INTEGRATED SUPPLY CHAIN MODELS WITH RANDOM DEMAND AND FLEXIBLE PRODUCTION PROCESS

BY

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Dedication

I dedicate this project to God Almighty, who is the mystery behind my success and through whose help and favor, I obtained this degree. Humanly, I dedicate this work to my parents,fiancee and brothers for the love and support they showed while away in Saudi-Arabia.

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THESIS ABSTRACT

NAME:	ADEGBOLA, KEHINDE ADEKUNLE
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Integrated inventory models have proven cost effectiveness in supply chain systems. Most models in the literature assume a fixed production rate, and for the few variable production rate models, deterministic demand is assumed. Also, in practice, some vendors restrict shipment size to multiples of full truckloads, a constraint that needs to be further studied within the context of integrated supply chain models. Motivated by a practical scenario, the impact of variable production rates in a flexible production system with stochastic demand is modeled and analyzed. A single vendor, single manufacturer mathematical and simulation models are developed, with the vendor sending shipments in multiples of full truckloads and keeping no inventory; the manufacturer needs to determine his optimal production rate, production quantity, number of full *truckloads from the vendor, and the re-order level as decision variables. A solution technique is suggested for the mathematical model. Illustrative examples are provided to explore the effect of demand, demand variation, holding cost of the manufacturer, truck size, vendor production rate, lead-time, and raw material consumption to production ratio.*

The problem is later extended to the Single-Vendor, Multiple-Manufacturers (SVMM) case. The extended problem is modeled using Arena simulation software. Simulation optimization is performed using OptQuest software to find the optimal operating parameters of two suggested distribution policies, regarding how best to manage the SVMM supply chain. Finally, illustrative examples are provided.

ملخص الرسالة

الاسم: **كيهندي اديكونلي اديجبولا**
العنوان: **نماذج ادارة المخزون في حالة الانتاج المرن وطلب عشوائي**
التخصص: **هندسة النظم**
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أثبتت النماذج الرياضية فاعلية اتخاذ القرارات بشكل متكامل في مجال ادارة سلاسل الامداد . معظم النماذج الرياضية تفترض معدل انتاج ثابت، والقليل من النماذج التي افترضت معدل انتاج متغير افترضت كذلك ان الطلب على المنتجات غير عشوائي. من الناحية العملية، بعض البائعين يقيد حجم الطلبات إلى مضاعفات حجم شاحنة كاملة وهو القيد الذي يحتاج إلى مزيد من الدراسة في إطار نماذج سلاسل الامداد المتكاملة. بناء على ما سبق، تهدف هذه الرسلة الى تحليل ونمذجة تأثير معدلات الإنتاج المتغيرة في نظام إنتاج مرن مع وجود طلب عشوائي على المنتجات. في هذه الدراسة، تم تطوير نموذج رياضي وبعض نماذج المحاكاة الحاسوبية بافتراض وجود بائع و زبون. تستخدم هذه النماذج لتحديد معدل الإنتاج الأمثل للزبون، كمية الانتاج المثلى، عدد الشحنات للطلبية الواحدة، ومستوى المخزون الأمثل لتجديد طلب الشراء كمتغيرات. لمزيد من الايضاح تم عرض بعض الأمثلة. لتبيان تاثير معدل الطلب، التغير العشوائي في معدل الطلب، حجم الشاحنة، معدل الإنتاج عند البائع، وكذلك نسبة استخدام المواد الخام إلى نسبة الإنتاج.

لاحقا، تم تطوير المسألة إلى حالة بائع وعدد من الزبائن. تم نمذجة هذه المسألة باستخدام برنامج المحاكاة Arena . كما تمت أمثلة المحاكاة باستخدام برنامج OptQuest لايجاد الحلول المثلى. أخيرا تم عرض بعض الأمثلة التوضيحية.

CHAPTER 1

INTRODUCTION

1.1 Introduction

This research considers inventory control in an integrated supply chain systems. An integrated supply chain system represents a system that has a full responsibility across the corporation(geographies and business units) so as to enhance management and planning of every activities involved in the end-to-end supply chain processes. These activities might range from procurements to direct sourcing, manufacturing and logistics management. The literature has reported many benefits of supply chain integration. This provides system optimization through high visibility, lower inventory, more effective capacity utilization, reduce lead time and high product quality.

Material management refers to those functions channel towards achieving optimal coordination, planning, sourcing, purchasing, moving, storing and controlling of materials so as to render a pre-decided service to customers or client at an optimized cost. It ensure that the right kind of materials are at the right place whenever needed at reasonable cost. Traditionally, materials needed for production purpose are normally procured in advance, stored in the plant and issued to manufacturing when there is requisition.

Contradicting this fundamental procedure are most inventory management policies. Inventory are generally referred to as material in stock and they represent items that are either stocked for sale or in process or materials that are waiting for utilization. They are been considered as frozen capital that offers no proportionate return on investment. In a stochastic demand environment,keeping inventory might be one way to guard against shortages. Another approach might be to control productivity through flexible production systems.

1.2 General Statement of the Problem

In this section, a general statement of the problems addressed in this research work are presented.

1.2.1 Single-Vendor, Single-Manufacturer Model

1. Consider a major manufacturer of polymers (vendor) who supplies manufacturers with different grades of polymers. The manufacturer delivers shipments in multiples of full truckloads. One of the customers is a manufacturer who faces highly random demand; hence, inventory of raw material is kept in his ware-

house. The manufacturer can increase his production rate via accelerating the production process, which includes mainly a blending and filling process.

2. The supply chain profile shown in Figure 1.1 represents a manufacturer with stochastic demand for his products. Assuming he orders the main raw material used for his product from a vendor who produces this material at a constant rate P_v and, as practiced by many companies, the vendor send shipments in multiples of full truckload (q). The manufacturer starts production immediately upon the first shipments arrival in his warehouse (after a lead-time , $t_i + \triangle$) by depleting the raw material received at a rate that is proportional to his production rate (P). The manufacturer faces random demand for his product and uses a continuous review system (Q, R). The objective will be to determine the production rate, the number of full truck shipments, the re-order point, and the production lot size which minimizes the total supply chain cost.

1.2.2 Single-Vendor, Multiple-Manufacturer Model

This section set out to relax the single-manufacturer assumption of the single-vendor, single-manufacturer (SVMM) supply chain system. Similar to the previous section, consider a single vendor who supplies manufacturers with the same product. The vendor delivers shipments to the manufacturers in multiples of full truckloads. All the manufacturers are assumed to face highly random demands that are independent of each other; hence, inventory of raw materials are kept in their warehouses. Meanwhile, to simplify the problem, we assume that the manufacturer's can have different but fixed

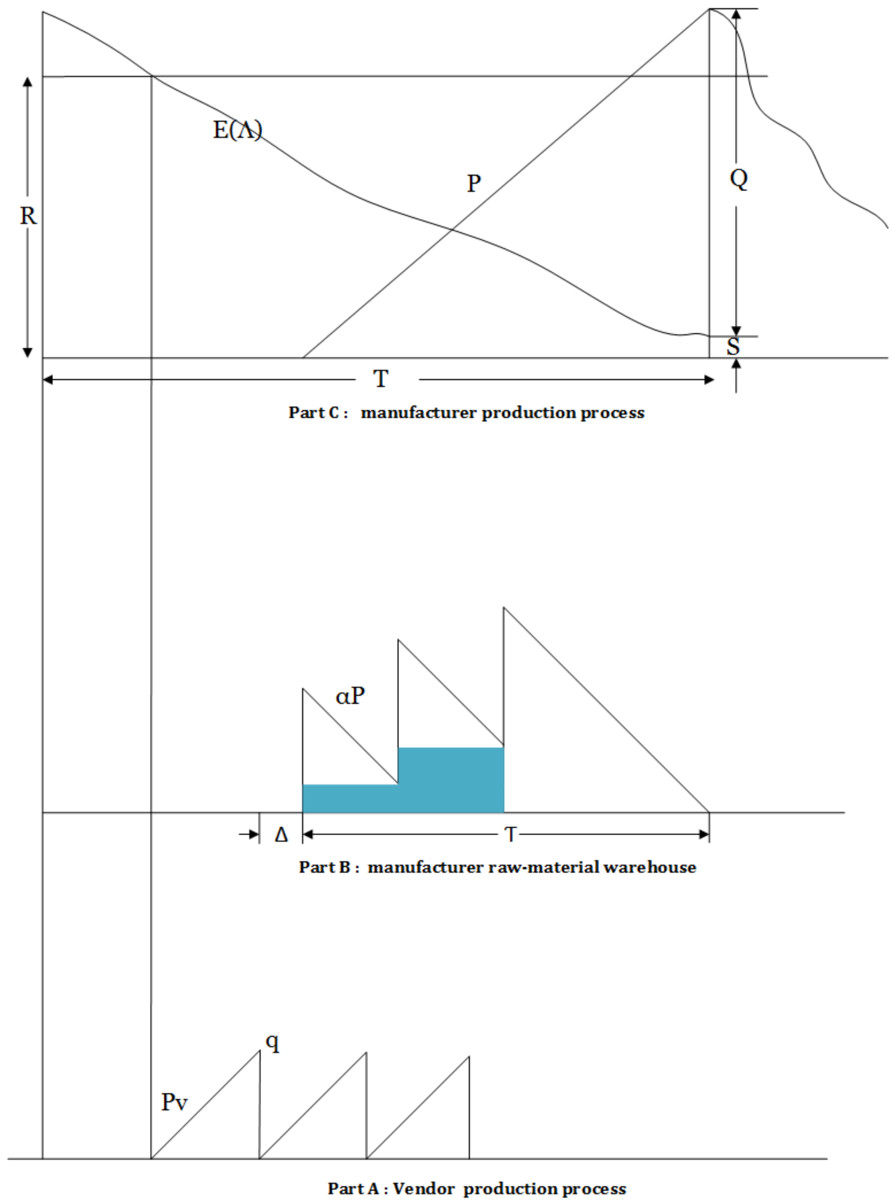


Figure 1.1: Inventory profile of the single-vendor, single-manufacturer supply chain.

production rates.

1.3 Motivation

The following points provide the motivation behind pursuing research in this area

1. Supply chain management offers several benefits that range from inventory cost reduction, improve customers satisfaction , improve quality and higher profit margin, increase cash flow and better collaboration(trust) between stakeholders to mention few.

2. To the best of our knowledge, most single-vendor, single-manufacturers models in the literature assume a fixed production rate, and for the few variable production rate models, deterministic demand is assumed.

3. In practice, some vendors restrict shipment size to multiples of full truckloads, a constraint that needs to be further studied within the context of integrated supply chain models.

4. The analytical models of the single-vendor, single-manufacturer problem with stochastic demand are based on some assumptions, such as the existence of a renewal point. Hence the robustness of the proposed model against this assumption will be studied.

5. Most single-vendor, single-manufacturer models in literature assume deterministic demand. Hence, the need to consider the single-vendor, multiple-manufacturer problem in a stochastic demand environment.

1.4 Thesis Objectives

1. To develop a single-vendor, single-manufacturer supply chain mathematical model using the inventory profile shown in Figure 1.1.
2. Solve the proposed model
3. To build a discrete event simulation model for the same problem in (1) above.
4. The analytical model in (1) will be used to validate the simulation model in (3) and vice versa.
5. Detailed sensitivity analysis will be performed using one of the models in (1) and (3).
6. The simulation model will be extended to single-vendor, three-customer case as an illustrative example for the multi-customer case and some stationary distribution policies will be explored.

1.5 Thesis Contributions

The main contributions of this thesis are listed below:

1. A novel single-vendor, single-manufacturer model is developed, with the vendor sending shipments in multiples of full truckloads and keeping no inventory. The manufacturer needs to determine his optimal production rate, production quantity, number of full truckloads from the vendor, and the re-order level as the decision variables.

2. A simulation model is developed for the same problem to investigate the impact of some approximations made in the analytical model.

3. The single-manufacturer assumption is relaxed using the simulation model so as to consider multiple manufacturers. Two policies are explored, namely:Common reorder point policy, and VMI policy where the vendor takes the lead in the distribution process.

1.6 Thesis Organization

The rest of this thesis is organized as follows:

The literature review is provided in chapter 2 followed by the mathematical model for the Single-Vendor, Single-Manufacturer (SVSM) in chapter 3. SVSM simulation model is presented in chapter 4 and this is extended to single-Vendor,Multiple-Manufacturers(SVMM), assuming fixed production rates in chapter 5. Lastly, the thesis conclusion and some suggested future works are the subject of chapter 6.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter considers the literature of integrated Single-Vendor, Single-Manufacturer (SVSM) and Single-Vendor,Multiple-Manufactures (SVMM) supply chain models. Inventory control in supply chain has the advantages of improving firm liquidity position by reducing capital tied down in excess inventories, it equally facilitates better customer service through adequate stocks of finished products.

The literature has many models and many solution approaches for the addressed problem. A brief review of literature that are pertinent to this research will be provided in this chapter. For detailed survey on integrated supply chain models, refer to Maloni and Benton (1997), Vidal and Goetschalckx (1997), Tsay et al. (1999), Shen (2007), Van der Vaart and van Donk (2008) and Glock (2012).

The rest of this chapter is organized as follows:Variable production rate models are presented in section(2.2), integrated SVSM models in section (2.3), SVMM models in section (2.4) under the following subsections:deterministic models (2.4.1) and stochastic analytical models (2.4.2) and discrete event simulation models in section (2.5).

2.2 Variable Production Rate Models

The determination of the optimal production rate as a decision variable for a manufacturing system has long been investigated, Buzacott and Ozkarahan (1983) considered the problem of product scheduling on machines by varying the production rate through an idle time inserted in the production run time. The authors were able to show that it is optimal to select the production rate in such a way that machines are subjected to full utilization. Silver (1990) modified the work of Buzacott and Ozkarahan (1983) by analyzing how a family of items are produced on a single facility. The author assumed that the products are produced once in the same production cycle and further allow the production rate be varied within a defined limit. Sarker and Sobhan Babu (1993) shows how the production rate can impact the shelf life of perishable items. The authors affirmed that it will be advantageous to reduce the production cycle or the production rate of products so as to control the time spent on shelf.

Khouja (1994) was the first to extend the classical economic production quantity model which assumed a fixed production rate. In his model, the author assumed a variable production rate so as to enhance the volume flexibility of a manufacturing system under managerial control. Khouja and Mehrez (1994) extended the work of Khouja (1994) by linking the quality of the production process with the production rate. The authors proposed a model which was solved for a special case of unit production cost and mean time to shift out of control. The result showed that for cases where an increase in production rate causes a high decline in quality, the optimal production rate might be lesser than the production rate that minimizes the unit production cost, and for situations where quality is autonomous of production rate, the optimal production rate might be larger than the rate that minimizes the unit production cost.

Khouja (1999) extended Khouja (1994) by assuming that the production process may shift out of control with a probability that depends on the production rate. The author showed that by incorporating quality, there will be a reduction in the cycle time and the optimal lot size. Similarly, Eiamkanchanalai and Banerjee (1999) developed a model which determines concurrently the optimal run length and production rate for a single item.

Giri et al. (2005) studied the economic manufacturing problem, in which the production rate affects the stress level and failure rate of the production facility. The unit production cost is expressed as a function of the production rate and the basic economic manufacturing quantity model was developed under general failure and repair time distributions. Larsen (2005) developed an EPQ model with the production rate and their corresponding runs time as the decision variables. The author was able to show that the optimal production rate that minimizes the unit production cost lies in an interval between demand and production rate. Glock (2010) developed a model for the case of equal and unequal batch shipment in a single vendor, single buyer system . The author assumed that every batch received was consumed at a discrete time interval and the effect of the variable production rate on cost and inventory build-up were properly investigated. AlDurgam and Duffuaa (2013) considered maximizing the overall systems effectiveness by choosing the optimal process rate, and maintenance schedule. However, a common point among the reviewed models is the assumption of deterministic demand.

2.3 Integrated Single-Vendor, Single-Manufacturer (SVSM) Models

Many authors considered integrated inventory models (a.k.a. joint economic lot size models). In this section we review some of the relevant research. For a comprehensive review, the reader is referred to Glock (2012) and the references therein, where a detailed literature review on the joint economic lot size models is provided. The author provided an in-depth review and classified the literature as follows: basic integrated inventory models which include: two-stage and multi-stage models, and extended integrated inventory models which include models that consider: stochastic demand and/or stochastic lead-time, ordering/setup cost and/or lead-time reductions, product quality, product deterioration and decay, and models which consider learning.

From literature, Goyal (1976) developed one of the first joint economic lot sizing models and demonstrated the advantage of integration. Goyal (1977) extended Goyal (1976) by anticipating an infinite production rate for the products. Banerjee (1986) relaxed the infinite production rate assumption by proposing a finite production rate with a lot-for-lot shipment policy for the products. Lu (1995) extended the work of Banerjee (1986) by replacing the joint economic lot size model, where a vendor produced to order from a purchaser on a lot-for-lot basis under deterministic conditions with a more generalized model that assumed an equal size shipment to the buyer from the vendor. Goyal (1995) extended the work of Banerjee (1986) and Lu (1995) by expressing the size of the i^{th} shipment send to the buyer in a given batch as a function of the production rate, demand rate and first shipment size i.e.

$$\mathrm{i^{th}\ \ shipment\ \ size = first\ \ shipment\ \ size} * \frac{\mathrm{P}}{\mathrm{D}}^{i-1}$$

P: rate of production, D: rate of demand.

This was later generalized by Hill (1997) who expressed the size of the ith shipment as

$$\mathrm{i^{th}\ \ shipment\ \ size = first\ \ shipment\ \ size} * y^{i-1}$$

where

$$1 \le y \le \frac{P}{D}$$

Later on Goyal and Nebebe (2000) developed a model that determines the economic production quantities, optimal shipment size and the optimal number of shipment in which a batch will be sent from the vendor to the buyer. The model was developed to address the buyers problem of what quantities to order in each purchase, and what should be the most economic production batch quantity and shipment size from the vendors perspective. The policy is to send n shipments, consisting of n-1 equal shipments and one smaller shipment to the buyer, as it is assumed that the cumulative sum of each shipments size make up the vendor batch quantity.

