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A consignment stock policy for a two-level supply chain with imperfect quality items

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A CONSIGNMENT STOCK POLICY FOR A TWO-LEVEL SUPPLY CHAIN WITH IMPERFECT QUALITY ITEMS

by

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Ehab Bazan

Abstract

A CONSIGNMENT STOCK POLICY FOR A TWO-LEVEL SUPPLY CHAIN WITH IMPERFECT QUALITY ITEMS

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A consignment stock is a type of supply-chain coordination for the management of supply-chains in which there is a joint vendor and buyer policy that is mainly focused on having the vendor manage the buyer's inventory. This thesis aims to investigate the consignment stock strategy in a single-vendor single-buyer supply-chain context considering imperfect items that may be produced from an imperfect production process. It develops a flexible mathematical model that allows for managerial decisions with regards to imperfect items and seeks to minimize costs (maximize profits) of the supply-chain. Such managerial decisions include scrapping items at a cost, selling them for a marginal profit to a secondary market, applying re-work, and/or applying minor setups to restore the production process. Results show that the introduction of imperfect items increases the batch size and reduces the number of shipments. Minor setups were shown to reduce cost, increase the number of shipments and reduce its size.

Acknowledgements

This thesis is the result of numerous efforts from various bodies and individuals. The author would like to primarily acknowledge the Natural Sciences and Engineering Research Council (NSERC) of Canada, the Social Sciences and Humanities Research Council (SSHRC) of Canada, the Canadian Environmental Issues, and Ryerson University.

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Nomenclature

A_1	batch set-up cost (vendor's side)	[$/setup]
A_2	order emission cost (buyer's side)	[$/setup]
h_1	vendor holding cost per item and per time period	[$/item.year]
h_2	buyer holding cost per item and per time period	[$/item.year]
P	vendor production rate (continuous production)	[items/year]
D	demand rate (continuous demand seen by buyer)	[items/year]
n	number of transport shipments	
q	quantity transported per shipment	[items]
C	average total costs of the system per time unit	[$]
u_p	unit production cost for regular production	[$/item]
T	total cycle time	[year]
x	production batch quantity for regular production	[items]
λ	factor to determine the process producing imperfect items	
U	the total number of imperfect items resulting from regular production	[items]
t_p	time required for production of one batch (regular production)	[years]
u_k	unit cost for scrapping an item	[$/item]
V	total number of imperfect items after re-work production	[items]
q_r	total number of imperfect items after re-work production	[items]
μ	factor to account for difference in re-work setup cost from that of A_1	
β	factor to account for difference in re-work unit production cost from that of u_p	
γ	factor to account for difference in order emission cost from that of A_2	

b_1	percent profit assumed for the vendor (manufacturer per)	[%]
u_b	buyer purchasing unit cost for buyer each item consumed	[$/item]
ϕ	factor to account for cost of minor setup from that of A_1	
q_i	shipped quantity per batch i (constant value)	[items]
U_i	number of imperfect items per batch i (constant value)	[items]

$P_D = [0,1]$	0 = production cost not considered	1 = production cost considered
$H = [0,1]$	0 = no holding of imperfect items	1 = holding of imperfect items
$K = [0,1]$	0 = scrapping cost not considered	1 = scrapping cost considered
$R = [0,1]$	0 = no re-work applied	1 = re-work applied
$B = [0,1]$	0 = buyer purchasing not considerer	1 = buyer purchasing considered
$M = [0,1]$	0 = no-minor setups applied	1 = minor setups applied for restoration

Chapter 1

Introduction

1.1. Overview of Supply Chain

1.1.1. The Importance of the Supply Chain

Supply Chains have become a vital element of any current business whether manufacturing products or providing a service. Its introduction is a direct result of differences and discrepancies between supply and demand throughout the different stages of the business. Assume the following scenario of a vendor who supplies products to a buyer: if the demand is more than what the supplier has to offer, shortages will occur and may lead to back-logs or lost sales. On the contrary, if the supply available is greater than the buyer's demand, excess inventory will be on hand leading to additional costs.

The vendor and buyer could be considered any two participants in a supply chain whereby one precedes the other, for example: two production stages within a facility, or a supplier and manufacturer, etc. *Figure 1.1* depicts a simple supply chain structure.

Figure 1.1 Schematic representing a simplified supply chain network

Furthermore, there could be more than two parties involved in a supply chain: many suppliers providing many materials to a manufacturer which produces products to be shipped to warehouses and later to distributors, before the products finally reach the customer. *Figure 1.2* depicts a complex supply chain structure. The more parties there are in a supply chain, the more complex and costly it becomes. In brief, for a supply chain to be successful, it has to be efficient and responsive.

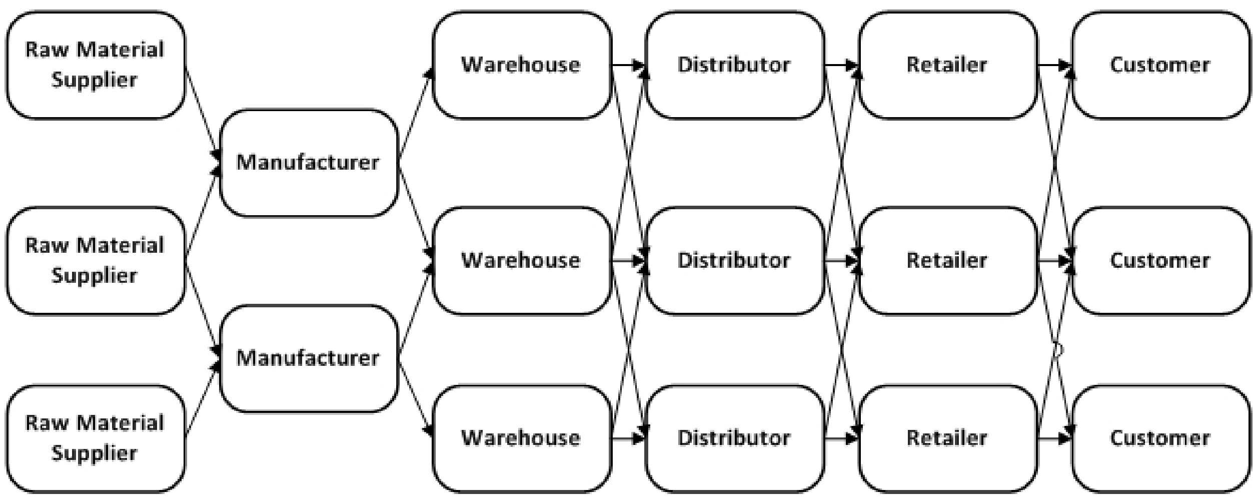

Figure 1.2 Schematic representing a more complex supply chain network

In addition, storage and material handling costs in such supply chain networks can be as high as 50% of a product's indirect operating expenses (Rosenblatt, 1986). So reducing inventory related costs in a supply chain remains a pressing issue which this thesis will address. The next section will provide readers with some of the definitions of a supply chain and its functional areas that are available in the literature.

1.1.2. Supply Chain Definitions and Key Concepts

There are various definitions of a supply chain, some of which are:

- "A supply chain is the alignment of firms that bring products or services to market."
  (Lambert et al., 2003)
- "A supply chain consists of all stages involved, directly or indirectly, in fulfilling a customer request. The supply chain not only includes the manufacturer and suppliers, but also transporters, warehouses, retailers, and customers themselves . . ."
  (Chopra et al., 2003)
- "A supply chain is a network of facilities and distribution options that performs the functions of procurement of materials, transformation of these materials into intermediate and finished products, and the distribution of these finished products to customers."
  (Ganeshan et al., 1995)

Although different, all the definitions share the common essence in that there is a network (as depicted in *figure 1.2*), there are participants playing roles in this network, and that the overall objective of all the parties is to bring the service or product to the end user customer. The entities or participants in such networks have conflicting objectives, where each entity would like to maximize (minimize) its profit (cost). Supply chain management provides the tools to effectively and efficiently manage such complex supply chain networks.

Supply chain management can be defined as:

- “The systematic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purpose of improving the long-term performance of the individual companies and the supply chain as a whole.”
  (Mentzer et al., 2001)

From this definition, an entity within a supply chain must make individual and group decisions concerning five functional areas: production, inventory, facility location, transportation, and information. For example, if a business’ strategy is to target a mass market and compete on the basis of price, the combined result of the decisions to be made must optimize the supply chain for the lowest cost. However, if a business' strategy is to target a specific market segment and compete on customer service, the supply chain managerial decisions must optimize for responsiveness. Generally, it can be said that supply chain management is the coordination of the aforementioned five functional areas to achieve the optimal scenario for the target market.

Examples of the decisions to be made could be answers to the following questions concerning the five functional areas:

- Production
    - Products to be produced (as determined by the target market)
    - Amount of each product produced and delivery times (market demands)
- Inventory
    - The amount of inventory to be stored at each stage
    - The amount to be held as raw-materials, semi-finished, or finished goods
    - Optimal inventory level and re-order points
- Facility location
    - Location of production and inventory storage facilities
- Transportation
    - Inventory movement from one facility location to another
    - Means of transportation
- Information
    - Data that should be collected
    - Information to be shared
    - Timeliness and accuracy of information

1.1.3. Supply Chain Performance Metrics

As previously mentioned, the overall objective a supply chain is dependent on the market to which the business is targeting, and accordingly, this shifts the optimization process towards different optimal parameters. Compulsory to determining these optimal parameters is the ability to measure the performance of a given supply chain. Basically, each market type requires a different mix of performance measures. Four performance measurement categories cover this scope. They are: customer service, internal efficiency, demand flexibility, and product development. The metrics that measure the performance in these four categories can be applied to the individual business or collectively to the entire supply chain.

Customer Service Metrics

- "Service relates to the ability to anticipate, capture and fulfill customer demand with personalized products and on-time delivery"
  (Hausman, 2000)

There are two main scenarios of concern: build-to-order and build-to-stock. A build-to-order scenario is a situation where a customized product is ordered by a customer. Hence, the product is 'built' for a specific 'order'. A build-to-stock scenario is one where a general product is supplied to a large market. Hence the product is 'built' and 'stocked' in inventory for a certain period before satisfying market demands to utilize means of mass production and economies of scale.

Popular metrics for a build-to-order scenario include:

- Quoted customer response time and on-time completion rate
- On-time delivery rate
- Value of late orders and number of late orders
- Frequency and duration of late orders
- Number of warranty returns and repairs

Popular metrics for a build-to-stock scenario include:

- Complete order fill rate and order line item fill rate
- On-time delivery rate
- Value of total backorders and number of backorders
- Frequency and distribution of backorders
- Line item return rate

Internal Efficiency Metrics

When a business or a supply chain utilizes their assets as profitable as possible, this is referred to as internal efficiency. Some measures for internal efficiency include:

- Inventory value

- Inventory turns
- Return on sales
- Cash-to-cash cycle times

Demand Flexibility Metrics

Demand flexibility refers to a business or supply chain's ability to respond to change in new demands such as additional order volume or with the provision of additional 'new' products that are currently not part of the regular products usually provided. Some metrics for demand flexibility include:

- Activity cycle time
- Upside flexibility (when considering flexibility in demand volume)
- Outside flexibility (when considering additional 'new' products)

Product Development Metrics

Markets constantly evolve with time. If a business or supply chain does not evolve accordingly with the market it targets, it will be replaced. Product development measures the business or supply chain's ability to design, build, and deliver new products to serve their target markets. Some performance metrics include:

- Percentage of total products sold that were introduced in the last year
- Percentage of total sales from products introduced in the last year
- Cycle time to develop and deliver a new product

SCOR Model

There are several layers or levels of performance metrics available to measure the performance of a given supply chain. The Supply-Chain Council's SCOR models suggests each business or supply chain is required to build a system that can present data at three levels of details:

- Strategic: to assist management in deciding 'what to do' (SCOR Level 1 data)
- Tactical: to assist middle management in deciding 'how to do it' (SCOR Level 2 data or Level 2 Performance Metrics)
- Operational: to assist people 'actually to do it' (SCOR Level 3 data, or Level 3 Diagnostic Metrics)

1.2. Supply Chain Coordination

1.2.1. The 'Bull-Whip' Effect

Businesses at different stages in the supply chain have different forecasts and estimates of market demands. The 'bull-whip' effect is the effect that happens when large variations in demands experienced by businesses further back in the supply-chain happen as a result of small changes in demand by the consumer at the forefront of the supply chain as depicted in *figure 1.3*.

Research into the bull-whip effect leads us to five major factors that cause this effect:

- Demand forecasting
- Order batching
- Product rationing
- Product pricing
- Performance incentives

The aforementioned five factors may act together in different combinations in different supply chains. However, the overall effect is that together they produce undisciplined demand swings that make it difficult to manage an efficient supply chain.

