one of the three flows in the supply chain system, is an important part we would consider in our model. This sub-sector will introduce the structure of the finance flow sub-model as well as the equations of the key variables. The SFD is in figure 5.10.

As discussed in chapter 3, the *Average Unit Procurement Cost* is regarded as a factor to determine the share of different contracts. In the long-term contract, this value is equal to the pre-paid procurement cost, which is pre-agreed by buyer and supplier. Therefore, *Average Unit Procurement Cost* in long-term contract is just the pre-agreed unit cost, which is influenced by the spot market price. In the option contract, since the total cost is the sum of reservation cost and execution cost, the *Average Unit Procurement Cost* is calculated in the following equation.

$$\begin{array}{c} \textit{Average Unit} \\ \textit{Procurement Cost} \end{array} = \frac{\text{Procurement Cost with Option Contract}}{\text{Total Procurement Quantity}}$$

Where,
Total Procurement Quantity accumulates the total raw material purchased from the supplier for a time period. In the option contract, it is the accumulation of the actual executed pre-booked quantity.

$$\begin{array}{lll} \textit{Total Procurement} \\ \textit{Quantity} \end{array} \quad = \quad \int_0^t (\text{Execution Rate })dt \quad + \quad \begin{array}{l} \text{Initial Procurement} \\ \text{Quantity} \end{array}$$

Procurement Cost with Option Contract represents the sum of execution cost and reservation cost over a certain time period.

$$\begin{array}{l} \textit{Procurement Cost with} \\ \textit{Option Contract} \end{array} \quad = \quad \int_0^t (\text{Pay for Reservation - Pay for Execution})dt \quad + \quad \begin{array}{l} \text{Initial} \\ \text{Cost} \end{array}$$

And,

$$\begin{array}{l} \textit{Pay for} \\ \textit{Reservation} \end{array} \quad = \quad \text{Reservation Price} \quad * \quad \text{Reservation Rate}$$

$$\begin{array}{l} \textit{Pay for} \\ \textit{Execution} \end{array} \quad = \quad \text{Execution Price} \quad * \quad \text{Execution Rate}$$

In the above two equations, the *Execution Rate* and *Reservation Rate* are two variables relative to the material flow and have been discussed in the 'Supplier Part' sub-sector. We need to know the *Execution Price* and *Reservation Price*. Here, the *Reservation Price* is assumed to be an exogenous.
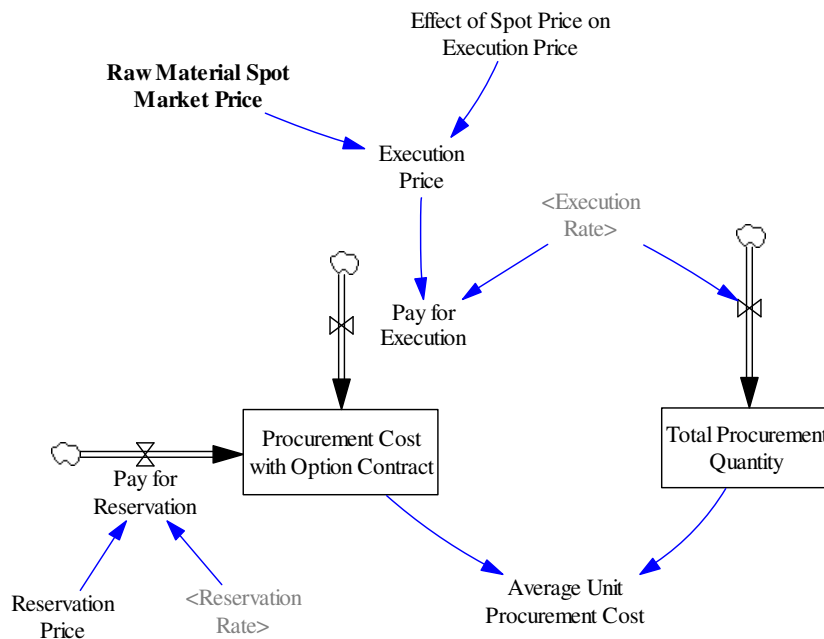
**Figure 5.10: Finance Flow Sub-model Structure (Option Contract)**

And the *Execution Price* is modelled as a graph function of the *Raw Material Spot Market Price*. It is thus an endogenous variable as it is directly affected by the

spot market price. The actual value of 'Execution Price' is equal to the 'spot market price' times the 'effect of spot price on execution price'.

$$
\begin{array}{ccc}
\text{Execution} \\
\text{Price}
\end{array}
=
\begin{array}{c}
\text{Effect of Spot Price on} \\
\text{Execution Price}
\end{array}
*
\begin{array}{c}
\text{Raw Material Spot} \\
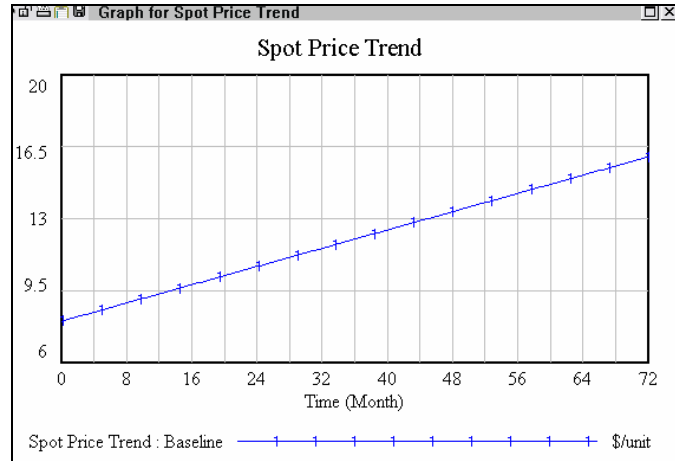\text{Market Price}
\end{array}
$$

Here, we make use of the Graph Lookup Function in Vensim and the *Effect of Spot Price on Execution Price* is formulated as a table function shown in Figure 5.11. On the whole, the execution price is in the same trend as spot price is. But their change rates are different. When the spot price is zero, the corresponding value of execution price is zero. When the spot price reaches 15, the execution price is only 10. It is necessary to point out that these two variables are non-linearly linked.
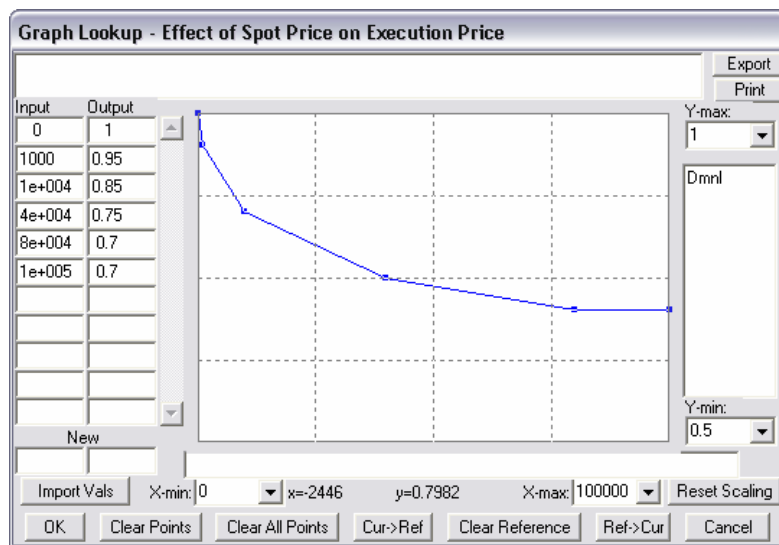
Figure 5.11: Graph of Execution Price as a function of Spot Price

According to the assumptions we discussed before, the spot market price of raw material is in the upper trend. In our model, is set to depict this trend.

$$
\textit{Spot Price Trend} \quad = \quad 8*(1+\text{Time}/72)
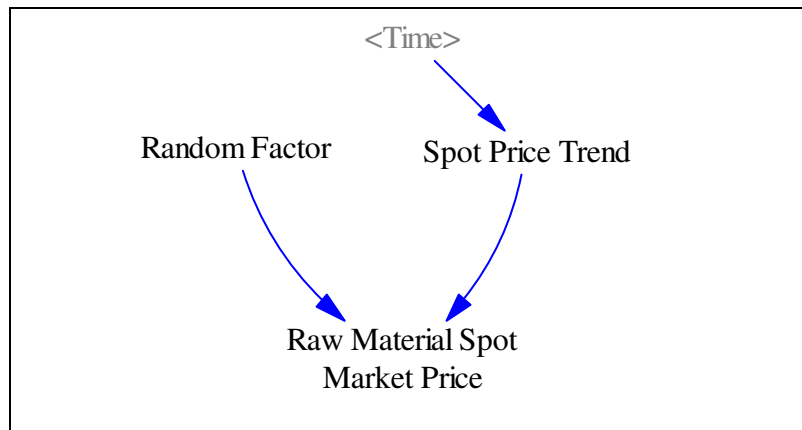$$

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Figure 5.12: Spot Price Trend

We use the exponential random function to show the uncertainty of the spot price.

Random Factor = RANDOM EXPONENTIAL(0.8 , 1.2, 1, 1 , 0)

Then the *Raw Material Spot Market Price* can be illustrated as follow:

Raw Material Spot Market Price = Spot Price Trend * Random Factor

The relationship between the above variables can refer to figure 5.13.

Figure 5.13: Function of Raw Material Spot Price

Chapter 6

Model Testing

6.1 Introduction

Last chapter describes the model structures and equations in details. In order to justify confidence in the model, this chapter focuses on the model testing and try to show the appropriateness of underlying assumptions, robustness, and the sensitivity of results to assumptions about the model boundary and feedback structure.

In this chapter, a wide range of tests including boundary adequacy tests, structure assessment tests, extreme condition tests and sensitivity tests are carried out to show the robustness and trustfulness of the model in this paper.

6.2 Boundary Adequacy Test

Boundary adequacy tests assess the appropriateness of the model boundary for the purpose at hand. They help to judge whether the endogens and exogenesis in our model is set in a suitable way or not. We would carry out the tests by investigating model boundary. Through the tests, we hope that the effect of the extensions of model boundary on the proposed policies can be estimated in advance.

Firstly, we consider those important concepts endogenous to the model. We test these variables in details to see whether they influence or are influenced by other variables in a reasonable way. For example, as discussed in Chapter 5, we test raw material inventory and prove that it is one of the key endogenous variables bridging feedback loops. After making tests on the endogenous, we make sure that these variables can portray the structural mechanism of the system and important for the purpose of our research.

Besides, constants in the model are exogenous but may be variable over time in reality. Take the adjustment time for example, it could be changed over time as the efficiency of manufacturer improves. But as our purpose is to compare the performance of the supply chain system under difference purchasing contracts, adjustment time would not influence the comparison results even though it changes the behavior pattern of some variables to some extent. Hence, this constant assumption is adequate for the boundary of our model.

Also, we can refer to chapter 5, where the charts and subsystem diagrams about the model boundary are described. They would be the effective tools to help test whether the boundary is properly considered.

Based on the above discussion and regarding the purpose of this research, we are confident that the established model boundary is appropriate for the purpose of the research.

6.3 Structure Assessment Tests

In this paper, the purpose of structure assessment tests is to know whether the model properly depicts the supply chain system and the procurement problems in reality. Therefore, the tests focus on model's consistency with knowledge of the real system, the aggregation level, the model conformance and the model structure behavior.

6.3.1 Test on Level of Aggregation

The first structure assessment test is to check the level of aggregation. The level of aggregation refers the level of details in the model. In this research, we mainly focus on the effect of purchasing contracts on the performance of manufacturer. Meanwhile, since the manufacturer is a part of supply chain system, three dynamically related flows --- material flow, finance flow and information flow are simultaneously considered in the model. The aggregation level is relatively low in my

case.

The structure assessment test is carried out to demonstrate whether the level of detail I chose to represent is appropriate for the purpose of the model. The test result demonstrates that all the three flows are closely related with feedbacks. The variables in all the subsystems have their corresponding meanings in the real world. Thus, the level of aggregation in our model is in coherent with the purpose of this research to some extent.

6.3.2 Test on the Model Conformance

The second structure assessment test is conducted to examine the conformance of the model to the basic physical conservation laws. In reality, the stocks are required to be non-negative. Therefore, we firstly conduct the tests by directly inspecting the equations of the stocks such as raw material inventory to make sure that none of them would become negative due to the control mechanism by their flows. Besides, we would check the relationship between flows and stocks. For example, if the stock approaches zero, the outflows from all stocks approach zero.

6.3.3 Test on the Structure Behavior

In this part, we would test on the structure behaviour by cutting the feedback loops so that the source of particular dynamic behaviours can be demonstrated and explained.

Test : *RM Usage Per Product* $\quad 1 \rightarrow 0$

Figure 6.1 depicts the causal loop diagram of the material flow part in option contract and figure 6.2 represents CLD in the long-term contract. These two CLDs have the difference in their purchasing part. As we can see from them, the *RM Usage per Product* is an exogenous but it directly influences the key variable *Desired RM Usage Rate* which lies in the feedback.

The *RM Usage per Product* means how many raw materials are needed for producing one product. In the original model, its value is set to be 1. In our Structure Behavior test, we change it from 1 to 0. Correspondingly, the *Desired RM Usage Rate* is zero regardless of other relative inputs. Referring to figure 6.1 and figure 6.2, this is

almost equal to cutting the feedback loops. Then we run the model again to see the responds of other key variables in the CLD.

The test results are shown in figure 6.3 to figure 6.5. Each figure includes two panels. The left one depicts the behaviour in option contract and the right one in long-term contract.
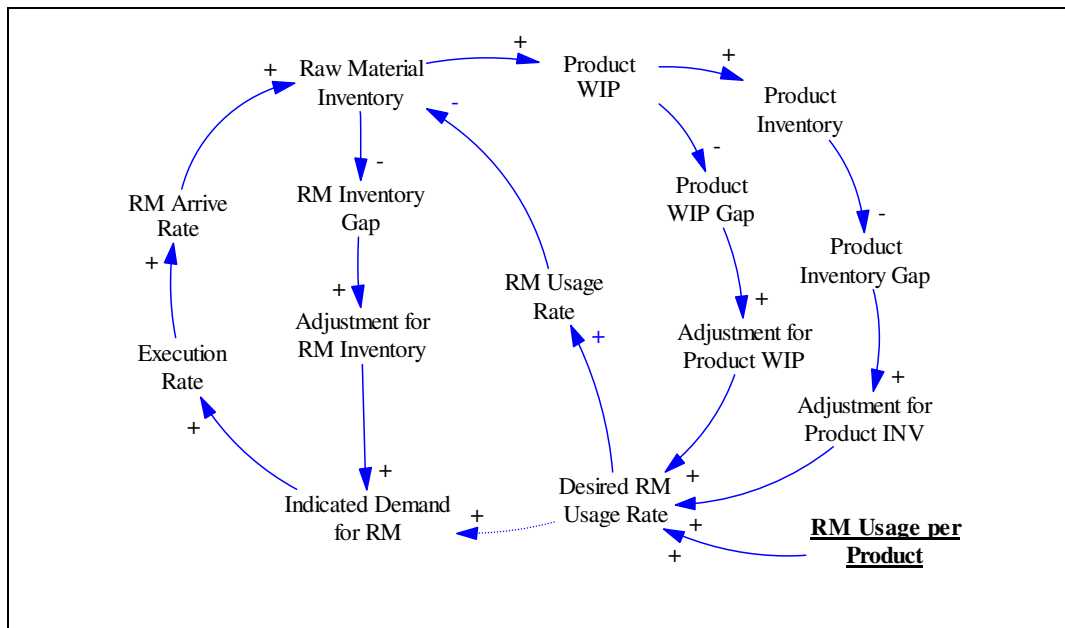

Figure 6.1: CLD of Main Material Flow Part (Option Contract)
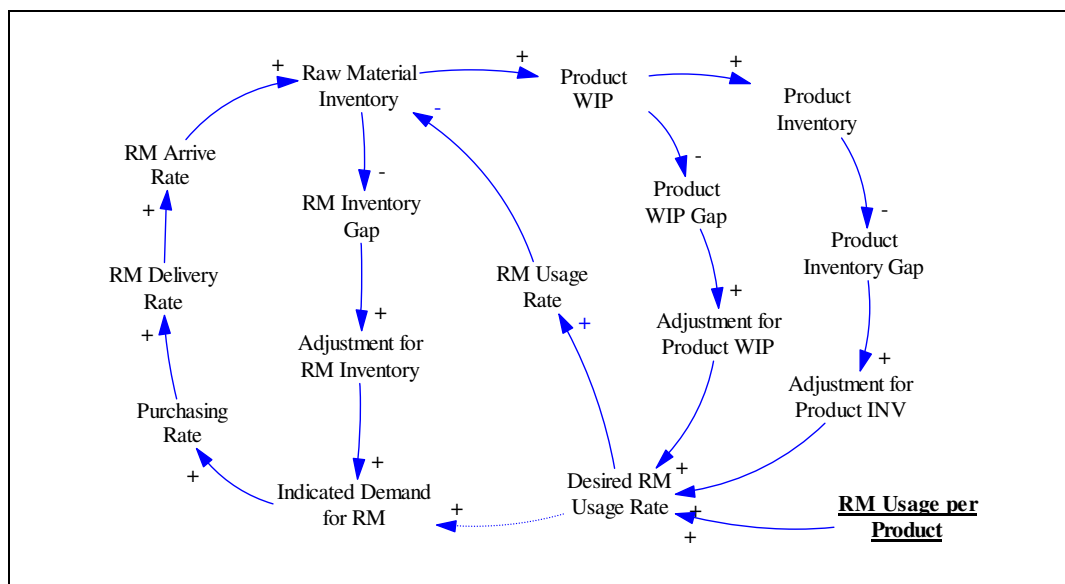
**Figure 6.2: CLD of Main Material Flow Part (Long-term Contract)**

Figure 6.3 demonstrates the simulation results of *Indicated Demand for RM*.