Hoque and Goyal (2000) proposed a sequential batches integrated model that consist of a limited number of equal and unequal batches, with the successive unequal batches increasing by a constant factor. The transport facility transferring batches is assumed to have a limited capacity and based on the model a solution algorithm was developed. Huang (2004) developed a model that determines the optimal policy for a single buyer, single vendor joint production inventory system so as to cater for defective product in a just-in-time environment. The convexity of the cost function led to the development of an analytical procedure to determine the economic order quantity and numbers of deliveries in each order placed. The multiple deliveries models has proven cost efficiency in a supply chain, many of the authors assumed a perfect cycle, an assumption which was relaxed by Wee and Widyadana (2013) in their model.

Ben-Daya and Hariga (2004) relaxed the supposition of deterministic demand with probabilistic demand for a single-vendor, single-buyer integrated inventory system. In their model, the authors assumed that the lot size has a varying linear relationship with the lead time that consists of a lot size-dependent run time and a constant delay time. An algorithm was proposed to obtain an approximate solution of the suggested model. Later on, Glock (2009) modified the Ben-Daya and Hariga (2004) model by replacing the authors assumption of equal batch shipment with a constantly increasing batch size. The author further expressed the need for a different re-order point for batches sent to the buyer and the benefit of this was shown using a numerical example. Ouyang et al. (2004) proposed an extension for a single buyer, single vendor joint production inventory system by replacing the deterministic lead time demand with a stochastic demand with shortages allowed during the lead time. The authors further assumed that the lead time can be shortened through an additional cost. An iterative procedure was suggested to find the optimal policy. Considering lead time duration distribution Hoque (2013) considered normally distributed lead time, and discussed the practical implications of his model.

Glock (2011) suggested methods for reducing the lot size-dependent lead time in a stochastic environment. The author adopted the (Q,s) continuous review model for a single-vendor, single-buyer system, and the impact of these methods on safety stocks and expected total cost were thoroughly investigated.

Darwish et al. (2013) was the first to integrate process targeting and inventory problems together in a probabilistic environment. The model assumed a yield rate, which is the product of the production rate and the probability of conformance p, where p relies on the process mean μ. The decision variables considered were the optimal process mean, which indirectly dictated the production rate, lot size, and re-order point using the (Q, R) continuous review model. However, not all process targeting applications will impact production speed, as typified by the gravity-based filling.

Considering an integrated model with the production rate as the decision variable, Ouyang et al. (2008) developed an integrated inventory model with a price sensitive demand rate and variable production rate. The authors were able to show that it is possible to increase profit in the supply chain system through trade credit and freight rate policies on ordered quantities. Similar to Ouyang et al. (2008), Singh and Sharma (2013) proposed an integrated model for a supply chain management system that runs from the vendor down to the manufacturer. The model defined the production rate as a function of the demand rate with the impact of inflation and time value of money being perfectly considered. The model result shows that the holding cost can be reduced, if the manufacturer could receive a small quantity raw materials and supply the product in small lots to the buyer.

2.4 Integrated Single-Vendor, Multiple-Manufacturers (SVMM) Models

Overtime, inventory management problem for single-vendor, multiple-buyers has been of interest to several scholars. Practically, most supply chain systems consist of more than two principal actors or stakeholders that must be properly integrated to eliminate unnecessary cost that accrue from such complex system. From literature, many scenarios with different modeling assumptions and policies like common replenishment cycle, turnpike, previous order frequency and power of two to mention few, have all been studied under single-vendor, multiple buyer systems. Some of these research papers that are useful to this work are, however, presented under

- Deterministic models
- Stochastic models

2.4.1 Deterministic Models

Banerjee and Burton (1994) studied a situation where vendor products from batch production are dispatched to multiple manufacturers under deterministic condition. The authors investigated two coordinated policies, in which the first ensured that both stake holders operate independently i.e. the buyers independently determine their ordering policy while the vendor enforce the production policy. The second policy suggested a joint or coordinated inventory decision system. The result from both policies, however, showed the coordinated policy performing better comparatively than the independent optimization. Lu (1995) formulated a single-vendor, multi-buyer inventory model to minimize the total cost incurred by the vendor when given discount to the buyers through a constraint imposed on the buyers cost. The author showed that unlike other models that required annual buyers demand, holding and ordering cost for implementation, the proposed model used buyers demand and previous order frequency. A heuristic approach was however used to find the optimal solution to the model.

Bylka (1999) examined a single-vendor, multi-buyers problem when vendor produce in batches and make deliveries to multiple-buyers whose demands follow a periodic sequence. A deterministic dynamic programming model was developed to achieve turnpike policies with a forecast horizon for decisions. Woo et al. (2000) considered a single-vendor, multiple-buyer integrated inventory system in which all stakeholders are willing to reduce the joint total cost through a collective investment channeled towards reducing the ordering cost. The authors developed a model to determine the optimal investment and replenishment decision. The solved example however showed that all stakeholders will benefit substantially through this joint ordering cost reduction investment.

Yang and Wee (2002) incorporated deteriorating items into single-vendor, multi-buyers integrated inventory problem. The authors developed a deterministic mathematical model for the integrated system that was solved using a heuristic approach. The model result showed the advantage of the proposed integrated policy over independent decisions made by the vendor and buyers. Chan and Kingsman (2006) synchronized delivery and production cycles in a coordinated single-vendor, multi-buyers supply chain system. The synchronization was achieved by coordinating both the delivery date of the buyer and the vendor production cycle, with the buyers taking the lead by choosing their lot sizes and order cycles. The authors developed a mathematical model which was solved using a recommended algorithm to show that the synchronized policy gives better result compared to independent optimization. Wee et al. (2007) identified two possible shortcomings (Positive holding cost characteristics and total quantity equality) in the cost function developed by Woo et al. (2000).The authors suggested ways to remove the flaws.

Chu and Leon (2008) considered privacy restriction in the information needed to co-ordinate single-vendor, multi-buyer supply chain system. The objective is to minimize all inventory related cost for the supply chain system as information for each facility is considered separately and not to be shared with other facilities. Two different nested power of two policies of simultaneous and separate replenishment were considered and a viable heuristic was proposed which performed better than the existing method. Sarmah et al. (2008) investigated the coordination problem that exist between single manufacturer and multiple dissimilar buyers. Two models of ex-site delivery case, where manufacturer who bears the transportation cost delivered the products to the buyers at the same replenishment time through the same carrier and ex-factory delivery case where buyers with common replenishment time jointly bear the transportation cost for the goods supplied by the manufacturer. A coordination system that improve the supply chain system performance was however developed based on the sharing pattern accrued from the surplus generated from the coordination. Hoque (2008) considered single-vendor, multi-buyers supply chain system assuming the inventory and set-up cost of the vendor are known. The author developed three models in which two considered equal batches (part of a lot) and the third unequal batches. An optimal solution was proposed and the model with unequal batch supply performed better.

Abdul-Jalbar et al. (2008) considered a single-vendor, multi-buyers supply chain problem where the same items were supplied to the buyers. The authors allowed the replenishment interval of each buyer to be more than the vendor. A mathematical model was formulated for the problem as integer-ratio policies and a heuristic solution procedure was adopted. The result of the suggested model, however performed better than the decentralized policies which occur when the production rate and the set up cost of the vendor increases. Darwish and Odah (2009) considered vendor managed inventory (VMI) policy in a supply chain system consisting of a vendor and multiple retailers. A model was developed to describe this supply chain under capacity constraint with huge penalty cost and an efficient solution algorithm was proposed to solve the problem. Zavanella and Zanoni (2009) presented another VMI approach called the consignment stock case in which the vendor takes the lead by coordinating the inventory in the buyers warehouses so as to reduce or stabilize the holding cost while descending down the supply chain. A mathematical model that determines the optimal number of shipment to each buyer was developed and solved. The result of which showed that the joint inventory management gives a better result than the independent policy which can be modest based on the distribution policy adopted by the vendor. Chan and Lee (2010) considered both incentive scheme and coordination issues together in a single-vendor, multiple buyers supply chain system. Coordination was achieved through synchronization of production and ordering cycles, incentive was provided in the form of price discount that depends on the order frequency and not the cost information of the buyers. A mathematical model developed for the problem was solved using a proposed algorithm .The result of which of which was compared with the q_i-factor model that requires buyers information. The q_i-factor model performed better in terms of cost, however, a missing link might be the cost and credibility risk attached to such information from the buyers. Hoque (2011) extended Hoque (2008)by synchronizing production flow in such a way that equal, unequal or mixed sized batches can be transferred to the buyers. The authors relaxed some idealistic assumptions like unlimited capacities of the transport equipment, buyers storage space, infinite lead time and batches. A solution algorithm was later developed to solve the mathematical model.

2.4.2 Stochastic Analytical Models

Compared to the deterministic models, the stochastic multi-buyers problem has not received much attention.

Kim et al. (2004) developed centralized and decentralized inventory control models for single-supplier, multiple-retailers so as to cater for non-stationary demand situation. The objective is to fulfil a predefined service level set for the individual retailers through the safety lead time and safety stock. A simulation model was later developed for the two adaptive control models through a reinforcement learning techniques which was tested under stationary and non-stationary demand process. From the result, the centralized policy appeared more stable and gave a relatively better result Taleizadeh et al. (2012) relaxed the single product assumption by considering multi-product, multi-chance constraint single-vendor, multiple-buyers inventory problem in a stochastic demand environment. The authors assumed a variable lead time that increases linearly with the lot size, budget limitation for the buyers to make purchase and a combined shortage cost that contained both lost sales and back order. A mixed integer nonlinear programming model was formulated and solved using particle swarm optimization techniques.Jha and Shanker (2013) presented an integrated production-inventory model where an item produced in batches by the vendor is delivered to a set of buyers. The buyers demand is assumed to be independent and normally distributed while the lead time required to supply buyers can be crashed at a cost. The buyers adopted the continuous review inventory policy and all unsatisfied demand from the buyers are back-ordered. A model was developed to minimize the cost of the supply chain so as to ascertain the best policy and a service level was imposed on all customers to avoid stock-out. Lagrangian multiplier techniques was however used to determine the optimal order quantity, lead-time, number of shipment and safety factor in each production cycle.

Rad et al. (2014) considered a vendor supplying two buyers with the same item produced at a finite production rate under vendor managed inventory (VMI) and retailer managed inventory (RTI) policies respectively. A solution algorithm was proposed and the result from both policies were compared using a weighted factor. The comparison shows that VMI offers higher reduction in total cost while equally providing a detailed insight into selection of the optimal inventory policies to improve the performance of the supply chain.

2.5 Supply Chain Simulation Models

Chang and Makatsoris (2001) discussed extensively the possible challenges that necessitate the need of supply chain integration in the early 90s. The authors further discuss discrete event simulation as a tool for supply chain modeling and they gave recommendations on data requirements and the procedures required to simulate supply chain systems. Trkman and Groznik (2006) studied an analytical model developed for two-echelon supply chain system consisting of a single warehouse with multiple retailers. The authors developed a simulation model to check the performance of the studied analytical model under different conditions that violate the original model assumptions. The simulation result however shows error when approximating the total system cost under a violated assumptions.

As an extension, Köchel and Nieländer (2005) suggested a simulation optimization approach, where simulation is integrated with an optimization tool. Trkman and Groznik (2006) used simulation model to evaluate the performance and the procurement process of a petroleum company and several costs like the process execution cost, inventory management cost, change in lead time and process quality cost were estimated.

Similar to Tee and Rossetti (2002), Jie and Cong (2009) developed a simulation model to optimize multi-echelon inventory problem using Arena simulation software. The supply chain system consist of a manufacturer, three retailers and a distribution center. The model concentrate more on how frequent the retailers refilled their stock and the average inventory level maintained in the supply chain as customers demand and lead time were both uncertain.The simulation result, however, performed better than the result from the mathematical model. Benkõ (2010) developed a simulation model to imitate customer oriented issues in a supply chain system using arena software. In his model, the author considered a production system where a particular product is supplied to the warehouse through a facility. The production process is fed by the raw material storage system, and the finished product were consumed by customers; whose demand was assumed to follow a uniform distribution. The author assumed that raw material is always available in the storage so as to ensure that the production process is not idle.

Patil et al. (2011) developed a simulation model for multi-echelon inventory system using Arena 7.0 simulation software. Their model consist of few retailers, a distribution center and customers that represent the final consumer. The model objective is to improve customer service through sales that is enhanced by the mutual interdependent relationship that exist between retailers as justified from the model result. Hoshyar et al. (2014) also considered two inventory management policy using simulation. The authors compared the existing traditional inventory model and a proposed vendor managed inventory model. Two key performance indicator (average inventory level and system efficiency) were used and their results shows that the proposed vendor managed inventory policy had about 5% advantage in terms of system efficiency, over 50% advantage in terms of inventory or stock level.

In view of this chapter, and to the best of our knowledge, it was found that variable production rate is not well addressed in the integrated models literature, especially in a stochastic environment. In addition to that, some vendors restrict shipment size to be multiples of full truckloads, a constraint that needs to be further studied within the context of integrated supply chain models. A detailed description of the proposed mathematical model for the SVSM case is provided next in chapter 3 while chapter 5 addresses the SVMM problem using discrete event simulation

CHAPTER 3

MODEL DEVELOPMENT

3.1 Analytical Model Development

The objective of this chapter is to develop a mathematical model for the inventory profile shown in Figure 1.1. Detailed sensitivity analysis will be performed using some of the identified parameters so as to understand their effect on the addressed problem.

3.1.1 Problem Definition

The supply chain profile shown in Figure 1.1 represents a manufacturer with stochastic demand for his products. Assuming he orders the main raw material used for his product from a vendor who produces this material at a constant rate (P_v) and, as practiced by many companies, the vendor sends a full truckload (q) as the batch size received by the manufacturer over n-different shipments. The manufacturer goes into production immediately upon the first shipment's arrival in his warehouse (after a lead-time ,$t_i + \triangle$) by depleting the raw-material received at a rate that is proportional to his production rate (p). The manufacturer faces random demand for his product and a uses continuous review system (Q,R). The objective will be to determine the production rate, the number of full truck shipments,the re-order point, and the production lot size which minimizes the total supply chain cost.

3.1.2 Definition of Terms

Prior to model development, it will be necessary to define some key terminologies that are essential in developing the total cost function for the suggested supply chain problem.

- Holding cost (Inventory Carrying cost): These are cost associated with holding a given level of inventory at hand. It varies linearly with the period of holding and the quantity held. They include storage cost, handling cost, depreciation, taxes, insurance, spoilage, cost of record keeping, product deterioration and obsolescence to mention few.

- Shortage cost: These are the cost incurred when the demand for an item outweighed its supply. The shortage costs comprise of huge backorder cost, loss of future sales, loss of customers goodwill, extra cost associated with urgent and small quantity shipment, loss of expected profit from lost sales revenue.

- Purchasing or Acquisition cost: This refer to the value of an item. It is the amount a customer is willing to pay in exchange for the item.

- Set up cost: This cost required to set up equipment for the processing of another batch of goods. It is often regarded as activity based costing.

- Production costs: These are the cost incurred when transforming raw-materials into finished products. It may include the direct cost of labour, tools cost, maintenance cost and the cost of rework.

- Demand: This is the number of items (products) required by a customer per unit time. It can be deterministic or stochastic.

- Lead time: The length of time between placing an order and receipt of items (raw-materials).

- Safety stock: This is otherwise called the buffer or minimum stock. It is the stock needed to account for the delay in material supply or for sudden increase in demand due to rush orders.

- Re-order level (ROL): This is the point where the replenishment action for the raw material is initiated for production to commence.

- Production quantity: This corresponds to the quantity of finished goods being produced from the raw material supplied by the vendor. In this case, it equal the economic production quantity.

3.2 Model Assumptions

In developing the model, the following assumptions were considered

- The production rate of the vendor P_v is known and fixed and shipments are made in full truck loads q over a known time t.

- The production rate of the raw-material by the vendor is greater than the inventory depletion rate of the manufacturer i.e. $P_v > d$.

- The rate at which the raw material is depleted from the manufacturer's warehouse has a direct relationship with the production rate of the manufacturer i.e.$d = \alpha p$.

- All shortages are backordered.

- There is no more than a single production run outstanding and the average rate of demand is the same over an infinite horizon. (Darwish et.al, 2013).

- The expected number of back orders incurred per time is independent of the expected numbers of production runs per year, provided the stochastic process generating demand is time-homogeneous.

- The demand pattern is random and modeled by the normal probability distribution.

- The variable production rate of the manufacturer is determined prior to the start of the production run i.e a rigid system where machine set-up during production is technically impossible or involves an outrageous cost. This same assumption can be found in Buzacott and Ozkanahan (1980), Silver (1990), Saka and Babu (1993), Goyal (1994), Silver (1995) and Viswanathan (1995) to mention few.

- The production cost will be expressed as a function of the production rate using

$f(p) = C + \frac{g}{p} + bp^{\beta}$,Khouja (1994). C is the unit acquisition cost of raw material, $\frac{g}{p}$ represents the per unit cost component that is reduced with increased production rate e.g. labour cost,and bp^{β} is the unit cost component which rises with an increased production rate, e.g. tools and rework cost.