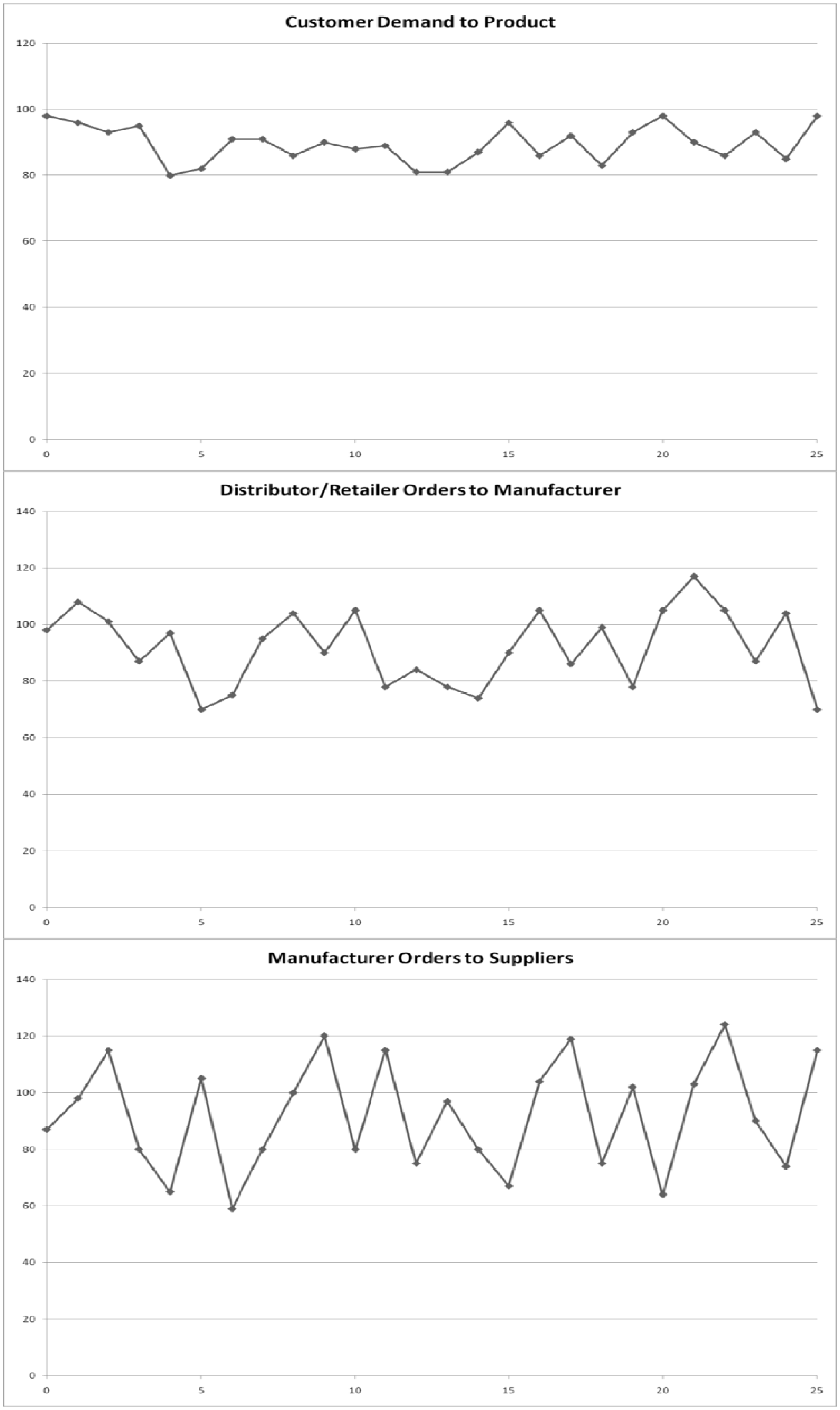

Figure 1.3 The 'bull-whip' effect: demand as reflected on the different participants in the supply-chain

1.2.2. Supply Chain Data Synchronization

As products move through a supply chain, they are transferred from participants in the supply chain that are not necessarily under the same business. They may be different companies or service providers. Regardless, the products need to be identified and traced so that the amounts of products moving through the supply chain are known. Moreover, the products need to be classified so that it is known which type of product is being handled.

There are many standards and coding techniques present. However, if the codes are standardized and synchronized within the supply chain, time spent in translating the product codes from one party to another may be eliminated and possible errors in translation in invoicing and making payments can be eliminated. Furthermore, other consequences from the lack of accuracy and clarity in sales history can be avoided. Even with the use of a universal code for the product between the parties in the supply chain, it should be noted that business may keep their existing internal part numbers and codes for internal operations.

1.2.3. Collaborative Planning, Forecasting and Replenishment

Collaborative planning, forecasting and replenishment issues are vital to supply chains. Supply chains that use technology to support these issues are the more efficient supply chains as they can best manage factors that give rise to the bull-whip effect.

Collaborative planning includes negotiations of front-end agreements that define the responsibilities and roles of the businesses collaborating with each other within the supply chain. It also includes the infrastructure of a joint business-plan that illustrates how the businesses will work together to meet market demands.

Collaborative forecasting comprises of creating a sales forecast for all the collaborating businesses in the supply chain. This includes identifying and resolving any exceptions or differences between businesses to provide a common forecast.

Collaborative replenishment uses the collaborative forecasts and allows for resolving exceptions to provide efficient production and delivery schedules. It is where actual orders are generated to meet customer demands.

It should be noted that in general, the more a product is simpler in design, the less complex a supply chain will be required, which in turn will reduce production costs and allow for increase in responsiveness to market demands.

1.2.4. Centralized and De-centralized Policies

Coordination decisions in supply chains are either centralized or de-centralized. De-centralized policies involve numerous decisions within the different participants in a supply-chain. It is not uncommon that the different decisions have conflicting objectives resulting from each participant’s perspective. This leads to centralized policies, where a single decision maker (or a team of decision makers) manages the entire supply chain to achieve the overall objective, whether it be minimizing the supply chain costs or maximizing its profits.

There are many research literatures discussing centralized coordination in supply chains. These include quantitative models concerning two-level, three-level, and four-or-more-level supply chains. The bulk of the research literature involves two-level supply chains. In these research studies, the economic order quantity model (EOQ model) is considered the base foundation for most models. It is where coordination is applied between a vendor and a buyer to optimize their combined costs (Jaber and Zolfaghari, 2008).

1.2.5. The Consignment Stock Policy

The concept of inventory consignment is an arrangement where a ‘buyer’ business would physically hold items in its inventory without ‘owning’ the items. (Simchi-Levi 2000, Coughlan 2001). Upon use of the items in production or rather consumed, the buyer business will make the appropriate payments for the purchase of the consumed items. That is to say, within the consignment stock inventory model the ‘change of ownership’ of the items is unrelated to the shipment of the items from one party (the vendor) to the other (the buyer). This is contrary to the basic design of most inventory systems.

The consignment stock strategy was observed as an industrial practice in the automotive manufacturing environment (Braglia and Zavanella 2003). Braglia and Zavanella (2003) provided analytical modeling that refers to a single-vendor single-buyer scenario to help in understanding the behavior and aptitude of the consignment stock policy in the supply chain coordination context. Briefly, consignment stock is considered an innovative approach to supply and stock management designed to achieve gains to all parties in the supply chain. This can only be achieved when the foundation is laid for a robust and accurate collaboration between the parties concerned. As discussed in *section 1.2.3* this will provide a more efficient supply chain as it best manages the factors that give rise to the bull-whip effect.

1.2.6. The Issue of Imperfect Production

With regards to research concerning supply chain and coordination in supply chains, two main assumptions are evident in initial studies: the equipment and machinery used in a production process are not subject to failures and the output produced from the process has no defectives (Wang, Lin, Chen, 2009). In the real world, this assumption is less valid, and research has introduced the concept of imperfect items in their context. Porteus (1985, 1986) and Rosenblatt and Lee (1986) assume that a process is in-control and then will shift with a specified probability to an out-of-control state and remain as such until the next setup in the process. Their work has provided a foundation for later research considering minor interruptions and minor setups to restore process quality (Khouja, 2005 and El Saadany, Jaber, 2005). The concept of imperfect production in the consignment stock context has not been thoroughly investigated.

1.3. Objective of the Thesis

Being industry induced, the supply chain coordination known as the consignment stock requires further investigation to develop a complete understanding of the policy, its strategy and how it behaves under various circumstances.

Specifically, the overall objective of this study is to develop and apply a mathematical model to simulate the behavior of a consignment stock model susceptible to imperfect production. In addition, the model shall accommodate various managerial decisions that may emerge and transpire as a result of the reality of imperfect production.

1.4. Organization of the Thesis

Chapter 1

Chapter 1 introduces the topic of supply chain, coordination mechanisms focusing on the consignment stock policy and imperfect production relating to supply coordination mechanisms.

Chapter 2

Chapter 2 provides a literature review surveying research in three directions discussing Hill's model, a classical approach to supply chain coordination, the consignment stock model, and related research covering the issue of imperfect production as related to the two supply chain coordination policies. The chapter will also provide a clear definition of the problem and conclude with a comprehensive list of objectives for the study.

Chapter 3

Chapter 3 is divided into two three main sections. The first section discusses the mathematical modeling of the consignment stock model as presented by Braglia and Zavanella (2003). This model shall be considered the base-model for this study. The second section extends the current base-model model to allow for other cost parameters to be incorporated in the model to accommodate imperfect production scenarios. The third section proposes a new model that accommodates the scenarios of the extended-model and permits minor setups for restoration of the process.

Chapter 4

Chapter 4 discusses the application of the various scenarios in the extended and proposed models comparing them to develop insights and a more complete understanding of the consignment stock policy relating it closer to the real world.

Chapter 5

Chapter 5 looks into the results of the various experiments of the models and their respective scenarios, present conclusions, and suggests further points of research that can be extended to the current study.

Chapter 2

Literature Review

2.1 Literature Review

This chapter will provide a review of available literature concerning three lines of research, namely: supply chain coordination, the issue of imperfect quality items in supply chains and consignment stock coordination. Subsequently, the chapter will provide a problem definition to confine the research objectives of this thesis to challenge certain research gaps within the review that was conducted. Hence, this chapter will provide a conceptual skeleton to this thesis and a comprehensive list of specific research objectives.

2.1.1 Supply Chain Coordination

Chapter one of this thesis discussed supply chain and supply chain coordination visiting areas such as the importance of supply chains, supply chain definitions and key concepts, performance metrics, the bull-whip effect, and centralized and decentralized policies. In general, it can be said that the effectiveness of supply chains can be evaluated by optimizing the supply chain through minimizing costs or maximizing profits, or through providing superior services (e.g., demand flexibility, reduced lead times…). Supply chain coordination seeks to harmonize efforts between the members of the supply chain to enhance the chain's performance.

The literature discussing supply chain coordination, in general, considers two main decision variables for coordination: the amount of materials transported from one member to another in the chain, and the number of transport shipments required. It can be said that the regulation and fine-tuning of both decision variables is a means of coordinating a supply chain.

This section will discuss supply chain coordination focusing on quantitative models showing how members in a supply chain seek to optimize their performance through adopting various centralized decision making processes, incentive schemes, and other policies.

Jaber and Zolfaghari (2008) review the literature for quantitative models for centralized supply chain coordination that put emphasis on inventory management from the year 1990 to the end of 2007. They classify the models presented in the literature on the basis of incentive schemes, supply chain levels and assumptions taken into consideration. They review the literature under the following subject headers: centralized coordination, two-level supply chain models, three level supply chain models and four-level or more supply chain models.

The framework of this thesis research focuses on a two-level supply chain model and hence, this section shall only refer to literature reviewed by Jaber and Zolfaghari (2008) present related to two-level supply chain models.

Jaber and Zolfaghari (2008) cited the work of Goyal and Gupta (1989) that suggests the coordination in a supply chain be realized through the integration of lot-sizing models. Goyal and Gupta (1989) also mention that such coordination cannot be possible unless orders between members in the supply chain provide trade credit options, with the most common being quantity discount and delay in payment mechanisms.

Jaber and Zolfaghari (2008) move on to address the work of Thomas and Griffin (1996) that reviews previous literature concerned with coordinated planning between two or more stages of the supply chain. This review has made clear the three categories of operational coordination: vendor-buyer coordination, production-distribution coordination and inventory-distribution coordination. Furthermore, the review was concerned with models that concentrated on batch size, the type of transportation and the production quantity. Subsequently, Jaber and Zolfaghari (2008) discuss the work of Maloni and Benton (1997), Sarmah et al. (2006) and Li and Wang (2007), and how these studies lacked the surveying of mathematical models. What the work of Jaber and Zolfaghari aims at accomplishing is the presentation of mathematical models in its review that facilitates observable findings of similarities and differences between the various models.