When in equilibrium, its value is 1000 unit per month. Under the structure test, its value becomes zero. As we can see from the CLDs in figure 6.1 and 6.2, the *Indicated Demand for RM* is determined by *Desired RM Usage Rate* and *Adj. for RM Inventory*. In equilibrium, the *Adj. for RM Inventory* is zero. Therefore, when the Desired RM Usage Rate becomes zero, the value of *Indicated Demand for RM* is correspondingly zero as the figure 6.3 indicates.
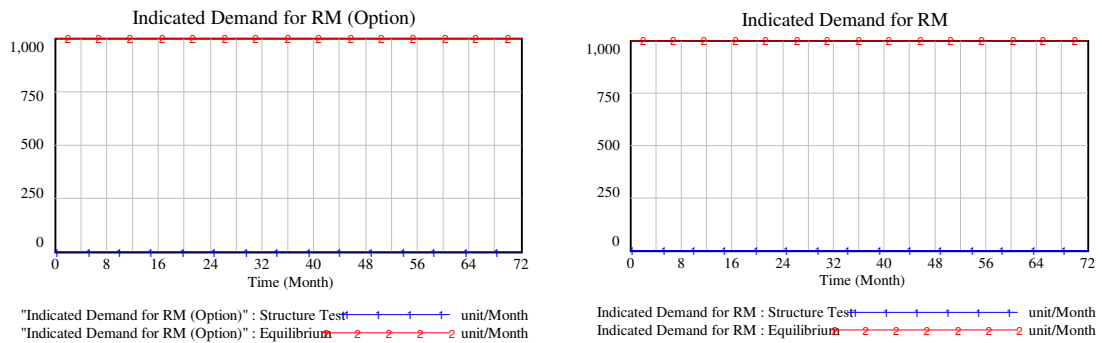

Figure 6.3：Indicated Demand for RM under Structure Test

Then it comes to the behaviors of raw material inventory. Figure 6.4 depicts the situations with two different contracts. Referring to the above CLDs, we get to know that *Indicated Demand for RM* directly determines the *RM Usage Rate,* which is the outflow to the stock *Raw Material Inventory*. Therefore, when the *Indicated Demand for RM* becomes zero, correspondingly the *RM Usage Rate* drops to zero immediately. In addition, due to the existence of time delay and raw material delivery time, the *RM Arrive Rate*, which plays the role of inflow to the stock *Raw Material Inventory*, keeps its original value and drops to 0 after a period of delay time. As a result, the net flow is positive and then becomes zero. Correspondingly, we can see from figure 6.4 how the behaviors of *Raw Material Inventory* perform under the structure test. For instance, in option contract its value increases at the beginning but quickly reach the equilibrium.
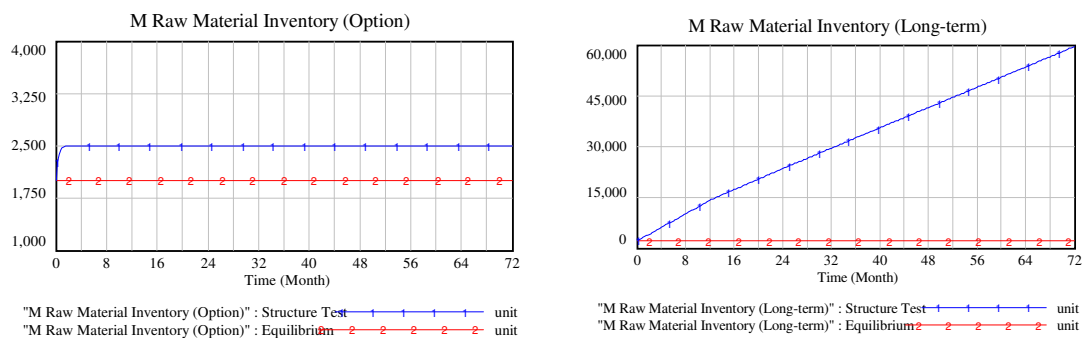
Figure 6.4：Raw Material Inventory under Structure Test

Similarly, the behaviors of *Product Inventory* under structure tests are shown and compared as figure 6.5 depicts. Observe two panels and the test results conform to the causal relationship between variables as the CLDs show.
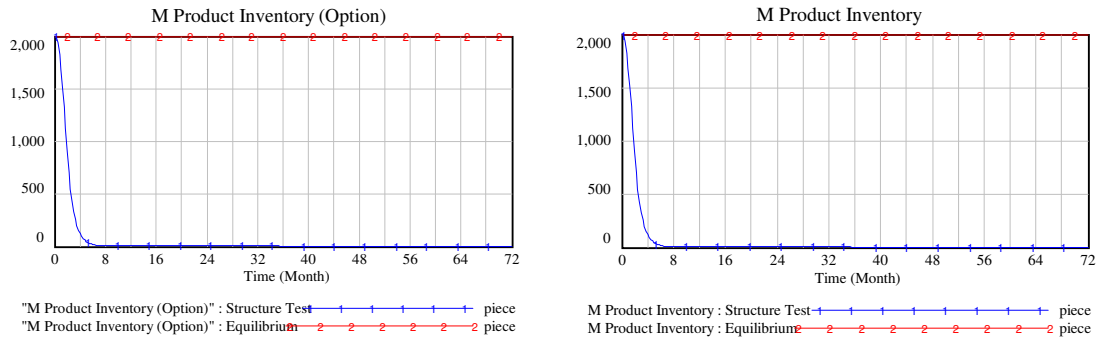
Figure 6.5：Product Inventory under Structure Test

Based on the above structure tests and analysis of the results, it is demonstrated that the model has passed this test and prove the reasonability of the structure.

6.4 Dimensional Consistency Test

Dimensional consistency plays a critical role in constructing the models. Unit errors reveal important flaws in the understanding of the structure or decision process.

All the parameters in the system dynamic models have dimensions and it is noted that 'dimensionless' can be labelled as 'Dmnl'. Dimensional consistency tests check whether each equation is dimensionally consistent without the use of parameters having no real world meaning.

In this model, with the help of the simulation software Vensim, which include automated dimensional analysis, we conduct the dimensional consistency test. The results of test show that all the parameters in my model pass the test and conform to the dimensional consistency.

6.5 Parameter Assessment Test

In system dynamics models, all the parameters should have the real world counterparts. Also, the parameter values are required to be in consistence with

relevant descriptive and numerical knowledge of the system. Because of the above two points, the parameter assessment tests are conducted.

Usually, two methods are used to estimate values of parameters in the model: a formal statistical estimation from numerical data and a judgmental estimation based on our knowledge (Sterman, 2000). Consider the model and parameters in this research. With the same parameters and basic model structure, if only the parameters are set in a reasonable range, the comparison results can be achieved and analyzed. Therefore, we estimate some of the parameters by using a judgemental estimation method based on our knowledge and the information indicated by data available.

By testing the parameters, we demonstrate that the parameters are suitably chosen and the values are in the reasonable range.

Furthermore, in order to demonstrate that the model, which generates the reasonable behaviour, is set up on the basis of suitable chosen parameters, the sensitivity analysis tests would be carried out as the supplementary to the parameter assessment tests.

6.6 Extreme Condition Tests

The purpose of the extreme condition tests is to check the robustness of model under extreme conditions. By conducting such tests, we get to know whether the models behave appropriately when the inputs take on extreme values like zero or infinity.

In this sector, the extreme tests would be carried out in two ways. One is to inspect the model equations in extreme conditions. By doing so, the adequacy of the formula is tested. The other way is the model extreme tests which would show whether the responses of the model behaviour to the extreme values of some key variables are reasonable.

6.6.1 Extreme Tests on Equations

Each equation should make sense even when the inputs are in extreme conditions. Here, we select one equation in the portfolio contract model as an example.

$$\textit{Share from Option Contract} = Initial\_Share \times \left[\frac{w}{1+w} \cdot \frac{\text{AUPC\_Option}}{\text{AUPC\_L-term}} + \frac{1}{1+w} \cdot \frac{RM\_Inventory}{Desired\_RM\_Inv} \right]$$

The above equation calculates the percentage of purchasing from option contract. The variable w represents the weight of the average unit cost's influence on the share and it is set as an exogenous. Here we would make extreme tests on w to know how the *Share from Option Contract* reacts. Firstly, it is assumed that w is equal to zero, which means the average unit cost (AUPC) will not influence the *share from Option Contract*. Run the model again and find out that *share from Option Contract* doesn't react to the changes of AUPC any more, which is in coherent with the above analysis. Then we assume w goes to infinity and make observations on the responds of *Share from Option Contract* again. The simulation results show that the behaviour of *Share from Option Contract* is directly influenced by the inventory level but has no relationship with the changes of AUPC. Check the equation, we find the above analysis conforms to the reality.

6.6.2 Extreme Tests on Models

The extreme test evaluates the robustness of the model by checking how the model works in extreme conditions. A robust model should behave in a realistic pattern no mater how extreme the inputs are.

In this part, two extreme tests would be conducted to test the model's robustness. The key variables are selected to show their responses to the extreme conditions with option contract and long-term contract respectively.

- ***Test 1: Customer Demand for Product drops to 0***

The test 1 is to analyze the model under the extreme condition that *Customer Demand for Product* becomes extremely low, i.e., 0. For the purpose of comparison, we set it firstly to its reference values, 1000 unit/month. Then we put a step decrease on it towards 0 at time 10. The equation is as follows:

$$\frac{Customer\ Demand}{For\ Product} \quad = \quad \text{IF THEN ELSE (Time<10, 1000, 0)}$$

Figure 6-6 shows the extreme condition of the parameter *Customer Demand for Product*, which is compared with its original value.
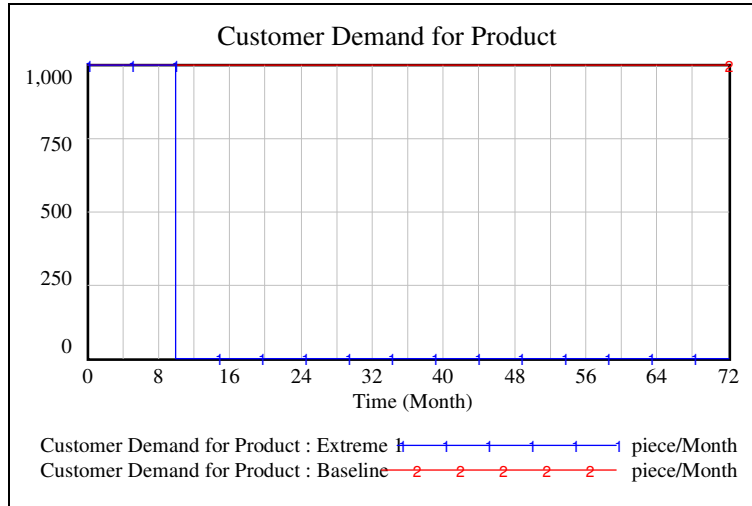
Figure 6.6: Customer Demand for Product under Extreme Test 1

The following figures show the simulation and comparison results. There are two panels in each figure. The left one shows the situations in long-term contract and the right one is with the option contract.

With the drop of *Customer Demand for Product*, the *Indicated Demand for RM* and *Desired Production Start Rate* drop quickly to zero as figure 6.7 and 6.8 shows. It's noticeable that both in option contract and long-term contract, the response of these two variables to the change of *Customer Demand for Product* are almost the same. In reality, the *Customer Demand for Product* directly influences the value of *Indicated Demand for RM* and *Desired Production Start Rate*. Thus, the simulation results conform to the reality.
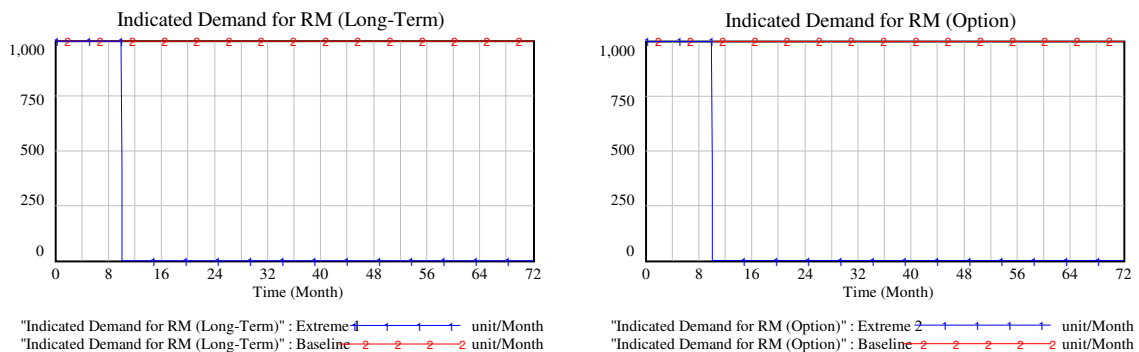
Figure 6.7: Indicated Demand for RM under Extreme Test 1
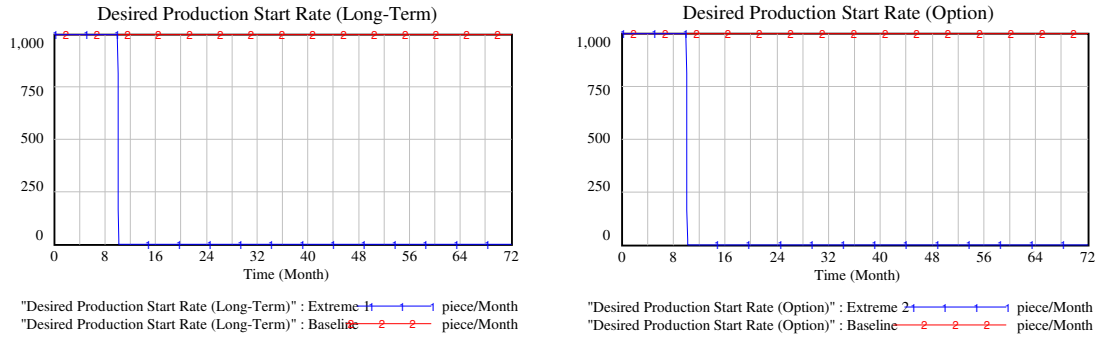
Figure 6.8: Desired Production Start Rate under Extreme Test 1

Figure 6.9 shows the behaviors of the raw material usage rate in two contracts. Since this parameter is directly determined by the *Indicated RM Usage Rate*, the value of this variable also goes to zero after time 10. And the same situation happens to *M shipment rate* as figure 6.10 indicates.
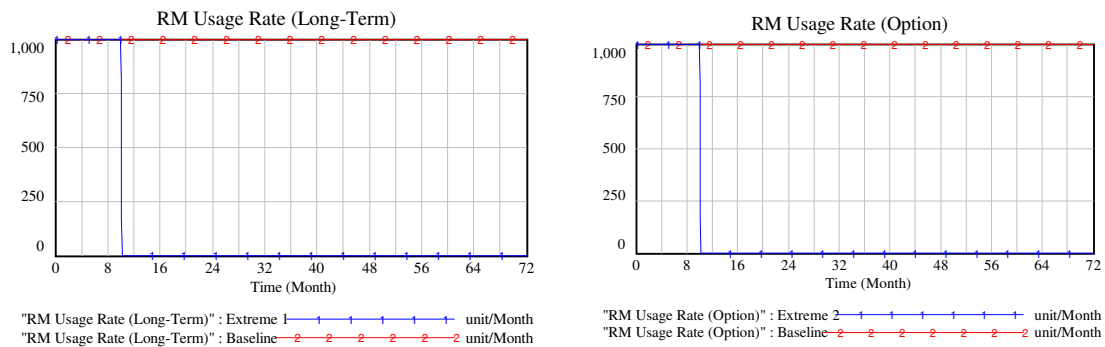
Figure 6.9: RM Usage Rate under Extreme Test 1
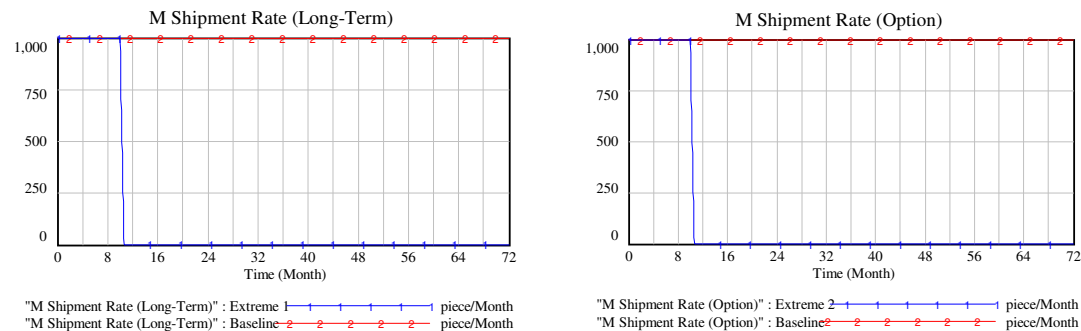
Figure 6.10: M Shipment Rate under Extreme Test 1

The following three figures indicate the responses of the three stocks: *M Raw Material Inventory, M WIP Inventory* and *M Product Inventory*.

Figure 6.11 indicates the behaviors of the *M Raw Material Inventory*. Firstly, we

find that the responds of this variable to the extreme condition in long-term contact and option contract are quite different. In long-term contract, the raw material order rate from the manufacturer is pre-decided and not changed with the real demand until the end of the pre-agree contract period. Therefore, as we can see in the left panel of figure 6.11, the *Raw Material Inventory* goes up linearly after time 10. In option contract, the situation is opposite. The manufacturer can change the demand of raw material by adjusting the execution rate, quickly responding to the down-stream market demand. It is noticeable that the raw material usage rate immediately reduces to zero at time 10, which means no raw material would be consumed after time 10 Thus, the general trend of *Raw Material Inventory* in extreme condition is increasing.
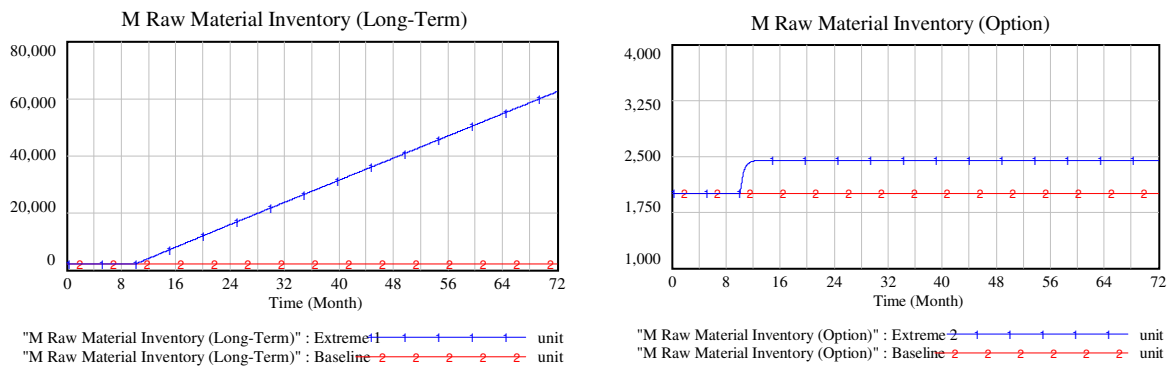
Figure 6.11：M Raw Material Inventory under Extreme Test 1

Figure 6.12 compares the behavior of *M Product WIP* in extreme conditions. The left and right panels show the same pattern. When the *Customer Demand for Product* drops to zero at time 10, the need for product becomes zero and therefore the demand for raw material is none. *RM Usage Rate* correspondingly becomes zero. At that time the product finish rate keeps the same level because of the time delay. Thus, the working in process product is reducing quickly until it goes to zero. It is because no new raw material is requested to be processed but the finished products are in the same rate.

The behaviors of *M Product Inventory* are shown in figure 6.13. In reality, the finished products are delivered to the inventory until no products are in process. Meanwhile, the down-stream demand for products drops to zero whenever the final market demand becomes zero. Therefore, the product inventory will go up and then keep stable. The responds of *M Product Inventory* to the extreme test shown in figure 6.13 conforms to the above analysis.
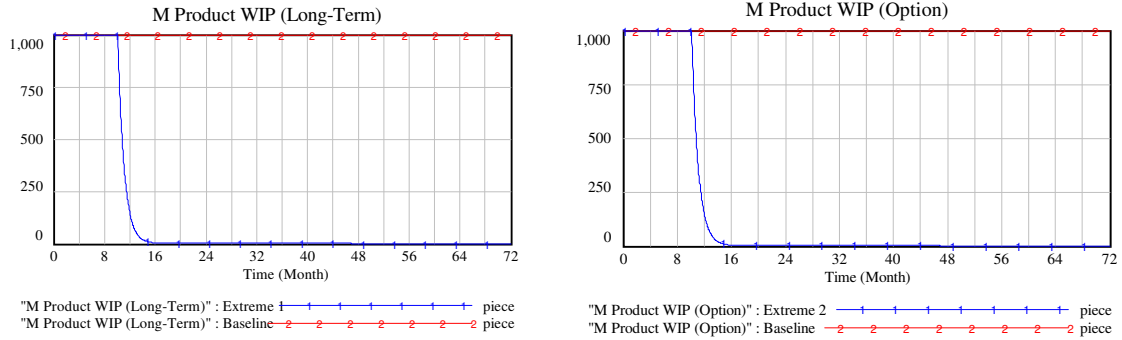
Figure 6.12: M Product WIP under Extreme Test 1
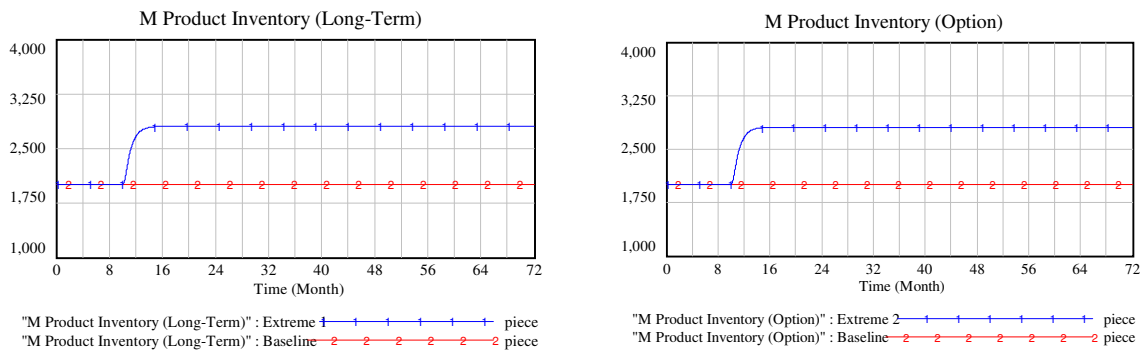
Figure 6.13: M Product Inventory under Extreme Test 1

- *Test 2: Manufacturing Cycle Time is extremely high*

It takes time to produce the raw material into products. In our model, we use the variable *Manufacturing Cycle Time* to show the production time. To test the responds of other key variables to its extreme value, we set the value of it to be 10000 months and run the model again to compare the results.