3.2.1 Model Notations

The proposed model will be developed using the following notations

Table 3.1: Model notations

Parameter	Definition
AC_m	Total acquisition cost of raw material per unit time.
AP_v	Production cost of vendor per unit time.
A_M	Set up cost of manufacturer per cycle.
A_r	Transportation cost of raw material per truck.
A_s	Vendor Setup cost per cycle.
$b\ b \geq 0$	Multiplier component of the production cost formula.
$B\ B \geq 0$	Exponent component of the production cost formula.
C	Unit acquisition cost of raw material by the manufacturer.
X	Unit production cost of vendor.
C_p	Total production cost of the manufacturer per unit time.
DPC	Direct production cost by the manufacturer per unit.
$E[\wedge]$	Expected value of demand per unit time.
$E[Y]$	Expected value of lead time demand,$E[Y]$= $E[\wedge]$ $[\tau+\triangle+t_i]$.
$f(y)\,dy$	Probability that lead time is between y and $y+dy$.
$g\ g \geq 0$	numerator constant of the production cost formula .
h_v	Holding cost of the vendor per item per unit time.
h_r	Holding cost of raw material in the manufacturers warehouse per unit per unit time.
h_m	Holding cost of finished goods by the manufacturer per unit per unit time .
$M.HC_r$	Manufacturer's raw material holding cost per unit time
$M.E_c$	Manufacturer ordering and transportation cost for raw materials per unit time .
MS_c	Manufacturing set up cost per unit time.
n	Number of full truck shipments from vendor per cycle.
p	Production rate per unit time of manufacturer.
P_v	Production rate of vendor per unit time.
Q	Manufacturers production lot size per cycle.
q	Full truck size.
R	Raw material re-order point.
S_c	Expected shortage cost by the manufacturer per unit time.
S	A random variable representing safety stock.
s	Expected safety stock(s=$E[S]$).
t	The time needed by the vendor to produce a full truck load (q).
T	Inventory cycle length.
τ	Manufacturer's production lead-time.
$T.C$	Expected average total cost of the integrated model.
$T.C_v$	The long run average cost of the vendor.
$T.C_r$	The long run average cost of raw material at the manufacturers warehouse.
$T.C_M$	The long run average manufacturing cost.
$V.S_C$	Vendor's set up cost per unit time.
$V.H_C$	Vendor's holding cost per unit time.
Y	A random variable depicting lead time demand $[Y=\wedge[\tau+t_i+\triangle]]$.
Z	Ordering or administrative cost per cycle.
αp	Manufacturer's raw-material consumption rate.
$\wedge$	A random variable representing demand per unit time.
ϕ	Standard normal probability density function.
π	Fixed penalty cost incurred by the manufacturer per shortage.
$\triangle$	Constant lead time for loading,transporting and offloading full truck.
σ_a	Standard deviation of the demand per unit time.
σ_y	Standard deviation of lead time demand.

g, b, and B are non-negative real numbers representing the parameters of the unit production cost formula

3.2.2 Model Formulation

In this section, we present the formulation for the integrated model. The model investigate how the uncertainty in demand for the manufacturers product influences the manufacturer's production rate, possible number of full truck shipments, re-order level and the optimal production quantity that minimizes the total cost incurred during a complete cycle. In developing the total cost model, the classical cycle approach was adopted and the cost associated with the model are enumerated below:

1. Vendor set up cost per unit time: The cost A_s is incurred during each production runs by the vendor every cycle. The long run average set-up cost per time for the vendor is thus given as

   $$V.S_c = \frac{A_s}{T}$$

   which can be approximated as

   $$V.S_c = \frac{A_s}{T} = \frac{A_s E\left[\wedge\right]}{Q}(Darwish\ \ et.al(2013),\ \ Ben-Daya\ \ and\ \ Hariga(2004)) \tag{3.1}$$

2. Vendor holding cost per unit time:This refers to the cost associated with holding a given level of inventory on hand. It varies directly with both the amount held and the period of holding the stock. It is the total area under part A, 1.1 divided by the cycle time.

Total inventory of the vendor

$$\frac{nq}{2}t_i$$

but

$$P_v t_i = q$$

Substituting t_i into the expression for the vendor total inventory gives

$$\frac{nq^2}{2P_v}$$

Since

$$\tau \alpha P = nq, P\tau = Q$$

$$\alpha Q = nq$$

Total inventory of the vendor

$$\frac{\alpha^2 Q^2}{2nP_v}$$

The long run average holding cost of the vendor per time

$$\frac{\alpha^2 Q^2 h_v}{2nP_v T}$$

$$V.H_c = \frac{\alpha^2 QE[\wedge] h_v}{2nP_v} \tag{3.2}$$

3. Vendor production cost per unit time:This is the cost of producing the raw material by the vendor per unit time .It is the unit production cost multiplied by the

total quantity produced in a cycle per unit time.It is computed as the unit production cost multiplied by the total quantity produced in a cycle per expected cycle time.

$$AP_V = \frac{Xnq}{T}$$

replacing T in the equation above

$$AP_V = \alpha XE\left[\wedge\right] \tag{3.3}$$

4. The long run average total cost per unit time of the vendor is thus given as

$$T.C_v\left(Q,n\right) = V.S_c + V.H_c + AP_V$$

$$T.C_v\left(Q,n\right) = \frac{\alpha^2 QE\left[\wedge\right] h_v}{2nP_v} + \alpha XE\left[\wedge\right] + \frac{A_s E\left[\wedge\right]}{Q} \tag{3.4}$$

5. Inventory control costs related to raw-materials: The costs considered here are the ordering, transportation and holding cost of raw material i.e. for every raw material delivered by the vendor, the manufacturer incurred a one-time ordering cost, transportation cost per truck and holding cost for holding a given level of inventory on hand for a particular time period .The holding cost of raw material per cycle in the manufacturer ware-house is thus formulated as

From Figure 3.1,

$$\alpha p t_i = y$$

$$P_v t_i = q$$

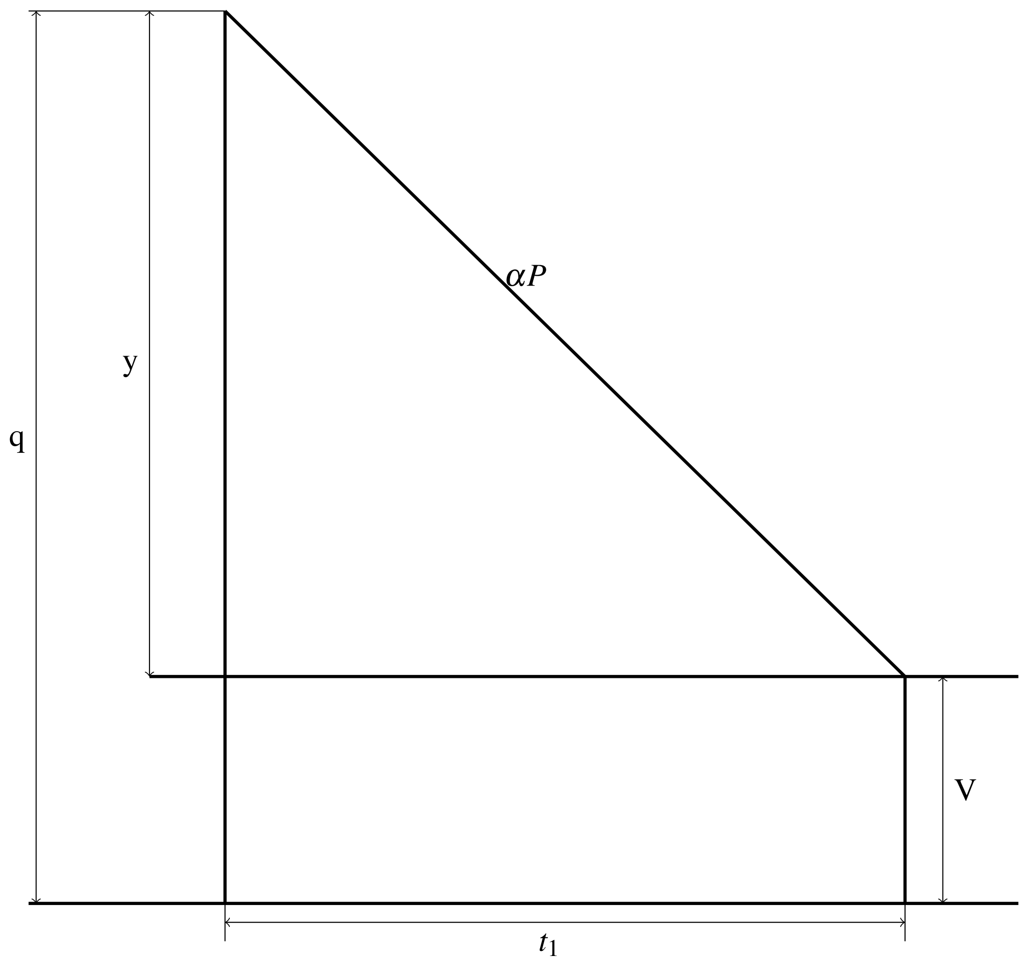


Figure 3.1: Schematic diagram showing manufacturer depletion of the material.

and

$$V = q - y$$

substituting

$$y = \frac{\alpha pq}{P_v}$$

$$v = q(1 - \frac{\alpha p}{P_v})$$

Partitioning Figure 3.1 so as to compute the total inventory held in the manufacturer's warehouse,we have $n-1$ small triangles,$\frac{n(n-1)}{2}$ rectangles and one big triangle.(Ben-Daya et al. (2013))

Calculating area under $n-1$ small triangles(A_1),

$$A_1 = n - 1 * \frac{1}{2} * t_i * y$$

$$A_1 = (n-1)\frac{1}{2}\frac{\alpha pq^2}{P_v^2}$$

$$A_1 = \frac{n\alpha pq^2}{2P_v^2} - \frac{\alpha pq^2}{2P_v^2}$$

Calculating area under $\frac{n(n-1)}{2}$ rectangles (A_2),

$$A_2 = \frac{n(n-1))}{2}q(1 - \frac{\alpha p}{p_v})t_i$$

$$A_2 = \frac{n(n-1)}{2}(\frac{q^2}{P_v} - \frac{\alpha pq^2}{P_v^2})$$

$$A_2 = \frac{n^2q^2}{2P_v} - \frac{n^2q^2\alpha p}{2P_v^2} - \frac{nq^2}{2P_v} + \frac{\alpha npq^2}{2P_v^2}$$

Calculating the area under the big triangle (A_3),

$A_3 = \frac{1}{2} *$base$*$ height, base = $\tau-(n-1)t_i$ and height = $q+(n-1)V$

$$A_3 = \frac{1}{2} * \tau-(n-1)t_i * q+(n-1)V$$

Since $t_i = \frac{q}{p_v}$, $v = q(1-\frac{\alpha p}{P_v})$ and $\tau = \frac{Q}{P}$

A$_3$=$\frac{nqQ}{2p} - \frac{(nq)^2}{2P_v} + \frac{nq^2}{2P_v} - \frac{\alpha nqQ}{2P_v} + \frac{\alpha (nq)^2 p}{2P_v^2} - \frac{\alpha npq^2}{2P_v^2} + \frac{\alpha qQ}{2P_v} - \frac{\alpha npq^2}{2P_v^2} + \frac{\alpha pq^2}{P_v^2}$.

Total inventory held in the manufacturer's warehouse =$\sum_{i=1}^{3} A_i$

Total holding cost of raw-material per unit time

$$\frac{h_r}{T}\sum_{i=1}^{3} A_i$$

Total holding cost of raw-material per unit time

$$\frac{h_r E\left[\wedge\right]}{Q}[\frac{nqQ}{2p} - \frac{\alpha nqQ}{2P_v} + \frac{\alpha qQ}{2P_v}]$$

$$MHC_R = \frac{\alpha Q E\left[\wedge\right] h_r}{2np}\left[n(1-\frac{\alpha p}{P_v}) + \frac{\alpha p}{P_v}\right]$$

Manufacturer's ordering and transportation cost per unit time

$$ME_c = \frac{E[\wedge]}{Q}[nA_r + Z]$$

The long run average total cost related to inventory control of raw material per unit time is therefore

$$T.C_r(Q,n,p) = \frac{E[\wedge]}{Q}[nA_r + Z] + \frac{\alpha QE[\wedge]h_r}{2np}\left[n(1-\frac{\alpha p}{P_v}) + \frac{\alpha p}{P_v}\right] \quad (3.5)$$

6. Holding cost of the manufacturer for finished products-The diagram above illustrate an evolution of net inventory over time. The expected net inventory at the beginning of a cycle is S+Q and S at the ending, where S represents the safety stock. It is however important to note that these are the average values of the on hand inventory when the expected number of back orders can be neglected, and since the expected demand rate is constant, the expected on hand inventory changes linearly from $S+Q$ to S. Thus the average inventory for the manufacturer product is $\frac{1}{2}(S+S+Q)$ i.e. $\left(S+\frac{Q}{2}\right)$ and the holding cost of finished goods in the manufactures warehouse is

$$\left(S+\frac{Q}{2}\right)h_m$$

Meanwhile, during the manufacturers production runs the average inventory holding cost for the produced goods is

$$\frac{QE[\wedge]}{2p}h_m$$

The total holding cost of the manufacturer per unit time is therefore the sum of both costs i.e

$$H.M_f p = \left(S + \frac{Q}{2}\right) h_m + \frac{QE[\wedge]}{2p} h_m$$

$$H.M_f p = h_m \left(\frac{Q}{2}\left(1 + \frac{E[\wedge]}{P}\right) + S\right) \quad (3.6)$$

Note, the computation of S (expected safety stock) however depends on the model assumption for shortages i.e. whether the shortages are satisfied or lost. Whenever the shortages are lost, the safety stock, which is a random variable, is unrestricted in sign and can be computed as follows,

$$S = R - Y$$

$$E[S] = R - E[Y]$$

since

$$E[Y] = \ E[\wedge](\tau + t_i + \triangle) \ \ then \ \ E[S] = R - E[\wedge](\tau + t_i + \triangle)$$

replacing t_i with $\frac{\alpha Q}{nP_v}$ and S with $R - E[\wedge](\tau + t_i + \triangle)$

The total holding cost of the manufacturer per unit time can be restated as

$$H.M_f p = h_m(\frac{Q}{2}(1 - \frac{E[\wedge]}{P}) + R - E[\wedge](\frac{\alpha Q}{nP_v} + \triangle)) \quad (3.7)$$

7. Shortage cost :This is the cost associated with stock out by the manufacturers.

It occurs if the demand over the lead time outweighs the quantities available at the re-order level.The shortage quantity is always a random variable and mathematically it is:

$N = Y - R$ if $Y > R$ and $N = 0$ if $Y < R$

The expected shortage cost per unit time is thus given as

$$S_c = \frac{\pi E[\wedge]}{Q} \int_R^{\infty} (Y - R) f(y) dy \tag{3.8}$$

the expected number of shortages in the equation above when f(y)is a normal density function can however be approximated in closed form as shown below

$$\int_R^{\infty} (Y - R) f(y) dy = \int_R^{\infty} y f(y) dy - R \int_R^{\infty} f(y) dy$$

Considering the first part of the R.H.S of the equation above:

$$\int_R^{\infty} y f(y) dy = \int_R^{\infty} \frac{y}{\sigma} \phi(\frac{y-\mu}{\sigma}) dy$$

if $z = \frac{y-\mu}{\sigma}$, $y = z\sigma + \mu$ and $dy = \sigma dz$.Then,

$$\int_R^{\infty} y f(y) dy = \int_{\frac{R-\mu}{\sigma}}^{\infty} (z\sigma + \mu) \phi(z) dz$$

$$\int_R^{\infty} y f(y) dy = \mu \left(1 - \Phi(\frac{R-\mu}{\sigma})\right) + \sigma \phi(\frac{R-\mu}{\sigma})$$

Considering the second part of the R.H.S of the equation above:

$$R\int_R^{\infty} f(y)dy = R(1-\Phi(\frac{R-\mu}{\sigma}))$$

The expected number of shortages per cycle can thus be approximated as

$$\int_R^{\infty} (Y-R)\, f(y)dy = (\mu - R)\,(1-\Phi(\frac{R-\mu}{\sigma})) + \sigma\phi(\frac{R-\mu}{\sigma})$$

8. Direct production cost-This refers to the direct cost of producing the final product by the manufacturer. Similar to Khouja (1994), we assumed that the unit production cost is a function of the production rate and mathematically it is represented by the polynomial

$$f(p) = (\frac{g}{p} + bp^{\beta})$$

The direct production cost per unit time is thus be approximated as

$$DPC = \frac{Q}{T}(\frac{g}{p} + bp^{\beta})$$

since

$$T = \frac{Q}{E[\wedge]}$$

$$DPC = E[\wedge]\left(\frac{g}{p} + bp^{\beta}\right) \tag{3.9}$$

9. Manufacturer acquisition cost per unit time:This is the total cost of purchasing n full trucks of raw material by the manufacturer in one cycle. The manufacturer raw material cost per unit time is thus

$$AC_m = \alpha CE\left[\wedge\right]$$

The total production cost per unit time is therefore the sum of the direct production cost per unit time and acquisition cost per unit time,given as

$$C_P = DPC + AC_m = E\left[\wedge\right]\left(\frac{g}{p} + bp^{\beta}\right) + \alpha CE\left[\wedge\right] \tag{3.10}$$

10. The Manufacturer's set up cost for finished goods is given as

$$\frac{A_m E\left[\wedge\right]}{Q} \tag{3.11}$$

The total cost incurred by the manufacturer per unit time is thus the sum of all cost considered for the manufacturer.

$$\begin{aligned} T.C_m(Q,n,P,R) = {} & \frac{A_m E\left[\wedge\right]}{Q} + h_m(\frac{Q}{2}(1 - \frac{E\left[\wedge\right]}{P}) + R - E\left[\wedge\right](\frac{\alpha Q}{nP_v} + \triangle)) + \\ & \frac{\pi E[\wedge]}{Q}\int_R^{\infty}(Y-R)\,f(y)dy + E\left[\wedge\right]\left(\frac{g}{p} + bp^{\beta}\right) + \alpha CE\left[\wedge\right] \end{aligned} \tag{3.12}$$

and for the whole supply chain system the total cost is determined by aggregating both cost from the vendor and manufacturer i.e.

$$T.C_s(Q,n,p,R) = T.C_v(Q,n) + T.C_r(Q,n,p) + T.C_m(Q,n,p,R)$$

$$
\begin{aligned}
T.C_s(Q,n,p,R) = {} & \frac{\alpha^2 QE[\wedge]\,h_v}{2nP_v} + \alpha XE[\wedge] + \frac{A_s E[\wedge]}{Q} + \\
& \frac{E[\wedge]}{Q}[nA_r + Z] + \frac{\alpha QE[\wedge]\,h_r}{2np}\left[n(1-\frac{\alpha p}{P_v}) + \frac{\alpha p}{P_v}\right] + \\
& \frac{A_m E[\wedge]}{Q} + h_m(\frac{Q}{2}(1-\frac{E[\wedge]}{P}) + R - E[\wedge](\frac{\alpha Q}{nP_v} + \triangle)) + \\
& \frac{\pi E[\wedge]}{Q}\int_R^\infty (Y-R)\,f(y)dy + E[\wedge]\left(\frac{g}{p} + bp^\beta\right) + \alpha CE[\wedge]
\end{aligned}
\tag{3.13}
$$

The objective of this work is to minimize the total cost function of the supply chain with respect to the full truck capacity received from the vendor. The model can thus be summarized as follow:

Objective function

$$
\begin{aligned}
T.C_s(Q,n,p,R) = {} & \frac{\alpha^2 QE[\wedge]\,h_v}{2nP_v} + \alpha XE[\wedge] + \frac{A_s E[\wedge]}{Q} + \\
& \frac{E[\wedge]}{Q}[nA_r + Z] + \frac{\alpha QE[\wedge]\,h_r}{2np}\left[n(1-\frac{\alpha p}{P_v}) + \frac{\alpha p}{P_v}\right] + \\
& \frac{A_m E[\wedge]}{Q} + h_m(\frac{Q}{2}(1-\frac{E[\wedge]}{P}) + R - E[\wedge](\frac{\alpha Q}{nP_v} + \triangle)) + \\
& \frac{\pi E[\wedge]}{Q}\int_R^\infty (Y-R)\,f(y)dy + E[\wedge]\left(\frac{g}{p} + bp^\beta\right) + \alpha CE[\wedge]
\end{aligned}
$$

Subject to the constraint

$$
Q = \frac{nq}{\alpha} \tag{3.14}
$$

3.2.3 Solution Method

To minimize the objective function, the optimal production quantity (Q), the re-order level(R), the production rate (p) and the optimal number of full truck loads (n) must be determined. The objective function is non-convex. Hence, we use total enumeration search over three decision variables out of four due to n and Q been linked through constraint 3.14

Note that in case $\left(h_m - \alpha^2 \frac{E[\wedge]h_r}{P_v}\right) \geq 0$ and $(\alpha E[\wedge] h_r - h_m E[\wedge]) \geq 0$ and for fixed value of R, the overall cost function for the integrated supply chain model above becomes a geometric program.