As mentioned by Jaber and Zolfaghari (2008), the economic order quantity (EOQ) model is the foundation for almost all available models presented in the literature. The EOQ model is a two-level chain whereby coordination occurs between a vendor (manufacturer or supplier) and a buyer to optimize their joint costs. Jaber and Zolfaghari (2008) continue through their review to discuss the works considering vendor-buyer coordination including the works of Dolan (1987), Goyal (1997), Hill (1997), Munson and Rosenblatt (1998), Woo et al. (2000), Yang and Wee (2003), and Zhou and Wang (2007).

Jaber and Zolfaghari (2008), continue their review by surveying studies that have built on the foundation of the basic vendor-buyer coordination problem. They categorize the research based on the assumptions relaxed in the studies, which include:

- Finite production rate
- Non-uniform demand
- Permissible delay in payments
- Multiple buyers
- Multiple items
- Product/process quality
- Deterioration
- Entropy cost
- Stochastic models

The following table (*Table 2.1*) summarizes the research studies reviewed by Jaber and Zolfaghari categorized under each relaxed assumption.

RESEARCH PAPER	Finite production rate	Non-uniform demand	Permissible delay in payments	Multiple buyers	Multiple items	Product/process quality	Deterioration	Entropy Cost	Stochastic Models	COMMENTS
Banerjee (1986)	●									Assumed lot-for-lot policy
Goyal (1988)	●									Relaxed lot-for-lot policy assumption
Joglekar and Tharthare (1990)	●									Presented refined Joint Economic Lot Size (JELS) model; propose a new approach to the problem that minimizes the required coordination between vendor and buyers
Wu and Ouyang (2003)	●									EOQ with shortage
Grubbström and Erdem (1999)	●									EOQ with backlogging
Ertogral et al. (2007)										Integration of transportation cost
Li et al. (1995)		●								Buyer is monopolistic with respect to vendor
Boyaci and Gallego (2002)		●								One vendor, one or more buyers; deterministic price dependant demand
Jamal et. Al (2000)			●							Cost minimization problem to determine optimal payment time
Yang and Wee (2006a)			●							Includes deteriorating items and allows for negotiation factor to balance extra profit sharing
Abad and Jaggi (2003)			●							Demand is price sensitive; seller may offer trade credit to the buyer
Jaber and Osman (2006)			●							To minimize local costs and that of the supply chain; permissible delay in payments is a decision variable, implemented as a trade credit scenario to coordinate the order quantity between the two levels
Chen and Gang (2007)			●							Similar to Jaber and Osman (2006) but permissible delay in payments is not considered as a decision variable
Sheen and Tsao (2007)			●							Determining vendor's credit period, buyer's retail price and order quantity to maximize profits; how trade credit can be affected by quantity discounts for freight cost; search for optimal length of this credit from the vendor's perspective, not from that of the supply chain
Affisco et al. (1993)				●						Comparative analysis of JELS and individually responsible and rational decision (IRDD) models for one

RESEARCH PAPER	Finite production rate	Non-uniform demand	Permissible delay in payments	Multiple buyers	Multiple items	Product/process quality	Deterioration	Entropy Cost	Stochastic Models	COMMENTS
										vendor, many non-identical buyer
Lu (1995)				●						Vendor minimizes total annual cost subject to the maximum cost that the buyer is prepared to incur; mixed integer programming problem
Yao and Chiou (2004)				●						Propose a more efficient heuristic to solve the problem of Lu (1995)
Goyal (1995)				●						Suggests a joint inventory cost function for the work of Lu (1995)
Hill (1997)				●						Analyze the work for Lu (1995) and Goyal (1995)
Viswanathan (1998)				●						Analyze the work for Lu (1995) and Goyal (1995)
Chen et al. (2001)				●						Coordination model for centralized two-echelon system; maximizing profits
Viswanathan and Piplani (2001)				●						Model for coordinating supply chain inventories through the use of common replenishment epochs (CRE) or time periods
Viswanathan and Piplani (2004)				●						Further investigates Viswanathan and Piplani (2001)
Woo et al. (2001)				●						Extended work of Woo et al. (2000) to account for case of multiple buyers; assumed all buyers are willing to invest in reducing the ordering cost
Yu et al. (2006)				●						Improved upon the work of Woo et al. (2001)
Zhang et al. (2007)				●						Extended work of Woo et al. (2001) by relaxing the assumption of a common cycle time for the vendor and all buyers
Yang and Wee (2006b)				●						Considered pricing policy; three scenarios discussed, i. neglect integration and quantity discount, ii. Integration of all members of the supply chain without considering quantity discount, iii. Considers integration and quantity discount of all members in the supply chain simultaneously
Yang (2007)				●						Similar work to Yang and Wee of (2006b)

RESEARCH PAPER	Finite production rate	Non-uniform demand	Permissible delay in payments	Multiple buyers	Multiple items	Product/process quality	Deterioration	Entropy Cost	Stochastic Models	COMMENTS
Yang et al. (2007)				●						Developed an optimal pricing and replenishment policy in a lean and agile supply chain; considers just-in-time (JIT) concept and price reduction to buyers for ordering larger quantities
Kohli and Park (1994)					●					Examined joint ordering policy as a method for reducing the transactions cost for multiple products
Chen and Chen (2005a)					●					Proposed both centralized and decentralized decision policies
Chen and Chen (2007)					●					Focused on managing a multi-product and multi-echelon supply chain which produces and sells deteriorating goods; profit maximization model
Huang (2002)						●				Investigated work of Salameh and Jaber (2000); imperfect items at the buyer's end are withdrawn from inventory as a single batch and sold for a discounted price
Khouja (2003a)						●				Assumed lot size quality relationship to follow that of Porteus (1986); investigated model for cases when the vendor has a constant failure rate and when demand is stochastic
Goyal et al. (2003)						●				Similar to Huang (2002); number of perfect units is at least equal to the demand during the screening time and defective units are sold as a single batch at the end of the period
Huang (2004)						●				Similar model to Goyal et al. (2003)
Siajadi et al. (2005)						●				Back-orders not allowed; 100% inspection performed for each lot; defective items reworked instantaneously at a cost and kept in stock and considered as-good-as-new
Comeaux and Sarker (2005)						●				Addressed shortcomings within existing models concerned with implementation problems for practical and industrial applications
El Saadany and Jaber						●				Investigated work of Khouja (2005);

RESEARCH PAPER	Finite production rate	Non-uniform demand	Permissible delay in payments	Multiple buyers	Multiple items	Product/process quality	Deterioration	Entropy Cost	Stochastic Models	COMMENTS
(2008)										applies minor setups (interruptions) to the process to restore the production process to an 'in-control' state (to produce quality conforming units again); three cases, i. restores the process after delivering a lot to the buyer, ii. restoring the process before delivering a lot to the buyer, iii. restoring the production process at any time
Lin and Lin (2004)							●			Deterioration occurs at buyer's side only; considered partial back-ordering and constant service level
Lin and Lin (2007)							●			Consider the deterioration property and complete back-ordering
Jaber et al. (2004)								●		Modeled commodity flow (demand rate) as a heat flow
Jaber et al. (2006)								●		Accounted for hidden and difficult to estimate costs of an inventory system
Sharafali and Co (2000)									●	Considered some cooperative strategies that include the analysis of the impact of: i. price changes, ii. Discount policies, iii. Partial deliveries; demand at the buyer is random and follows a Poisson distribution
Pan and Yang (2002)									●	Presents an integrated inventory model with controllable lead time; demand assumed to follow a normal distribution
Hoque (2007)									●	Solved same numerical example of Pan and Yang (2002) using a developed heuristic solution algorithm
Pan and Yang (2008)									●	Fuzzy model accounting for fuzziness in production and demand rates
Wee et al. (2006)									●	Proposed production-inventory model for an on-going deteriorating item with partial backordering and imperfect quality, with shortages due to imperfect items being completely backordered
Ritvirool & Ferrell									●	Developed a cost based model that

RESEARCH PAPER	Finite production rate	Non-uniform demand	Permissible delay in payments	Multiple buyers	Multiple items	Product/process quality	Deterioration	Entropy Cost	Stochastic Models	COMMENTS
(2007)										is used to determine the optimal order quantity and reorder point as well as the safety stock levels for both the vendor and buyer

Table 2.1 Summary of research presented and reviewed by Jaber and Zolfaghari (2008)

Beyond the literature reviewed by Jaber and Zolfaghari (2008) much research has been extended along different lines of study regarding supply chain coordination. Li and Wang (2007) provide a framework highlighting the behavioral aspects and information needed in the coordination of a supply chain. Their work offers a review of coordination mechanisms in supply chain systems. Li and Wang (2007) classify supply chain coordination mechanisms into four categories based on the supply chain decision structure, whether it be centralized or decentralized, and on the nature of the demand, whether it be deterministic or stochastic. They further discuss existing models in the four categories and point out several directions for future work.

Xue et al. (2007) focus on the construction industry and how it differs from other manufacturing industries with regards to their high fragmentation, low productivity, costs, delays, conflicts and disputes. These characteristics give construction supply chains a unique coordination problem. Xue et al. (2007) present two internet-enabled coordination mechanisms for improving construction performance. Their work highlights the fact the supply chain coordination is vital to all industries regardless of their nature.

Xiao, Qi and Yu (2007) investigate coordination mechanisms in a non-conventional supply chain coordination model. Their model consists of one manufacturer and two competing retailers. They assume market demands could be disrupted, which makes their model differ from the conventional supply chain models. Examples for market demand disruptions are provided that include breakout of medical diseases, or the reputation of a defective part, or an event that may make a book/product a best seller. Xiao, Qi and Yu (2007) consider the cases where the production deviation cost may be incurred by the manufacturer or the retailers, and cases where there is no discount, linear quantity-discount and an all-unit quantity discount schedule.

Xiao and Qi (2008), extend along the line of research by Xiao, Qi and Yu (2007). They investigate the coordination of supply chains with both demand disruptions in addition to production cost disruptions. They refer the term production cost disruptions to situations where production costs change from their expected values that have been used to design the coordination mechanism to be implemented. Such cost disruptions may result from increase in government tariffs, for example, or from peaks in costs due to shortages of raw materials resulting from an environmental catastrophe, or other unanticipated reasons. Xiao and Qi (2008) consider the coordination mechanisms for both an all-quantity discount and incremental quantity discount policies.

Li and Liu (2008) take an alternative approach to modeling a discount policy to allocate the expected increased profits between two sides of the supply chain. They consider a supply chain with one manufacturer and one retailer. Li and Liu (2008) develop an extended newsboy model and presents a coordination mechanism designed to increase the supply chain's total profit.

In general, quantity discounts allow a practical method for inventory coordination in supply chains. Shin and Benton (2007) put forward difficulties facing supply chain participants in implementing coordination policies. Their main objective is to develop a model that resolves these practical challenges. Shin and Benton (2007) show that such implementation difficulties are due to possible lot sizes adjustments deviating from the original economic lot sizes and possible overstocking risks related to increased order quantities. They propose a Buyer's Risk Adjustment (B-RA) model which is considered a feasible alternative for supply chain coordination under certain demand conditions mentioned in their work.

Ro et al. (2007) look at modularity as a strategy for supply chain coordination and discuss its implementation in the United States automotive industry. They portray the success of modularity applied by Dell Computers and investigate how modularity may be emulated in the United States automotive industry as part of a cost reduction and mass-customization approach to achieve build-to-order. They suggest that the shift to modularity has led to changes in the industry's supply chain. Their findings are a result of interviews and no model is developed, however, they shed light to important aspects of the United States automotive industry supply chains and the barriers that face them in shifting the industry towards modularity.

Zhou, Min and Goyal (2008) consider the coordination issues of a decentralized two-level supply chain composed of a manufacturer and retailer, where the demand for the product is dependent on the inventory level on display. They develop a profit-sharing mechanism to coordinate the behavior of the two partners in the supply chain to maximize profits. In their work they discuss the manufacturer-Stackelberg game structure to determine how the manufacturer sets the wholesale price of the product and, in turn, the retailer determines the order quantity. Zhou, Min and Goyal (2008) assume that relevant cost information is shared and hence provide a discount scheme to further maximize profits.

Hennet and Arda (2008) acknowledge the fact that in any supply chain, each participant targets to optimize their own production and supply policy with respect to their own economic criterion and that conflicts of interests are natural to occur. Hennet and Arda (2008) highlight that the process of deciding on a policy to coordinate between participants in the supply chain may result in loss of overall efficiency of the supply chain performance. They direct their work to evaluate the different types of contracts between participants in a supply chain. They assume a chain with a supplier and producer where the producer is confronted with random demand and the supplier faces random lead-time. Hennet and Arda (2008) also draw attention to the fact the dominant player in the supply chain leads to a Stackelberg game, yet global optimal conditions may be reached provided the contracts between the participants allow for shifting of local optimal values.