- Manufacturing Cycle time = $\left\{\begin{array}{lll} 10000 & \text{(months)} & \textbf{\textit{Baseline}} \\ 1 & \text{(months)} & \textbf{\textit{Extreme Condition}} \end{array}\right.$

When the manufacturing cycle time is extremely large, it means it takes very long time to produce. Therefore, the raw material is used much less than that in baseline situation, which leads to the high inventory of raw material and WIP products.

Figure 6.14 depicts the behaviours of the *M Raw Material Inventory* under Extreme Test 2. From the two panels, we can see the value increases sharply. However, due to the characteristics of long-term contract and option contract, their patterns are a bit different.

M Raw Material Inventory (Long-Term)

M Raw Material Inventory (Option)

"M Raw Material Inventory (Long-Term)" : Extreme 2 —1—1—1—1— unit
"M Raw Material Inventory (Long-Term)" : Baseline —2—2—2—2—2— unit

"M Raw Material Inventory (Option)" : Extreme 2 —1—1—1—1— unit
"M Raw Material Inventory (Option)" : Baseline —2—2—2—2—2— unit
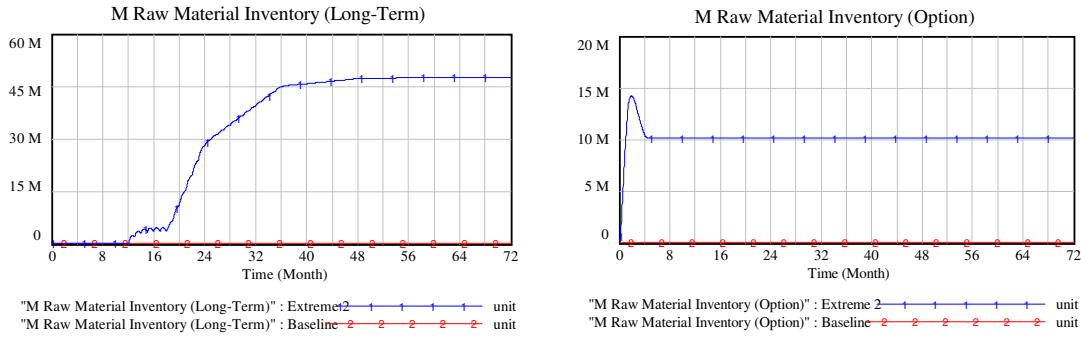
Figure 6.14：M Raw Material Inventory under Extreme Test 2

M Product WIP goes up sharply after time 10 and soon reaches the equilibrium statues. With long-term contract and option contract, their changes of behaviours in extreme condition are the same but in option contract, the equilibrium value is larger. It can be explained as follows. When the manufacturing cycle time becomes large, few finished products can be sent to the inventory and further the downstream demand can't be met because of the stakeout. The shortage of finished products causes larger demand for products as well as the raw material indirectly. As a result, the indicated demand for raw material increases. Since the option contracts allow the manufacturer executes the option according to the indicated demand for RM, they respond more quickly to the changes. More raw material arrive rate, more *M Product WIP*.

M Product WIP (Long-Term)

M Product WIP (Option)

"M Product WIP (Long-Term)" : Extreme 2 —1—1—1—1— piece
"M Product WIP (Long-Term)" : Baseline —2—2—2—2—2— piece

"M Product WIP (Option)" : Extreme 2 —1—1—1—1— piece
"M Product WIP (Option)" : Baseline —2—2—2—2—2— piece
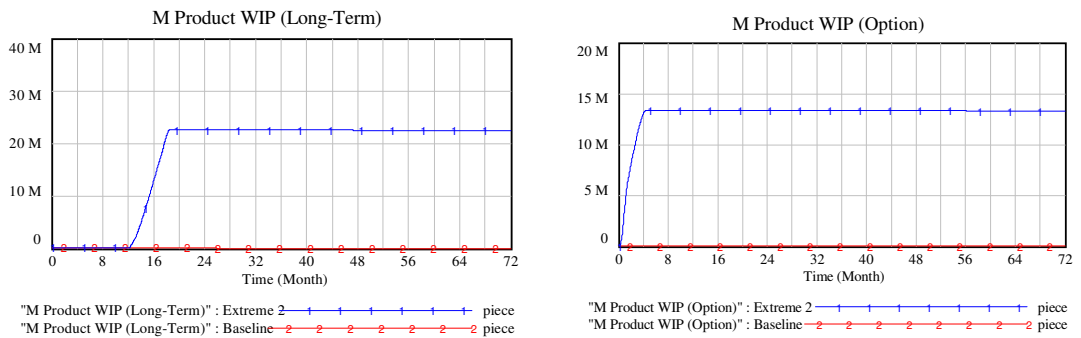
Figure 6.15: M Product WIP under Extreme Test 2
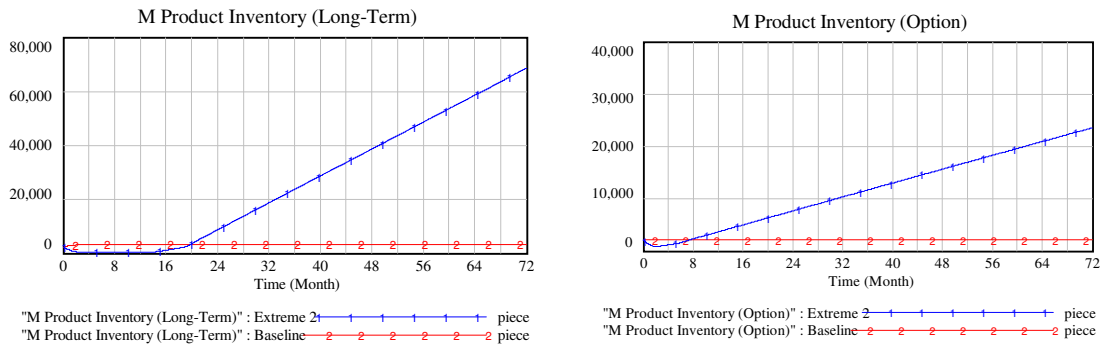
Figure 6.16：M Product Inventory under Extreme Test 2

The behaviours resulting from the model successfully meet our expectation under these extreme conditions, which demonstrates that the structure of the model captures the underlying realities.

6.7 Sensitivity Analysis Test

Due to the limitation of time and resources, it's impossible to test all combinations of assumptions over their wide range of uncertainty. Therefore, the sensitivity tests are conducted to test the robustness of the conclusions to the uncertainty in model assumptions. The focuses are on those relationships and parameters involved in delays and interactions that we suspect to be influential.

There exist three types of sensitivity tests: numerical, behaviour mode and policy tests. In this sector, we would mainly test the numerical and behaviour mode and the policy sensitivity test will be carried out in chapter 8.

6.7.1 Numerical Sensitivity Test

Numerical sensitivity tests are conducted to test the uncertainty of the values of parameters. The parameters chosen for the tests are usually the key parameters which describe the important aspects of the model.

In our model, there are mainly three types of important parameters.
1) Adjustment time (e.g. *RM Inventory adj. time*; *WIP adj. time*; *In-transit adj. time*)
2) Delivery time (e.g. *RM Delivery Time*; *Product Delivery Time*)
3) Other key variables (e.g. *RM usage Per Product*; *Contract Period*)

Based on the above statement, here we select three parameters to carry out numerical sensitivity tests. They are *RM Inventory adj. time, Product Delivery Time* and *RM usage Per Product*.

These three parameters are the typical and representative exogenous variables in the model. By controlling changes of these parameters, we simulate the models and collect the simulation results for comparison and analysis. In this research, we select the variable **M Raw Material Inventory** as the assessment factor and the results of numerical sensitivity tests on this parameter are illustrated in Table 4.1. In Table 4.1, the first column shows variables that are tested on. Each variable is tested with the

original value built in the model, one test condition resulting from a 50% increase (for the third parameter, 100% increase) and the other resulting from a 50% decrease.

The results of the sensitivity test are listed in the second and third columns, representing the **Raw Material Inventory** with long-term contract and option contract respectively. The data not only show the values and the percentages of corresponding changes in the test variables.

Table 4.1: Sensitivity Test Results

| Parameters and Values		Raw Material Inventory (Long-Term Contract)		Raw Material Inventory (Option Contract)	
		Unit	Change %	Unit	Change %
RM Inventory adj. time	Original Value (1)	1981	0	2130	0
	50% Increase (1.5)	2160	9.0%	2099	3.2%
	50% Decrease (0.5)	2186	1.2%	2051	-6.7%
Product Delivery Time	Original Value (1)	1981	0	2130	0
	50% Increase (1.5)	2007	-8.2%	2215	8.0%
	50% Decrease (0.5)	2069	3.1%	2064	-6.8%
RM usage Per Product	Original Value (1)	1981	0	2130	0
	100% Increase (2)	2160	4.4%	2642	28.0%
	50% Decrease (0.5)	2593	20.0%	2191	-17.1%

As table 4.1 indicates, the results from a test on the numerical sensitivity tests suggest that key variable in the model are not sensitive to reasonable modifications in parameters RM Inventory adj. time, Product Delivery Time. Meanwhile, we find the model is more sensitive to the parameter *RM usage Per Product.*

6.7.2 Behaviour Mode Sensitivity Test

By behaviour mode sensitivity test, we can get to know whether a change in assumptions changes the patterns of behaviour generated by the model.

In the original model, we assume that the *Customer Demand for Product* is exogenous and independent. In the real life, the demand for product is influenced by the price to some extent. Even the fluctuation of raw material's price would cause the instability of the demand.

In the behaviour mode test, we try to set *Customer Demand for Product* as an endogenous and determined by the spot market price of the products.

Effect of Market Spot
Price on the demand

<Raw Material Spot
Market Price>

Customer Demand
for Product
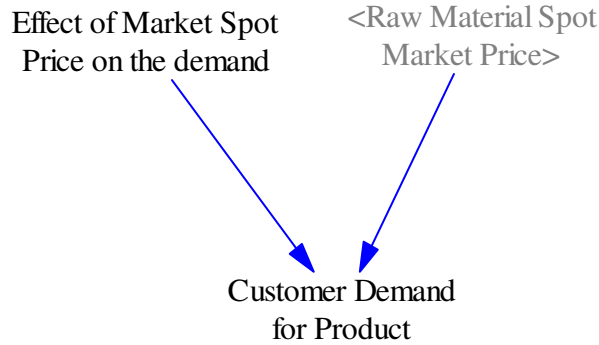
Figure 6.17: Change in the Model Structure

M Raw Material Inventory (Long-term)

"M Raw Material Inventory (Long-term)" : baseline   unit
"M Raw Material Inventory (Long-term)" : Sensitivity Test 2   unit

M Raw Material Inventory (Option)

"M Raw Material Inventory (Option)" : Baseline   unit
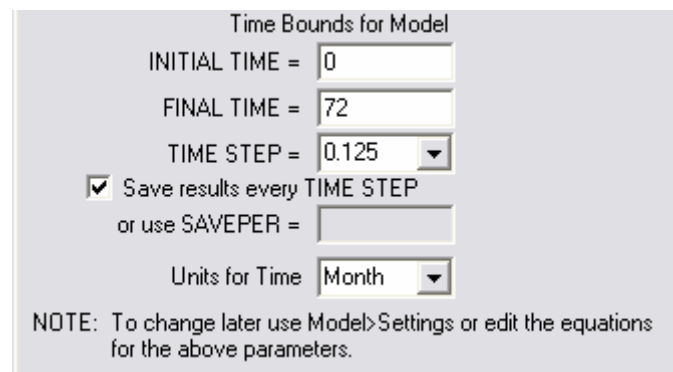"M Raw Material Inventory (Option)" : Sensitivity Test 2   unit
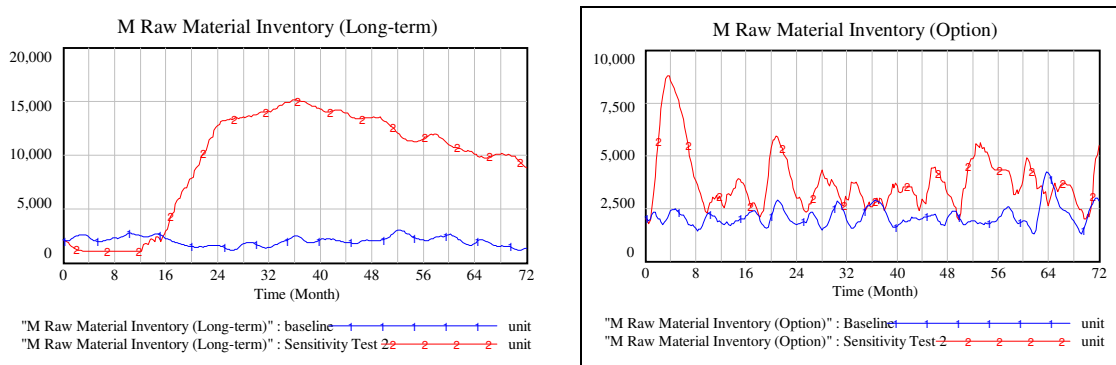
Figure 6.18：M Raw Material Inventory under Sensitivity Test

Figure 6.18 shows the behaviours of *M Raw Material Inventory* under behaviour sensitivity test. The red curve represents how the behaviour changes when the *Customer Demand for Product* is assumed to be an endogenous as figure 6.17 indicates instead of the exogenous. And the blue one is the situation when the *Customer Demand for Product* is an exogenous and conforms to the normal distribution. In figure 6.18, the left panel indicates the situation in long-term contract while the right one is in the option contract. Observe these two panels and we can see that the two curves in each panel show similar pattern, which means that the behaviour mode of *M Raw Material Inventory* is not sensitive to the changes of model structure. Besides, we compare the behaviours of other key variables and get the similar results as analyzed above. Therefore, modes of the key variable's behavior in the model are not sensitive to the structural change of model.

6.8 Integration Error Test

Since SD models are simulated in continuous time, it is necessary to ensure that the results of the models are not sensitive to the choice of time step. Therefore, the integration error test is carried out to check whether the time step is suitably selected for the model. Cut the time step in half and run the model again to see the responds of

the model behaviour. If the results change in ways that matter, the time step was too large. Otherwise, the model has passed the test and proved appropriate.

Fig 6.19 Time step setting in the model

In our model, we first set the time step to be 0.125 and run the model. Then we cut it further half and run the model at a time step of 0.0625. The model behaviors keep the same, which prove that the model is not sensitive to our particular choice of the integration time step for simulation.

6.9 Summary

This chapter describes model testing and focuses on the process of carrying out the tests. The purpose of model testing is to make sure the appropriation of the models by checking the parameters, structures and so on. By doing so, this chapter is aimed to set up the confidences of the clients and the modellers.

We carry out several kinds of tests in this chapter. Based on these tests, we show that the model is revealing the dynamic mechanism of the supply chain system and reflecting the procurement problems in a proper way. For instance, the structure assessment test shows that the structure of the model can properly represent the real world system; the boundary adequacy test illustrates the appropriateness of the model boundary and the extreme tests prove the adequacy of the formula and suitableness of the equations in our model. Besides, the dimensional consistency tests, sensitivity tests and parameter tests help to check the appropriateness of the model in a more detailed way.

Chapter 7

Behaviour Analysis

7.1 Introduction

This chapter presents results of model simulations under two basic procurement contracts: long-term contract and option contract. Firstly, we run the model under an initial equilibrium where the *Customer Demand for Product* is a constant and the values of all stock variables keep stable. The resulting behaviours indicate the equilibrium state which can be regarded as the benchmark and from which we can measure how the model responds to exogenous shocks. Then we make the behaviour tests on the exogenous *Customer Demand for Product* under two conditions. One assumes it conforms to the random normal distribution and the other assumes a shock increase on the *Customer Demand for Product*. In doing so, it is aimed to find the risk problems in long-term contract and option contract.

7.2 Resulting Behaviours in Long-term Contract

This sector discusses the model behaviours with long-term contract. Firstly, the initial equilibrium scenario would be considered, which is regarded as the benchmark for the comparison. Then, we would propose another two scenarios to test the model and analyze the behaviours.

7.2.1 Initial Equilibrium Scenario

In this scenario, we run the model under the assumption that there is no change in the *Customer Demand for Product* (see figure 7.1). It is a constant and its value is set to be 1000 piece/month.
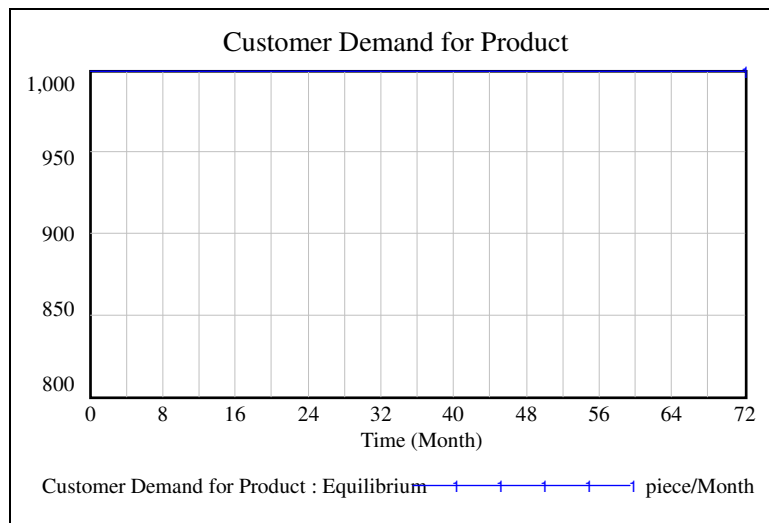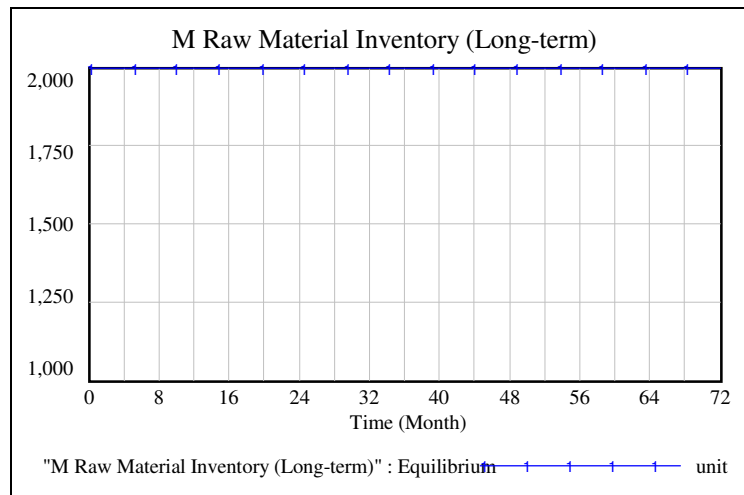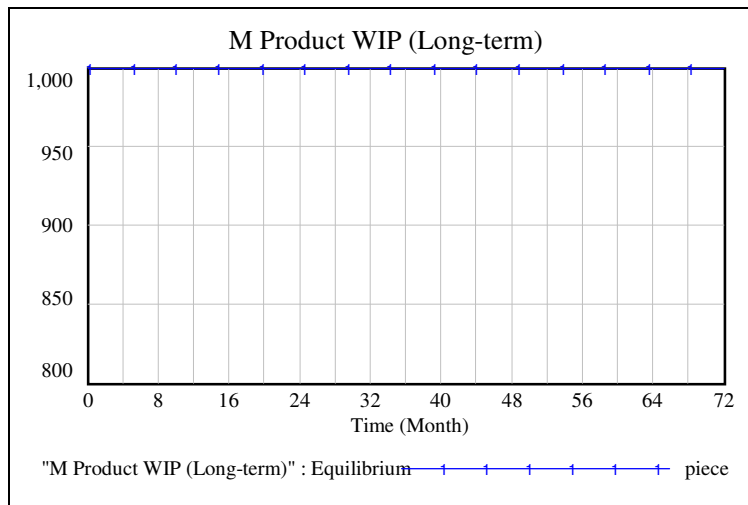

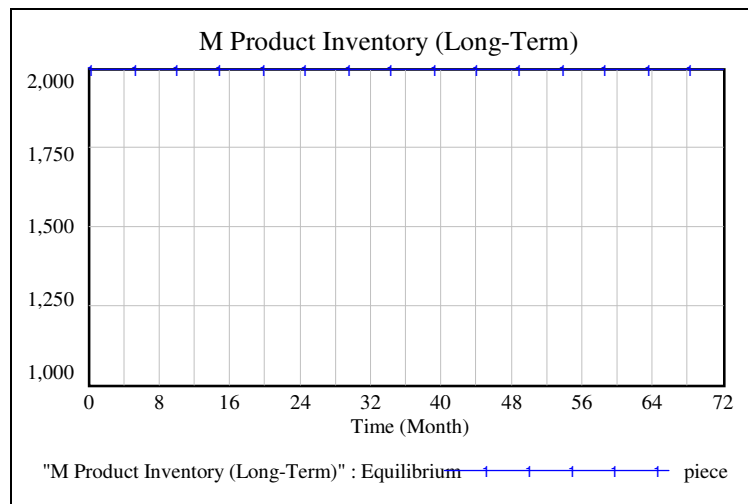**Figure 7.1 Customer Demand for Product**

Run the model under this scenario, the key stock variables are correspondingly in their equilibrium states just as figure 7.2 – 7.4 shows. Their values keep the same as the initial values throughout the simulation time period. There is no driving force to push the system away from its initial conditions.