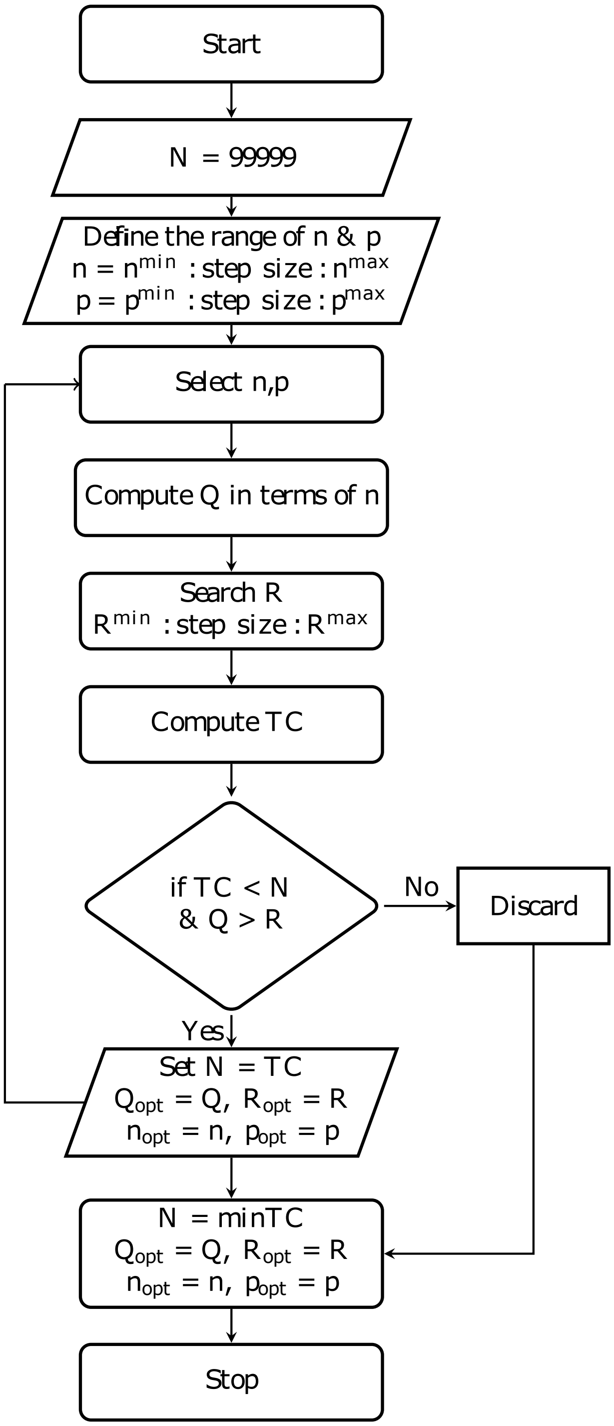


Figure 3.2: A flow chart describing a solution algorithm for the proposed model using total enumeration search techniques

Table 3.2: Model data.

Parameter	Definition	Value
$E[\wedge]$	Expected value of demand per unit time	140
σ_a	Standard deviation of demand per unit time	20
A_m	Set up cost of manufacturer per cycle	2500
A_s	Vendor set up cost per cycle	2000
A_r	Transportation cost of raw material per full truck	500
h_v	Holding cost of vendor per item per unit time	3
h_r	Holding cost of raw material per item per unit time	1
h_m	Holding cost of finished goods in the manufacturer warehouse per item per unit time	5
$\triangle$	Constant lead time for loading,transporting and offloading full truck	1
π	Fixed penalty cost	200
X	Unit production cost of vendor	1.5
C	Unit acquisition cost of manufacturer	3.5
α	Ratio of raw material consumption rate to production rate	2
g	Cost of operating time(per unit time)	2000
B	Exponent component of the production cost formula	1
b	Multiplier component of the production cost formula	0.065
z	Ordering cost per unit time	1000

3.3 Numerical Example and Sensitivity Analysis

In this section, we illustrate our model with a numerical example using the list of parameters given in Table 3.2, this example represents the base-case scenario, and by varying some of the model parameters one at a time we study their effect on the decision variables and the formulated total cost function:

3.3.1 Numerical Example

Table 3.3: Example result.

n	p	Q	R	$T.C_s$
1	348	1600	1379	14198

The application of the solution algorithm above with the given parameters yielded the result shown in table 3.3

3.3.2 Sensitivity Analysis

Now, we consider the previous example as the base-case scenario and vary the model parameters one at a time to study their effect.

- Effect of expected demand rate

  This section illustrates the effect of the manufacturers end item demand on the supply chain. Figure 3.3 shows the increase in demand through a rise in the number of trucks received by the manufacturer coupled with a frequently increasing re-order level and production rate. This has a direct impact on the cost of the supply chain that grows as the demand increases. Of note is the effect of the full truck load constraint, where n and Q do not increase linearly.

- Effect of demand variation

  In push systems, manufacturers tend to stock more inventory to account for demand variability i.e. increasing R or both Q and R in a (Q, R) system. Figure 3.4 illustrates this result. However, our model indicates that increasing the production rate contributes to keeping the total supply chain cost low.

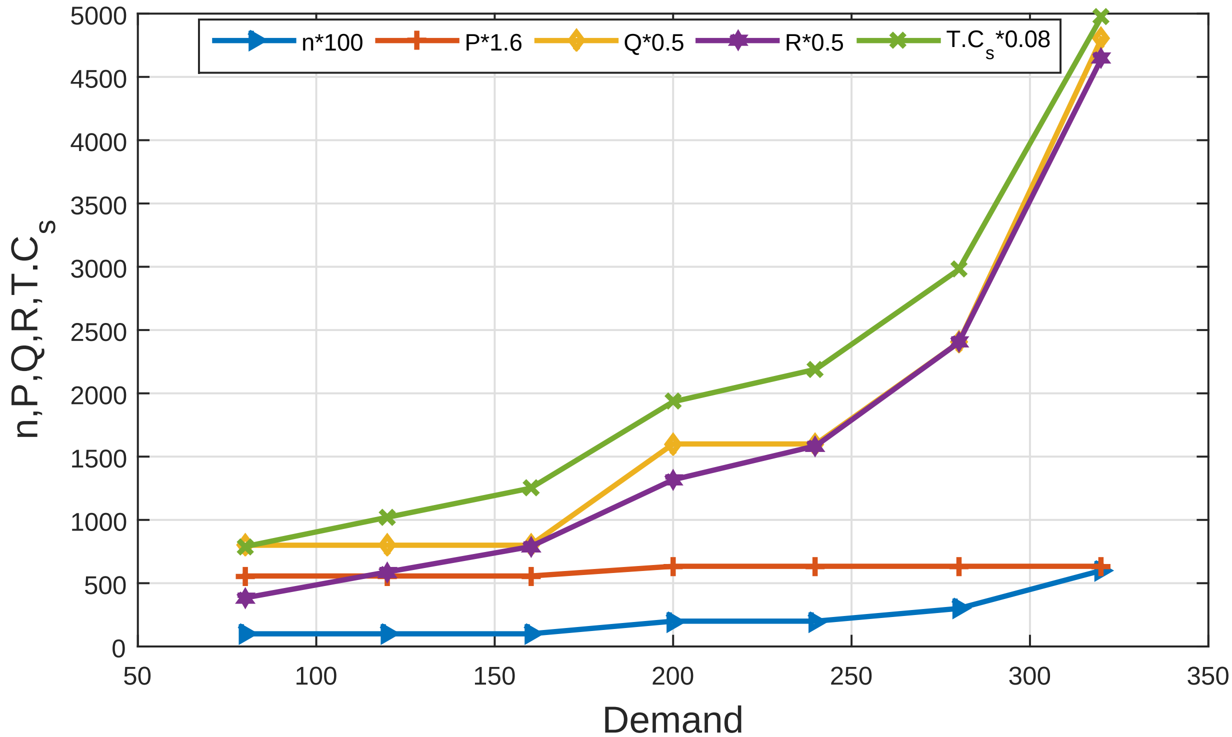


Figure 3.3: Effect of manufacturers end item expected demand ($E[\wedge]$)

- Effect of truck size(q)

  To study the effect of the truck size capacity, we considered different truck sizes that can accommodate between 1600 to 4800 units of the raw material. Figure 3.5 shows that, as the truck capacity increases, the economic production quantities, the re-order point, the production rate together with the cost of the supply chain, increases. Several factors, such as the acquisition cost, which varies with truck size, the holding cost of the raw materials and the production cost are responsible for this increase in cost, which some small companies cant afford. The situation gets even worse in the case of deteriorating items. In practice, as in the cardboard industry, some vendors lose potential customers/markets due to their restricting the shipment size to multiples of large truckloads.

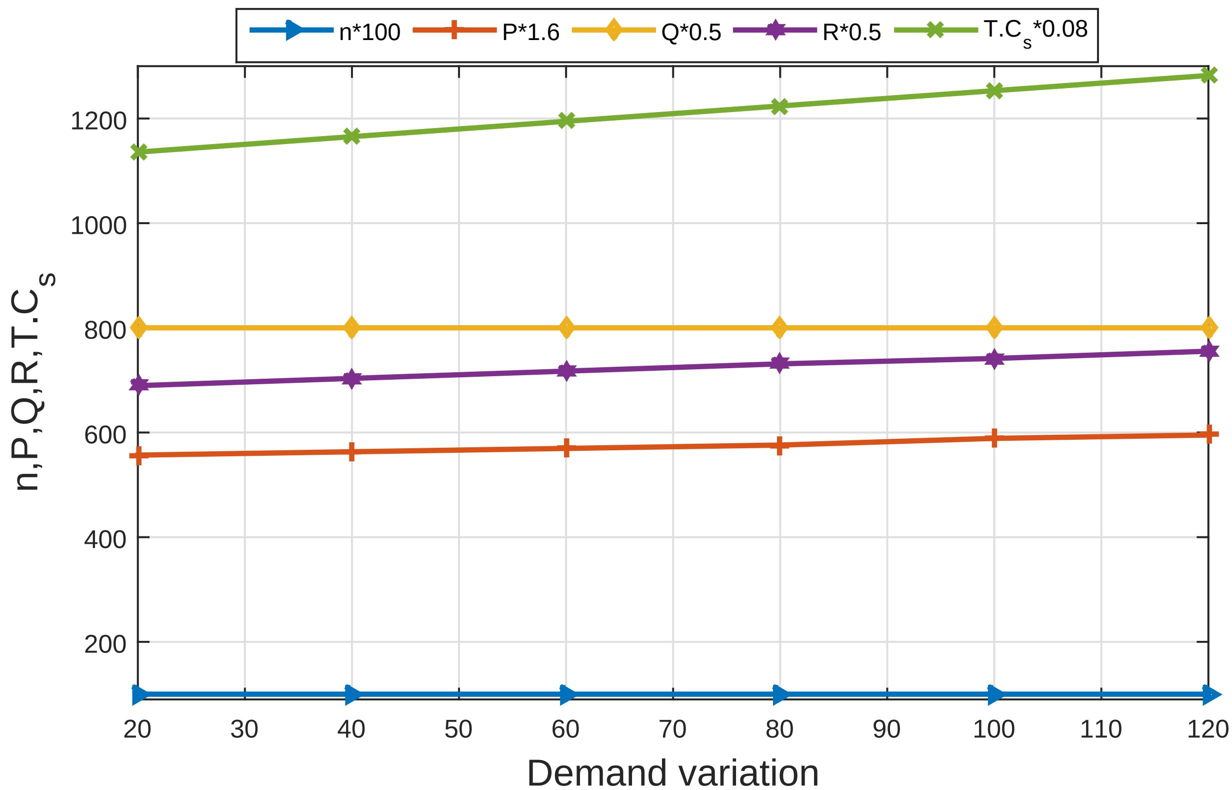


Figure 3.4: Effect of demand standard deviation (σ_A)

- Effect of manufacturer's holding cost

  Figure 3.6 shows the effect of the manufacturer's holding cost on the supply chain system. It shows that an increase in the holding cost of the manufacturer results in a fall in the re-order point of the manufacturer. This is to minimize the cost incurred from holding the finished goods. Meanwhile, to avoid shortages the production rate increases. The total cost of the supply chain system, however, increases based on the high cost of production.

- Effect of delay time

  The effect of the shipment lead-time is presented in Figure 3.7. The figure shows that increasing the delay time results in a rise in the economic production quantity

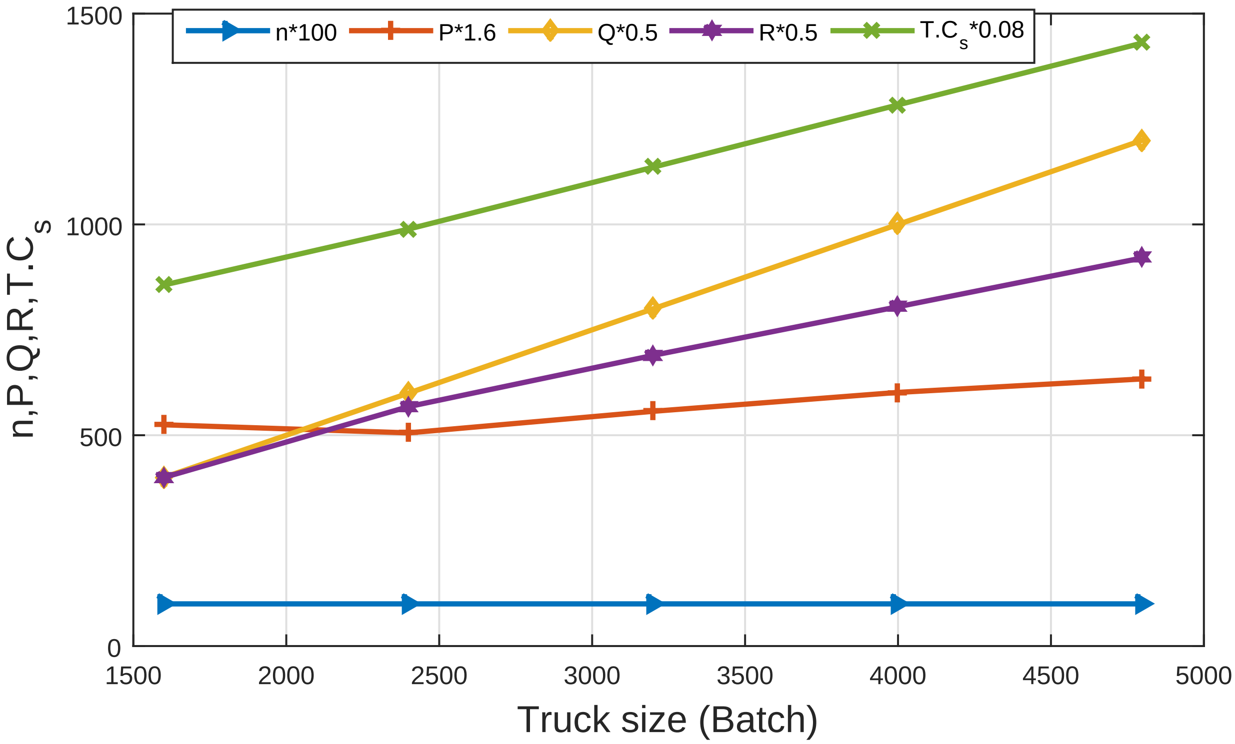


Figure 3.5: Effect of truck size (q)

and number of full truck shipments, both follow a step function as a result of the the full truck load constraint. The reorder point and the production rate equally increase to ensure that the shortage cost is minimized. The total cost of the supply chain will, however, continue to increase as a result of higher production, holding and acquisition costs.