As can be seen from the literature presented contracts are merely tools to achieve coordination between participants in a supply chain. Such contracts can be summarized to include quantity flexibility contracts, backup agreements, buy-back or return policies, incentive mechanisms and revenue sharing contracts. Wang, Zhao and Tang (2008) focus on revenue-sharing in a supply chain with one retailer and one supplier considering fuzzy demand. Wang, Zhao and Tang (2008) consider two kind of fuzzy demand: iso-price elastic demand and linear demand. They conclude by stating that future work considering more complex fuzzy demands should be considered.

Choi et al. (2008) investigate the issues of channel coordination in a supply chain. They draw attention to that most of the literature is focused on either maximizing expected profits or minimizing expected costs in a supply chain, however, the literature does not mention different risk preferences of the individual participants in the supply chain. They take a fashion product and its corresponding supply chain as an example where different risk preferences are significantly important and different. They formulate mean-variance (MV) objectives to capture the risk preference for each individual participant. Choi et al. (2008) propose strategies and discuss managerial insights that may help in achieving channel coordination.

Wang et al. (2008) talk about the emergence of e-business to drive supply chain coordination, the use of internet based computing and communications to execute business processes, and how the focus of supply chain management has been diverted from "production-efficiency to customer-driven and partnership synchronization approaches". Wang et al. (2008) mention the need for coordination of information flow among the services of the participants in the supply chain and the need to link business processes as key to supply chain success. Concisely, Wang et al. (2008) address the issues of uncertainties and dynamics involved in a real-world environment. They develop a multi-agent system which makes constraint-based decisions and coordinates among software agents through independent analysis and negotiation of constraints.

Soroor, Tarokh and Shemshadi (2009) devise an innovative model based on Intelligent Wireless Web (IWW) service for a mobile real-time supply chain coordination system. They utilize the capabilities IWW services which allows access to information anywhere at any time to effectively integrate information and material flows within a supply chain. Soroor, Tarokh and Shemshadi (2009) exploit and converge existing technologies to implement a system that can deliver IWW support to a supply chain, and suggest the benefits for improved productivity, cost reduction, and customer service are enormous.

Sarmah, Acharya and Goyal (2008) further extend work beyond one manufacturer/supplier and/or one retailer in a two level supply chain. They study a supply chain in which there is a single manufacturer and multiple, non-identical, buyers. Sarmah, Acharya and Goyal (2008) also focus on how negotiations can be realized to further reduce costs and increase savings for the participants in the supply chain. Furthermore, Ding and Chen (2008) study coordination in a three level supply chain. They consider a product with a short life cycle in a single period model. Ding and Chen (2008) construct a flexible return policy and show that a three level supply chain can be fully coordinated.

Similar to Xiao, Qi and Yu (2007) and Xiao and Qi (2008), Chen and Xiao (2009) investigate supply chains coordination with demand disruptions. However, their work considers supply chains with one manufacturer and multiple retailers containing one dominant retailer.

There are numerous research and studies in the literature that discuss multi-buyers and three level supply chains; however, these shall be omitted in this review.

2.1.2 Issue of Imperfect Quality

This section will explore the issue of imperfect quality on lot size policies and coordination in supply chains.

Rosenblatt and Lee (1986) investigates the effect of an imperfect production process on the optimal production cycle time. They derive a modified economic manufacturing quantity (EMQ) formula for both the cases of dynamic nature of deterioration where the process is assumed to deteriorate linearly and after a certain time where it assumes an exponential deterioration. Furthermore, Rosenblatt and Lee (1986) derive a generalized model for the case where there are multiple states of the process and deterioration follows a step-wise manner. The key assumption to the work of Rosenblatt and Lee (1986) is that at the beginning of the production cycle, items of perfect quality are being produced and the process is identified as 'in-control state'. However, as time progresses, the process deteriorates and begins to produce a proportion of defective items and the process is said to be in an 'out-of-control state'. Equally important is the assumption that at the beginning of each cycle the process is 'in-control' as a result of some maintenance or restoration process that is part of the set-up process. These aforementioned assumptions provide the initial foundation to which most following research base their investigations upon. Rosenblatt and Lee (1986) provide numerical examples to illustrate the derivation of the optimal production cycle times for each assumed situation and show that this optimal production cycle time derived is shorter than that of the classical EMQ model. Principally, it decreases as the defective rate or the cost of the defective items increases.

Of equal importance to the emergence of research regarding imperfect quality items in supply chain is the work of Porteus (1986). The objective of the work of Porteus (1986) is to demonstrate that lower setup costs can benefit production systems by improving quality control. Porteus (1986) does this by introducing a simple model that portrays the significant relationship between quality and lot size. Similar to Rosenblatt and Lee (1986), Porteus (1986) suggests that a process is in-control at start. However, Porteus (1986) assumes that there is a probability, with each item it produces, that the process can shift to an out-of-control of state. Again similar to Rosenblatt and Lee (1986), Porteus (1986) assumes once the process is out-of-control it remains as such until the end of the lot where a set-up is performed by which the process is restored to an in-control state. In the model of Porteus (1986), the system incurs an additional cost for rework and related operations for each defective item it produces. In essence, this creates an incentive to produce smaller lots and hence have smaller fraction of defectives. Porteus (1986) introduces three options for investing in quality improvement: reducing the probability that the process will shift out-of-control, reducing setup costs, and simultaneously doing both.

Khouja and Mehrez (1994) aim to extend the classical economic production lot size (EPL) models to cases where: the production rate is a decision variable, the unit production cost a function of the production rate, and the quality of the production process deteriorate with an increase in production rate. In consistency with the aforementioned assumptions of a process being in-control and shifting to an out-of-control state, Khouja and Mehrez (1994) develop a model and solve it numerically. They show that when the optimal production rate is smaller than the rate that minimizes unit production cost, then an increase in the production rate will lead to a significant deterioration in quality. However, in the cases where the optimal production rate may be larger than the rate that minimizes the unit production cost, quality is considered for the most part independent of the production rate.

Analyzing the interactions between quality defaults and work-in-process (WIP) is the purpose of the study of Cordon (1995). Cordon (1995) presents a model and the outcome effects between WIP and quality defects are evaluated. Key assumptions to this study include arrival of defective items be Markovian, defective items are reworked or substituted by good ones, and defects produced in one station can only be detected at the next station. Cordon (1995) shows that under general conditions the inventory between two stations will continue to grow infinitely for any given failure rate. This indicates that the expected throughput is not necessarily increased by increasing the WIP inventory buffer and provides justification for the practice of limiting inventory through just-in-time (JIT) policy.

Agnihothri and Kenett (1995) investigate and present the impact of defects on system performance measures for a production process with 100% inspection followed by rework. System performance measures of consideration included yield, production lead time and work-in-process inventory. Agnihothri and Kenett (1995) develop a mathematical model and apply simulation to achieve their objective. Agnihothri and Kenett (1995) model the number of defects as a random variable having any general discrete distribution. Moreover, defects are defined and classified one at a time and the manufacturing process is under statistical control and hence defects are independent of each other. Other assumptions include the arrival rate of items following a Poisson process, each work-center consisting of multiple parallel servers, service times for each work-center are assumed independent random variables with exponential distributions, unlimited buffer space for each work-center, first-come-first-serve service discipline implemented at all work-centers, the servers at the inspection and re-work centers are perfect and the system is under steady-state. Agnihothri and Kenett (1995) provide management guidelines for short term control decisions such as identifying bottlenecks and assigning additional resources to discharge bottlenecks. In addition, Agnihothri and Kenett (1995) propose a budget allocation method for process improvement projects to meet long term objectives to decrease the number of defectives.

Urban (1998) formulated appropriate models to account for either positive or negative learning effects in production processes. Urban (1998) achieves this by developing a model that takes into consideration the interaction between lot size and the defective rate. It is assumed that the defect rate of the process is modeled as a function of the run length. From Urban's (1998) conclusions is that when there is a significant inverse relationship between run length and product quality, the lot sizes of considerably smaller size are more suitable, whether with or without reduction in setup costs.

Goyal et al. (2003) assume defective items are produced throughout a production process and that items of poor quality detected in the screening process of a lot are sold at a discounted price. They apply these assumptions in developing a simple approach to determine an optimal integrated vendor-buyer inventory policy for an item with imperfect quality. The objective is to minimize the total joint annual costs sustained by both the vendor and buyer. Goyal et al. (2003) derive an annual integrated total cost function and provide a numerical example to illustrate the proposed solution procedure to determine the optimal policy. It is concluded that as the holding cost for the buyer increases, the number of shipments per lot will increase. Correspondingly, when the holding cost for the vendor increases, the number of shipments per lot will decrease.

Khouja (2003) investigate and solve a two-stage supply chain inventory model involving a producer and retailer, in which the proportion of defective products increases with increased production lot sizes. Khouja (2003) considers both deterministic and stochastic demand. The following key assumptions were assumed for the investigation: the producer produces the product on a single machine, the production and usage rates are deterministic and constant, both the producer and the retailer incur linear holding costs on inventory, and materials are inspected and reworked if needed at the producer's site. Khouja (2003) derives closed form expressions and presents numerical examples for the model formulated. Some findings from Khouja (2003) include showing that quality considerations can lead to significant reduction in product lot sizes, and that the inclusion of rework cost can lead to large reduction in the production lot sizes of suppliers and may lead to complete synchronization of the supply chain.

Khouja (2005) reformulates some inventory models which take into account the negative relationship between lot size and quality. Further, Khouja (2005) considers the possibility of performing minor setups within each cycle. In addition to assumptions proposed in Khouja (2003), Khouja (2005) assume defective units are reworked at a fixed cost per unit, minor setups are equally spaced within the production cycle, and that the quality assumptions used are those previously proposed by Porteus (1986) and Rosenblatt and Lee (1986). The models reformulated by Khouja (2005) allow for adjustments to the process within a production cycle to restore it to an in-control state. These adjustments can be performed without interrupting the system or may require system stoppage and can be thought of as minor setups. Khouja (2005) derived closed form expressions for the optimal lot sizes and the optimal number of minor setups under both instantaneous and non non-instaneous minor setups. For both cases, the incorporation of minor setups leads to an increased optimal lot size and improved yield. Khouja (2005) provides numerical examples to illustrate the developed models.

El Saadany and Jaber (2008) investigate the work of Khouja (2005) in a centralized decision model where participants in a two-level (manufacturer-retailer) supply chain coordinate their orders to minimize their local costs and that of the chain. The model of El Saadany and Jaber (2008) adopts the approximation for defective items suggested by Porteus (1986) and follows the recommendations of Khouja (2005) to this approximation. They assume the manufacturer performs minor setups, of equal length and equally spaced, to restore the production process to an in-control state. El Saadany and Jaber (2008) develop mathematical models and present numerical examples with discussions. They have developed models for three cases. When there is no coordination and the manufacturer's inventory either follows the cases where the process is restored after delivering a lot to the retailer or when the process is restored before delivering a lot to the retailer, it is optimal to not perform any minor setups for restoration. However, if there is coordination and the process is restored at any time during the production, then it is more optimal to perform minor setups as it will reduce holding and reworking costs.

Wang et al. (2009) develop an integrated model for the joint determination of both economic production quantity (EPQ) and preventive maintenance (PM). They consider the situations of an imperfect process with imperfect maintenance and inspection time. The objective of the model of Wang et al. (2009) is to minimize the expected total cost. They investigate: optimal EPQ, the optimal number of inspections, optimal inspection periods and optimal PM policy in a Weibull shock model.

2.1.3 Consignment Stock Coordination

Section 1.2.5 briefly introduces the concept of the consignment stock policy and its introduction as a new strategy in coordinating inventory models. This section will review research within the literature that investigates and discusses this relatively new supply chain coordination policy.

Braglia and Zavanella (2003) point out that the consignment stock strategy was observed as an industrial practice in the automotive manufacturing environment. Although the concept of consignment stock is not new, it is their work that provides an initial foundation for most of the later work with regards to the consignment stock policy. In fact, the mathematical model from Braglia and Zavanella (2003) will be considered the base model for which this study shall build and expand upon. Braglia and Zavanella (2003) seek to understand the potentiality of the consignment stock policy by providing analytical modeling. They consider the problem of a single-vendor and single-buyer supply chain situation. Not only does Braglia and Zavenella (2003) develop a model, but furthermore they provide a comparison with the classical model of Hill (1997, 1999) and concluding with a proposal for identifying situations in which the consignment stock policy's implementation could be advantageous. In general, Braglia and Zavanella (2003) conclude that the consignment stock policy might be a strategic and profitable approach to supply chain in coordination in situations where delivery lead times or market demands vary with respect to time. Further discussion and details of the model developed by Braglia and Zavanella (2003) will be presented in *Chapter 3* of this thesis.

Zanoni and Grubbström (2004) extend upon the work of Braglia and Zavanella (2003). They develop an explicit form of the implicit analytical solution given in Braglia and Zavanella (2003). The results obtained with their derived formula were shown to be consistent with the numerical outcomes proposed by Braglia and Zavanella (2003) in the original solution.