Figure 7.2 Manufacturer Raw Material Inventory in Equilibrium

M Product WIP (Long-term)

"M Product WIP (Long-term)" : Equilibrium —+—+—+—+—+—+— piece

Figure 7.3 Manufacturer Product WIP in Equilibrium

M Product Inventory (Long-Term)

"M Product Inventory (Long-Term)" : Equilibrium —+—+—+—+—+— piece

Figure 7.4 Manufacturer Product Inventory in Equilibrium

According to the model assumptions, the exogenous *Contract Period* is set to be 12 months and *Customer Demand for Product* is 1000. Combined with the reality, the *Purchasing Rate* is determined at the beginning of each contract period under long-term contract. Figure 7.5 depicts the *Purchasing Rate* in equilibrium and every 12 months, at the beginning of each contract period, its value is 12,000 units while at other time it equals zero. It is easy to find out that the *Purchasing Rate* is just equal to the monthly demand multiplied by the contract period.
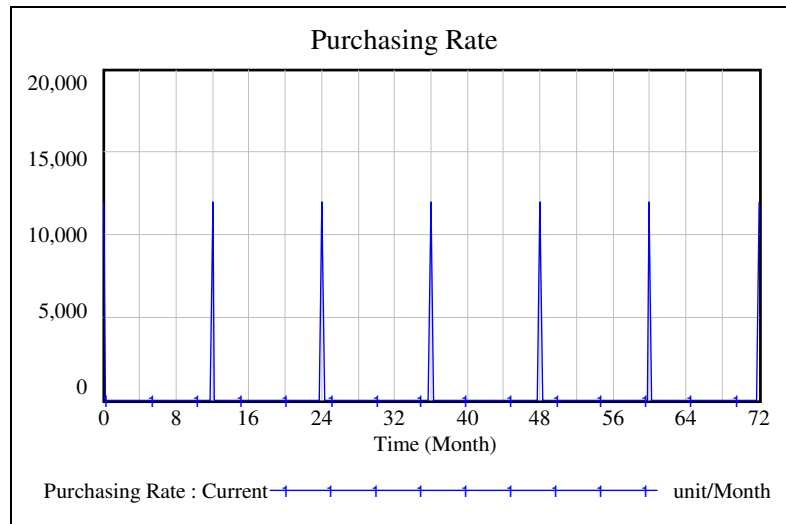
Figure 7.5 Purchasing Rate in Equilibrium

The purpose of this paper is to research on the effect of purchasing contracts on the performance of the manufacturer. We not only concern about manufacturer's inventory levels but also focus on its procurement cost. Figure 7.5 depicts the behaviours of the *Average Unit Procurement Cost* under initial equilibrium scenario. In our model, the *Spot Market Price* is assumed to change randomly with increasing trend. And the *Average Unit Procurement Cost* in long-term contract is determined by the *Spot Market Price* and *Purchasing Rate*. Therefore, *Average Unit Procurement Cost* appears in a random pattern as figure 7.6 demonstrates.
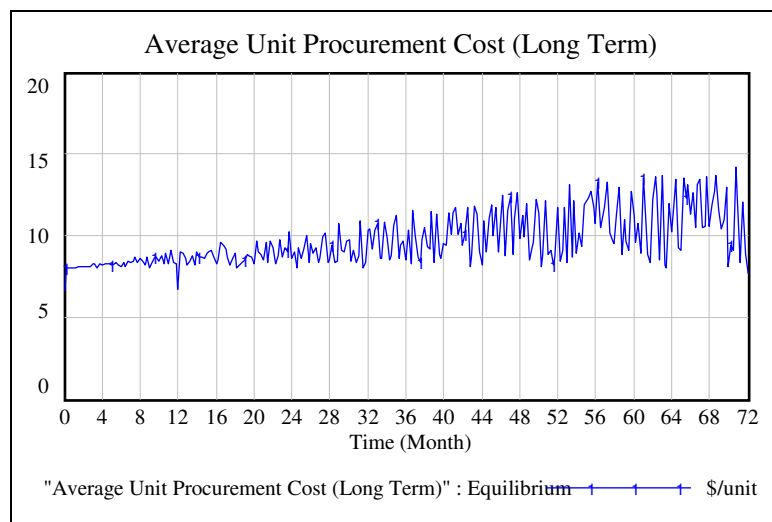
Figure 7.6 Average Unit Procurement Cost in Equilibrium Scenario

Generally speaking, the initial equilibrium scenario is very simplified. There are two main reasons for investigating behaviours of the model under such simple assumption. Firstly, we expect to demonstrate that the supply chain system itself can reach equilibrium if no exogenous change takes place. Secondly, it also gives us an insight into the initial equilibrium status of the system. In the subsequent problem

scenario and policy design, results of equilibrium are taken as a reference for comparison purposes.

7.2.2 Behaviour Analysis of Equilibrium Scenario

In the equilibrium scenario, all variables in the model remain at their reference levels. Just as the above figures indicate, there is consequently no change in the key stock variables like **M Raw Material Inventory**, **M Product Inventory** and **Distributor Product Inventory**.

The equilibrium of the stocks implies that all net rates of change equal to zero. Actually, the simulation results also indicate that the flows like *RM Arrive Rate, RM Usage Rate, Product Finish Rate, M Shipment Rate* and *Sales Rate* remain unchanged when *Customer Demand for Product* is assumed to be constant. All their value is 1000 unit/month, which explains why the net rates keep zero.

The equilibrium in this part of model would ever exist as long as *Customer Demand for Product* keeps constant at 1000 unit/month. However, there are always variations in the real world. Thus, the equilibrium scenario is a simplification of the reality with the main purpose of showing the effect of Customer Demand for Product on the flows and stocks. Also, the equilibrium statues of these variables can be studied as a reference for further research on the problem scenario.

We also concern about the behaviour of key variable in the procurement decision-making part. Figure 7.5 shows the behaviour of *Purchasing Rate*. In long-term contract, *Purchasing Rate* represents how many raw materials are pre-agreed by the manufacturer to purchase from the supplier in each contract period. Therefore, its value is directly determined by the *Indicated Demand for Raw Material*, which represents the anticipated demand for raw material. This variable is adjusted by the downstream demand as well as the inventory level of raw material. Since the actual inventory is the same as the desired level, no inventory gap exists and the *Indicated Demand for Raw Material* is only decided by downstream demand.

7.2.3 Problem Scenario 1：A Random Demand

In this scenario, we relax the constant customer demand assumption and simulate the model with a random demand. Here, we assume the *Customer Demand for Product* conforms to the normal distribution with average value of 2000 and standard deviation of 100 as the following equation indicates.

Customer Demand for Product = RANDOM NORMAL (0,2000,1000,100)

For better comparison, each figure in this sector includes two lines. The blue one depicts the behaviour with problem scenario while the red one represents the behaviour in equilibrium as the benchmark. Figure 7.7 shows the dynamics of *Customer Demand for Product* over the time period.
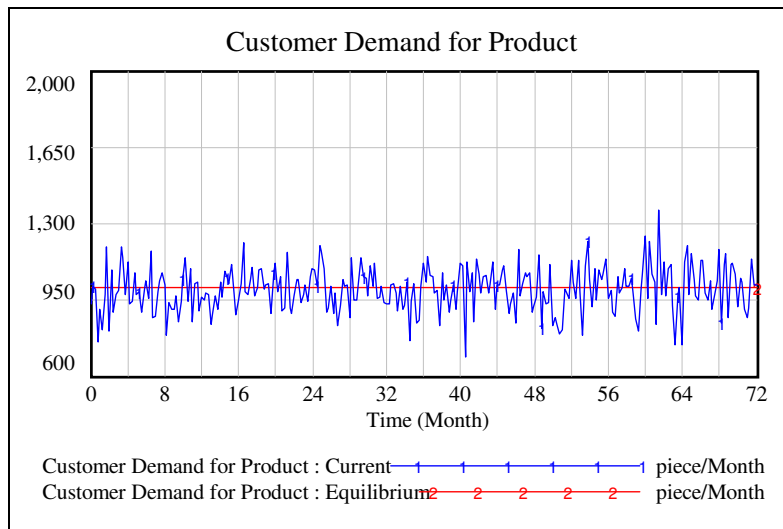
Figure 7.7 Customer Demand for Product under Scenario 1

By simulating the model with random customer demand, we get the responding behaviours of the key variables shown in figure 7.8 to figure 7.12.

7.2.4 Behaviour Analysis of Problem Scenario 1

According to the above scenario, run the model again and we can get the simulation results under long-term contract with the assumption of random value of *Customer Demand for Product*. The following analyses explain the root of their corresponding behaviours by observing and analyzing the relevant variables in the model over time. It is also a way to explain system behaviours from a structural point of view.

Observe the performance the *Raw Material Inventory* in figure 7.8. Its behaviour experiences great fluctuation under problem scenario 1 throughout the simulation period. In long-term contract, the purchasing rate is pre-agreed at the beginning of each contract period and the raw material will be delivered to the manufacture according to the contract no matter how the real market demand changes. Therefore, the manufacturer is unable to adjust the purchasing rate and control the inventory level timely. Besides, the information delay further strengthens the fluctuation and instability of raw material inventory.
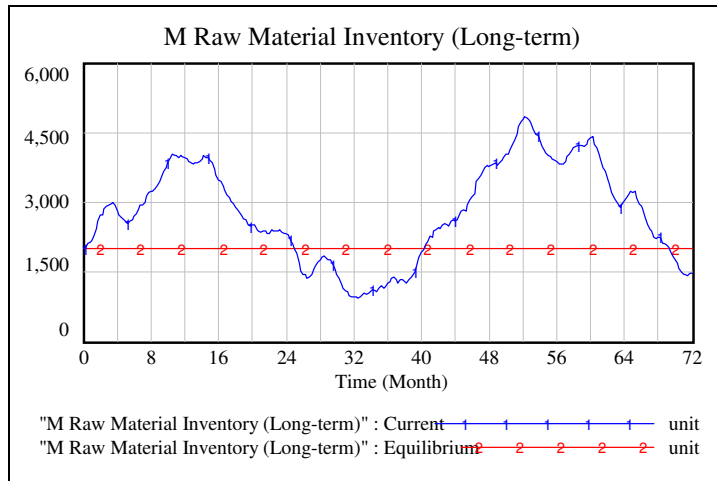
Figure 7.8 Manufacturer Raw Material Inventory under Problem Scenario 1

Then it comes to analyzing the behaviours of Manufacturer's work-in-process (WIP) products and finished products inventory. When the customer demand changes randomly as we assumed before, these two variables correspondingly behave fluctuated as figure 7.9 and 7.10 show. Observe and compare them with the behaviour of *Customer Demand for Product* (figure 7.7). We find that their amplifications of fluctuation are of difference although their modes of behaviours are quite similar.

In supply chain system, due to the time delay, bullwhip effect exists so that the upper stream companies often suffer from the fluctuation and amplification of the demand when the final customer demand is not stable. The instability of the demand would lead to the fluctuation of the inventory as figure 7.9 and 7.10 demonstrate. Thus, the behaviours of these stocks conform to the reality with random *Customer Demand for Products*.
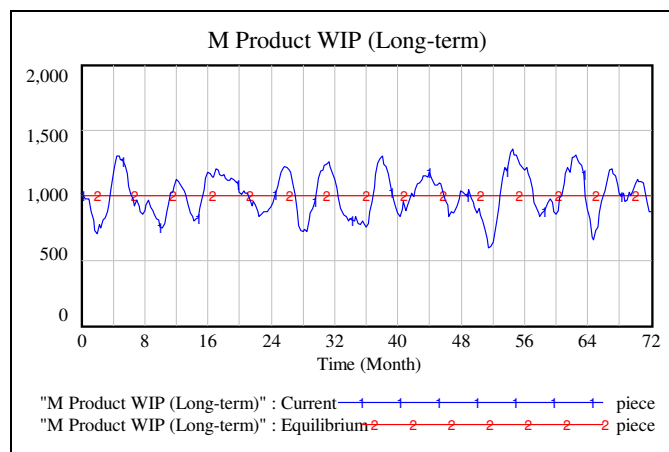
Figure 7.9 Manufacturer Products WIP under Problem Scenario 1
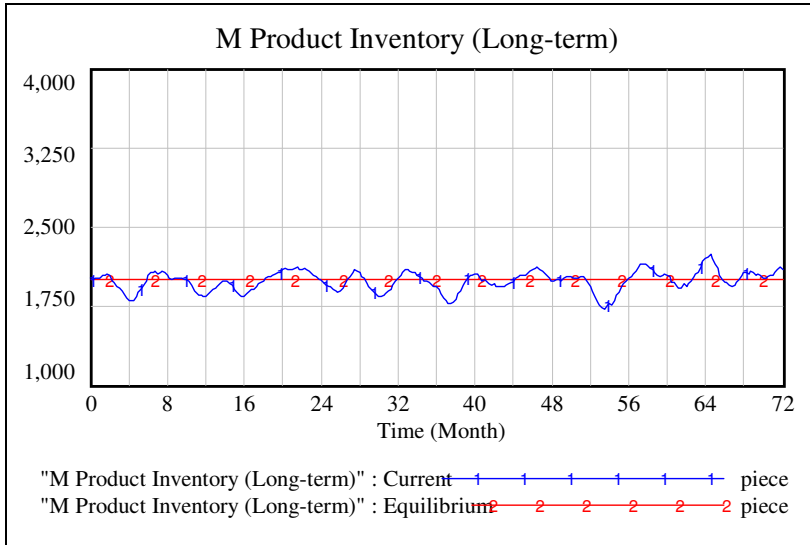
Figure 7.10 Manufacturer Product Inventory under Problem Scenario 1

In order to explicitly demonstrate and compare the behaviours of main stocks in our model when the customer demand conforms to the random normal distribution, figure 7.11 shows the manufacturer's raw material inventory, work-in-process product and product inventory simultaneously for better comparison. From it, we find that three variables behave in similar mode but show different fluctuation range.
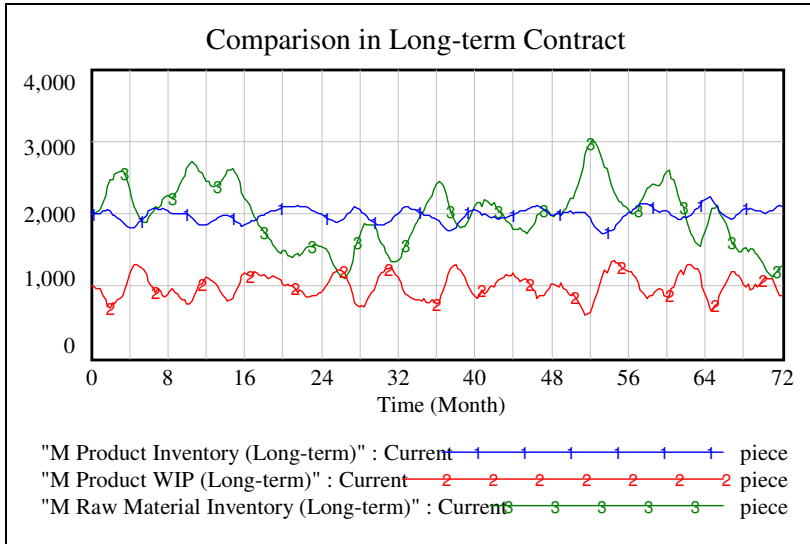
Figure 7.11 Comparison of three stocks under Problem Scenario 1

Compared with the equilibrium, the *Purchasing Rate* in problem scenario shows more instability. Referring to figure 7.5, *Purchasing Rate* in each contract period is 12,000 units when it is in equilibrium. From figure 7.12, we find that value of *Purchasing Rate* changes in a wider range in disequilibrium state, from 0 to 30,000 or so. It can be explained from two sides. Firstly, when the final market demand is changing randomly, the supplier who exists in the source of the supply chain system

can't get the information immediately. The existence of the delay time in transferring the demand information causes the bullwhip effect. As a result, the raw material quantity, manufacturer purchased from the upper-stream supplier, fluctuates in a wider range. Secondly, the characteristic of the long-term contract makes the manufacturer slow to respond to the market demand, which further strengthens the bullwhip effect.
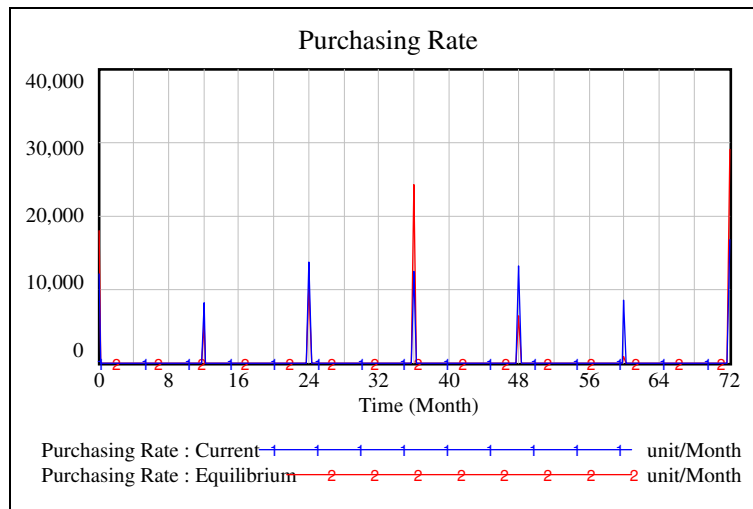
Figure 7.12 Purchasing Rate under Problem Scenario 1

Average Unit Procurement Cost is regarded as criteria for measuring and comparing the performance of the enterprisers under different contracts. In long-term contract, the average value of this variable in problem scenario is lower than that in equilibrium but the oscillation is much serious as figure 7.13 indicates. According to the definition of *Average Unit Procurement Cost*, it is partly determined by the *Purchasing Rate*.
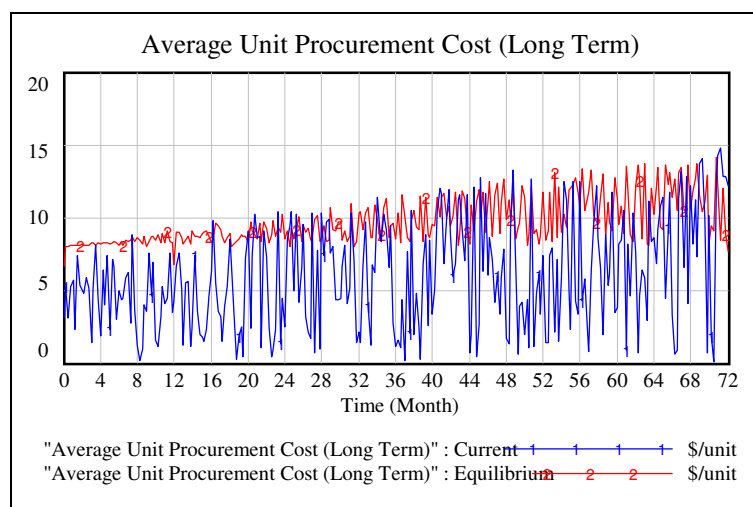
Figure 7.13 Average Unit Procurement Cost under Problem Scenario 1

7.2.5 Problem Scenario 2：A Sudden Increase in Demand

In order to test the behaviours when the demand experiences a sudden increase, here we assume an increase of 100% in the *Customer Demand for Products* after 20 months of simulation. That is, the *Customer Demand for Products* suddenly increases from 1000 to 2000 (piece/month) at time 20 and then keeps constant (see Figure 7.14).
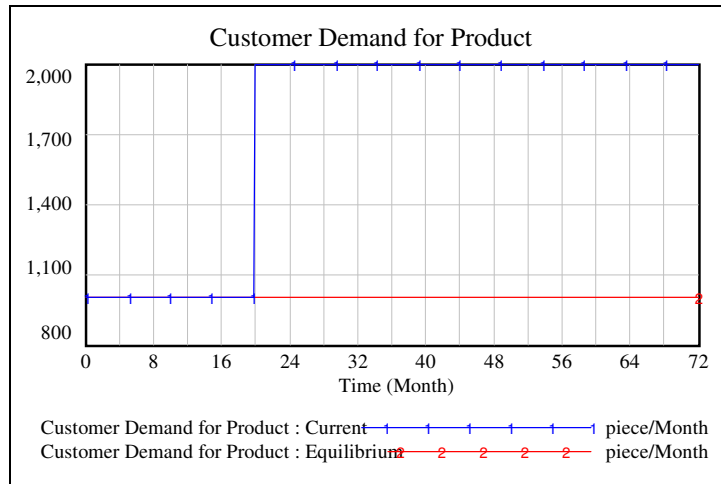
Figure 7.14 Customer Demand for Product under Problem Scenario 2

Equation: *Customer Demand for Product* = 1000+STEP(1000,20)

Run the model under this scenario. The simulation results are shown as follows and detailed analysis of behaviours would be illustrated in chapter 7.2.6.