- Effect of vendor's production rate

  One of the model's assumption is that the vendor will produce the full truckload at a constant rate. The impact of the vendors production rate is presented by Figure 3.8.The model responded to the increase in the vendors production rate through a fall in the manufacturers re-order level, production rate, number of full

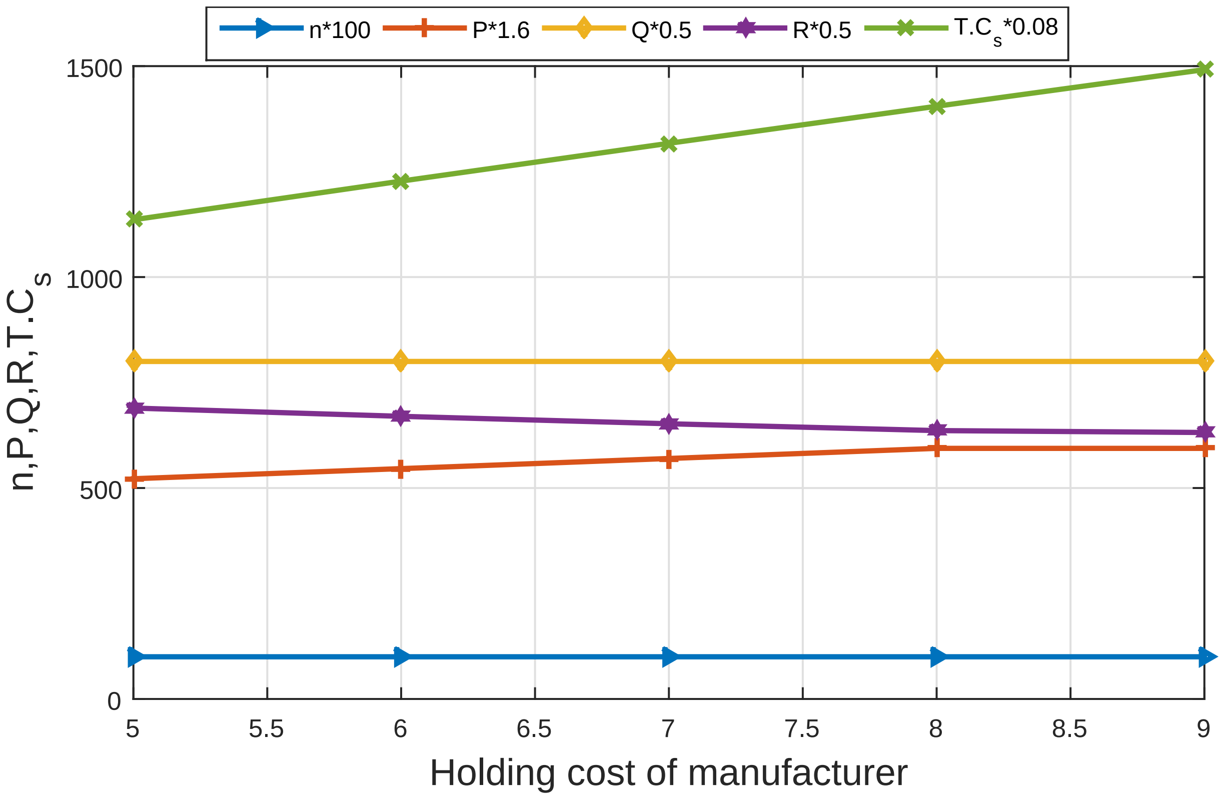


Figure 3.6: Effect of manufacturers holding cost (hm)

truck shipments, economic production quantity and, ultimately, the overall cost of the supply chain.

- Effect of α (Consumption to Production ratio)

  α denoted the ratio of the manufacturers consumption rate of the raw material to the production rate. As an example, when α=0.5 then half a unit of the raw material is needed to produce one unit of the final product. To study the effect of α, six different values were considered as shown in Figure 3.9, and from the plot the production quantity, production rate and re-order point decrease as α increases until the point (α=2), where the number of trucks required increases to avoid shortages. This behavior is perfectly reflected in the total cost of the supply

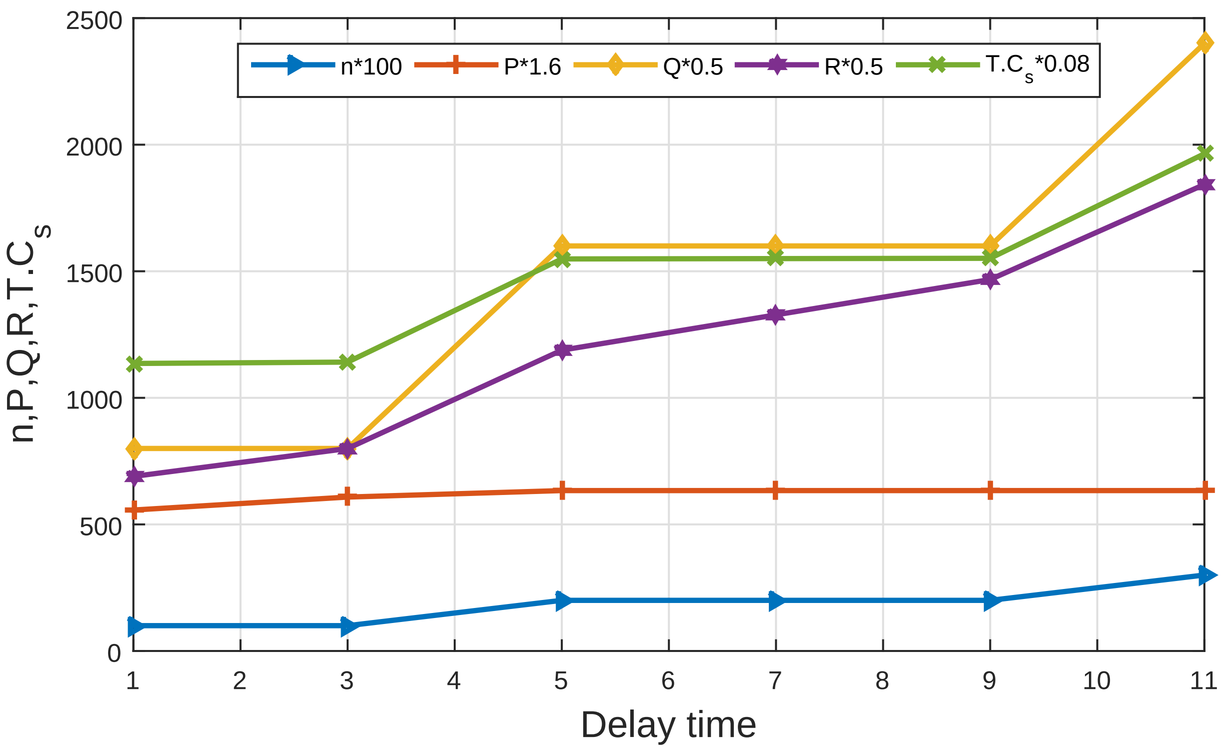


Figure 3.7: Effect of delay time (△)

chain system, which was high when α was less than 1, owing to high holding and production costs. As the quantities produced decrease, these cost were saved until an additional shipment was required to minimize the shortages.

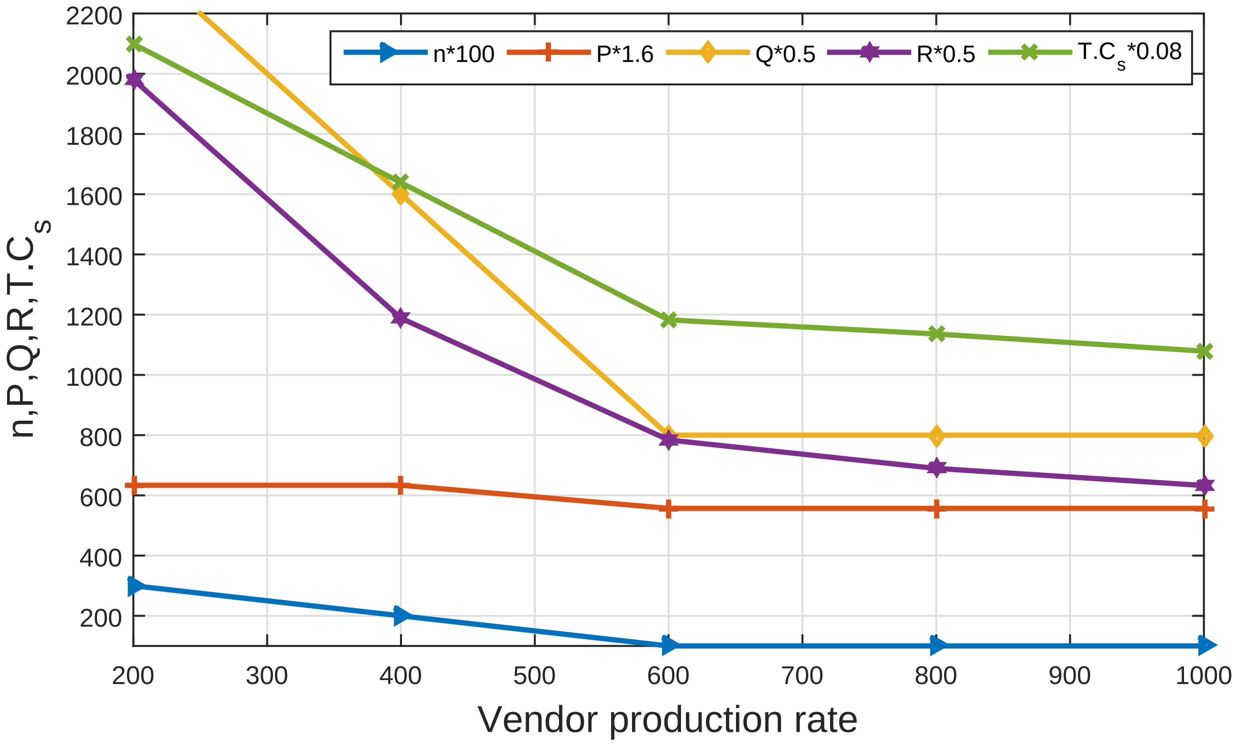


Figure 3.8: Effect of vendors production rate (P_v)

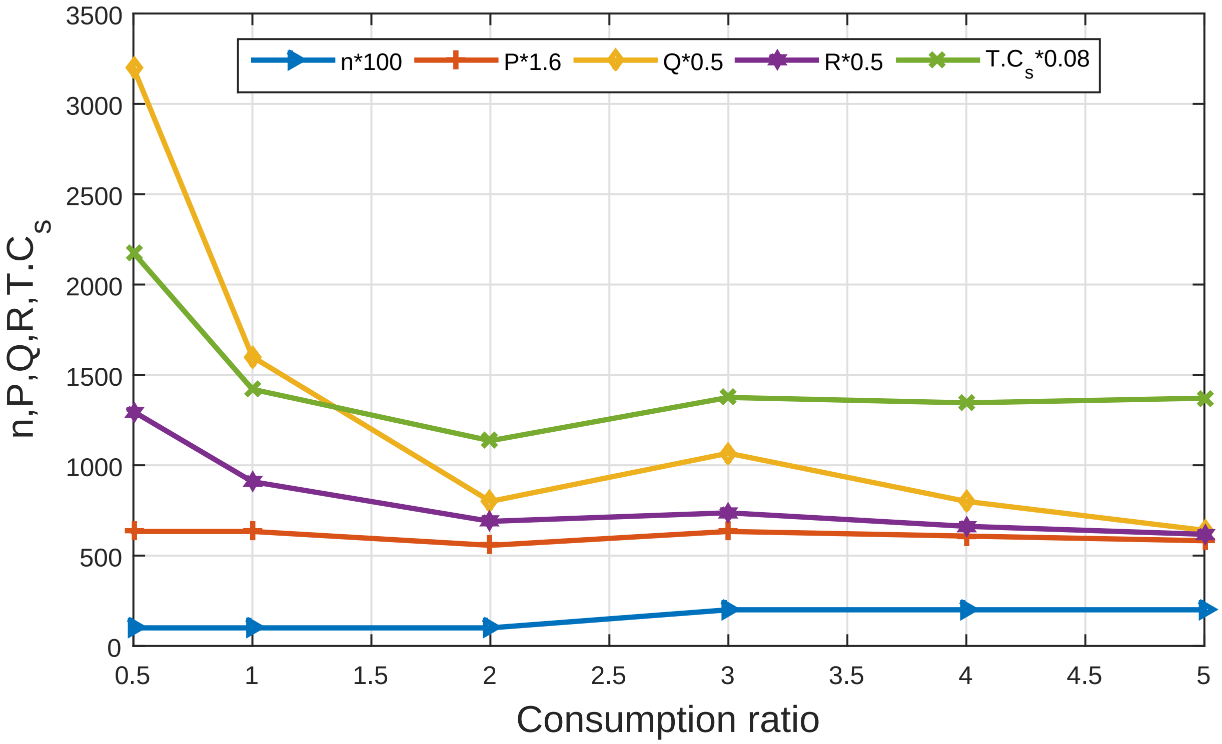


Figure 3.9: Effect of raw material consumption to production ratio (α)

Next in chapter 4, the same problem of this chapter is modeled using Arena simulation software.

CHAPTER 4

SIMULATION MODEL FOR THE SINGLE VENDOR, SINGLE MANUFACTURER SUPPLY CHAIN SYSTEM

4.1 Introduction

In this chapter, a discrete event Arena simulation model for the inventory profile shown in Figure1.1 (chapter 1) is developed. The objectives of this chapter are to :

- validate the analytical model developed earlier in chapter 3
- evaluate the accuracy (robustness) of the analytical model against several approximations assumed.

- help verify the Single-Vendor, Multiple-Manufacturers (SVMM) simulation models of chapter 5

The rest of this chapter is organized as follows:Section (4.2) describes the steps required for the simulation study and section (4.3) evaluates the robustness of the analytical model.

4.2 Steps Required for a Simulation Study

Simulation refers to a broad collection of methods and applications that mimic the behavior of a real system mostly on a computer system through the use of appropriate software. To develop the simulation model for the suggested two-stage supply chain problem, Arena simulation software will be used.

The following basic steps are essential for simulation-based case studies.

1. Problem Formulation: The analyst and the decision-maker must agree mutually on the nature and details of the problem to be study.

2. Setting Objectives and Planning the study: This step identifies the performance measures (e.g. total cost of the supply chain system, average daily inventory, average number of shortages incurred e.t.c) level of detail, system configuration, time frame, resources and the type of software to be used.

3. Gathering of data and defining the problem in details: A conceptual ”model” should be developed at this stage and all data required to specify the model pa-

rameter must also be collected.

4. Checking the validity of the conceptual model (validation of the conceptual model): This is done with the project manager to ensure that all details are captured in the modeling so as to avoid significant redesigning of the model later.

5. Verification: Using a known simulation application software,construct a computer model, check if the developed model entails all required details.

6. Validation: Compare the result from the simulation with an existing known performance measure.

7. Designing experiments or simulation optimization and output analysis: This final stage involved specifying the exact setting of the operational parameters or scenarios to be analyzed, which is then preceded with proper documentation as shown in Figure 4.1.

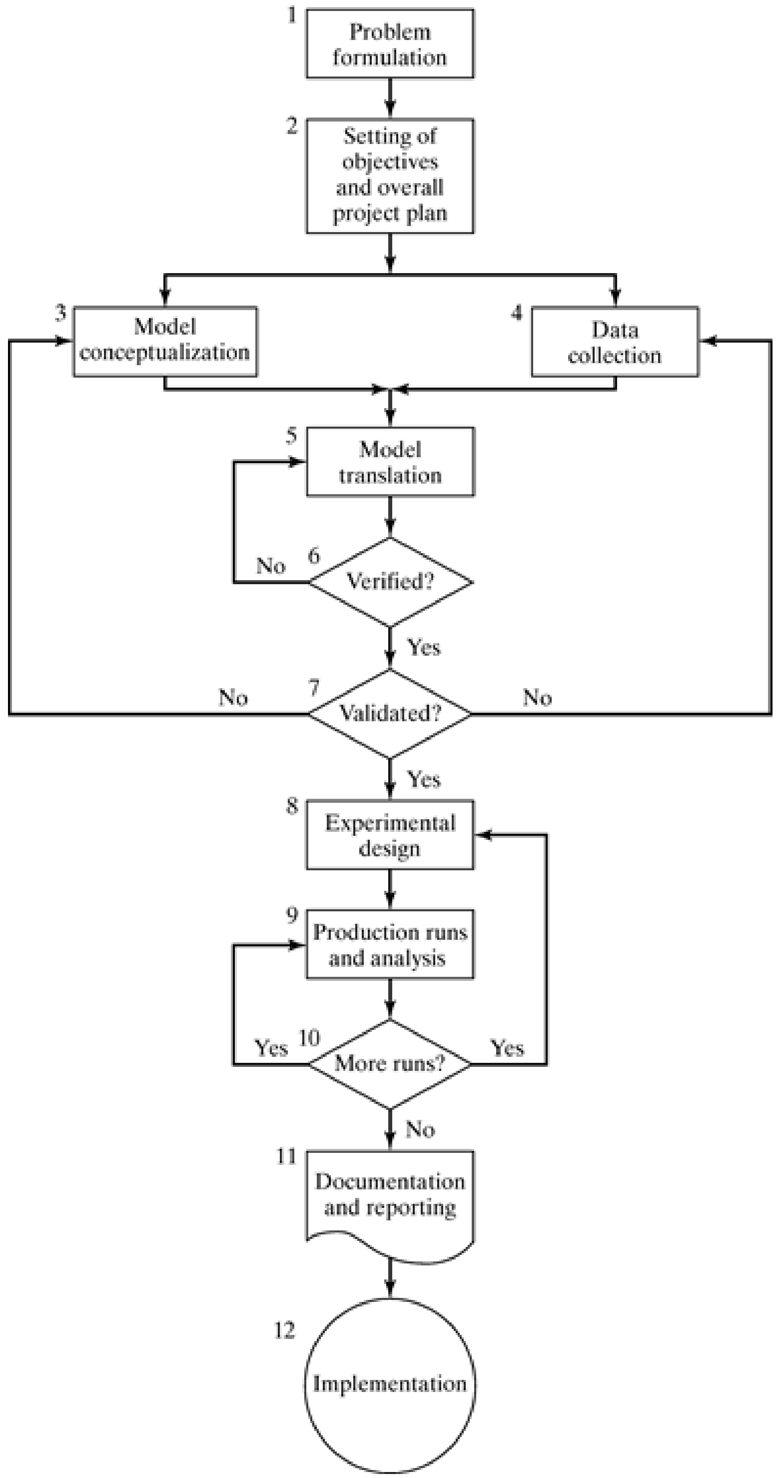


Figure 4.1: A flow chart representing the basic steps of simulation, (Banks et.al, 2007)

Since the addressed problem in this chapter is theoretical, we only follow steps 3, 5 and 7. Next, we defined these steps extensively in accordance with this simulation study.