Persona, Grassi and Catena (2005) propose an analytical model to take into account the effects of obsolescence in a supply chain managed with a consignment stock policy. The analytical model is based on the deterministic single-vendor single-buyer productive situation proposed by Braglia and Zavanella (2003). The model of Persona, Grassi and Catena (2005) allows identification of the optimal inventory level and shipment policy for optimizing (minimizing) total costs when products are characterized by a finite lifetime. Persona, Grassi and Catena (2005) perform simulations to assess the impact of the stochastic estimation of the item lifetime period. Conclusions from Persona, Grassi and Catena (2005) indicate that the presence of obsolescence reduces the optimal inventory level, especially in situations where the products have a short lifetime. Moreover, the effects of obsolescence on the correct estimation of the optimal shipment are higher when the production is rate is closer to the demand rate. The simulations show that the optimal shipment for cases of stochastic lifetime is always smaller than of those of the deterministic case. They also show, with respect to the deterministic case, that the higher the uncertainty of estimating the product lifetime, the lower the optimal shipment. Furthermore, results point out that there is no relation between the number of deliveries and total costs.

Wallin et al., (2006) seek to identify and explain the critical factors that steer the decision how a firm should choose between one of four choices that is most appropriate to adopt. The four choices are: inventory speculation, inventory postponement, inventory consignment and reverse inventory consignment. Wallin et al. (2006) do this by reviewing relevant literature to derive subjective observations. Their comparison is based on three critical factors: customer demand or usage requirements, nature of the supply chain, and bargaining power of a firm relative to the supplier. From the conclusions of Wallin et al. (2006) are guidelines as to when the inventory consignment approach is to be used. Summarizing their findings under the three critical factors for comparison, the inventory consignment approach is to be used when:

- Customer requirements:
    - … it is difficult to predict customer demand
    - … there are rapidly changing customer preferences

    - … customer order-to-delivery lead time is less than the sum of the supplier order-to-fulfillment lead-time, the firm's cycle time and the delivery-to-customer lead-time
- Nature of the supply chain:
    - … there is an unreliable supply line
    - … there is unpredictable delivery and quantity performance
- Bargaining power:
    - … there are many suppliers to choose from
    - … the supplier provides a non-unique product

Srinivas and Rao (2007) develop an inventory model where the replenishment lead time is assumed to be dependant. Srinivas and Rao (2007) consider the case of a single-vendor single-buyer scenario under stochastic nature in both the classical and consignment stock coordination models and seek to determine an efficient ordering strategy. Numerical examples are provided.

In another research, Srinivas and Rao (2007) also develop and solve a controllable-lead-time inventory model where the lead time is assumed to be dependant, however, this time using a genetic algorithm. Four models were developed: a basic consignment stock model, consignment stock policy with delays, consignment stock policy with information sharing and delays, and finally consignment stock policy with lead time. They present numerical examples to illustrate the solution procedures for the developed models.

Battini et al. (2010) extend the work of Persona et al. (2005). They consider new critical factors that are present in several industrial environments, specifically, demand variability, stock-out risk and limited warehouse space. With regards to performing feasibility studies for supply chains to shift from a traditional inventory management policy to a consignment stock policy they have developed and presented a methodological framework. Battini et al. (2010) suggest their model can be applied to manage inventories of consumable items that are characterized with low unit costs, high demand and are small in size or easy to store. For such items, they prove their model to be effective regardless of variable demand, obsolescence risk or space constraints available at the buyer's end.

2.2 Problem Definition

As presented in the literature review, supply chain coordination is vital to the success of any business. Furthermore, its optimization is essential to improve a business's performance. This has lead to the extensive studies with regards to supply chain coordination in numerous as researchers try to formulate real-world behaviors to develop better understandings of scenarios and provide accurate information for correct decision making. According to the previous classification aforementioned in the literature review to classifying supply chain models into two-level, three-level and four-or-more level, it can be clearly seen that most of the research and models has been developed for two-level supply chains. The work has been extended to three and four-or-more level supply chain models, however, there is still a need to further investigate these models as their complexity remains an obstacle.

The consignment stock is an industrial strategy for inventory management in supply chains that may be a strategic and profitable approach to stock management in uncertain environments where delivery lead times and/or market demand vary over time. This policy as a strategic method for coordinating supply chain models is a relatively recent development. It has not been investigated until its introduction into the automobile industry and moreover, until the work of Braglia and Zavenella (2003). The literature shows that there are numerous directions of research to address the consignment stock policy. Further relaxations of assumptions are required to allow a more thorough understanding of the consignment stock as a strategy, policy, its benefits, its drawbacks and implications, and implementation issues.

One of the main issues that have been addressed within supply chain coordination is the issue of imperfect production. This issue has been addressed throughout supply chain coordination models in numerous aspects as discussed in the literature review; however, it has not been addressed within the scope of a consignment stock policy. It should be noted that Xu and Chen (2006) have attempted such an investigation. They seek to develop a consignment stock policy model with defective items. Conversely their attempt lacks in many aspects conceptually and mathematically. They provide a numerical example from the work of Salameh and Jaber (2000) with no reference to their and fail to apply the correction by Maddah and Jaber (2008) of using the renewal theory in the model initially developed by Salameh and Jaber (2000). Furthermore, the work of Xu and Chen (2006) lacks sufficient explanation and modeling to portray a real-world situation. There is no mention in their work to the handling of defective items asides a warranty cost attached to each item.

The emergence of the consignment stock policy and its use, as well as the lack of investigation concerning imperfect production is the main driving forces for this study. This thesis seeks to expand on the model developed by Braglia and Zavanella (2003) by the relaxation of the assumption of a perfect production process. As a result imperfect items will be introduced into the supply chain and their implications shall be addressed with respect to the model and associated managerial decisions for the supply chain.

2.3 Research Objectives

The main goal of this study is to further explore the modeling of the 'Consignment Stock Case' as presented by Braglia and Zavanella (2003). The main focus is to expand the model presented in their literature by introducing the possibility of having the vendor producing imperfect items. This will allow the developed model to represent the real-world more accurately. It also will open further managerial decisions to be made and provide a more thorough understanding of the nature of the consignment stock policy.

Consequently, the following objectives are to be achieved through this study:

1. Develop a supply chain model that refers to the problem of a single-vendor and single-buyer productive situation that portrays the consignment stock policy subject to:
    a. Imperfect production
    b. Managerial decisions to scrap or re-work imperfect items
    c. Application of minor setups for restoration

2. Develop insights concerning the behavior of the model with regards to fluctuations in demand, unit price, and product quality

3. Provide a tool for management to use to assist in supply chain managerial decisions for determining production policies for pre-specified production scenarios

Chapter 3

Model Construction

3.1 Model Concept

This chapter discusses the developed model from its conceptual design to its implementation highlighting the construction process of the model and its mathematical formulation. The chapter is divided such that it first introduces the scope of the model where a clear understanding of the real-world situation is introduced and the limitations of the study and modeling. Then a conceptual design is presented providing a rationale for the model and the foundation for the mathematical modeling. The second half of the chapter shall present the construction process of the model. The model construction is split into three phases. For each phase, the assumptions presented and mathematical modeling discussed.

3.1.1 Scope of the Model

The situation considered is the problem of a single-vendor single-buyer supply chain scenario. Coordination between these two participants will be in the form of a consignment stock policy. This form of strategic coordination requires continuous exchange of information between both the vendor and the buyer. The vendor will produce items and later ship them to be stored at the buyer's warehouse. This warehouse is close to the buyer's production line so that material may be picked up when needed. A radical application of the consignment stock policy may lead to having no inventory stored at the vendor's side as the vendor will seek to utilize the buyer's warehouse to stock material.

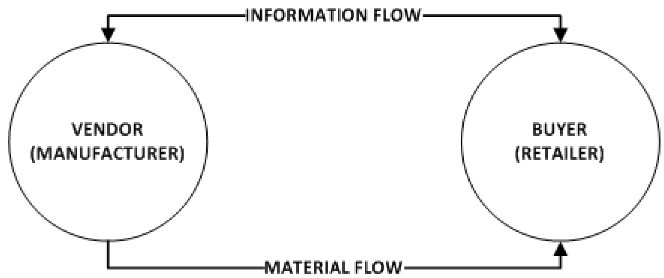

Figure 3.1 Schematic representing a single-vendor single-buyer supply chain concept

In this type of coordination, the vendor will guarantee that the quantity stored in the buyer's warehouse will be kept within a maximum and minimum level, also accounting for any additional costs induced by stock-out situations. The buyer will withdraw the required items to cover production from the buyer's warehouse, and the vendor will be paid for the items withdrawn by the retailer (buyer). This consumption on behalf of the buyer demands for accurate and fast transmission of information between both participants of the supply chain.

To complete the overall conceptual picture of the consignment stock policy under study, the following must be noted with regards to both the buyer and vendor (Braglia and Zavanella, 2003):

- With regards to the buyer
    - Has a constant guaranteed minimum stock level
    - Does not have to take care of order emission costs (excluding administrative costs)
    - Pays for items only when they are effectively used (excluding the quantity of frozen capital)
    - Does not pay for capital-linked holding costs (charged to the vendor)
- With regards to the vendor
    - Has access to the final demand
    - Has the opportunity to empty his warehouse (which could be used for other tasks) – depending on the relative values of certain parameters in the supply chain
    - May be more flexible in organizing production schemes differently, being less closely linked to the buyer's requirements

Pertaining to the maximum and minimum inventory levels of the buyer that shall be guaranteed by the vendor, there may be conflict of interest between the vendor and the buyer. The vendor will seek to set the minimum stock level as low as possible to reduce the cost of safety stock, and will try to set the maximum level as high as possible to take advantage of production until the buyer's warehouses are full. Conversely, the buyer will seek to set a higher level of minimum stock to reduce the probability of stock-out (regardless of the fact such costs will be charged to the vendor as aforementioned). The buyer will also seek to set the maximum inventory level as low as possible to reduce occupied space and the relative costs linked to investment in structures.

As mentioned in the previous chapters, the consignment stock policy is seen to be a strategic and profitable to stock management in uncertain environments where delivery lead times and/or markets demands fluctuate. Furthermore, another important benefit to be highlighted is the reduction or elimination of the bullwhip effect. It should be noted that this reduction or elimination is not attributed to the consignment stock policy as it is to the strategic partnership and communication between the buyer and vendor, which is obligatory to the consignment stock policy being implemented.

3.1.2 Conceptual Design

This study is concerned with further exploration of the consignment stock strategies and its potentials. Conceptually, the study will be based on the single-vendor single-buyer supply chain model developed in Braglia and Zavanella (2003). This model will then be modified to account for the possibility of an imperfect production process and hence production of imperfect items. This modified model will also take into account for managerial decisions associated with the new supply chain model with regards to storage and disposal of imperfect items. The development of the modifications to be made to the base model is to be performed in stages. Finally, a new model will be developed based on the modified models to include the concept of minor setups for restoration of the process.

3.2 Model Construction

The construction of the model will be categorized into three phases. Phase 1 describes the base model as presented by Braglia and Zavanella (2003). The modification of the base model will be considered 'Phase 2'. Finally, the development of the new model with minor setups for restoration of the process will be categorized as 'Phase 3'. Table 3.1 summarizes the phases and the stages of development of the models.

Phase	Stage	Description
1		Base Model (The model of Braglia and Zavanella, 2003)
2	1	Base Model + Considers production cost of produced items
	2	Base Model + Production cost + Introduction of imperfect production
	3	Base Model + Production cost + Imperfect production + Considers holding of imperfect items to end of production cycle
	4	Base Model + Production cost + Imperfect production + Holding of imperfect items + Consideration of scrapping cost
	5	Base Model + Production cost + Imperfect production + Holding of imperfect items + scrapping cost + Re-work for imperfect items
	6	Base Model + Production cost + Imperfect production + Holding of imperfect items + scrapping cost + Re-work for imperfect items + Consider items sold to buyer for profit
	7	MODIFIED MODEL (A complete model that can be reduced to present any of the previous stages)
3		DEVELOPED MODEL (MODIFIED MODEL + Minor setups for restoration)

Table 3.1 The phases and stages of the model during the model development and construction

3.2.1 PHASE 1 - Base Model - Braglia and Zavenella (2003)

The following section will illustrate the concepts, assumptions and mathematics of the base model as illustrated by Braglia and Zavanella (2003).

Concept

We have a single-vendor (manufacturer) single-buyer situation where:

- The manufacturer produces a predefined production batch
- Upon completion of the batch, the batch is shipped instantaneously to the buyer
- The buyer begins to consume
- Simultaneously, the manufacturer is producing a new batch
- Once it is complete, the batch is shipped to the buyer (instantaneously)
- The manufacturer repeats until the total number of required items are shipped to the buyer
- The buyer consumes all the items before re-ordering a new order (and hence beginning a new cycle)

The decision variables are to determine the batch size and the number of shipments to be made per cycle.