7.2.6 Behaviour Analysis of Problem Scenario 2

Figure 7.15 to figure 7.17 explicitly shows the disequilibrium of the key variables with long-term contract in a supply chain system due to an exogenous increase in the *Customer Demand for Product*.

Seen from figure 7.15, between time 20 and 30, the *Raw Material Inventory* experiences small fluctuation but after 30 it goes up quickly, peaks and then drops again.

Combine with the mechanism of the long-term contract to analyze the behaviour of it. Firstly, the purchasing contract is set every contract period in long-term contract. As a result, the results show the cyclicality to some extent. Besides, the existence of bullwhip effect in supply chain system leads to the irregular changes in *Purchasing Rate, RM Delivery Rate* and *RM Arrive Rate*.

M Raw Material Inventory (Long-term)

"M Raw Material Inventory (Long-term)" : Step Increase Test —1——1——1— unit
"M Raw Material Inventory (Long-term)" : Equilibrium —2——2——2——2— unit
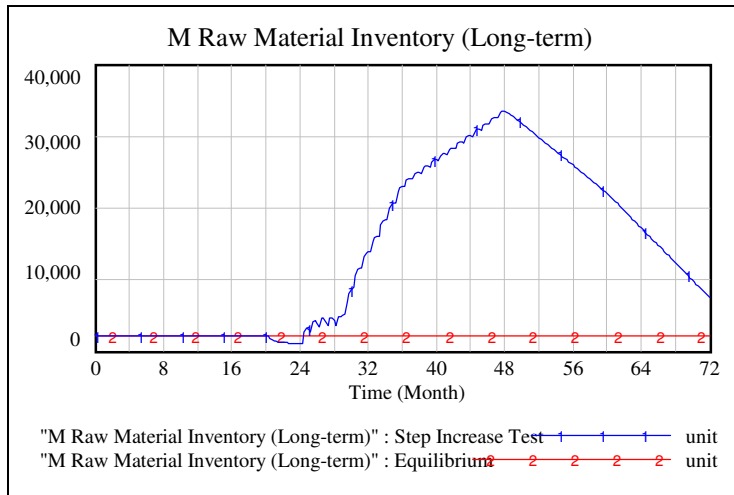
Figure 7.15 Manufacturer Raw Material Inventory
under Problem Scenario 2

The following two figures (7.16 and 7.17) depict the responds of Manufacturer's work-in-process products and finished products inventory to the sudden increase in the customer demand after time 20. Simulation results demonstrate the same mode of behaviour. That is, the inventory goes up, fluctuates and soon reaches the equilibrium again. Besides, their new equilibriums are higher than the original values. The results of this scenario tests conform to the characteristics of the supply chain system, which has been explained by Sterman (1989).

M Product WIP (Long-term)

"M Product WIP (Long-term)" : Step Increase Test —1——1——1——1— piece
"M Product WIP (Long-term)" : Equilibrium —2——2——2——2— piece

Figure 7.16 Manufacturer Product WIP under Problem Scenario 2
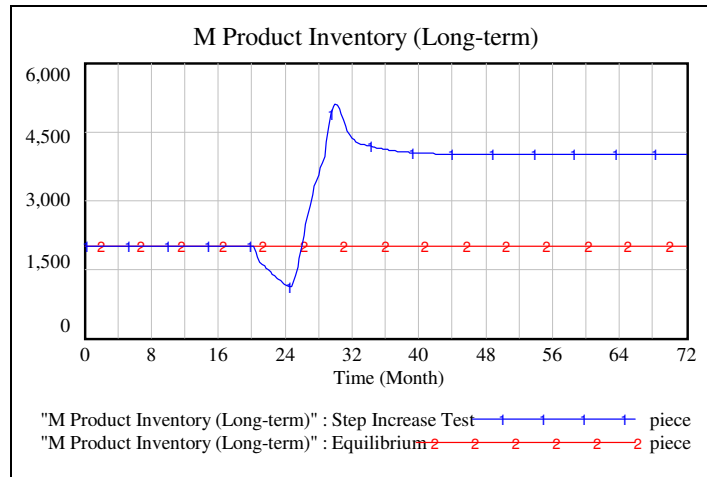
Figure 7.17 Manufacturer Product Inventory under Problem Scenario 2

7.3 Resulting Behaviours in Option Contract

This part focuses on the model behaviours under option contract. Firstly, the model is run with constant *Customer Demand for Product* to find the equilibrium of the system as the benchmark. Then two question scenarios, the same as those in chapter 7.2, are proposed.

7.3.1 Initial Equilibrium Scenario

In our model, in order to compare different purchasing contracts in a persuasive way, the exogenous are set to be the same in both long-term contract and option contract. Correspondingly, the scenarios proposed in this sector are the same as those in long-term contract sector. As a result, the equilibrium scenario is the assumption that the *Customer Demand for Product* is constant throughout the simulation time period. The details of the assumption can be referred to in sector 7.2.1.

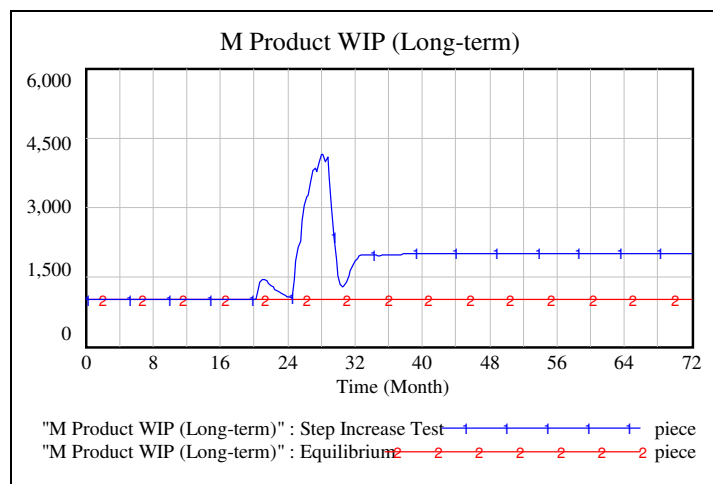### 7.3.2 Behaviour Analysis of Equilibrium Scenario

Some Parts of the option contract model and long-term contract model are overlapping. In equilibrium, the variables in such sub-model part show the same behaviour. In order to avoid the repeat, here we focus on the *Reservation Rate* and *Execution Rate*. Use the mechanism of the option contract to analyze their behaviours.

In option contract, the *Reservation Rate* represents the quantity of raw materials, which the manufacturer pays the supplier for reserving. Figure 7.11 depicts the *Reservation Rate* in equilibrium. Note that, both the behaviour pattern and the value are the same as the *Purchasing Rate* in long-term contract. It is because that both variables are determined by *Expected Demand for Raw Material*. But they represent different concepts.
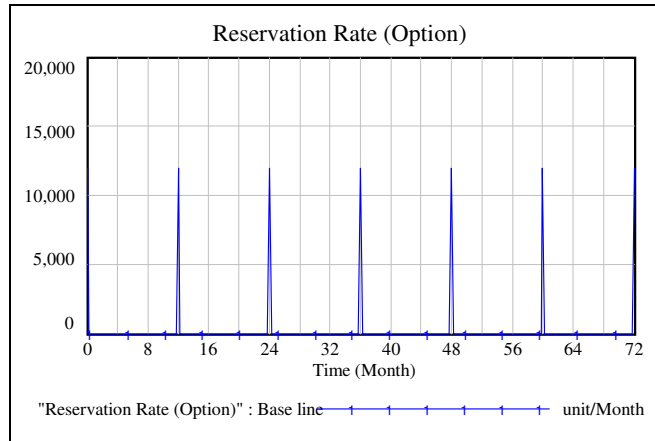
Figure 7.11 Reservation Rate in equilibrium

The *Execution Rate* means how much option would be executed each month. It equals to the *Indicated Demand for RM*. With the equilibrium scenario, all the inflows and outflows to the stock variables are the same and the net flows equal to zero. The stocks are in equilibrium and keep unchangeable over the time. As a result, there is no gap in raw material inventory and the *Indicated Demand for RM* is only influenced by the downstream demand. The above analysis explains why the behaviour of *Execution Rate* is as figure 7.12 indicates.
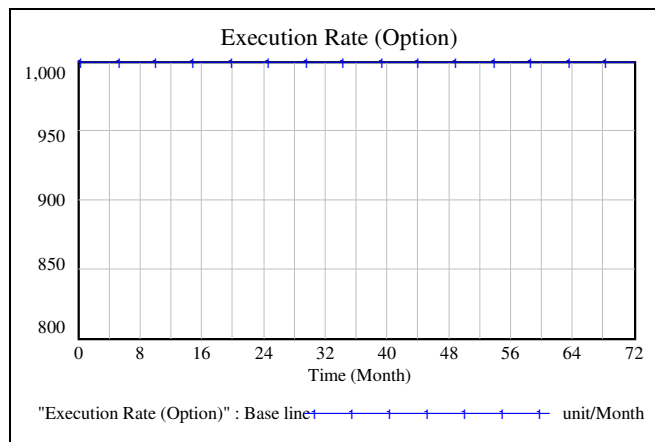
Figure 7.12 Execution Rate in equilibrium

7.3.3 Problem Scenarios

Similar to the equilibrium scenario, the problem scenarios for option contract is the same as those for long-term contract. One assumes a sudden increase in demand and the other sets the demand to change randomly. Their equations are as follows:

- Problem Scenario 1：A Random Demand

  Customer Demand for Product = RANDOM NORMAL (0,2000,1000,100)

- Problem Scenario 2：A Sudden Increase in Demand

Customer Demand for Product = 1000+STEP(1000,20)

In order to avoid repetition, we don't explain these two scenarios explicitly and the details can be referred to in sector 7.2.3.

7.3.4 Behaviour Analysis of Problem Scenarios

The difference of long-term contract model and option contract model mainly exists in the supplier sub-model and thus the structure of other sub-model are almost the same. Due to the time limitation and in the purpose of simplification, here we only focus on the analysis of the behaviours of *Execution Rate* under the above three scenarios. The behaviours of the stocks like *M Raw Material Inventory*, *Product WIP* and *Product Inventory* are not analyzed here but their behaviours under option contract are to be compared with those in long-term contract in chapter 7.3.5.

Figure 7.13 compares the behaviours of Execution Rate in option contract under three conditions simultaneously. The green straight line represents the *Execution Rate* in equilibrium state. Take it as the benchmark to observe the behaviours in scenario 1 and scenario 2. When the *Customer Demand for Raw Material* conforms to random normal distribution, the *Execution Rate* correspondingly fluctuates as the red curve depicts. When the *Customer Demand for Raw Material* goes up suddenly and keeps constant after that, the *Execution Rate* shows serious fluctuation and then reaches the new equilibrium. Explore the roots of these behaviours and we can explain them on the basis of the mechanism of the supply chain system as well as the characteristics of the option contract.

As stated before, *Execution Rate* is the real purchasing rate which manufacturer buys from the supplier. This variable changes with the *Indicated Demand for Raw Material* synchronically. On the other hand, since the purchasing procedure exists in the upper-stream of the supply chain system, the demand changes in the down stream can't be transferred to the manufacturer immediately. The time delay causes the bullwhip effect. Thus, the upper stream *Execution Rate* would show the same behaviour mode as the down stream *Customer Demand for Raw Material* does but it fluctuates more seriously. Similarly, the behaviours of *Execution Rate* under shock increase scenario can be explained.
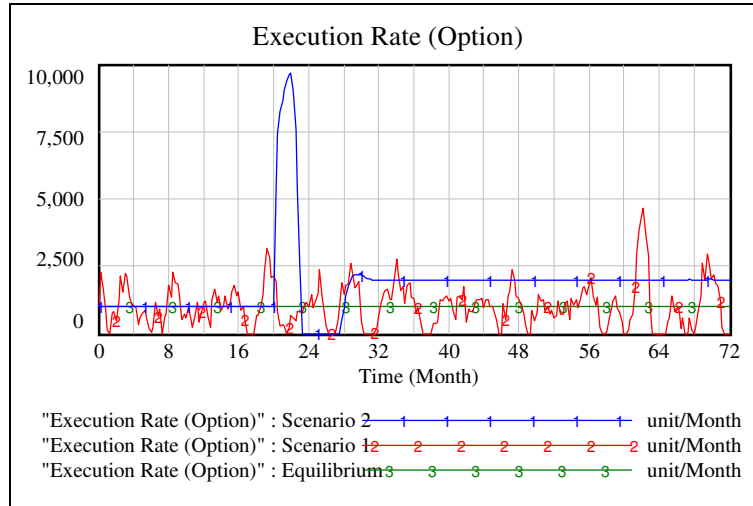
Figure 7.13 Execution Rate Comparisons in Three Conditions

7.4 Comparisons of Behaviours in Two Contracts

The above sectors analyze the behaviours of the key variables in long-term contract model and option contract model respectively. By comparing the simulation results under two scenarios, their behaviours are described and explained.

In order to research on these two purchasing contracts in a deeper way and know more about their dynamic effects on the performance of the manufacturer, we make the horizontal comparison by doing statistic analysis on the resulting data of models.

In this research, we focus on the manufacturer. It makes decisions on choosing proper purchasing contracts, takes charge of production, manages the inventory and ensures the supply of the finished products to the downstream company. As a result, manufacturer plays the key role in the supply chain system although it is just one of the partners.

Table 7.1 and 7.2 list the statistical results of the main variables, which measure the performance of the manufacturer in option contract and long-term contract respectively. In each table, four variables are considered; that is, *Raw Material Inventory, Product WIP, Product Inventory* and *Average Procurement Unit Cost*. For each variable, two statistical criteria are calculated: *Average* and *Standard Deviation*, which measure the average level of the variables and their fluctuations over the simulation time period. Columns 3 to 5 demonstrate the above two statistic criteria under three scenarios which are described in sector 7.2. Note that the Equilibrium Scenario can be regarded as the benchmark for another two scenarios.

As we discussed in Chapter 5, *Raw Material Inventory* and *Average Procurement Unit Cost (APUC)* are the most important two variables to compare effects of long-term contract and option contract on the performance of the manufacturer. As a result, we focus on comparing and analyzing these two variables according to the statistic results in table 7.1 and 7.2.

No wonder which problem scenario the model is set in, the average level of Raw Material Inventory in option contract is much lower than that in long-term contract and oscillates less. Then it comes to the comparison of Average Procurement Unit Cost (APUC), in option contract, this variable is higher than that in long-term contract.

Since the manufacturer hopes to control the inventory risk and cost risk simultaneously, either long-term contract or option contract can meet the requirement.

Table 7.1: Manufacturer's Performance under Option Contract

Variable	Major Criteria	Equilibrium Scenario	Problem Scenarios	
			Scenario 1	Scenario 2
Raw Material Inventory	Average	2000	2099	3792.39
	Standard Deviation	0	479.96	1804.76
Product WIP	Average	1000	1010	1772.88
	Standard Deviation	0	147.64	640.67
Product Inventory	Average	2000	1997	3468.37
	Standard Deviation	0	87.71	1038.98
Avg. Procurement Unit Cost	Average	10	11.54	12.98
	Standard Deviation	2.8	4.56	2.47

Table 7.2: Manufacturer's Performance under Long-term Contract

Variable	Major Criteria	Equilibrium Scenario	Problem Scenarios	
			Scenario 1	Scenario 2
Raw Material Inventory	Average	2000	2774	14071.86
	Standard Deviation	0	1043.46	11499.89
Product WIP	Average	1000	997	1733.81
	Standard Deviation	0	160.79	636.78
Product Inventory	Average	2000	1977	3244.81
	Standard Deviation	0	98.50	1079.00
Avg. Procurement Unit Cost	Average	10	9.6	8.78
	Standard Deviation	2.8	3.26	3.45

Chapter 8

Policy Development

8.1 Introduction

In this chapter, policy aiming at reducing the risk problems and achieving a more desirable performance of the supply chain system, esp. the manufacturer, is studied by means of simulation. We investigate into the portfolio contract, which is proposed as the policy to compensate for the weakness of long-term contract and option contracts discussed in last chapter.

In order to demonstrate the effectiveness and robustness of the portfolio contracts, policy sensitivity tests are made. Then, we run the portfolio contract model and compare the behaviours with those under long-term contract model and option contract model. Finally, assessments and comments on implementation are made as a brief conclusion.

8.2 Portfolio Contract Policy

As the core partner of the supply chain system and the research focus of this paper, the manufacturer aims to control the inventory risk and cost risk simultaneously. However, on the basis of last chapter's analysis and comparison, we get to know that those two most frequently used purchasing contracts---option contract and long-term contract fail to meet the requirements of optimization.

As a result, we propose the portfolio contract as the policy, aiming to help the manufacturer find the suitable purchasing strategy to control the risks and optimize the performance.

On the basis of long-term contract and option contract sub-model structure we illustrate in chapter 5, the portfolio contract sub-model is constructed as figure 8.1 shows. Figure 8.1 mainly depicts the supplier sub-model. Although the supplier is not the focus of this study, the sub-model structure of the supplier part is worth our attention. In this part, we get to know the difference of three procurement contracts, how they work as well as how the material flows go through this part.

The portfolio contract is the combination of two kinds of contracts: long-term contract and option contract. How to find the optimal combination so as to maximize the profit as well as reduce the inventory risk is the focus of this study.

The *Share from Option Contract* is the ratio of using the option contract to purchase the raw materials from the supplier while the *Share from Long-term Contract* is for long-term contract.

Since these two variables represent the relative ratio, they are dimensionless and their relation is assumed as the following equation shows:

- *Share from Option Contract+ Share from Long-term Contract*=1

Average Unit Procurement Cost and *M_Raw Material Inventory* determine the *Share from Option Contract* together. The following equation depicts their relations.

$$\textbf{\textit{Share from Option Contract}} = Initial\_Share \times \left[\frac{w}{1+w} \cdot \frac{\text{AUPC\_Option}}{\text{AUPC\_L-term}} + \frac{1}{1+w} \cdot \frac{RM\_Inventory}{Desired\_RM\_Inv} \right]$$

Note that *AUPC* is the abbreviation of *Average Unit Procurement Cost*.

Here w is the weight and $\frac{w}{1+w}$ measures the effect of the *AUPC* on deciding

the share and $\dfrac{1}{1+w}$ represents the influence of inventory level.

Initial Share refers to the share from option contract from the beginning of the simulation. It is set in advance as the exogenous and can also be regarded as the benchmark.