1. Conceptual model: The conceptual model is developed to mimic the problem defined in Section (3.1.1).

2. Computer modeling and verification: Arena simulation software was used to construct the single-vendor, single-manufacturer supply chain model. Appendix A1 provides a brief introduction on the functions of the simulation modules used in this study. The details of the simulation model logic and how it was built using Arena are presented in Appendix A2 (Figure 6.2).

   To verify the correctness of the simulation model, we performed the following:

   - Animation of the simulation model
   - Systematic inspection of the sub-models
   - Direct comparison of results for both analytical and simulation model as shown in Table 4.1, assuming demand is deterministic ($\sigma = 0.01$).

Table 4.1: Comparison of results from the simulation and analytical model,σ=0.01

E[$\wedge$]	Q	R	P	n	$T.C$(Analytical)	$T.C$(Simulation)	Percentage difference(%)
80	1600	776.47	340	1	9614.6	9572.39	0.44
120	1600	1164.72	340	1	12424	12337.39	0.70
160	1600	1552.96	340	1	15232.67	15161.19	0.47
200	3200	2616.17	396	2	23821.09	23767.49	0.23
240	3200	3139.41	396	2	26985.30	26824.16	0.60
280	4800	4793.95	396	3	36825.00	36659.28	0.45
320	9600	9357.54	396	6	61927.92	61711.26	0.35

The results shown by Table 4.1, indicate that the simulation model results matches those of the analytical model. Hence, we conclude that the mathematical model is valid.

3. Output analysis: Since we are interested in the steady state behavior of the addressed system; non terminating simulation will be assumed. To achieve this, a warm-up period of 200 days was determined for the single-vendor, single-manufacturer supply chain system using the Output Analyzer software and for the replication parameters, the simulation was run for a replication length of fifty (50) years, with each run been replicated fifty times.

4. System Optimization: OptQuest is a powerful optimization tool that is part of the Arena simulation software. It offers an efficient way to search for the optimal solution of the objective function. Like every optimization software, OptQuest allows the users to define their decision variables, constraints and objective function through: controls (decision variables), constraints and responses(objectives) modules. Using the same data set of Table 3.2 in chapter 3, the result from OptQuest as compared with the analytical model result are presented below:

Table 4.2: Comparison of optimal solution using simulation and mathematical modeling

SOLUTION METHOD	E[∧]	Q	R	P	n	T.C
Simulation with OptQuest	80	1600	738.303	340	1	9483.33
Analytical Method using mathematical programming	80	1600	776.4706	340	1	9614.6

Table 4.3: Comparison of optimal solution using simulation and mathematical modeling

SOLUTION METHOD	E[∧]	Q	R	P	n	T.C
Simulation with OptQuest	120	1600	1128.56	340	1	12321.18
Analytical Method using mathematical programming	120	1600	1164.719	340	1	12424

Table 4.4: Comparison of optimal solution using simulation and mathematical modeling

SOLUTION METHOD	E[∧]	Q	R	P	n	T.C
Simulation with OptQuest	320	9600	9357.4	392	6	61601.516
Analytical Method using mathematical programming	320	9600	9357.54	396	6	61927.92

4.3 Robustness of the Analytical Model

To study the robustness of the analytical model against the assumption of the existence of a renewal point as assumed in the mathematical formulation of the problem, the demand standard deviation was increased from 0.01 to 20, 40, 60 and 80 to obtain Tables 4.5, 4.6, 4.7 and 4.8 that are presented below:

Table 4.5: Impact of demand variation at σ=20

E[$\wedge$]	$T.C$(Analytical)	$T.C$(Simulation)	Percentage difference(%)
80	9863.912	9619.08	2.55
120	12763.02	12553.89	1.67
160	15627.25	15438.95	1.22
200	24170.24	23904.83	1.11
240	27379.61	27133.21	0.91
280	37209	36779.58	1.17
320	62156.93	61614.49	0.88

Table 4.6: Impact of demand variation at σ=40

E[$\wedge$]	$T.C$(Analytical)	$T.C$(Simulation)	Percentage difference(%)
80	10110.7	9636.10	4.93
120	13100.53	12688.95	3.24
160	16021.70	15636.35	2.47
200	24519.57	23996.17	2.18
240	27774.30	27274.71	1.83
280	37595.01	36828.49	2.08
320	62386.06	61436.98	1.55

Table 4.7: Impact of demand variation at σ=60

E[$\wedge$]	$T.C$(Analytical)	$T.C$(Simulation)	Percentage difference(%)
80	10356.5	9750.92	6.21
120	13436.92	12822.60	4.79
160	16423.04	15812.92	3.86
200	24868.9	24088.38	3.24
240	28184.25	27266.72	3.37
280	37980.07	37117.09	2.33
320	62615	61380.47	2.01

Table 4.8: Impact of demand variation at σ=80

E[$\wedge$]	$T.C$(Analytical)	$T.C$(Simulation)	Percentage difference(%)
80	10601.41	9699.82	9.30
120	13772.11	12959.14	6.27
160	16831.91	15943.89	5.57
200	25218.22	24180.45	4.29
240	28606.39	27250.55	5.15
280	38366.47	39623.33	3.17
320	62844.31	61447.58	2.27

These results are summarized in Figure 4.2. From the figure it is obvious that the percentage difference rises as the demand standard deviation increases and vice versa. Also, these differences tend to decrease as the value of expected demand increases (because the coefficient of variation decreases). Hence, care should be taken when using the mathematical model especially at high coefficients of variation values (low expected demand and high demand variation)

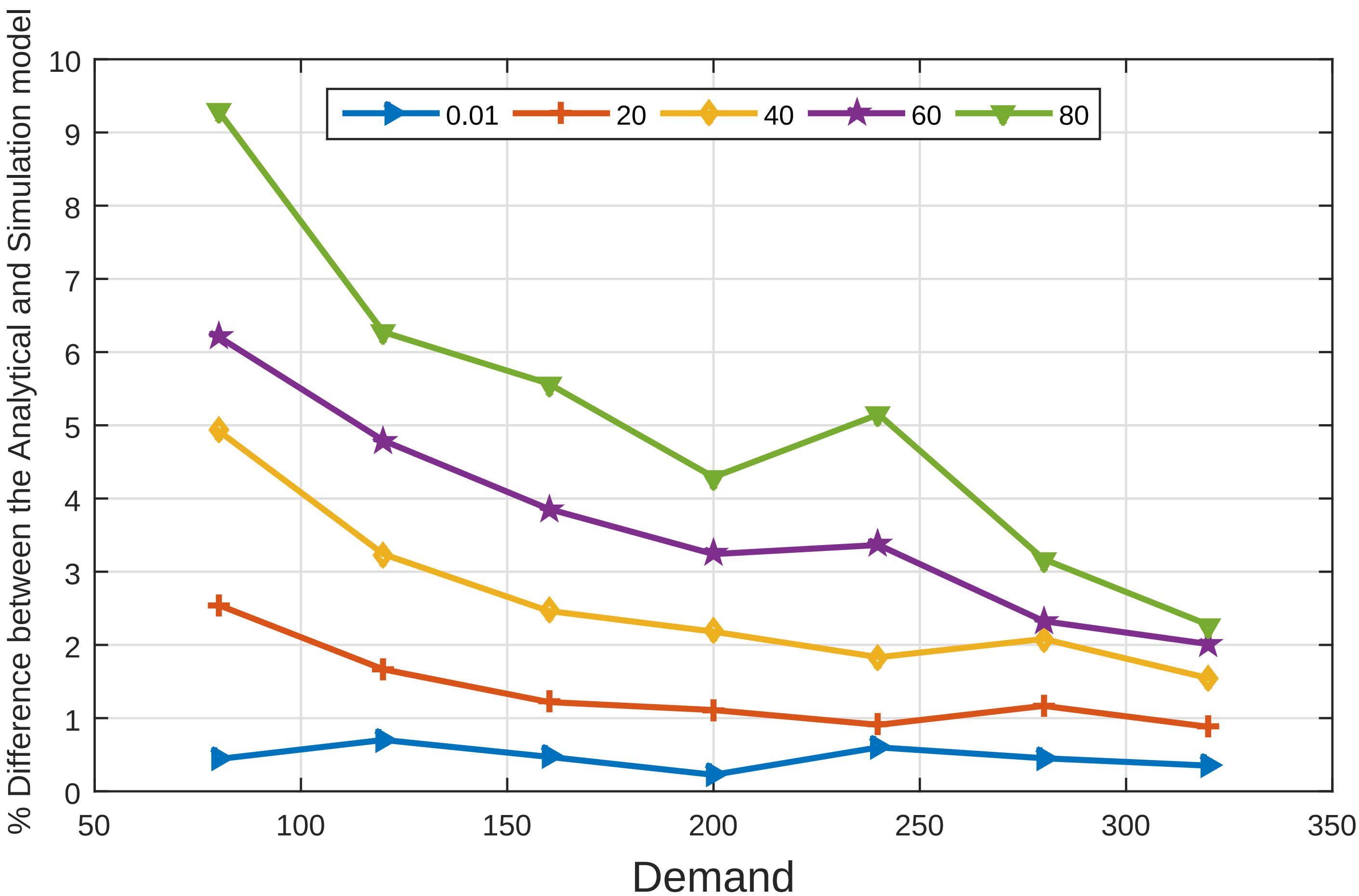


Figure 4.2: Percentage difference between the analytical and simulation model

CHAPTER 5

SINGLE VENDOR, MULTIPLE MANUFACTURERS SUPPLY CHAIN SYSTEM

5.1 Introduction

In this chapter, we extend the single-vendor, single-manufacturer discrete event simulation model presented in chapter four to the case of single-vendor, multiple-manufacturers. As shown earlier in the literature reviewed (chapter 2, section 2.4.2), there is no much work done on the stochastic single-vendor, multiple-manufacturers problem. The objectives of this chapter are :

- to model the stochastic single-vendor, multiple-manufacturers integrated supply chain model using simulation.
- to implement two different distribution policies and find their optimal parameters

using simulation optimization. The two policies are :

1. Common re-order point: This policy assumes a common re-order point for the supply chain system. It requires the vendor to have full information about the level of raw material in each manufacturers' warehouse through the data retrieved from the Warehouse Management System (WMS), so as to know when to commence the production of raw material, and how many full-truck loads will be deliver to each manufacturer.

2. Vendor managed inventory (VMI): In this policy, the vendor takes the lead by deciding the numbers of full truck shipments to be send to each manufacturer and ultimately the time to initiate production.

The rest of the chapter is organized as follows :Section (5.2) explains the steps adopted for the single-vendor, multiple-manufacturer simulation study, section (5.3) describes the common re-order point policy, while section (5.4) elucidates the vendor managed inventory policy.

5.2 Steps for Single-Vendor, Multiple-manufacturers Simulation Study

1. Conceptual Model: The conceptual model is developed to mimic a vendor who supplies three manufacturers with the same raw material. The vendor delivers shipments to his customers in multiples of full truckloads. Assuming all his customers are manufacturers who transform this material into a homogeneous

products in terms of mix and whose demands are highly random and independent; hence, inventory are kept in their warehouses. The vendor must determine

- the best stationary policy to distribute this raw-material in full trucks loads to the manufacturers.
- the appropriate time to initiate the raw-material production.

This problem is however considered under

- Common re-order point
- Vendor managed inventory

2. Computer modeling and verification: To verify the correctness of the simulation model, we performed the following:

   - Animation of the simulation model
   - Systematic inspection of the sub-models
   - Extending the verified single-vendor, single-manufacturer simulation model in chapter four (4) to accommodate multiple manufacturers

3. Output analysis: Like the single-vendor, single-manufacturer simulation model, the output analyzer software in Arena was used to determine the warm-up period for the single-vendor, multiple-manufacturers simulation model. A warm-up period of three years was used and the simulation was run for a period of twenty (20) years, with each run been replicated ten times.

4. System Optimization: As we aimed at finding the best policy for this integrated single-vendor, multiple-manufacturers supply chain system, OptQuest optimization software will be used to find the decision variables, which are mainly the common re-order point, and the number of full truck shipments being delivered to each buyer (manufacturer) for policy one. For the second policy, the decision variables will be the number of full truck shipments delivered to each buyer (manufacturer), and the hold time of the vendor prior to initializing another production cycle.

5.3 Common Re-order Point

In this policy, the vendor can determine the raw material inventory level in each manufacturers' warehouse through the data gathered from the WMS. This can help to reduce or eliminate the bull-whip effect that might result from keeping excessive raw-material inventory in each manufacturer ware-house.

Mathematically, the reorder point will be a function of the raw material delivered by the vendor in full truck shipments. Once the sum of the raw material inventory in all warehouses goes beyond this re-order point, the vendor begin the production of the raw-material. Appendix A3 (Figure 6.3) shows the snapshot of the proposed single-vendor, multiple-manufacturers supply chain model with common re-order point as developed using Arena software. The model is a systematic extension of the single-vendor, single manufacturer simulation model and the general flow chart is presented in Figure 5.1

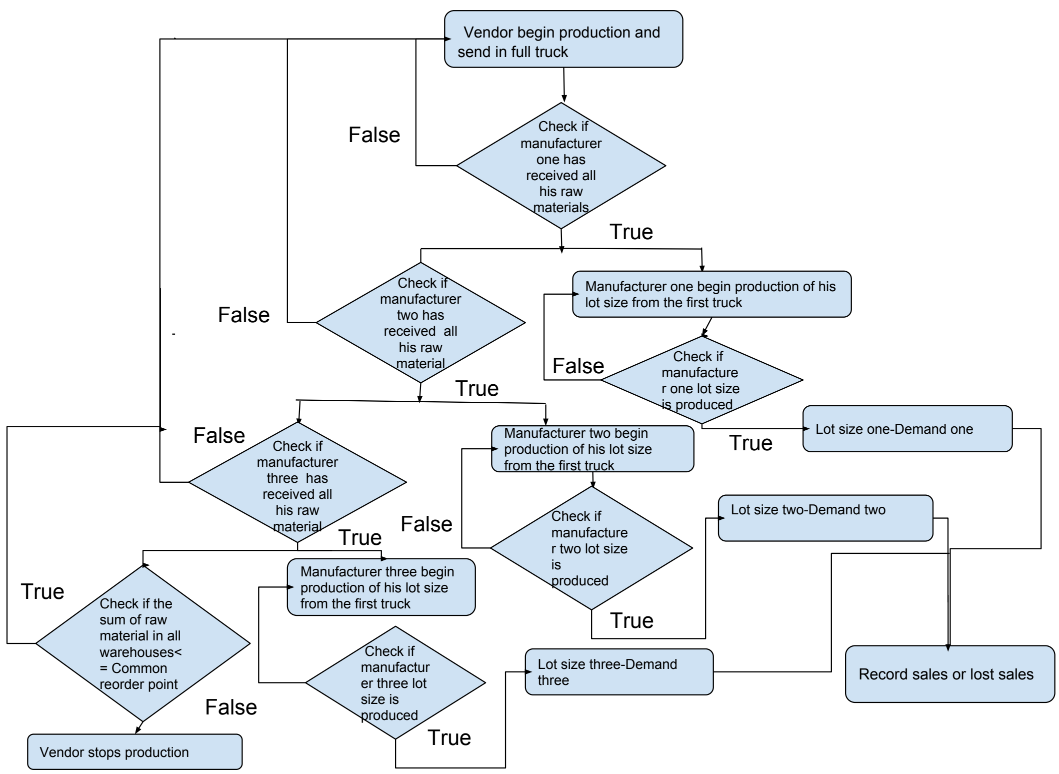


Figure 5.1: Flowchart for common re-order point policy

5.3.1 Model Example

To illustrate the common re-order point policy using the single-vendor, multiple-manufacturers simulation model proposed above, we adopted the values of the parameters in Table 3.1 with slight modification in manufacturers' average demands, standard deviations and vendor's production rate. Also, unlike the analytical model and the single manufacturer simulation model, we assumed fixed production rate for the manufacturers as depicted in Table 5.1. The decision variables are the numbers of shipment received by each manufacturer and the re-order point where the vendor begins production.

Figure 5.2 shows the OptQuest software searching for the optimal solution. The result from OptQuest is, however, presented in Table 5.2.

Table 5.1: Modified parameters for the SVMM common re-order point simulation model

Component	Average demand per day	Standard deviation	Production rate per unit time
Manufacturer 1	280	40	396
Manufacturer 2	200	20	396
Manufacturer 3	120	0.01	340
Vendor	-	-	3000

Table 5.2: OptQuest result for the SVMM common re-order point simulation model

Manufacturer	Number of shipments	Backlog cost per manufacturer	Common re-order point	Long run average cost
1	12	0.00	290.711	695700.41
2	8	3965.20		
3	5	0.00		

Figure 5.2: OptQuest searching for the optimal values of the decision variables

5.4 Vendor Managed Inventory Policy

In this policy, the vendor determines when to initiate production and the number of full truck shipments received by each manufacturer. Unlike the common re-order point policy where the raw material production is triggered after crossing a common re-order point, here production by the vendor takes place after a specific delay time, which is a decision variable. Appendix A4 (Figure 6.4) shows the snapshot of the proposed model for the single-vendor, multiple-manufacturers supply chain system with VMI policy as developed using Arena software. Like the previous model, it is a systematic extension of the single-vendor, single-manufacturer simulation model and the general flow chart is presented in Figure 5.3.