Notation

A_1	batch set-up cost (vendor's side)	[$/setup]
A_2	order emission cost (buyer's side) - includes transportation cost, …	[$/setup]
h_1	vendor holding cost per item per time period	[$/item.year]
h_2	buyer holding cost per item per time period	[$/item.year]
P	vendor production rate (continuous production)	[items/year]
D	demand rate (continuous demand seen by buyer)	[items/year]
n	number of transport shipments	
q	quantity transported per shipment	[items]
C	average total costs of the system per time unit	[$]

Assumptions

It should be emphasized that in the consignment stock policy, the buyer pays an order emission cost every time inventory is withdrawn/consumed from the stock (Valentini and Zavanella, 2003)

- The model is deterministic
- Single-vendor, single-buyer, single-item supply chain scenario
- $P > D$ and shortages or back-orders are not permissable
- $h_2 > h_1$, due to the fact that an item increases in value as it descends through the supply chain

Mathematical Model

The average setup cost per year (vendor's side) is given by:

$$C_1 = A_1 \frac{D}{n \cdot q} \quad [3.01]$$

The average holding costs per year (vendor's side) is given by:

$$C_2 = h_1 \left(\frac{q \cdot D}{2 \cdot P}\right) \quad [3.02]$$

The average order emission costs per year (buyer's side) is given by:

$$C_3 = A_2 \frac{D}{q} \quad [3.03]$$

The average holding costs per year (buyer's side) is given by:

$$C_4 = \frac{h_2}{2}\left(n \cdot q - (n-1)\frac{q}{P}D\right) \qquad [3.04]$$

The total cost per year for the system is the sum of the previous costs and can be stated as:

$$C = C_1 + C_2 + C_3 + C_4 \qquad [3.05]$$

Inventory Behavior Chart

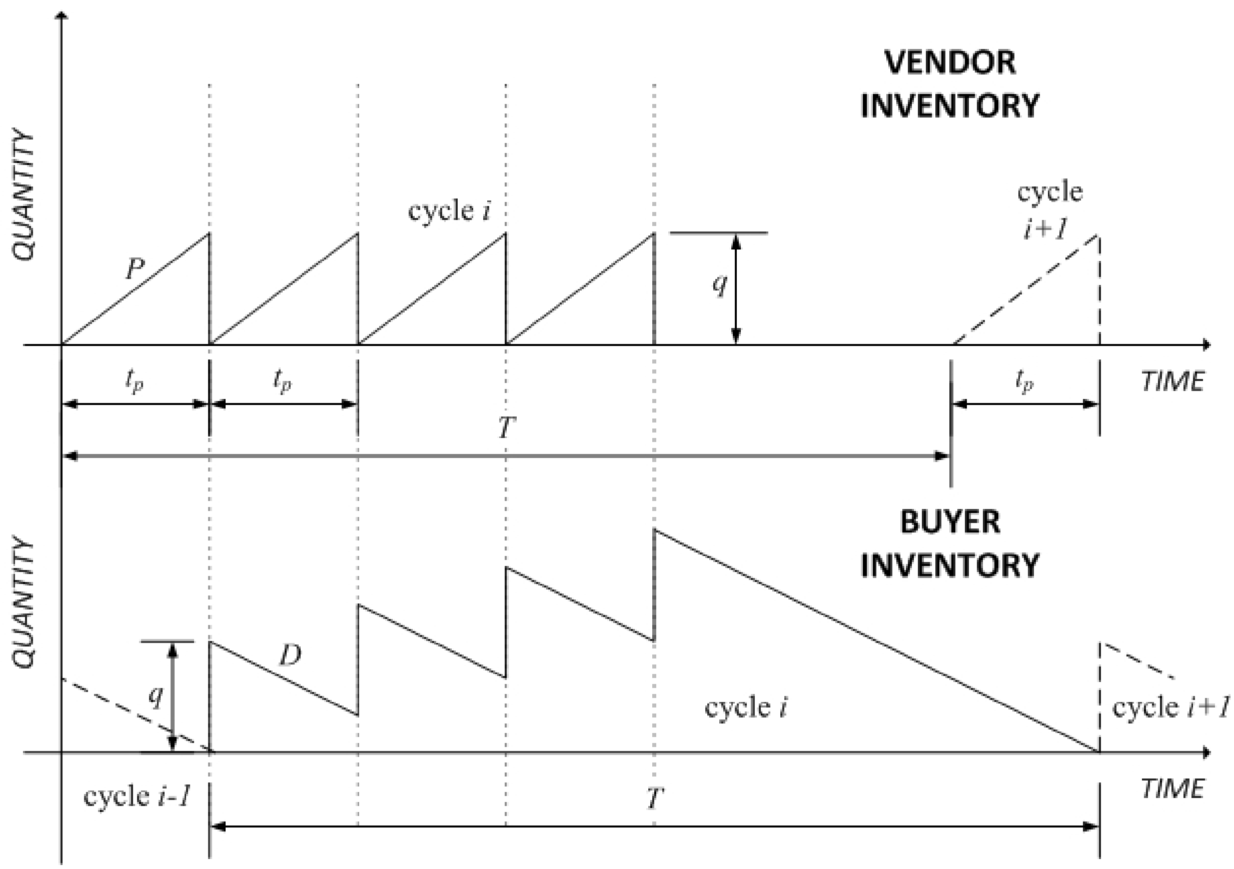

Figure 3.2 Inventory behavior of the Base Model (the model of Braglia and Zavanella, 2003)

Figure 3.2 illustrates the inventory behavior at both the vendor and buyer sides of the modeled system. Items are produced at the vendor's side during a specified production time. Once the batch is complete, it is shipped immediately to the vendor. As the vendor consumes the items at a rate slower than the production rate another batch shipment is received after the same specified production time. As this is repeated for the production cycle, the inventory is accumulated at the vendor's side until it is finally depleted. Cycles $i-1$ and $i+1$ are represented in *Figure 3.2* only, but they follow for all following figures illustrating inventory behavior.

3.2.2 PHASE 2 - Modifications to the Base Model

The following section will introduce, through gradual stages, the modifications made to the base model.

3.2.2.1 Stage 1 - Base Model + Considers Production Cost of Produced Items

Concept

The first modification performed to the base model is the inclusion of production cost to the model. This modification is seen compulsory to the further modifications that are to be included regarding the introduction of the imperfect processing and the possibility of producing imperfect items. It is only common sense to include production costs if the considerations of quality costs are to be included.

The inventory behavior is the same, as the base model, and so is the mathematics with the exception of an additional cost component to account for the production cost.

Notation

u_p	unit production cost for regular production	[$/item]
T	total cycle time	[year]

Assumptions

- The cost or producing one unit under regular production is assumed constant

Mathematical Model

The average production costs per year (vendor's side) is given by:

$$C_5 = \frac{u_p q n}{T} \qquad [3.06]$$

The total cycle time is given by:

$$T = \frac{nq}{D} \qquad [3.07]$$

The total cost per year for the system is the sum of the previous costs and can be stated as:

$$C = C_1 + C_2 + C_3 + C_4 + C_5 \qquad [3.08]$$

Inventory Behavior

There is no change in the inventory behavior from that presented in the base model.

3.2.2.2 Stage 2 - Base Model + Production cost + Introduction of Imperfect Production

Concept

It is important to highlight an important difference from this modified model, to the models previously presented; that is, the production batch quantity produced by the manufacturer is different from the quantity shipped to the buyer. This is a result from a 100% inspection process performed at the vendor that ensures only items of perfect quality will only be shipped to the buyer.

The concept is that as the production process is running, there is a probability that this process run out-of-control; that is the process may produce items that do not conform to quality standards defined by the process. Similar to the work of Porteus (1986), the process once out-of-control it will remain out-of-control until a setup is performed that includes a correction process to restore the process back to control.

Notation

x	production batch quantity for regular production	[items]
λ	factor to determine the process producing imperfect items	
U	the total number of imperfect items resulting from regular production	[items]
t_p	time required for production of one batch (regular production)	[years]

Assumptions

- 100% inspection performed at the manufacturer (vendor) and is instantaneous
- Inspection cost is assumed to be negligible and hence not considered
- The production batch quantity is constant for all batches
- $x > q_i$, that is the number of items shipped in a batch i is always less than the number of items produced by the respective production batch
- U is an exponential relationship that captures the behavior of imperfect items illustrated in Porteus (1986) and Rosenblatt and Lee (1986)

Mathematical Model

For the first production batch, the number of imperfect items can be approximated by:

$$U_1 = (x) - (x)e^{-\frac{x}{P}\lambda} \qquad [3.09]$$

Hence, the number of items shipped in the first batch can be represented as:

$$q_1 = x - U_1 \qquad [3.10]$$

For the second production batch, the number of imperfect items can be approximated by:

$$U_2 = (2x) - (2x)e^{-\frac{2x}{P}\lambda} \qquad [3.11]$$

And the number of items shipped in the second batch would be given as:

$$q_2 = x - U_2 \qquad [3.12]$$

Similarly, for the third batch:

$$U_3 = (3x) - (3x)e^{-\frac{3x}{P}\lambda} \qquad [3.13]$$

$$q_3 = x - U_3 \qquad [3.14]$$

Therefore it can be generalized that for batch i:

$$U_i = (ix) - (ix)e^{-\frac{ix}{P}\lambda} \qquad [3.15]$$

$$q_i = x - U_i = x - i\left(x - xe^{-\frac{ix}{P}\lambda}\right) \qquad [3.16]$$

Correspondingly, the total number of imperfect items resulting from regular production for each cycle can be approximated by:

$$U = n\left(x - xe^{-\frac{nx}{P}\lambda}\right) = nx\left(1 - e^{-\frac{nx}{P}\lambda}\right) \qquad [3.17]$$

Since the number of items in a batch shipped to the buyer has been adjusted as a result of imperfect items, and other aforementioned modifications, the cost components of the system requires modifications.

The total cycle time is now given by:

$$T = \frac{\sum_{i=1}^{n} q_i}{D} \qquad [3.18]$$

The batch production time can be given as:

$$t_p = \frac{x}{P} \qquad [3.19]$$

The average setup cost per year (vendor's side) is given by:

$$C_1 = \frac{A_1}{T} \qquad [3.20]$$

The average holding costs per year (vendor's side) is given by:

$$C_2 = \frac{\frac{1}{2} x t_p n h_1}{T} \qquad [3.21]$$

The average order emission costs per year (buyer's side) is given by:

$$C_3 = \frac{A_2}{T} \qquad [3.22]$$

The average holding costs per year (buyer's side) is given by:

$$C_4 = \frac{\frac{1}{2} D \left(t_p\right)^2 h_2 (n-1)}{T} + \frac{\left(\sum_{i=1}^{n-1} z_i t_p\right) h_2}{T} + \frac{\frac{1}{2D} (z_{n-1} + q_n)^2 h_2}{T} \qquad [3.23]$$

Note that (from the geometry of the graph illustrating the inventory behavior):

$$z_1 = q_1 - D t_p \qquad [3.24]$$

$$z_2 = z_1 + q_2 - D t_p$$

$$z_3 = z_2 + q_3 - D t_p$$

$$z_i = z_{i-1} + q_i - D t_p \quad , \forall\, i > 1 \qquad [3.25]$$

The average production costs per year (vendor's side) is given by:

$$C_5 = \frac{u_p x n}{T} \qquad [3.26]$$

Correspondingly, the total cost per year for the system is the sum of the previous costs and can be stated as:

$$C = C_1 + C_2 + C_3 + C_4 + C_5 \quad [3.27]$$

Inventory Behavior

Figure 3.3 illustrates the inventory behavior of the model under the aforementioned scenario. The general concept is the same as explained for the behavior of the inventory model for *Figure 3.1*; however, as a result of an imperfect production process, defective items are produced. These are not shipped. As the process continues, more and more defective items are produced. This allows for each batch shipped having different number of items within, although the production batch is the same.