As the rest of the model structure shown in figure 8.1 is the almost the same as that in figure 5.6 and figure 5.7, we don't repeat illustrating them.
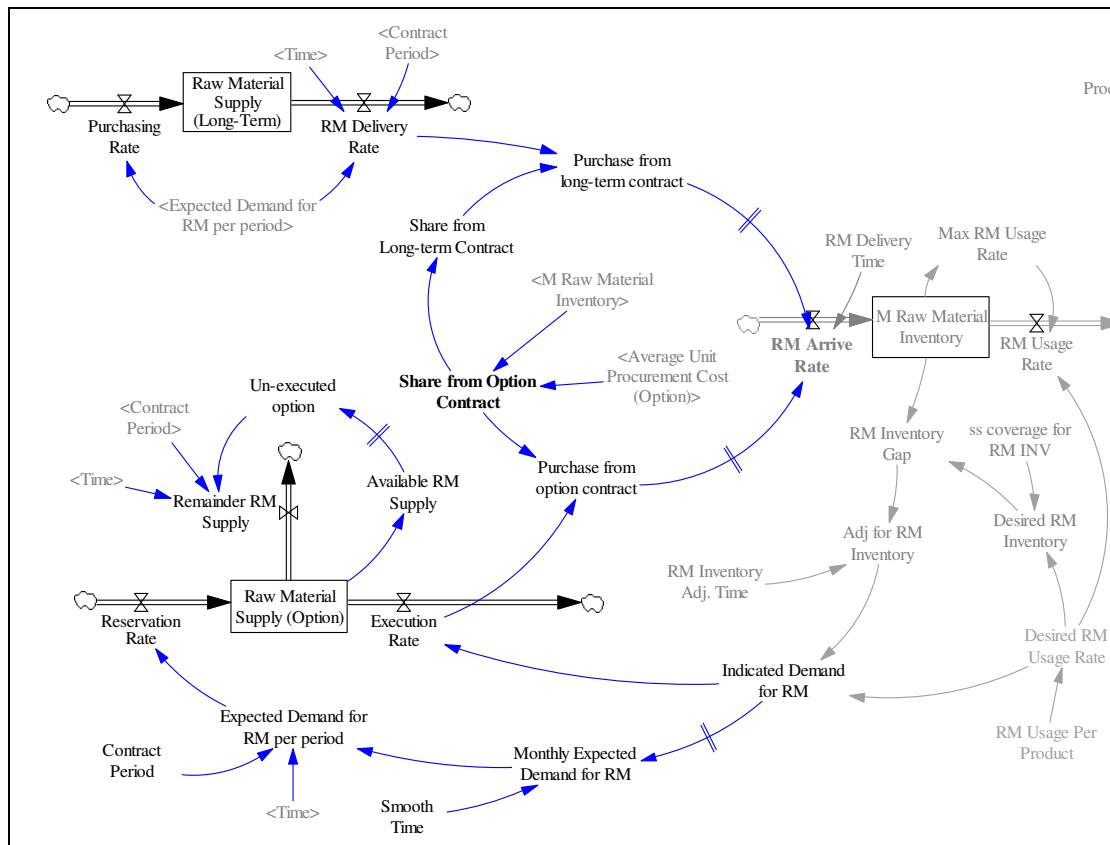
Figure 8.1: Supplier Sub-model Structure with Portfolio Contract

As illustrated in chapter 5 and chapter 7, the performance of the manufacturer is mainly measured by two variables: *Raw Material Inventory* and *Average Unit Procurement Cost (AUPC)*. In portfolio contract model, the *Raw Material Inventory* can be compared with the situation in option contract and long-term contract with the same structure. However, the *Average Unit Procurement Cost (AUPC)* can be calculated as figure 8.2 shows.
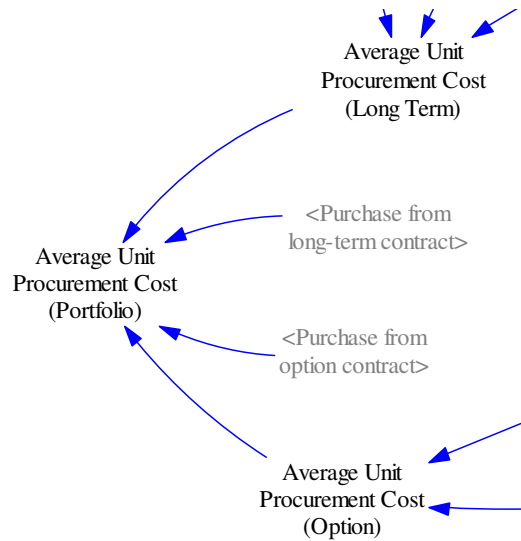
Figure 8.2: AUPC in Portfolio Contract Model

The key equations are as follows.

$$\substack{AUPC \\ (Portfolio)} = \frac{\substack{AUPC \\ (Option)} * \substack{Purchase\ from \\ Option\ Contract} + \substack{AUPC \\ (L\text{-}term)} * \substack{Purchase\ from \\ L\text{-}Term\ Contract}}{\substack{Purchase\ from \\ Option\ Contract} + \substack{Purchase\ from \\ L\text{-}term\ Contract}}$$

Where, *Purchase from Option Contract* and *Purchase from L-Term Contract* are shown in figure 8.1 and their equations are:

$$\substack{Purchase\ from \\ Option\ Contract} = \substack{Execution \\ Rate} * \substack{Share\ from \\ Option\ Contract}$$

$$\substack{Purchase\ from \\ L\text{-}Term\ Contract} = \substack{RM\ delivery \\ Rate} * \substack{Share\ from \\ Option\ Contract}$$

The above figures and description not only tell how the portfolio contract model is constructed but also illustrates its relationship with option contract and long-term contract. Besides, the key equations are given to show how the performance of manufacturer would be measured, which set a foundation for the behaviour analysis of portfolio contract model and the sensitivity tests as follows.

8.3 Behaviours Analysis

Corresponding to the behaviours analysis in chapter 7, firstly we would conduct

the behaviour tests on portfolio contract model under three conditions of the *Customer Demand for Raw Material*. Then behaviours analysis is to be done on the basis of the simulation results.

Table 8.1: Three Conditions of *Customer Demand for Raw Material*

	Conditions	*Customer Demand for Raw Material*
Equilibrium:	Constant Demand	1000
Scenario 1:	A Random Demand	RANDOM NORMAL (0,2000,1000,100)
Scenario 2:	A Sudden Increase in Demand	1000+STEP(500,20)

Figure 8.3 vividly shows how the *Customer Demand for Product* behaves under different scenarios, corresponding to the explicit illustration in table 8.1.
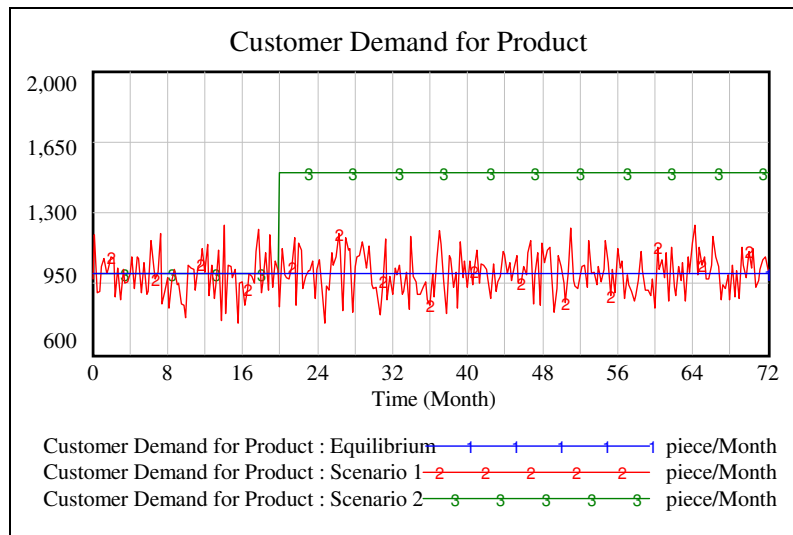
Figure 8.3: Three scenarios of Customer Demand for Product

Figure 8.4 and 8.5 depicts the *AUPC* and *Raw Material Inventory* under portfolio contract. In each figures, three curves are included to compare the different responds of these two key variables to three scenarios as described before. In figure 8.4, the behaviour patterns are similar but with the oscillation of customer demand, the AUPC under scenario 1 also shows the oscillation. As to the behaviours of *Raw Material Inventory* shown in figure 8.5, when the customer demand is constant, the *Raw Material Inventory* is in equilibrium as blue straight depicts. When the customer demand shows some oscillation, *Raw Material Inventory* behaves oscillated. When the customer demand increases rapidly and keeps stable, the *Raw Material Inventory* would fluctuate seriously but soon reaches new equilibrium.
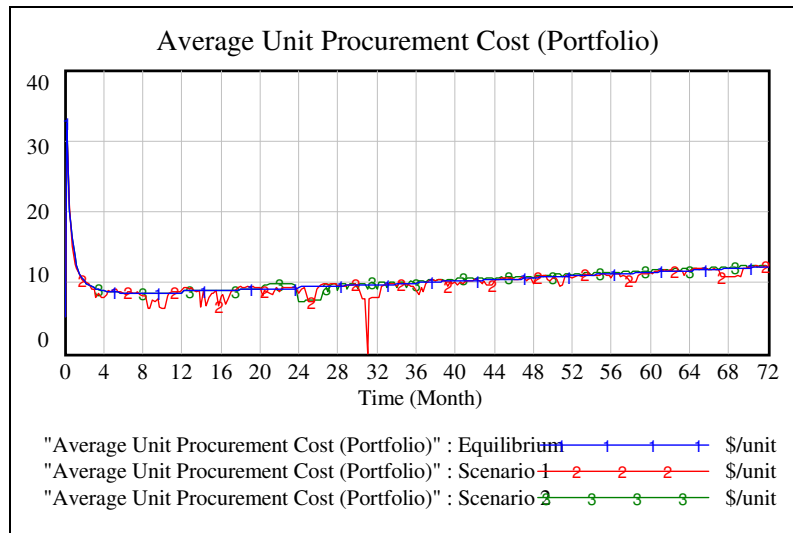
Figure 8.4: AUPC under three conditions
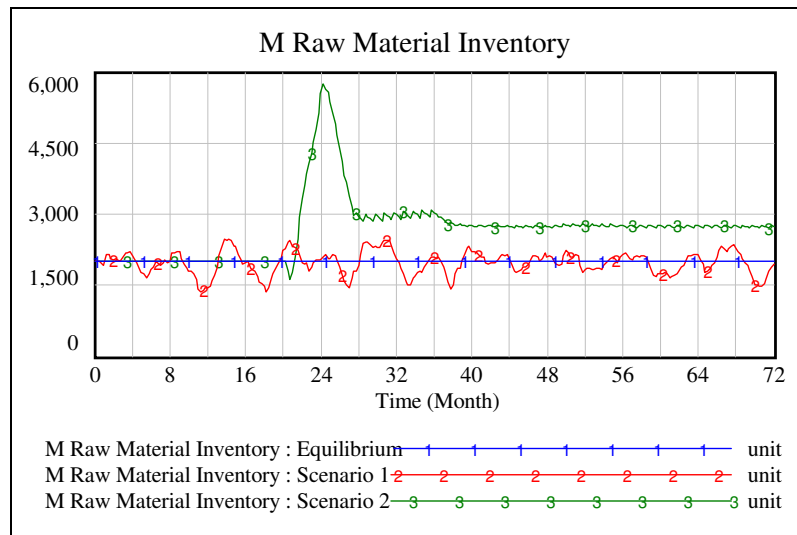
Figure 8.5: Raw Material INV under three conditions

In order to show the effectiveness of portfolio contracts on controlling the inventory risk and cost risk, the comparison of portfolio contract with the other two contracts would be made and described explicitly afterwards.

Here we run the model under scenario 2 --- a Sudden Increase in Demand (figure 8.6) and make the comparisons. The behaviours of *AUPC* and *Raw Material Inventory* under three contracts are compared as figure 8.7 and 8.8 depict.
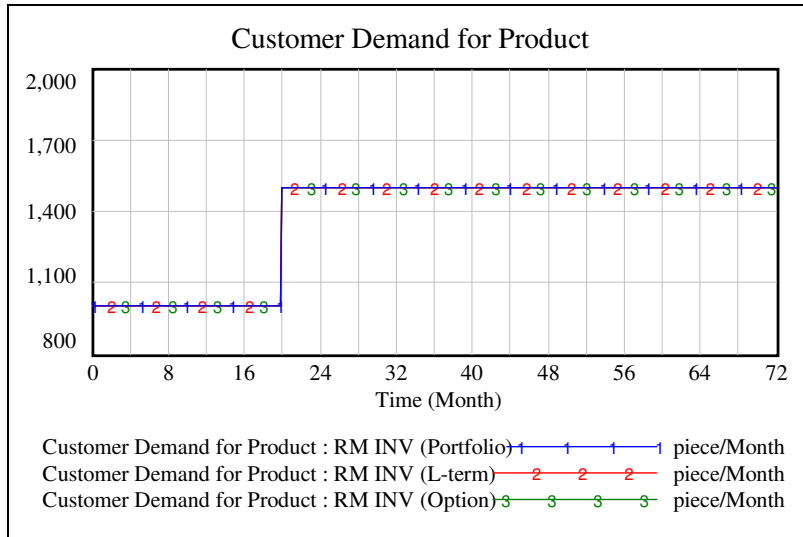
Figure 8.6: A sudden Increase in Demand

Figure 8.7 demonstrate that the AUPC is relatively high in option contract and portfolio contract can release the cost risk to some extent.
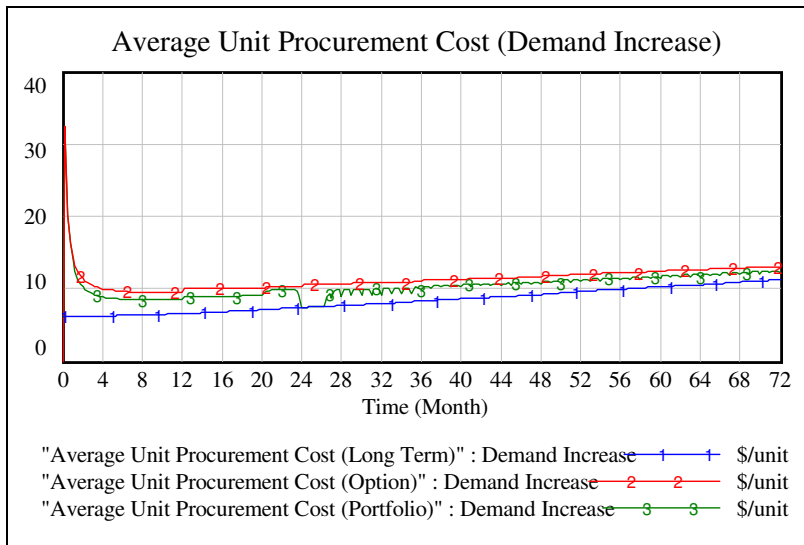
Figure 8.7: AUPC Comparison

Seen from figure 8.8, when the final customer demand for product encounters a sudden increase in time 20, correspondingly the upper flow *Raw Material Inventory* of manufacturer fluctuates a lot. Comparing the three curves in figure 8.8, it's easy to see that the *RM inventory* fluctuates most seriously when in long-term contract. In portfolio contract (see blue curve), the inventory level shows the best condition compared with those in option contract and long-term contract.
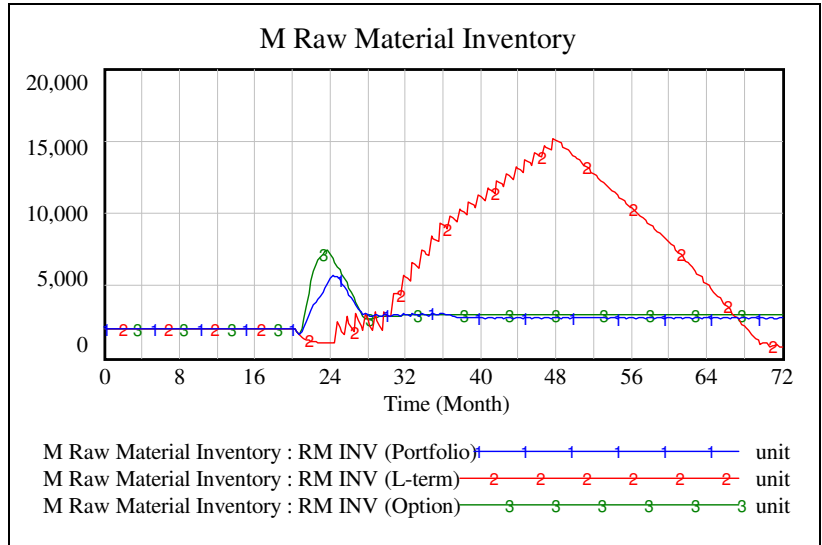
Figure 8.8: Raw Material INV Comparison

8.4 Policy Sensitivity Test

Firstly, we would conduct the policy sensitivity test on the weight w to see how the key variables like *Share from Option Contract* respond to different value of w. We set w to be 0.5, 2 and 5 respectively. Here it is assumed that *Customer Demand for Raw Material* keeps constant as 1000 unit/month. Figure 8.9 depicts the behaviours of *Share from Option Contract* under three conditions with different weight w. As illustrated in sector 8.2, as there are two major variables to measure the performance and determine the portfolio ratio, weight w is to measure the ratio of AUPC to inventory level of manufacturer determining the *Share from Option Contract*. Thus, the higher the w is, the more influence the AUPC occupies. Seen from figure 8.9, when weight w is 5, the highest value of w in three conditions, the value of the *Share from Option Contract* is relatively high. In contrast, when w is 0.5, the share is the lowest of three conditions (figure 8.10).
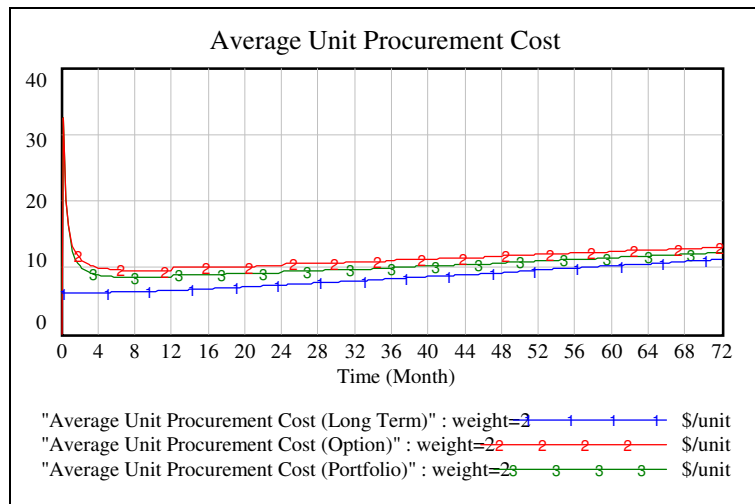
Figure 8.9: AUPC under Sensitivity Test 1
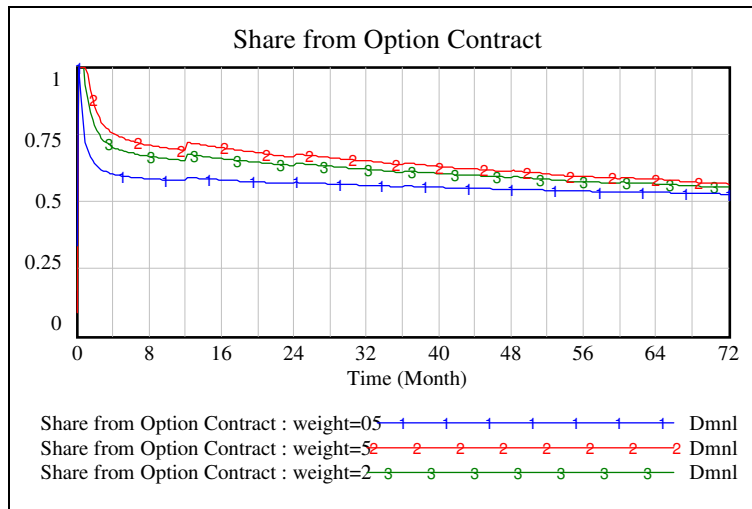
Figure 8.10: Share from Option Contract under Sensitivity Test 1

Since this policy sensitivity test assumes that the *Customer Demand for Products* keeps constant, correspondingly all stocks keep stable and net flows equal to zero. On the other hand, the simulation results (shown in figure 8.11) demonstrate that in equilibrium *Raw Material Inventory* are not influenced by the choice of weight w, which conform to the equilibrium state we illustrate before.
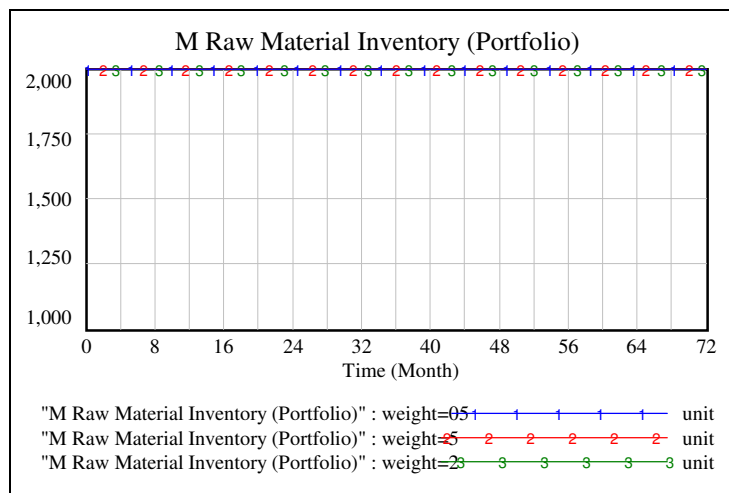
Figure 8.11: Raw Material Inventory under Sensitivity Test 1

As to the AUPC, one of the two main variables for measuring the performance, Figure 8.11 depicts its behaviours under three weights. Considering the equation of AUPC (Portfolio) in sector 8.2, the reason why the difference of AUPC under different weight is so tiny can be explained as follows. When Customer Demand for Product is constant and all stocks such as *Raw Material Inventory* are in equilibrium (see figure 8.11), the net flows correspondingly keep zero. As a result, the

denominator of the *AUPC (Option)* equation is a constant. On the other hand, the molecular in this equation is of little difference as we described in chapter 5. The behaviors under three different weights are almost the same just as figure 8.12 shows.
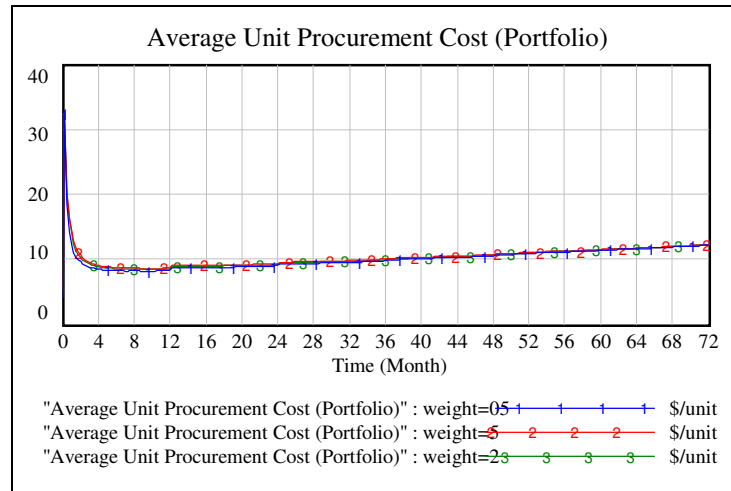
Figure 8.12: AUPC under Sensitivity Test 1

Chapter 9

Conclusion

Based on the previous chapters of presenting the work, in this final chapter, we would make some conclusion marks for the study. Firstly, a brief overview of the research is illustrated. Then the major features and findings of this study are presented. Thereafter, we would discuss the limitations of the work and point out the fields for future study.