5.4.1 Model Example

To illustrate the performance of the VMI simulation model, we used the same parameters employed for the common re-order point policy model to allow for fair comparison. OptQuest is used to find the optimal values of the decision variables, which are mainly the shipments number received by each manufacturer and the stoppage time of the vendor. The result obtained is presented in Table 5.3 and Figure 5.4 shows OptQuest software searching for the optimal solution for the decision variables. The result in Table 5.3, however, shows that with the VMI policy, the supply chain system was able to save almost 55.66 percent of the total cost incurred if compared directly with the common reorder point policy.This was due to very high holding cost induced by the common reorder point policy which ensured that the manufacturers produced more

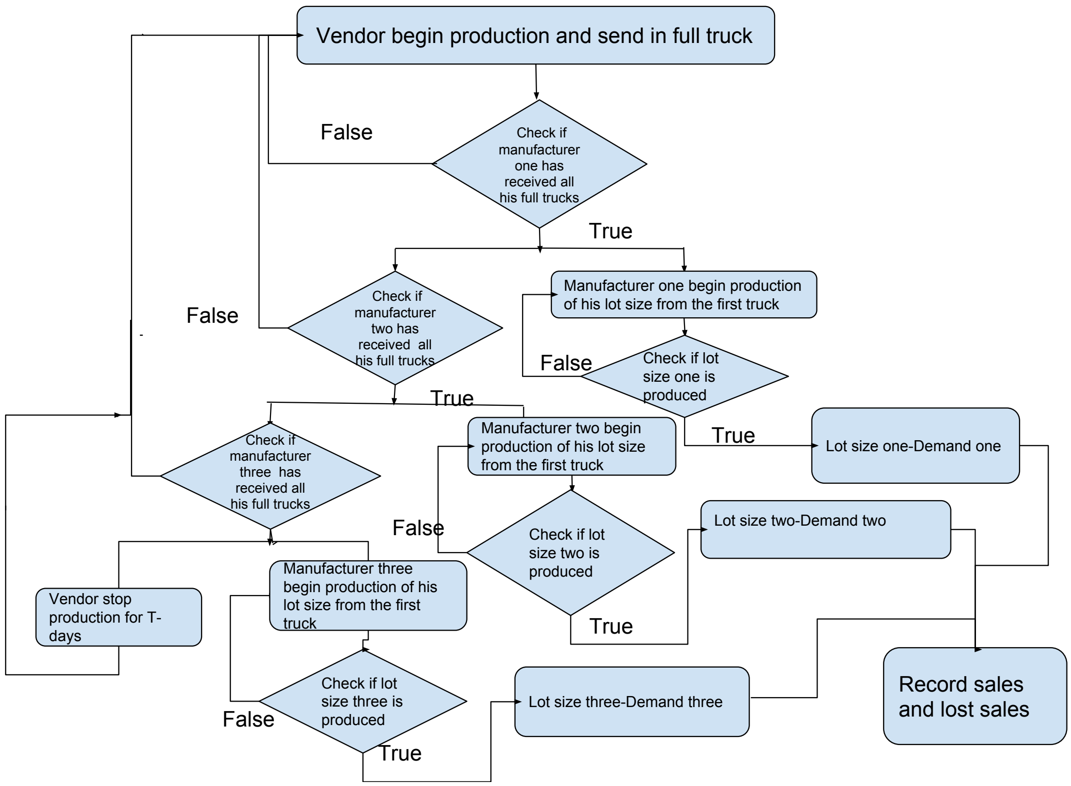


Figure 5.3: Flowchart for vendor managed inventory (VMI) policy

goods to avoid shortages as raw material replenishment time can be influence by any of the manufacturers depending on the numbers of full truck received.This is unlike the VMI policy where the vendor determines the most appropriate time to wait without any consultation to the manufacturers warehouses.

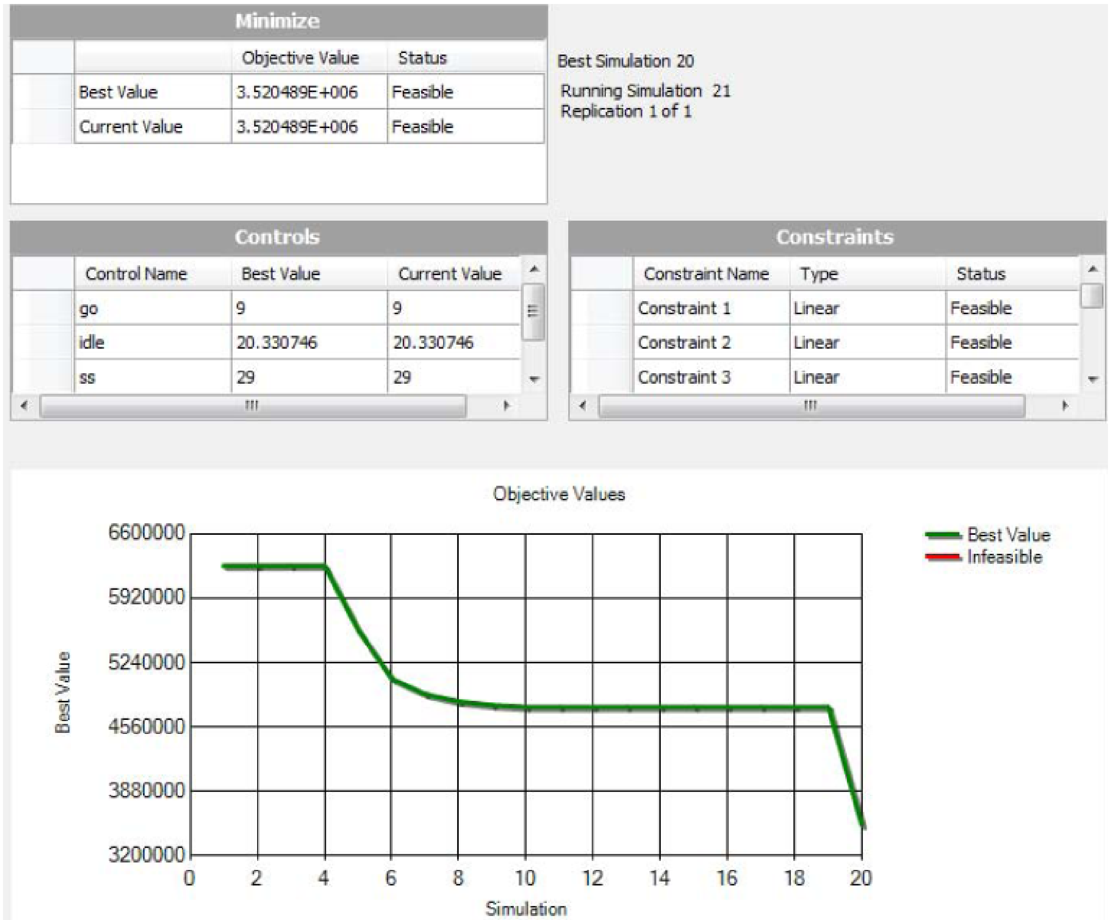


Figure 5.4: OptQuest searching for the optimal values of the decision variables

Table 5.3: OptQuest result for the VMI SVMM simulation model

Manufacturer	Number of shipments	Backlog cost per manufacturer	Stoppage time (days)	Long run average cost
1	11	4471.60	37.30487	308474.34
2	8	0.00		
3	5	0.00		

CHAPTER 6

SUMMARY AND FUTURE WORKS

6.1 Summary and Conclusion

This work studied the single-vendor,single-manufacturer and single-vendor,multiple-manufacturers inventory problem under stochastic demand conditions. In contrast to the previous work, we developed an integrated mathematical and simulation model that investigates the impact of a variable production rate in a flexible production system. Through the numerical examples, we showed that the cost incurred in a supply chain system can be reduced drastically by controlling the rate of consumption of the raw material which directly influence the production rate of the finished good and hence the size of the anticipated inventory holding cost. Different sensitivity analysis were performed on key parameters to investigate their effects on the expected total cost, production lot size, re-order point and the production schedule. A rise in the customers demand rate results in an increase in the number of trucks, production rate and re-order point of the manufacturer, so as to minimize the cost accrued from lost sales. An increase in demand variations cause the re-order point and production rate to increase to compensate for the level of uncertainty. The truck capacity size affects the production lot size directly, forcing a response through the re-order point and production rate for the lot to be produced within the predefined cycle. Increasing the holding cost of the manufacturer results in a fall in the re-order level, with the production rate going up to avoid shortages. Delay time influences the number of trucks received by the manufacturer so as to have sufficient goods on hand while waiting for material arrival. An increase in the production rate of the vendor necessitates a fall in the re-order point, production rate and lot size of the manufacturer to minimize costs resulting from holding raw materials and finished goods. The consumption ratio has a direct impact on the production lot size and this determines the re-order level, production rate and the total cost of the supply chain, with little or no influence on the number of truck received.

The developed single-vendor, single-manufacturer simulation model was used in validating the analytical model. Also, we investigated the robustness of the mathematical model by comparing both models at different demand standard deviation values. From the results obtained, it was deduced that as demand variation increases the percentage difference in the results from both models increases. The simulation model results, however, remain valid and reliable but at the cost of computation time.

Finally, using the simulation model, we relaxed the single-manufacturer assumption of the analytical model. Two policies were tested (common re-order point and VMI).

OptQuest optimization software in Arena was used to determine the optimal values of the decision variables for both policies .

In the next section, we suggest some future works

6.2 Recommendations (future works)

The work accomplished by this thesis can be extended in many ways. In this section, we suggest some possible future works.

1. Incorporating quality as an additional tradeoff in the SVSM model.

2. Performing full experimental design on different parameters of the SVSM simulation model.

3. Incorporating more policies in the SVMM simulation model.Examples include :

    - Vendor serving manufacturers on first come first serve (FCFS) basis.

    - Random distribution policy; though practically impossible.

    Then, comparing the policies using the data set.

4. Modeling the SVMM problem using control approach

5. Use of buffers as a means of getting the full truck while making the vendor shipment size a decision variable.

APPENDIX A1

Arena Simulation Software

In this appendix, some modules of the Arena simulation software are described. These modules were used to build the SVSM and SVMM simulation models.

Arena is an application software designed to mimic a real system so as to analyze the effect of system changes that might require huge capital expenditure and complex redesigning. It is associated with processes like logistics, supply chain, manufacturing and warehousing to mention few. It provided platform to analyze a system in its as-is configuration and under a myriad of possible to-be alternatives so as to make the best rational decision on how best to run and improve the system. In Arena,the three basic panels which contain the modules used in defining wide range of processes are basic process,advanced process and advanced transfer panel.

Prior to developing the flow chart for the supply chain system, it is necessary to describe key functions of the modules to be used;

- Basic Process Modules

  1. Create Module: This module create entities on schedule or inter-arrival time. The entities created from this module depart the module to initiate a process through the system. Example of entities are customers, cars, finished goods, materials and so on depending on the type of system that is being simulated.

  2. Dispose Module: It is used to truncate the process flow. Entities created by the create module leaves the simulation here.

  3. Process Module: This is used for performing task assigned by seizing and delaying the resources under a definable completion time and like other

modules described above it is from the basic panel.

4. Decision Module: This, provides options during a process flow usually by chance or condition.
5. Assign module: This is used in changing entity pictures and attributes. It is equally used to assign new values to system variables and parameters.
6. Separate Module: This is used for duplicating entities for parallel or concurrent processing.It is also employed to separate an already batched entities.
7. Batch Module: This module combined several entities into a single entity to continue the process.

- Advanced Process Module

1. Hold Module: This module is used to retain entities in queue until an initial set condition is true (scan) or signal is received from another module.
2. Signal Module: This module send signal value to the hold module so as to release a predefined number of entities.

- Advanced Transfer Module

1. Route Module: This is used to transfer entities to an already specified station under a predetermined delay time.
2. Station Module: This defines a physical location where an activity (processing) is carried out.

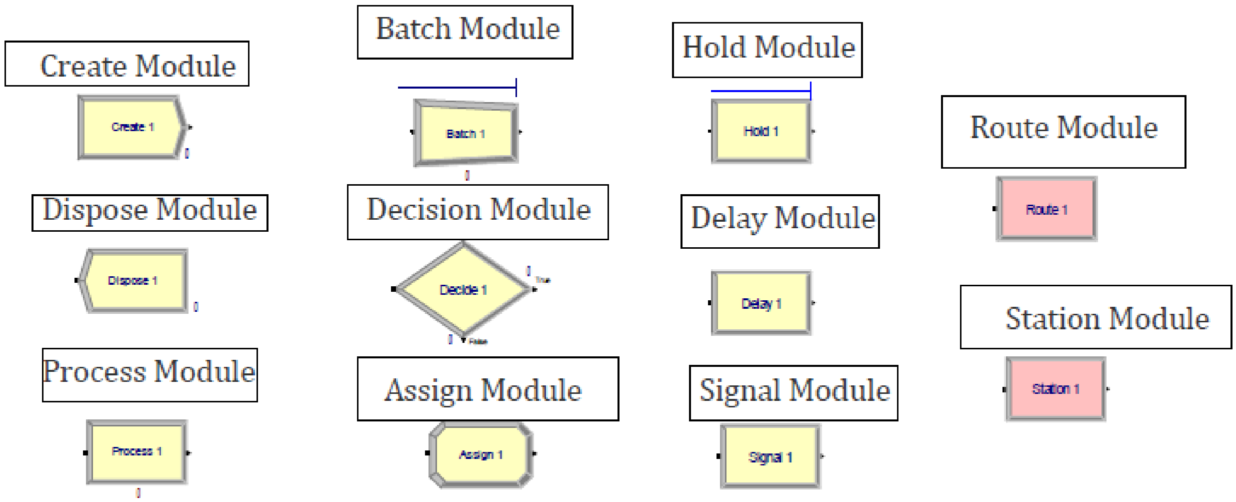


Figure 6.1: Symbolic representation of the Arena modules used in simulation model development

For further details, see Kelton, Sadowwski and Swets book. Simulation with Arena (2007).

APPENDIX A2

Simulation Model for the Single-Vendor, Single-Manufacturer Supply Chain

In this appendix, a snapshot of the SVSM simulation model is provided and it's design logic is described in details.Figure 6.2 shows the single-vendor,single-manufacturer supply chain system. The create module generate customers inform of entities every hour and each customers through the assign module make a random demand for the final product. This demand is deducted directly from the finished goods stock to determine the instantaneous value each time a sales is made. The decision module then perform an inspection role by checking if the inventory level of the finished good is less or equal to than the re-order quantity. Once this condition is satisfied, the signal module releases a signal for the production of raw materials to commence and if not, the customer is disposed without further action taken.

The create module at the production end of the simulation will always generate entities each time the simulation is run. These entities are held by the hold module, which releases them one by one, each time a signal is released from the signal module. It must be noted that through the assign module that preceded the signal module, a control mechanism is initiated which ensured that only one signal is released every cycle. This mimicked the activity of the vendor who produces once (single set up) every cycle. Once a signal is received, the entity released from the hold module goes to the separate module where it is duplicated into the truck capacity. As the vendor required some time period to produce a full truck load, the simulation model employed the process module to process each entity from the separate module continuously over an assigned period of time. The processed entities are then aggregated to form a batch through the batch module before being sent to the manufacturer's warehouse through the route and

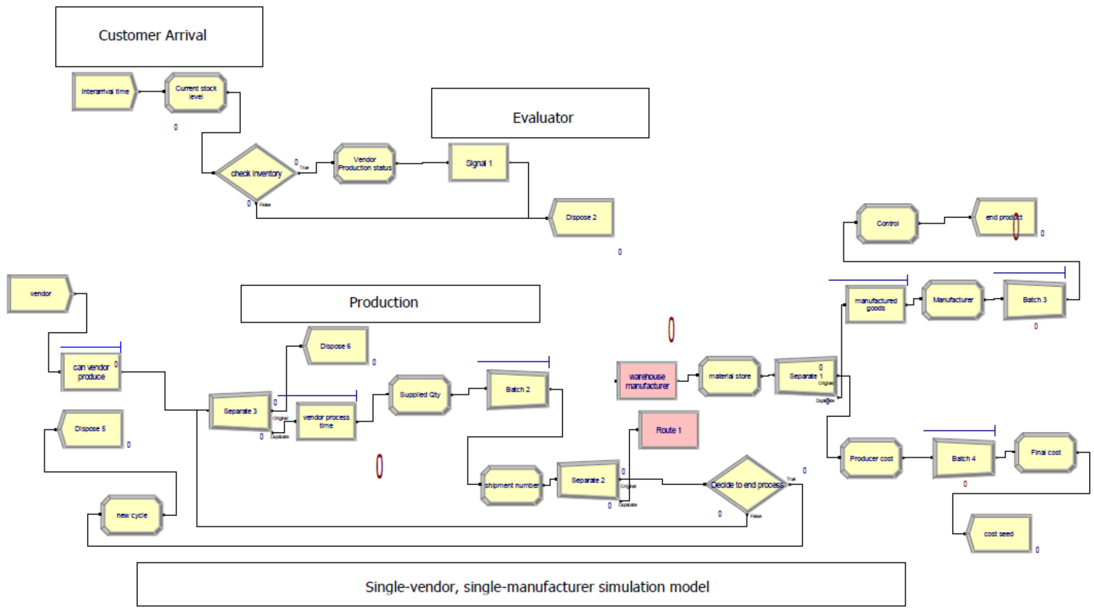


Figure 6.2: Single-vendor, single customer(manufacturer) simulation model

station module, which delay the delivery of every batch (full truck load)for a specified time period.

On arrival at the manufacturer warehouse, the processed raw material is consumed continuously at a known rate to produce the final good through the process module. The production rate of the final product and consumption rate of the raw material are however linked through a known constant that can assume the value of any positive real number. Once the economic quantity is produced, production ends and the finished goods are batched together before being added to the safety stock so as to form the finished good inventory to be consumed in the next cycle. It is important to know that the cycle continues over an infinite horizon and so the developed simulation model is non-terminating or steady state simulation. Different statistics were collected particularly in terms of cost as a performance measure.