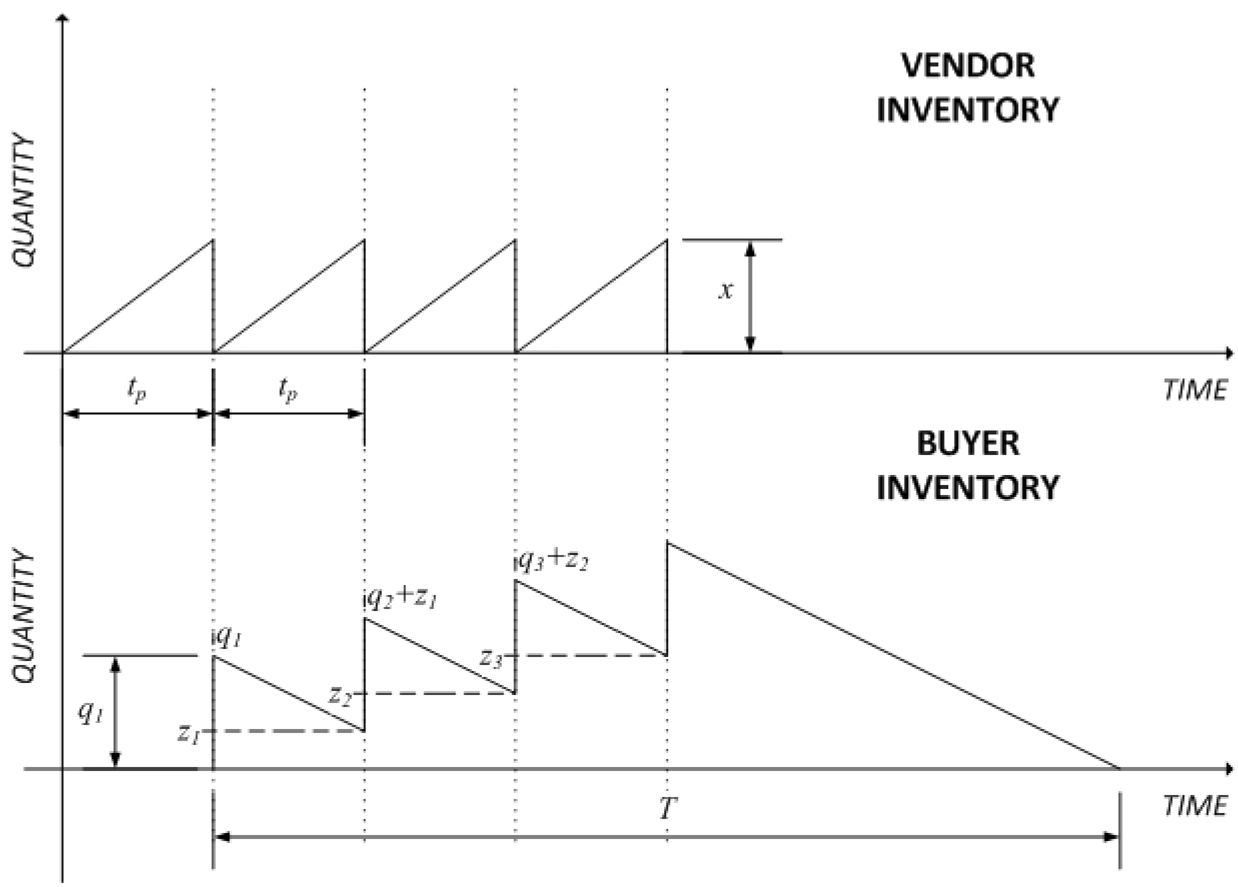

Figure 3.3 Inventory behavior for the model of Phase 2, Stage 2

3.2.2.3 Stage 3 - Base Model + Production cost + Imperfect Production + Considers Holding of Imperfect Items to End of Production Cycle

Concept

The model presented in Stage 2 can be related to a situation where a manufacturer internally recycles or disposes of the imperfect items for no extra costs. However, in general, this is not the case. For this reason, the modification in this stage of the model is to include the consideration and costs of holding the imperfect items until the end of the production cycle. Later on, in the upcoming modeling stages, managerial decisions as to how to manage these imperfect items shall be considered.

Assumptions

- The unit holding cost for an imperfect item is equivalent to the holding cost of a conforming item

Mathematical Model

The model in this case is exactly that of the model in Stage 2; however, an extra cost component must be included to account for the holding cost of imperfect items.

The average holding costs of imperfect items per year (vendor's side) is given by:

$$C_6 = \frac{\frac{1}{2}Unt_p h_1}{T} \qquad [3.28]$$

Correspondingly, the total cost per year for the system is the sum of the previous costs and can be stated as:

$$C = C_1 + C_2 + C_3 + C_4 + C_5 + C_6 \qquad [3.29]$$

Inventory Behavior

Figure 3.4 illustrates the inventory behavior of the current model is very similar to that of Stage 2, however, there is an additional representation at the vendor's side for the storage of the imperfect items.

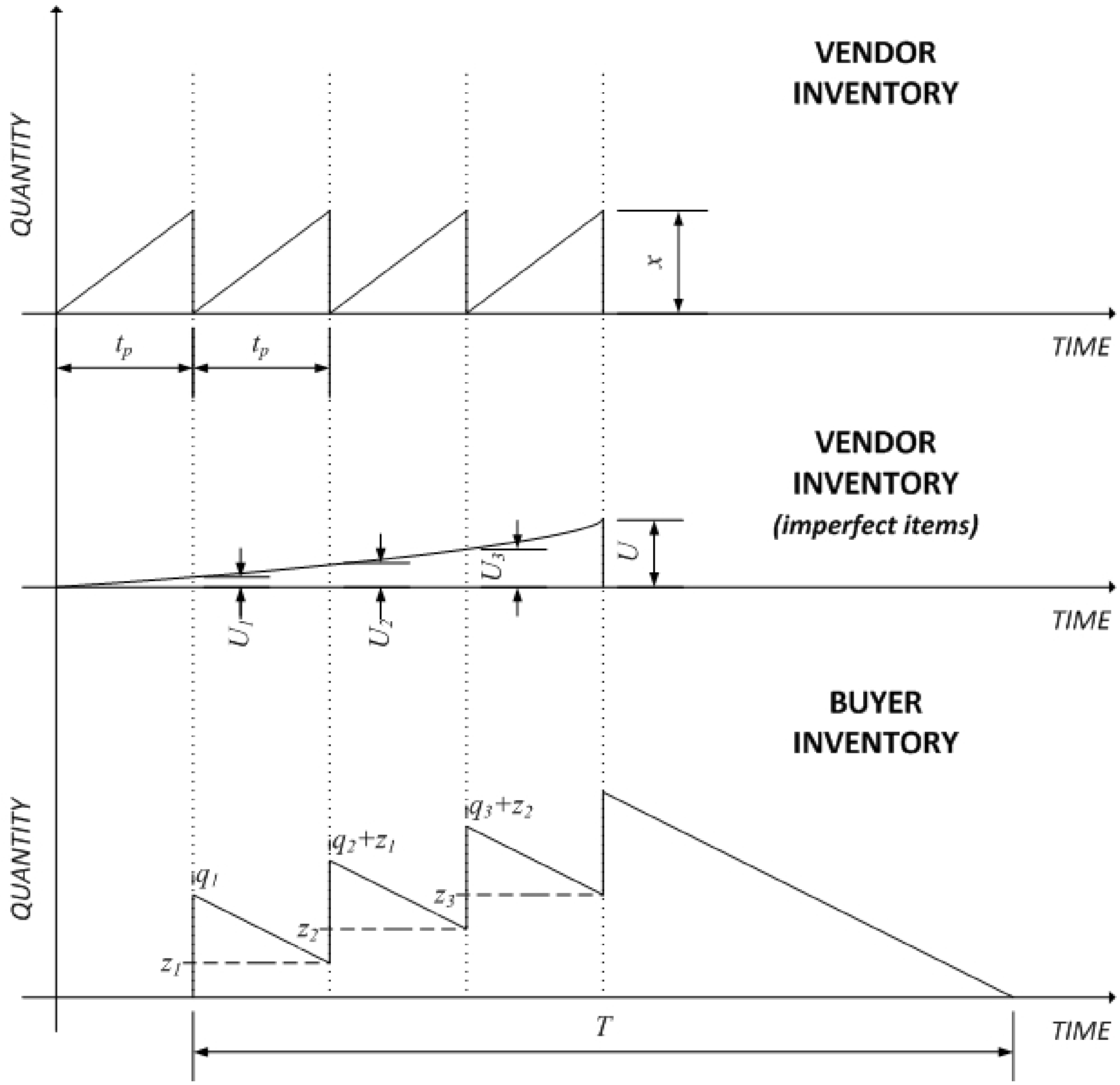

Figure 3.4 Inventory behavior for the model of Phase 2, Stage 3

3.2.2.4 Stage 4 - Base Model + Production Cost + Imperfect Production + Holding of Imperfect Items + Consideration of Scrapping Cost

Concept

The model in stage 3 cannot be considered as a model to accurately represent a real-world situation. The reason being that in the model of Stage 3, the imperfect items that are being held to the end of the production have not been used, shipped, or disposed of. Hence, in Stage 4, the model is modified to include scrapping cost. That is considering the disposal of the imperfect items, whether at a cost, or sold to a secondary market for a profit.

Notation

u_k	unit cost for scrapping an item	[$/item]

Assumptions

- Profit made from selling imperfect items should always be less than the profit from selling an item that has been labeled as conforming to standards

Mathematical Modeling

This model is the same as the model of Stage 3, however, an additional cost component is to be added to account for the cost scrapping items.

The average scrapping cost of imperfect items per year (vendor's side) is given by:

$$C_7 = \frac{u_k U}{T} \quad [3.30]$$

Correspondingly, the total cost per year for the system is the sum of the previous costs and can be stated as:

$$C = C_1 + C_2 + C_3 + C_4 + C_5 + C_6 + C_7 \quad [3.31]$$

Inventory Behavior

The behavior of the inventory is exactly the same as represented in Stage 4.

3.2.2.5 Stage 5 - Base Model + Production Cost + Imperfect Production + Holding of Imperfect Items + Scrapping Cost + Re-Work for Imperfect Items

Concept

If imperfect items are stored until the end of the production cycle, as presented in the model in Stage 3, there are managerial decisions to be made regarding them. The model in Stage 4 has illustrated one scenario in which the imperfect items are to be scrapped, whether at a cost or for a marginal profit. However, another possibility exists, and that is to re-work the imperfect items. The modification to the model in this stage allows for a single re-work process to be performed. After re-work, the items are considered as good or imperfect. The imperfect items will then be scrapped similarly to what has been presented in the model in Stage 4.

Notation

V	total number of imperfect items after re-work production	[items]
q_r	total number of imperfect items after re-work production	[items]
μ	factor to account for difference in re-work setup cost from that of A_1	
β	factor to account for difference in re-work unit production cost from that of u_p	
γ	factor to account for difference in order emission cost from that of A_2	

Assumptions

- Imperfect items are only re-worked at the end of the regular production cycle
- The re-work process is subject to imperfect production similar to the regular production
- Imperfect items are re-worked once

Mathematical Modeling

As a result of the re-working process, the number of items to be scrapped is changed and in essence the formula representing the average scrapping cost of imperfect items per year (vendor's side) is also modified. The imperfect items, U, will be re-worked once, and go through another 100% inspection process whereby the rejected items, denoted as V, will be considered imperfect items to be scrapped and the remaining good items, q_r, will be shipped in a separate batch to the vendor.

Correspondingly, the total number of imperfect items resulting at the end of the re-work process is approximated by:

$$V = U - Ue^{-\frac{U}{P}\lambda} \qquad [3.32]$$

As a result of the new modification in the behavior of the inventory, the cost component C_4 no longer represents the average holding costs per year (buyer's side). It shall be replaced in the total cost function with the cost component C_8. Therefore, the average holding costs per year (buyer's side) is denoted as:

$$C_8 = \frac{\frac{1}{2}D\left(t_p\right)^2(n-1)}{T}h_2 + \frac{\left(\sum_{i=1}^{n-1} z_i t_p\right)}{T}h_2 + \frac{z_n t_r}{T}h_2 + \frac{\frac{1}{2}D(t_r)^2}{T}h_2 + \frac{\frac{1}{2D}(z_n+q_r)^2}{T}h_2 \qquad [3.33]$$

Furthermore, the cost component C_6 representing the average holding costs of imperfect items per year (vendor's side) is not correct as it does not account for the holding of the imperfect items as they are undergoing re-work. Therefore, a new cost component, C_9, will replace C_6 and the average holding costs of imperfect items per year (vendor's side) is now given by:

$$C_9 = \frac{\frac{1}{2}Unt_p}{T}h_1 + \frac{Ut_r}{T}h_1 \qquad [3.34]$$

In similar fashion, the cost component C_7 will now be replaced with C_{10} and the average scrapping cost of imperfect items per year (vendor's side) is given by:

$$C_{10} = \frac{u_k V}{T} \qquad [3.35]$$

We also have an additional setup cost, C_{12}, and additional production cost, C_{13}, for the re-work batch, as well as an additional order emission cost, C_{14}. This is taken into account for by introducing the following:

$$C_{12} = \frac{A_1}{T}\mu \qquad [3.36]$$

$$C_{13} = \frac{u_p \beta U}{T} \qquad [3.37]$$

$$C_{14} = \frac{A_2 \gamma}{T} \qquad [3.38]$$

Correspondingly, the total cost per year for the system is the sum of the previous costs and can be stated as:

$$C = C_1 + C_2 + C_3 + C_8 + C_5 + C_9 + C_{10} + C_{12} + C_{13} + C_{14} \qquad [3.39]$$

Inventory Behavior

Figure 3.5 illustrates the inventory behavior for the current system that includes re-working of the imperfect items. The inventory behavior is similar to that illustrated in Figure 3.3 with the addition of the re-work that is performed at the end of the regular production. This re-work is illustrated in the imperfect items chart at the vendor's side, and the resulting shipment of the items that pass the quality control screening is delivered to the buyer's inventory in a single delivery batch.