9.1 Overview of the Research

This work presents how the sourcing strategies influence the performance of supply chain system dynamically. The beginning part of the paper introduces the background and intention of this research, which set a solid foundation for the modelling and policy development in the later chapters. By building the System Dynamics models and making related model tests, we compare two traditional purchasing contracts, analyze their features and show their dynamic problems. Then

the portfolio contract is proposed as the policy to optimize the performances of the system.

9.2 Major Features and Findings

Main features are concluded in three aspects as follows.

Firstly, the research focuses on the procurement problems in supply chain system. This problem has the practical value in reality and is also a good problem area in which to apply System Dynamics. By modelling the supply chain system dynamically, we can not only show the three flows and their interrelationship within one model, but also reveal the effect of purchasing strategy on the performances of the supply chain.

Secondly, we build two models to compare the different effects of the option contract and long-term contract. Each model is set on the basis of the procurement theory and thus can reflect the characteristics of certain contract, which set a good foundation for further simulation, tests and the analysis.

Thirdly, by comparing the performance of the key variables in option contract model and the long-term contract model, the risk problems in these two contracts are shown and proved. Meanwhile, this research is not limited in finding the problems but aims to propose the solutions to the risk problems in procurement.

Generally speaking, the model is simple and we mainly focus on the performance of the core partner in a supply chain system---manufacturer. The purpose of simplification is for a better illustration and time saving. Meanwhile, we hope the models in this research would work as the basic model so that the readers can expand the model to solve some practical problems in the future. Besides, I personally deeply appreciate the way of keeping things simple while still being close the truth.

There are mainly two findings in this paper. Firstly, we prove that the long-term contract can effectively reduce the procurement cost but cause higher risks of inventory increase. In contrast, option contract performs better in controlling inventory but the procurement cost is relatively high. Secondly, the portfolio contract, proposed as the policy in this study, is proved to be an effective way to reduce both inventory risk and cost risk.

9.3 Limitations and Future Research

In the current study, we focus on the manufacturer's performance under different purchasing contracts. The model is constructed in a lower aggregated level. In

addition, due to limited time and resource, the models built in this paper contain a number of rough assumptions (illustrated in chapter 5) and relatively simplified. These factors lead to some limitations in our work.

In this paper, we assume the spot market price of the products is in an increasing trend. For future study, this assumption can be relaxed and consider the spot price in random situations. Also, future research can consider the situations where the price and demand are interrelated or we can study the situation when the contract period is not fixed but can be changed on the basis of the real demand.

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Appendix

Gama=
    Effect of Spot Price on Execution Price(Indicated Demand for RM)
    ~   Dmnl

Alpha=
    0.7
    ~   Dmnl

"Average Unit Procurement Cost (Long Term)"=
    smooth(Alpha*Raw Material Spot Market Price,Contract Period)
    ~ $/unit

RM Arrive Rate= DELAY FIXED (
    "Purchase from long-term contract"+Purchase from option contract,RM Delivery Time,1000)
    ~   unit/Month

RM Delivery Rate=
    IF THEN ELSE(INTEGER(Time/Contract Period)=Time/Contract Period, Expected Demand
for RM per period\
        /Contract Period,a)
    ~   unit/Month

Purchase from option contract=
    Execution Rate*Share from Option Contract
    ~   unit/Month

Purchasing Rate=
    Expected Demand for RM per period
    ~   unit/Month

Execution Rate=
    Indicated Demand for RM
    ~   unit/Month

"Average Unit Procurement Cost (Portfolio)"=
    ("Average   Unit   Procurement   Cost   (Long   Term)"*"Purchase   from   long-term
contract"+"Average Unit Procurement Cost (Option)"\
        *Purchase from option contract)/("Purchase from long-term contract"+Purchase from
option contract\
)
    ~ $/unit

"Purchase from long-term contract"=
    RM Delivery Rate*"Share from Long-Term Contract"

96

~   unit/Month

Execution Price=

    Raw Material Spot Market Price*Gama

~ $/unit

Reservation Rate=

    Expected Demand for RM per period

~   unit/Month

Spot Price Trend=

    8*(1+Time/72)

~ $/unit

~ |

Random Factor=

    RANDOM EXPONENTIAL(0.8 , 1.2, 1, 1 , 0)

~   Dmnl

Raw Material Spot Market Price=

    Random Factor*Spot Price Trend

~ $/unit

Effect of Purchase Rate on Alpha(

    [(0,0)-(100000,1)],(0,1),(1000,0.8),(10000,0.7),(40000,0.65),(80000,0.6),(100000,0.6\

        ))

~   Dmnl

"Average Unit Procurement Cost (Option)"=

    IF   THEN   ELSE (Total   Procurement   Quantity=0,0,   "Procurement   Cost   (Option

Contract)"/Total Procurement Quantity\

)

~ $/unit

a= DELAY FIXED (

    RM Delivery Rate, 1 , 1000)

~

RM Inventory Gap=

    Desired RM Inventory-M Raw Material Inventory

~   unit

"Raw Material Supply (Long-Term)"= INTEG (Purchasing Rate-RM Delivery Rate,0)

~   unit

Share from Option Contract=

     min(1,Initial   Share*(1/(1+Weight)*(M   Raw   Material   Inventory/Desired   RM Inventory)+Weight/(1+Weight)*("Average   Unit   Procurement   Cost   (Option)"/"Average   Unit Procurement Cost (Long Term)")))

    ~   Dmnl

    ~ |

"Share from Long-Term Contract"=1-Share from Option Contract

    ~   Dmnl

Weight= 2

    ~   Dmnl

Initial Share= 0.5

    ~   Dmnl

Reservation Price= 2

    ~ $/unit

"Procurement Cost (Option Contract)"= INTEG (Pay for Execution+Pay for Reservation,0)

    ~ $

Pay for Execution= Execution Price*Execution Rate

    ~ $/Month

Pay for Reservation=Reservation Price*Reservation Rate

    ~ $/Month

Total Procurement Quantity= INTEG (Execution Rate,0)

    ~   unit

Effect of Spot Price on Execution Price(

    [(0,0)-(100000,1)],(0,1),(1000,0.8),(10000,0.7),(40000,0.65),(80000,0.6),(100000,0.6

    ))

    ~   Dmnl

Desired Product WIP=   Manufacturing Cycle time*Desired Product Shipment Rate

    ~   piece

Monthly   Expected   Demand   for   RM   =SMOOTHI(Indicated   Demand   for   RM, SmoothTime,1000)*Beta

    ~   unit/Month

SmoothTime= 6
    ~   Month

Beta=1
    ~   Dmnl

"Un-executed option"= DELAY FIXED (Available RM Supply,0, 0)
    ~   unit

Product Arrive Rate="Distributor Product In-Transit"/Product Delivery Time
    ~   piece/Month

Product Finish Rate=   M Product WIP/Manufacturing Cycle time
    ~   piece/Month

"Raw Material Supply (Option)"= INTEG (+Reservation Rate-Execution Rate-Remainder RM
Supply,0)
    ~   unit
    ~ |

Remainder RM Supply=
    IF THEN ELSE(INTEGER(Time/Contract Period)=Time/Contract Period, "Un-executed
option"\
        ,0)
    ~   unit/Month

Expected Demand for RM per period= IF   THEN   ELSE   (INTEGER(Time/Contract
Period)=Time/Contract Period, Monthly Expected Demand for RM*Contract Period,0)

Distributor Product Inventory= INTEG (Product Arrive Rate-Sales Rate,2000)
    ~   piece

M Product Inventory= INTEG (Product Finish Rate-Shipment Rate,2000)
    ~   piece

M Product WIP= INTEG (+RM Usage Rate-Product Finish Rate,1000)
    ~   piece

M Raw Material Inventory= INTEG (RM Arrive Rate-RM Usage Rate,2000)

"Distributor Product In-Transit"= INTEG (+Shipment Rate-Product Arrive Rate,   1000)
    ~   piece

Desired Production Start Rate=
    max(0, Adj for Product INV+Adj for Product WIP+Shipment Rate)
    ~   piece/Month

adj for D Product INV=D Product INV Gap/D Product INV adj time
    ~   piece/Month

"Adj for In-transit"="In-Transit Gap"/"In-transit adj time"
    ~   piece/Month

Adj for Product INV=M Product INV Gap/Product INV adj time

Adj for Product WIP=
    M Prodcut WIP Gap/WIP adj time
    ~   piece/Month

Adj for RM Inventory=RM Inventory Gap/"RM Inventory Adj. Time"
    ~   unit/Month
    ~ |

Available RM Supply=max(0,"Raw Material Supply (Option)")
    ~   unit

Contract Period=12
    ~   Month

Customer Demand for Product=1000
    ~   piece/Month

D Desired Demand for Product=max(0,adj for D Product INV+Forecasted Customer Demand for Product)
    ~   piece/Month

D Product INV adj time=1
    ~   Month

D Product INV Gap=Desired D Product INV-Distributor Product Inventory
    ~   piece

Desired D Product INV=Forecasted Customer Demand for Product*ss coverage for D Product INV
    ~   piece

"Desired In-transit"=D Desired Demand for Product*Product Delivery Time

~   piece

Desired INV coverage=ss coverage
~   Month

Desired Product INV=Desired INV coverage*Desired Product Shipment Rate
~   piece

Desired Product Shipment Rate=max(0,"Adj for In-transit"+D Desired Demand for Product)
~   piece/Month

Desired RM Inventory= ss coverage for RM INV*Desired RM Usage Rate
~   unit

Desired RM Usage Rate=   Desired Production Start Rate*RM Usage Per Product
~   unit/Month

Forecasted Customer Demand for Product= SMOOTH3I(Customer Demand for Product, Smooth
Time , 1000)
~   piece/Month

"In-transit adj time"=1
~   Month

"In-Transit Gap"= "Desired In-transit"-"Distributor Product In-Transit"
~   piece

Indicated Demand for RM=max(0,Adj for RM Inventory+Desired RM Usage Rate)
~   unit/Month

M Prodcut WIP Gap=Desired Product WIP-M Product WIP
~   piece

M Product INV Gap=Desired Product INV-M Product Inventory
~   piece

Manufacturing Cycle time=   1
~   Month

Max RM Usage Rate=max(0,M Raw Material Inventory)
~   unit/Month

Max sales rate=max(Distributor Product Inventory,0)
~   piece/Month

Max Shipment Rate=   max(0,M Product Inventory)
    ~   piece

Product Delivery Time= 1
    ~   Month

Product INV adj time=   2
    ~   Month

RM Delivery Time=0.5
    ~   Month

"RM Inventory Adj. Time"= 1
    ~   Month
    ~ |

RM Usage Per Product= 1
    ~   unit/piece

RM Usage Rate=   min(Desired RM Usage Rate,Max RM Usage Rate)
    ~   unit/Month

Sales Rate=   min(Max sales rate,Customer Demand for Product)
    ~   piece/Month

Shipment Rate=   min(Desired Product Shipment Rate,Max Shipment Rate)
    ~   piece/Month

Smooth Time=3
    ~   Month

ss coverage=   2
    ~   Month

ss coverage for D Product INV=2
    ~   Month

ss coverage for RM INV=   2
    ~   Month

WIP adj time= 1
    ~   Month
****

.Control
**~
        Simulation Control Parameters

FINAL TIME   = 72
        ~   Month
        ~   The final time for the simulation.
        |

INITIAL TIME   = 0
        ~   Month
        ~   The initial time for the simulation.
        |

SAVEPER   =
            TIME STEP
        ~   Month [0,?]
        ~   The frequency with which output is stored.
        |

TIME STEP   = 0.03125
        ~   Month [0,?]
        ~   The time step for the simulation.
        |

\\\---/// Sketch information - do not modify anything except names
V300   Do not put anything below this section - it will be ignored
*Material flows
$192-192-192,0,Times New Roman|12||0-0-0|0-0-0|0-0-255|-1--1--1|-1--1--1|96,96,100
10,1,M Raw Material Inventory,866,200,53,28,3,3,0,0,0,0,0,0
10,2,M Product WIP,1107,198,48,29,3,3,0,0,0,0,0,0
10,3,M Product Inventory,1320,199,52,29,3,3,0,0,0,0,0,0
10,4,"Distributor Product In-Transit",1540,198,52,26,3,3,0,0,0,0,0,0
10,5,Distributor Product Inventory,1757,196,51,25,3,3,0,0,0,0,0,0
12,6,48,682,197,10,8,0,3,0,0,-1,0,0,0
1,7,9,1,4,0,0,22,0,0,0,-1--1--1,,1|(779,196)|
1,8,9,6,100,0,0,22,0,0,0,-1--1--1,,1|(712,196)|
11,9,48,739,196,6,8,34,3,0,0,1,0,0,0
10,10,RM Arrive Rate,739,228,48,24,40,131,0,16,-1,0,0,0,0-0-0,0-0-0,|12|B|0-0-0
1,11,13,2,4,0,0,22,0,0,0,-1--1--1,,1|(1022,196)|
1,12,13,1,100,0,0,22,0,0,0,-1--1--1,,1|(946,196)|
11,13,396,980,196,6,8,34,3,0,0,1,0,0,0
10,14,RM Usage Rate,980,224,42,20,40,3,0,0,-1,0,0,0
1,15,17,3,4,0,0,22,0,0,0,-1--1--1,,1|(1241,198)|

1,16,17,2,100,0,0,22,0,0,0,-1--1--1,,1|(1178,198)|

11,17,1292,1208,198,6,8,34,3,0,0,1,0,0,0

10,18,Product Finish Rate,1208,225,46,19,40,3,0,0,-1,0,0,0

1,19,21,4,4,0,0,22,0,0,0,-1--1--1,,1|(1462,198)|

1,20,21,3,100,0,0,22,0,0,0,-1--1--1,,1|(1398,198)|

11,21,1164,1430,198,6,8,34,3,0,0,1,0,0,0

10,22,Shipment Rate,1430,225,42,19,40,131,0,2,-1,0,0,0,0-0-0,0-0-0,|12||255-0-0

1,23,25,5,4,0,0,22,0,0,0,-1--1--1,,1|(1677,196)|

1,24,25,4,100,0,0,22,0,0,0,-1--1--1,,1|(1614,196)|

11,25,1276,1642,196,6,8,34,3,0,0,1,0,0,0

10,26,Product Arrive Rate,1642,223,48,19,40,3,0,0,-1,0,0,0

10,27,RM Inventory Gap,854,305,47,19,8,3,0,0,0,0,0,0

10,28,Adj for RM Inventory,841,395,39,19,8,3,0,0,0,0,0,0

10,29,"RM Inventory Adj. Time",706,392,45,19,8,3,0,0,0,0,0,0

1,30,1,27,1,0,0,0,0,64,0,-1--1--1,,1|(865,253)|

10,31,Desired RM Inventory,979,384,40,19,8,3,0,0,0,0,0,0

1,32,31,27,1,0,0,0,0,64,0,-1--1--1,,1|(936,341)|

1,33,27,28,1,0,0,0,0,64,0,-1--1--1,,1|(855,345)|

1,34,29,28,1,0,0,0,0,64,0,-1--1--1,,1|(767,419)|

10,35,Indicated Demand for RM,825,495,59,19,8,3,0,0,0,0,0,0

1,36,28,35,1,0,0,0,0,64,0,-1--1--1,,1|(844,438)|

10,37,Expected Demand for RM per period,307,612,70,19,8,3,0,0,0,0,0,0

10,38,Contract Period,205,707,45,22,8,3,0,0,0,0,0,0

10,39,Time,332,720,26,11,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,40,38,37,0,0,0,0,0,64,0,-1--1--1,,1|(251,662)|

1,41,35,148,1,0,0,0,2,65,0,-1--1--1,|12||0-0-0,1|(784,564)|

1,42,39,37,0,0,0,0,0,64,0,-1--1--1,,1|(322,676)|

10,43,"Raw Material Supply (Option)",306,452,53,24,3,3,0,0,0,0,0,0

1,44,45,43,100,0,0,22,0,0,0,-1--1--1,,1|(381,448)|

11,45,1196,409,448,6,8,34,3,0,0,1,0,0,0

10,46,Execution Rate,409,474,37,18,40,131,0,0,-1,0,0,0

12,47,48,122,446,10,8,0,3,0,0,-1,0,0,0

1,48,50,43,4,0,0,22,0,0,0,-1--1--1,,1|(215,448)|

1,49,50,47,100,0,0,22,0,0,0,-1--1--1,,1|(149,448)|

11,50,48,172,448,6,8,34,3,0,0,1,0,0,0

10,51,Reservation Rate,172,473,40,17,40,3,0,0,-1,0,0,0

1,52,37,51,1,0,0,0,0,64,0,-1--1--1,,1|(249,526)|

12,53,48,579,449,10,8,0,3,0,0,-1,0,0,0

1,54,45,53,4,0,0,22,0,0,0,-1--1--1,,1|(492,448)|

10,55,Desired RM Usage Rate,1007,488,40,19,8,3,0,0,0,0,0,0

1,56,55,35,1,0,0,0,0,64,0,-1--1--1,,1|(939,516)|

10,57,ss coverage for RM INV,965,302,49,19,8,3,0,0,0,0,0,0

1,58,57,31,1,0,0,0,0,64,0,-1--1--1,,1|(977,339)|

1,59,55,31,1,0,0,0,0,64,0,-1--1--1,,1|(1003,437)|

10,60,RM Usage Per Product,989,575,48,19,8,3,0,0,0,0,0,0

1,61,60,55,0,0,0,0,0,64,0,-1--1--1,,1|(995,538)|

10,62,M Prodcut WIP Gap,1128,305,48,21,8,3,0,2,0,0,0,0,0-0-0,0-0-0,|12||0-0-255

10,63,Desired Product WIP,1239,425,53,19,8,3,0,2,0,0,0,0,0-0-0,0-0-0,|12||0-0-255