APPENDIX A3

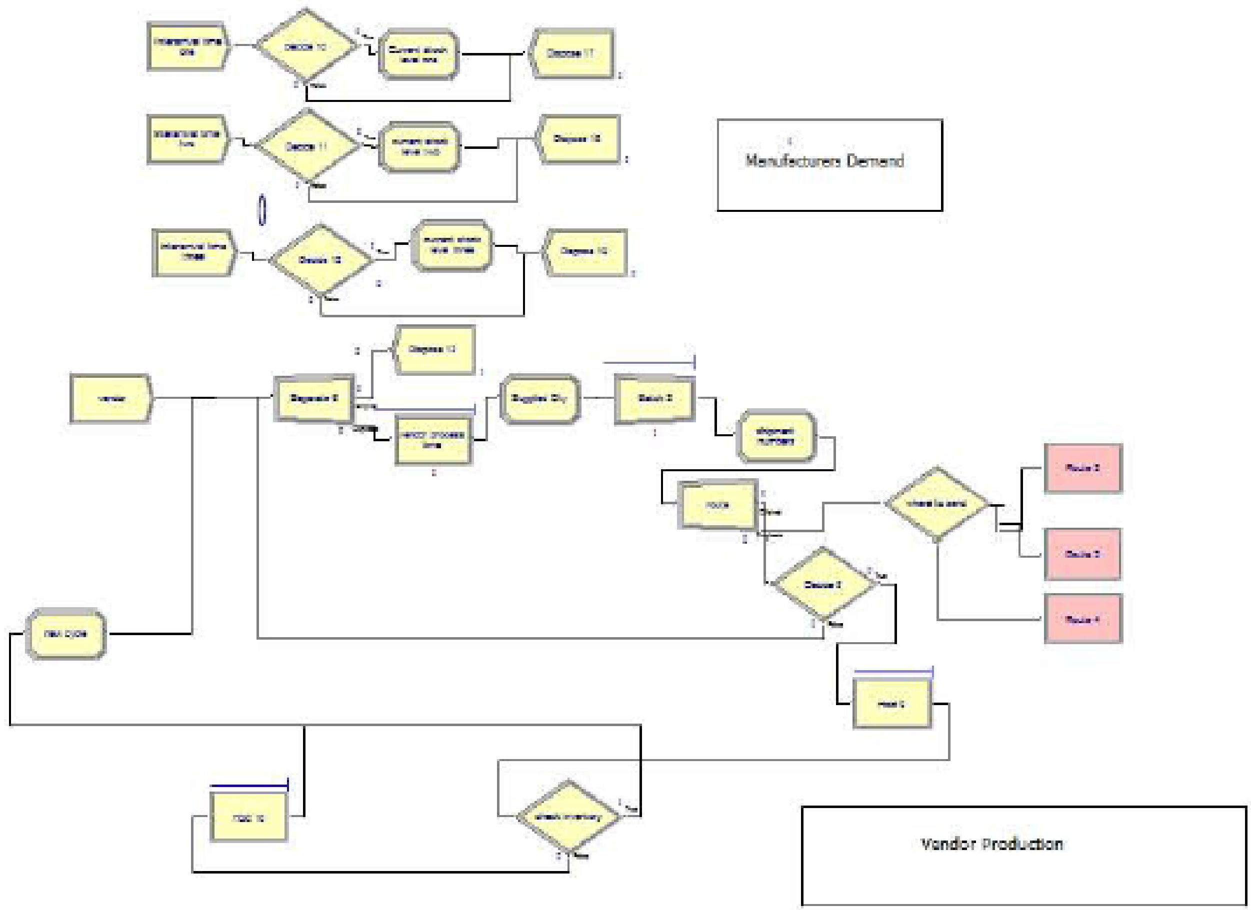
Arena Model for Single-Vendor, Multiple-Manufacturers with Common Reorder Point

In this section, a snapshot of the SVMM with common reorder point policy is provided. The same modules presented in Appendix A1 were used and the same logic of Appendix A2 was followed. Except for the following amendments if compared with SVSM simulation model.

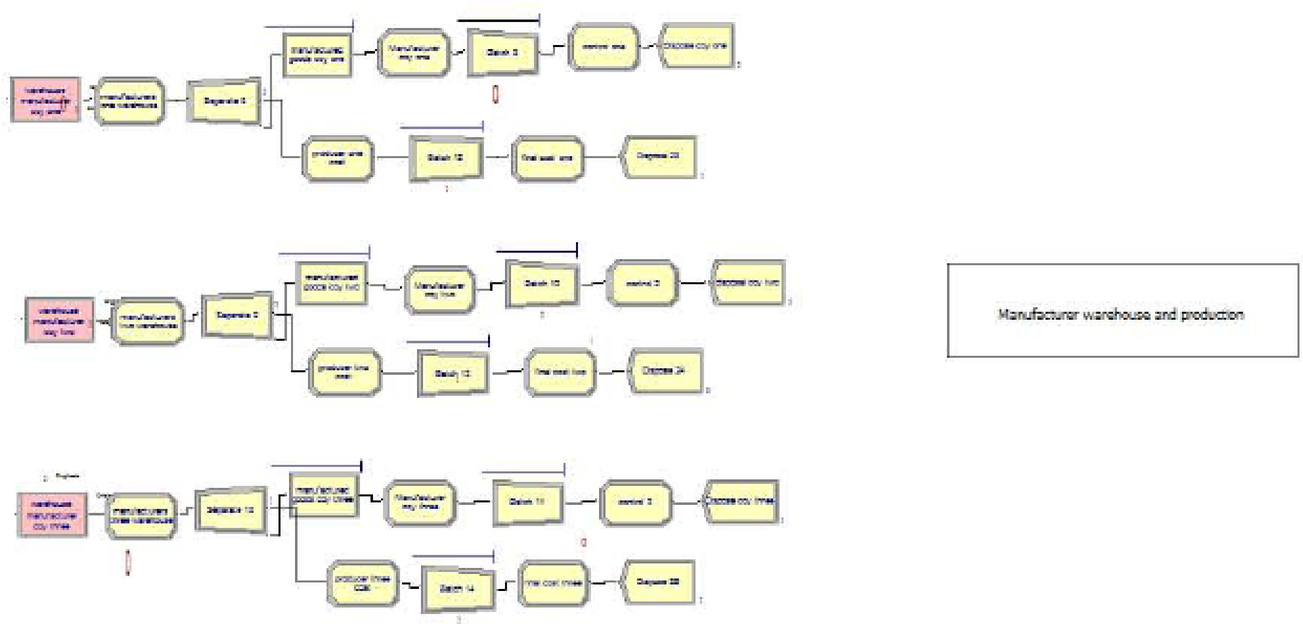
1. The manufacturers were assumed three instead of one.

2. Vendor's production is triggered after crossing a common re-order point.

3. Materials are route to three warehouses against one as assumed in the SVSM



(a) Demand arrival and vendor production and distribution process



(b) Manufacturer production process

Figure 6.3: Single-vendor, three-manufacturers simulation model with common re-order point policy

APPENDIX A4

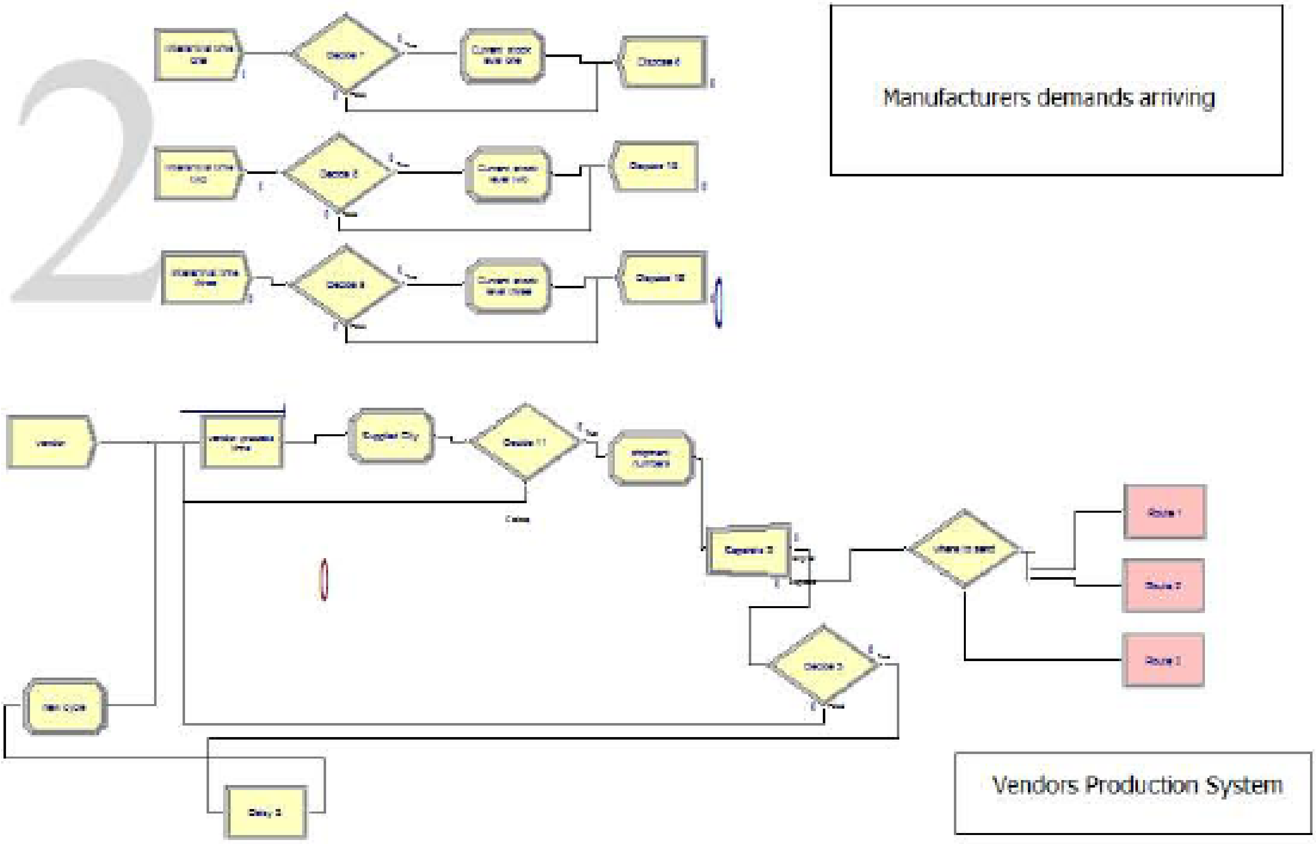
Arena Model for Single-Vendor, Multiple-Manufacturers with VMI

In this section, a snapshot of the SVMM with VMI is provided. Similar to Appendix A3, modules described in Appendix A1 were used and the same logic of Appendix A2 was followed with few modifications as enumerated below:

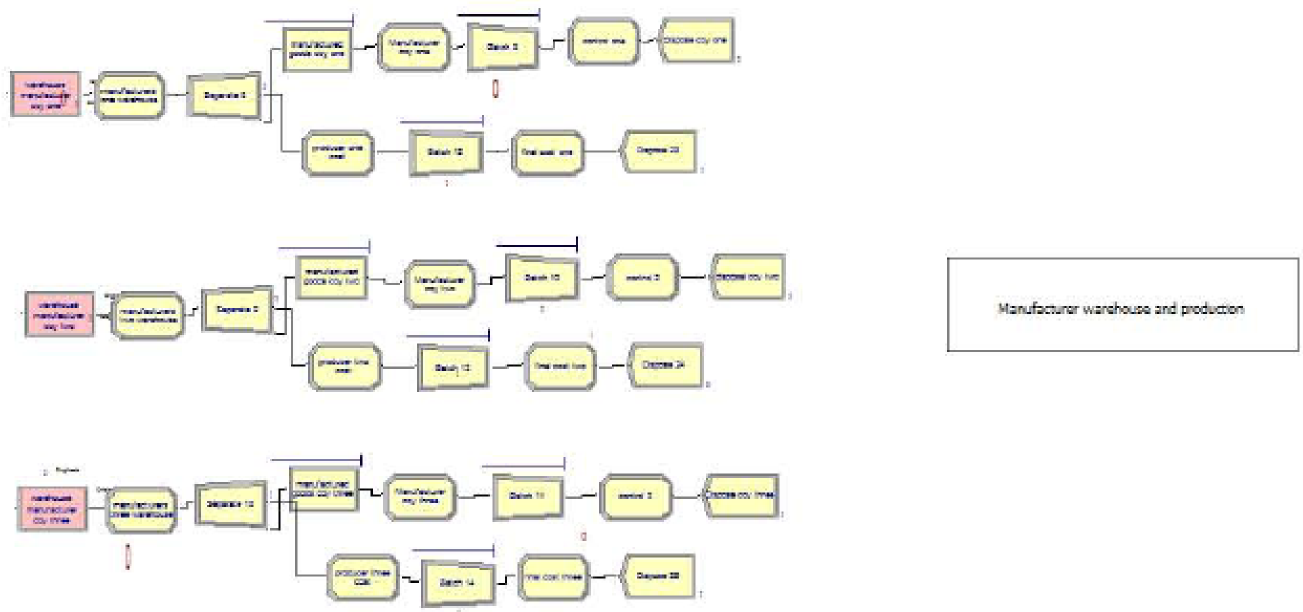
1. The manufacturers were assumed three instead of one.

2. Vendor's production is triggered after a specific delay time.

3. Materials are route to three warehouses against one as assumed in the SVSM



(a) Demand arrival and vendor production and distribution process



(b) Manufacturer production process

Figure 6.4: Single-vendor, three-manufacturers simulation model with VMI policy

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<table>
<tr><td>Responsibilities</td><td>Designing of Network diagrams and Gantt chart for activities
On-site supervision, monitoring and coordination of workers and machines
Preparing detailed work-plan for clients so as to determine the critical path, slacks, latest start time, earliest finish time, earliest start time and most importantly the latest finish time of the project.
Preparing bid and quotation for anticipated projects.</td></tr>
<tr><td>7up Bottling Company.

Industrial Engineering II(NYSC)</td><td>7up Bottling Company, 9Th Mile, Enugu-State, Nigeria.

"A technological based bottling company, producer of 7up,Pepsi,Mirinda”

April 2010-March 2011.</td></tr>
<tr><td>Responsibilities</td><td>Challenged with increasing product quality, improving process flow, and reducing cost while maintaining or improving safety in this bottling company. Develop, evaluate, document and advance manufacturing methods and processes through lean techniques and Kaizen events. Analyze and reengineer production layouts, designing and implementing efficient and quality projects across production lines. Collaborate with administrative and financial teams to establish viable support of safety standards. Provide ongoing production support and troubleshooting.

Selected Contributions:
Establish first preventive maintenance schedule, ensuring optimal equipment operation without costly downtime.
Created and implemented efficiency work-study which generates more than 5% improvement through associated cost reductions.
Significantly reduced waste and end to end production time by leveraging expertise with Statistical Process Control (SPC) methodology</td></tr>
</table>

Dana Groups, **Industrial Engineering Intern**	**Ashmina Nigeria Limited** (An infusion plant situated at Ibadan, Oyo-state) "A technological based pharmaceutical company, producing all forms of drips used in hospitals through their semi-automatic systems" April-November 2008
Responsibilities	• Regeneration of the infusion plant using concentrated acid and caustic soda • Infusion Plant maintenance officer(Mechanical, Electrical and Pneumatic systems trouble shooting) • Bore-Hole removal, installation and Panel trouble shooting • Steam Plant (Boiler)maintenance officer and operator • Plant facility layout re-designing • Rebuilding and Installing old and new plants(machines and equipment) • Installation and maintenance of utilities (electric modular light and power system, distribution fuse board trouble shooting etc. • Introduction of Peg-board chart as a means of achieving planned and preventive maintenance

PERSONAL WORKS

- **Integrated Supply chain model with random demands and flexible production process.** M.Sc. thesis submitted to the Department of System Engineering, King Fahd University of Petroleum and Minerals, Dhahran, Saudi-Arabia.

- **Anthropometric Data Gathering of two Ethnic Tribes in Nigeria (December 2009)**. B.Sc Ergonomic Project submitted to the Department of Industrial and Production Engineering, University of Ibadan, Ibadan, Nigeria.

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SUBMITTED RESEARCH PAPERS

- **Adegbola, K.,** AlDurgam, M**.** Single-vendor, Single-manufacturer inventory model with stochastic demand and variable production rate. **Submitted to International Journal of Production Research.**

- **Adegbola, K.,** Al-Haboubi, M**.** Minimizing noise in a facility**. Submitted to International Journal of Industrial Ergonomics.**
- Sanuade Oluseun Adetola**, Adegbola Kehinde**, Adefehinti Afolabi, and Oladunjoye, M. A. "Statistical Comparison of Thermal Properties of Tar Sand using Randomized Complete Block Design". **Submitted to Arab J Sci Eng.**

- Adetokunbo, P, Oluseun A Sanuade, Paul Edigbue, **Kehinde Adegbola** and Toluwani Daramola, "Statistical analysis of seismic refraction methods: A synthetic data Example" **Journal of the Geological Society of India (*Submitted*).**

SOFTWARE PROFICIENCY AREAS

- Good knowledge of Micro-soft packages (Word, Visio, Excel and Power-point), Latex.
- Proficiency in the use of Mat lab, GAMS, Minitab, Lingo, Arena(Simulation),

AREAS OF INTEREST

Operation research, Production management and supply chain management, Discrete event simulation, Ergonomics, Decision-making, Experimental design.

PERSONAL AWARD

- National Merit Award in mathematics presented by the National Mathematical Center, Abuja.(1994)
- Department of Industrial Maintenance Engineering, best graduating student. (September, 2003).
- King Fahd University all-expense paid global scholarship for graduate student. (August, 2013)

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