1,64,2,62,1,0,0,0,0,64,0,-1--1--1,,1|(1126,247)|

1,65,63,62,1,0,0,0,0,64,0,-1--1--1,,1|(1190,368)|

10,66,Adj for Product WIP,1137,428,48,24,8,3,0,2,0,0,0,0,0-0-0,0-0-0,|12||0-0-255

10,67,WIP adj time,1076,358,38,16,8,3,0,2,0,0,0,0,0-0-0,0-0-0,|12||0-0-255

1,68,62,66,1,0,0,0,0,64,0,-1--1--1,,1|(1135,355)|

1,69,67,66,1,0,0,0,0,64,0,-1--1--1,,1|(1095,385)|

10,70,Desired Production Start Rate,1155,556,68,19,8,3,0,18,0,0,0,0,0-0-0,0-0-0,|12|B|0-0-255

1,71,70,55,0,0,0,0,0,64,0,-1--1--1,,1|(1086,524)|

1,72,66,70,1,0,0,0,0,64,0,-1--1--1,,1|(1154,481)|

10,73,Manufacturing Cycle time,1241,306,46,19,8,3,0,2,0,0,0,0,0-0-0,0-0-0,|12||0-0-255

1,74,73,63,1,0,0,0,0,64,0,-1--1--1,,1|(1248,355)|

1,75,73,18,1,0,0,0,0,64,0,-1--1--1,,1|(1232,265)|

10,76,M Product INV Gap,1351,344,52,19,8,3,0,0,0,0,0,0

10,77,Desired Product INV,1440,423,53,19,8,3,0,0,0,0,0,0

1,78,3,76,1,0,0,0,0,64,0,-1--1--1,,1|(1343,269)|

1,79,77,76,1,0,0,0,0,64,0,-1--1--1,,1|(1378,390)|

10,80,Adj for Product INV,1343,467,51,19,8,3,0,0,0,0,0,0

10,81,Product INV adj time,1383,550,55,19,8,3,0,0,0,0,0,0

1,82,76,80,1,0,0,0,0,64,0,-1--1--1,,1|(1356,399)|

1,83,81,80,1,0,0,0,0,64,0,-1--1--1,,1|(1365,509)|

1,84,80,70,1,0,0,0,0,64,0,-1--1--1,,1|(1282,528)|

10,85,Max Shipment Rate,1375,119,47,19,8,3,0,0,0,0,0,0

1,86,3,85,1,0,0,0,0,64,0,-1--1--1,,1|(1307,150)|

1,87,85,22,1,0,0,0,0,64,0,-1--1--1,,1|(1434,159)|

10,88,Desired Product Shipment Rate,1479,320,53,19,8,3,0,0,0,0,0,0

1,89,88,77,1,0,0,0,0,64,0,-1--1--1,,1|(1482,369)|

1,90,88,22,1,0,0,0,0,64,0,-1--1--1,,1|(1464,263)|

10,91,Desired INV coverage,1482,499,42,19,8,3,0,0,0,0,0,0

10,92,ss coverage,1528,564,38,11,8,3,0,0,0,0,0,0

1,93,92,91,0,0,0,0,0,64,0,-1--1--1,,1|(1512,541)|

1,94,91,77,0,0,0,0,0,64,0,-1--1--1,,1|(1464,467)|

10,95,"Adj for In-transit",1594,415,43,20,8,3,0,0,0,0,0,0

10,96,"In-transit adj time",1669,345,38,21,8,3,0,0,0,0,0,0

1,97,96,95,1,0,0,0,0,64,0,-1--1--1,,1|(1658,382)|

1,98,95,88,1,0,0,0,0,64,0,-1--1--1,,1|(1531,374)|

12,99,48,1923,195,10,8,0,3,0,0,-1,0,0,0

1,100,102,99,4,0,0,22,0,0,0,-1--1--1,,1|(1890,197)|

1,101,102,5,100,0,0,22,0,0,0,-1--1--1,,1|(1831,197)|

11,102,48,1861,197,6,8,34,3,0,0,1,0,0,0

10,103,Sales Rate,1861,222,49,17,40,131,0,2,-1,0,0,0,0-0-0,0-0-0,|12||255-0-0

10,104,Customer Demand for Product,1904,286,60,19,8,3,0,0,0,0,0,0

10,105,Forecasted Customer Demand for Product,1995,378,69,19,8,3,0,0,0,0,0,0

10,106,Smooth Time,2046,314,43,11,8,3,0,0,0,0,0,0

1,107,104,105,0,0,0,0,0,64,0,-1--1--1,,1|(1944,327)|

1,108,106,105,0,0,0,0,0,64,0,-1--1--1,,1|(2028,336)|

1,109,104,103,0,0,0,0,0,64,0,-1--1--1,,1|(1886,258)|

10,110,D Product INV Gap,1790,352,50,19,8,3,0,0,0,0,0,0

10,111,Desired D Product INV,1996,513,43,19,8,3,0,0,0,0,0,0

1,112,105,111,1,0,0,0,0,64,0,-1--1--1,,1|(2010,436)|

1,113,111,110,1,0,0,0,0,64,0,-1--1--1,,1|(1917,396)|

1,114,5,110,1,0,0,0,0,64,0,-1--1--1,,1|(1789,269)|

10,115,adj for D Product INV,1766,476,57,19,8,3,0,0,0,0,0,0

1,116,110,115,1,0,0,0,0,64,0,-1--1--1,,1|(1785,411)|

10,117,D Product INV adj time,1854,417,50,19,8,3,0,0,0,0,0,0

1,118,117,115,1,0,0,0,0,64,0,-1--1--1,,1|(1843,450)|

10,119,D Desired Demand for Product,1664,545,62,19,8,3,0,0,0,0,0,0

1,120,115,119,1,0,0,0,0,64,0,-1--1--1,,1|(1737,512)|

1,121,105,119,1,0,0,0,1,64,0,128-128-128,|12||0-0-0,1|(1854,495)|

1,122,119,88,1,0,0,0,0,64,0,-1--1--1,,1|(1556,448)|

10,123,Product Delivery Time,1658,125,54,19,8,3,0,0,0,0,0,0

1,124,123,26,1,0,0,0,0,64,0,-1--1--1,,1|(1658,170)|

10,125,ss coverage for D Product INV,2037,588,57,19,8,3,0,0,0,0,0,0

1,126,125,111,0,0,0,0,0,64,0,-1--1--1,,1|(2019,556)|

10,127,"In-Transit Gap",1590,304,40,20,8,131,0,0,0,0,0,0

1,128,4,127,1,0,0,0,0,64,0,-1--1--1,,1|(1579,249)|

1,129,127,95,1,0,0,0,0,64,0,-1--1--1,,1|(1608,349)|

10,130,"Desired In-transit",1708,279,55,11,8,3,0,0,0,0,0,0

1,131,123,130,0,0,0,0,0,64,0,-1--1--1,,1|(1681,199)|

1,132,130,127,1,0,0,0,0,64,0,-1--1--1,,1|(1650,306)|

1,133,119,130,1,0,0,0,0,64,0,-1--1--1,,1|(1705,411)|

1,134,35,46,1,0,0,0,0,64,0,-1--1--1,,1|(708,515)|

10,135,Available RM Supply,408,349,45,19,8,3,0,0,0,0,0,0

1,136,43,135,1,0,0,0,0,64,0,-1--1--1,,1|(380,405)|

10,137,RM Delivery Time,776,125,52,19,8,131,0,0,0,0,0,0

1,138,137,10,1,0,0,0,0,64,0,-1--1--1,,1|(768,165)|

1,139,55,14,1,0,0,0,0,64,0,-1--1--1,,1|(1042,338)|

10,140,Max RM Usage Rate,938,125,52,19,8,3,0,0,0,0,0,0

1,141,1,140,1,0,0,0,0,64,0,-1--1--1,,1|(865,156)|

1,142,140,14,1,0,0,0,0,64,0,-1--1--1,,1|(994,171)|

10,143,Max sales rate,1801,120,37,16,8,3,0,0,0,0,0,0

1,144,5,143,1,0,0,0,0,64,0,-1--1--1,,1|(1764,155)|

1,145,143,103,1,0,0,0,0,64,0,-1--1--1,,1|(1846,146)|

10,146,Shipment Rate,1263,609,50,19,8,130,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,147,146,70,1,0,0,0,0,64,0,-1--1--1,,1|(1191,596)|

10,148,Monthly Expected Demand for RM,671,586,59,19,8,3,0,0,0,0,0,0

1,149,148,37,1,0,0,0,0,64,0,-1--1--1,,1|(467,636)|

1,150,2,17,1,0,0,0,0,64,0,-1--1--1,,1|(1161,151)|

1,151,4,26,1,0,0,0,0,64,0,-1--1--1,,1|(1596,151)|

10,152,"Un-executed option",310,248,42,19,8,131,0,0,0,0,0,0

1,153,135,152,1,0,0,0,2,65,0,-1--1--1,|12||0-0-0,1|(390,288)|

10,154,Time,130,324,26,11,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

12,155,48,305,298,10,8,0,3,0,0,-1,0,0,0

1,156,158,155,4,0,0,22,0,0,0,-1--1--1,,1|(305,333)|

1,157,158,43,100,0,0,22,0,0,0,-1--1--1,,1|(305,400)|

11,158,48,305,367,8,6,33,3,0,0,2,0,0,0

10,159,Remainder RM Supply,248,367,49,19,40,3,0,0,-1,0,0,0

1,160,152,159,1,0,0,0,0,64,0,-1--1--1,,1|(244,294)|

1,161,154,159,0,0,0,0,0,64,0,-1--1--1,,1|(170,338)|

10,162,Contract Period,167,270,49,22,8,130,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,163,162,159,0,0,0,0,0,64,0,-1--1--1,,1|(203,314)|

10,164,Beta,729,659,18,11,8,3,0,18,0,0,0,0,0-0-0,0-0-0,|12|B|255-0-255

1,165,164,148,1,0,0,0,0,64,0,-1--1--1,,1|(704,630)|

10,166,SmoothTime,620,662,36,19,8,131,0,0,0,0,0,0

1,167,166,148,0,0,0,0,0,64,0,-1--1--1,,1|(641,629)|

1,168,88,63,1,0,0,0,1,64,0,160-160-160,|12||0-0-0,1|(1376,405)|

10,169,"Raw Material Supply (Long-Term)",217,-80,49,27,3,131,0,0,0,0,0,0

12,170,48,61,-78,10,8,0,3,0,0,-1,0,0,0

1,171,173,169,4,0,0,22,0,0,0,-1--1--1,,1|(147,-78)|

1,172,173,170,100,0,0,22,0,0,0,-1--1--1,,1|(93,-78)|

11,173,48,121,-78,6,8,34,3,0,0,1,0,0,0

10,174,Purchasing Rate,121,-48,34,22,40,131,0,0,-1,0,0,0

12,175,48,447,-79,10,8,0,3,0,0,-1,0,0,0

1,176,178,175,4,0,0,22,0,0,0,-1--1--1,,1|(402,-79)|

1,177,178,169,100,0,0,22,0,0,0,-1--1--1,,1|(310,-79)|

11,178,48,361,-79,6,8,34,3,0,0,1,0,0,0

10,179,RM Delivery Rate,361,-48,48,23,40,131,0,0,-1,0,0,0

10,180,Time,320,-129,26,11,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

10,181,Contract Period,413,-134,49,19,8,130,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,182,181,179,1,0,0,0,0,64,0,-1--1--1,,1|(401,-97)|

1,183,180,179,0,0,0,0,0,64,0,-1--1--1,,1|(333,-100)|

10,184,a,379,42,6,11,8,3,0,0,0,0,0,0

1,185,184,179,1,0,0,0,0,64,0,-1--1--1,,1|(356,9)|

1,186,179,184,1,0,0,0,2,65,0,-1--1--1,|12||0-0-0,1|(392,-6)|

10,187,Expected Demand for RM per period,236,99,75,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,188,187,174,1,0,0,0,0,64,0,-1--1--1,,1|(115,21)|

1,189,187,179,1,0,0,0,0,64,0,-1--1--1,,1|(325,15)|

10,190,"Share from Long-Term

Contract",608,-3,71,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

10,191,Share   from   Option
Contract,522,240,61,19,8,130,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

10,192,"Purchase from long-term contract",572,112,59,19,8,3,0,0,0,0,0,0

10,193,Purchase from option contract,574,336,48,19,8,3,0,0,0,0,0,0

1,194,179,192,1,0,0,0,0,64,0,-1--1--1,,1|(497,9)|

1,195,190,192,0,0,0,0,0,64,0,-1--1--1,,1|(592,47)|

1,196,46,193,1,0,0,0,0,64,0,-1--1--1,,1|(505,416)|

1,197,191,193,0,0,0,0,0,64,0,-1--1--1,,1|(544,281)|

1,198,192,10,0,0,0,0,2,65,0,-1--1--1,|12||0-0-0,1|(645,163)|

1,199,193,10,1,0,0,0,2,65,0,-1--1--1,|12||0-0-0,1|(651,282)|

\\\---/// Sketch information - do not modify anything except names

V300   Do not put anything below this section - it will be ignored

*Financial flows

$192-192-192,0,Times New Roman|12||0-0-0|0-0-0|0-0-255|-1--1--1|-1--1--1|96,96,100

10,1,"Procurement Cost (Option Contract)",634,421,62,26,3,131,0,0,0,0,0,0

12,2,48,629,288,10,8,0,3,0,0,-1,0,0,0

1,3,5,1,4,0,0,22,0,0,0,-1--1--1,,1|(628,367)|

1,4,5,2,100,0,0,22,0,0,0,-1--1--1,,1|(628,312)|

11,5,48,628,334,8,6,33,3,0,0,4,0,0,0

10,6,Pay for Execution,684,334,48,17,40,131,0,0,-1,0,0,0

10,7,Execution Price,683,229,43,18,8,131,0,0,0,0,0,0

10,8,Raw Material Spot Market Price,552,145,66,20,8,3,0,18,0,0,0,0,0-0-0,0-0-0,|12|B|64-160-98

10,9,Effect   of   Spot   Price   on   Execution
Price,758,46,68,19,8,3,0,18,0,0,0,0,0-0-0,0-0-0,|12|B|0-255-0

1,10,8,7,0,0,0,0,0,64,0,-1--1--1,,1|(612,184)|

1,11,7,6,0,0,0,0,0,64,0,-1--1--1,,1|(683,275)|

12,12,48,444,420,10,8,0,3,0,0,-1,0,0,0

1,13,15,1,4,0,0,22,0,0,0,-1--1--1,,1|(542,418)|

1,14,15,12,100,0,0,22,0,0,0,-1--1--1,,1|(477,418)|

11,15,48,506,418,6,8,34,3,0,0,1,0,0,0

10,16,Pay for Reservation,506,443,46,17,40,3,0,0,-1,0,0,0

10,17,Reservation Price,439,525,44,19,8,131,0,18,0,0,0,0,0-0-0,0-0-0,|12|B|255-0-0

10,18,Total Procurement Quantity,933,420,52,26,3,131,0,0,0,0,0,0

12,19,48,932,281,10,8,0,3,0,0,-1,0,0,0

11,20,48,932,329,8,6,1,3,0,0,1,0,0,0

1,21,20,18,4,0,0,22,0,0,0,-1--1--1,,1|(932,364)|

1,22,20,19,100,0,0,22,0,0,0,-1--1--1,,1|(932,306)|

1,23,17,16,0,0,0,0,0,64,0,-1--1--1,,1|(468,488)|

10,24,Reservation Rate,577,525,43,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,25,24,16,0,0,0,0,0,64,0,-1--1--1,,1|(545,488)|

10,26,Execution Rate,810,257,48,20,8,130,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,27,26,6,1,0,0,0,0,64,0,-1--1--1,,1|(737,272)|

1,28,26,20,1,0,0,0,0,64,0,-1--1--1,,1|(883,277)|

10,29,"Average Unit Procurement Cost (Option)",813,532,58,28,8,3,0,0,0,0,0,0

1,30,1,29,0,0,0,0,0,64,0,-1--1--1,,1|(715,471)|

1,31,18,29,0,0,0,0,0,64,0,-1--1--1,,1|(879,470)|

10,32,Time,622,-12,26,11,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

10,33,"Average Unit Procurement Cost (Long Term)",407,231,74,29,8,131,0,0,0,0,0,0

1,34,8,33,0,0,0,0,0,64,0,-1--1--1,,1|(493,179)|

10,35,Alpha,310,139,20,11,8,3,0,2,0,0,0,0,0-0-0,0-0-0,|12||255-0-255

1,36,35,33,0,0,0,0,0,64,0,-1--1--1,,1|(343,171)|

10,37,Contract Period,813,579,60,11,8,2,1,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

10,38,Time,813,579,26,11,8,2,1,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

10,39,"Average Unit Procurement Cost (Portfolio)",163,394,58,28,8,3,0,0,0,0,0,0

1,40,33,39,1,0,0,0,0,64,0,-1--1--1,,1|(261,278)|

1,41,29,39,1,0,0,0,0,64,0,-1--1--1,,1|(424,596)|

10,42,Random Factor,515,62,42,19,136,3,0,0,0,0,0,0

1,43,42,8,0,0,0,0,0,64,0,-1--1--1,,1|(530,96)|

10,44,Spot Price Trend,618,63,47,22,136,3,0,0,0,0,0,0

1,45,44,8,0,0,0,0,0,64,0,-1--1--1,,1|(588,99)|

1,46,32,44,0,0,0,0,0,64,0,-1--1--1,,1|(620,13)|

10,47,RM Delivery Rate,199,442,46,19,8,2,1,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

10,48,Execution Rate,199,442,57,11,8,2,1,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

10,49,"Purchase   from   long-term

contract",328,325,64,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

10,50,Purchase   from   option

contract,321,449,53,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,51,49,39,1,0,0,0,0,64,0,-1--1--1,,1|(248,337)|

1,52,50,39,1,0,0,0,0,64,0,-1--1--1,,1|(245,441)|

10,53,Gama,791,142,20,11,8,3,0,2,0,0,0,0,0-0-0,0-0-0,|12||0-255-0

10,54,Indicated   Demand   for

RM,907,51,64,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,55,9,53,0,0,0,0,0,64,0,-1--1--1,,1|(773,91)|

1,56,54,53,0,0,0,0,0,64,0,-1--1--1,,1|(849,96)|

1,57,53,7,0,0,0,0,0,64,0,-1--1--1,,1|(746,177)|

10,58,Contract Period,187,230,52,22,136,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,59,58,33,0,0,0,0,0,64,0,-1--1--1,,1|(279,230)|

\\\---/// Sketch information - do not modify anything except names

V300   Do not put anything below this section - it will be ignored

*Share

$192-192-192,0,Times New Roman|12||0-0-0|0-0-0|0-0-255|-1--1--1|-1--1--1|96,96,100

10,1,Share from Option Contract,422,371,60,19,8,131,0,0,0,0,0,0

10,2,"Share from Long-Term Contract",424,108,67,19,8,3,0,0,0,0,0,0

1,3,1,2,0,0,0,0,0,64,0,-1--1--1,,1|(422,246)|

10,4,Desired RM Inventory,525,477,45,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

10,5,Weight,282,293,26,11,8,3,0,18,0,0,0,0,0-0-0,0-0-0,|12|BI|0-192-192

10,6,Initial Share,266,407,38,11,8,131,0,0,0,0,0,0

1,7,5,1,0,0,0,0,0,64,0,-1--1--1,,1|(337,324)|

1,8,6,1,0,0,0,0,0,64,0,-1--1--1,,1|(326,393)|

1,9,4,1,0,0,0,0,0,64,0,-1--1--1,,1|(478,428)|

10,10,M Raw Material Inventory,369,480,58,19,8,2,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,11,10,1,0,0,0,0,0,64,0,-1--1--1,,1|(391,431)|

10,12,"Average Unit Procurement Cost (Option)",662,370,58,28,8,130,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,13,12,1,0,0,0,0,0,64,0,-1--1--1,,1|(550,370)|

10,14,"Average Unit Procurement Cost (Long Term)",586,265,74,31,8,130,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,15,14,1,0,0,0,0,0,64,0,-1--1--1,,1|(500,320)|