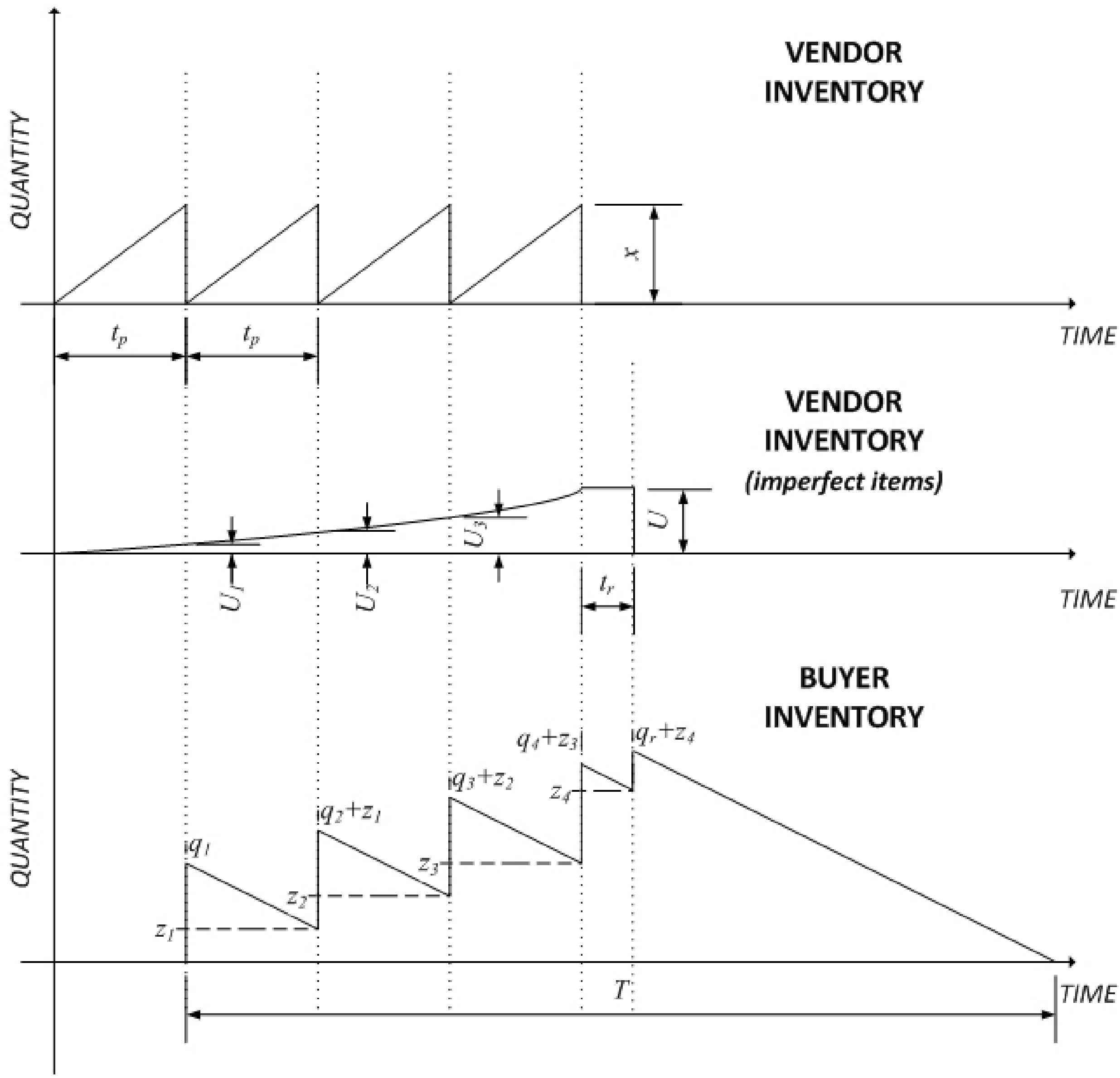

Figure 3.5 Inventory behavior for the model of Phase 2, Stage 5

3.2.2.6 Stage 6 - Base Model + Production Cost + Imperfect Production + Holding of Imperfect Items + Scrapping Cost + Re-Work for Imperfect Items + Consider Items Sold to Buyer for a Profit

Concept

What has not been considered so far, is the fact that for each of the items the buyer consumes, the vendor (manufacturer) should be compensated for and make a profit. In some of the previous stages there are situations where scrapped items may be sold for a marginal profit to a secondary market. It only makes sense, to consider the original items sold to the buyer in the model as well to allow for fair comparisons. The modification made to this model is a simple adjustment to account for the profit made to the buyer from the sales of items. A sale occurs when the item is consumed by the buyer.

Notation

b_1	percent profit assumed for the vendor (manufacturer per)	[%]
u_b	buyer purchasing unit cost for buyer each item consumed	[$/item]

Assumptions

- A fixed (constant) profit for the vendor is assumed for each item consumed for by the buyer

Mathematical Model

The unit purchase price for the buyer is a mark-up of the unit cost of that of the vendor and is given by:

$$u_b = (1 + b_1)u_p \qquad [3.40]$$

The profit made by the vendor from the buyer can be illustrated as a negative cost. Accordingly, the cost component that represents the profit made by the vendor from the buyer is represented as:

$$C_{11} = \frac{(\sum_{i=1}^{n} q_i)u_b}{T} + \frac{q_r u_b}{T} \qquad [3.41]$$

Correspondingly, the total cost per year for the system is the sum of the previous costs and can be stated as:

$$C = C_1 + C_2 + C_3 + C_8 + C_5 + C_9 + C_{10} + C_{12} + C_{13} + C_{14} - C_{11} \qquad [3.42]$$

It should be noted, that a negative value for the above cost equation implies a profit is made.

Inventory Behavior

The behavior of the inventory is exactly the same as that presented in Stage 5.

3.2.2.7 Stage 7 - Modified Model

Concept

In this final stage of Phase 2, the model shall be modified such that variables with binary values will be used to accommodate the various scenarios discussed in the previous stages of the model development. The model is basically formulated as presented in Stage 6, and based on the values of each variable; the model can be reduced to any of the previous stages.

Notation

$P_D = [0,1]$	0 = production cost not considered	1 = production cost considered
$H = [0,1]$	0 = no holding of imperfect items	1 = holding of imperfect items
$K = [0,1]$	0 = scrapping cost not considered	1 = scrapping cost considered
$R = [0,1]$	0 = no re-work applied	1 = re-work applied
$B = [0,1]$	0 = buyer purchasing not considerer	1 = buyer purchasing considered

Mathematical Modeling

PHASE	STAGE	P_D	H	K	R	B	λ
1	1	0	0	0	0	0	0
2	1	1	0	0	0	0	0
2	2	1	0	0	0	0	+ve
2	3	1	1	0	0	0	+ve
2	4	1	1	1	0	0	+ve
2	5	1	1	1	1	0	+ve
2	6	1	1	1	1	1	+ve

Table 3.2 Summary of the modeling parameters for the modeling of Phases 1 and 2
(note: "+ve" refers to a positive value greater than zero)

Note that when the parameter λ is equal to zero, all the terms that correspond to the imperfect items and cost of imperfect items will reduce to zero. Therefore, taking into consideration the above table, the mathematical model may be re-stated.

The total cost per year for the system is the sum of the previous costs and can be stated as:

$$C = C_1 + C_2 + C_3 + C_4 + C_5 + C_6 + C_7 - C_8 \quad [3.43]$$

Where:

The total cycle time is given by: $$T = \frac{\sum_{i=1}^{n} q_i}{D} + \frac{q_r}{D} R \quad [3.44]$$

And the individual cost components are given as follows:

Average setup cost per year (vendor's side):

$$C_1 = \frac{A_1}{T} + \frac{A_1 \mu}{T} R \quad [3.45]$$

Average production cost per year (vendor's side):

$$C_2 = \frac{u_p x n}{T} P_D + \frac{\beta u_p U}{T} R P_D \quad [3.46]$$

Average order emission cost per year (buyer's side):

$$C_3 = \frac{A_2 n}{T} + \frac{\gamma A_2}{T} R \quad [3.47]$$

Average scrapping cost of imperfect items per year (vendor's side):

$$C_4 = \frac{u_k U}{T} K(1 - R) + \frac{u_k V}{T} K R \quad [3.48]$$

Average holding cost of items at manufacturer/vendor (vendor's side):

$$C_5 = \frac{\frac{1}{2} x t_p n}{T} h_1 \quad [3.49]$$

Average holding cost of imperfect items per year (vendor's side):

$$C_6 = \frac{\frac{1}{2} U n t_p}{T} h_1 H + \frac{U t_r}{T} h_1 R H \quad [3.50]$$

Average holding cost of shipped items per year (buyer's side):

For $n > 1$,

$$C_7 = \frac{\frac{1}{2}D\left(t_p\right)^2(n-1)}{T}h_2 + \frac{\left(\sum_{i=1}^{n-1} z_i t_p\right)}{T}h_2 + \frac{z_n t_r}{T}h_2 R + \frac{\frac{1}{2}D(t_r)^2}{T}h_2 R + \frac{\frac{1}{2D}(z_n+q_r)^2}{T}h_2 R + \frac{\frac{1}{2D}(z_{n-1}+q_n)^2}{T}h_2(1-R)$$

[*3.51*]

For $n = 1$,

$$C_7 = \frac{\frac{1}{2D}(q_1)^2}{T}h_2(1-R) + \frac{(q_1 - Dt_r)t_r}{T}h_2 R + \frac{\frac{1}{2}D(t_r)^2}{T}h_2 R + \frac{\frac{1}{2D}(q_1 - Dt_r + q_r)^2}{T}h_2 R \qquad [3.52]$$

Cost component that represents the average profit made by the vendor per year (vendor's side):

$$C_8 = \frac{\left(\sum_{i=1}^{n} q_i\right)u_b}{T}B + \frac{q_r u_b}{T}RB \qquad [3.53]$$

3.2.3 PHASE 3 – Modified Model with Minor Setups for Restoration

Concept

The idea is to employ a minor setup upon the shipment of each delivery. This minor setup occurs at a cost much cheaper than a regular setup, but it allows the process to be restored (in terms of product quality). By employing minor setups it is perceived to reduce the number of imperfect quality items produced and hence the overall cost of the system.

Assumptions

In continuity with the assumption that setups are instantaneous, the minor setup is assumed to be instantaneous as well.

Notation

ϕ	factor to account for cost of minor setup from that of A_1	
q_i	shipped quantity per batch i (constant value)	[items]
U_i	number of imperfect items per batch i (constant value)	[items]

$M = [0,1]$ 0 = no-minor setups applied 1 = minor setups applied for restoration

Mathematical Modeling

The mathematical modeling of the system remains the same except for the factors that represent the holding cost of imperfect items at the vendor as well as the additional cost required for the minor setups.

As the process is being restored at each shipment, the approximation for the number of imperfect items will be the same and hence the shipped quantity per batch is also the same.

For simplicity reasons, the cost components used in the modified model (Phase 2, Stage 7) shall be kept, however, the following adjustment shall be made:

$$U_i = \left(x - xe^{-\frac{nx}{P}\lambda}\right) \cdot M \qquad [3.54]$$

$$U = (nU_i) \cdot M + n\left(x - xe^{-\frac{nx}{P}\lambda}\right) \cdot (1 - M) \qquad [3.55]$$

$$C_1 = \frac{A_1}{T} + \frac{A_1\mu}{T}R + \frac{\phi A_1 n}{T}M \qquad [3.56]$$

$$C_6 = \frac{\frac{1}{2}U_i t_p n}{T}h_1 HM + \frac{\frac{(n-1)n}{2}U_i t_p}{T}h_1 HM + \frac{nU_i t_r}{T}h_1 HRM + \frac{\frac{1}{2}Unt_p}{T}h_1 H(1 - M) + \frac{Ut_r}{T}h_1 RH(1 - M) \qquad [3.57]$$

And similar to the modified model (Phase 2, Stage 7), the total cost per year for the system is the sum of the previous costs and can be stated as:

$$C = C_1 + C_2 + C_3 + C_4 + C_5 + C_6 + C_7 - C_8 \qquad [3.58]$$

Inventory Behavior

The inventory behavior of the model is exactly as that portrayed in Phase 2 Stage 6, however, the inventory of the imperfect items has been changed as a result of the minor setups. This is illustrated in *Figure 3.6* for the more comprehensive case where re-work is applied at the end of the regular production.

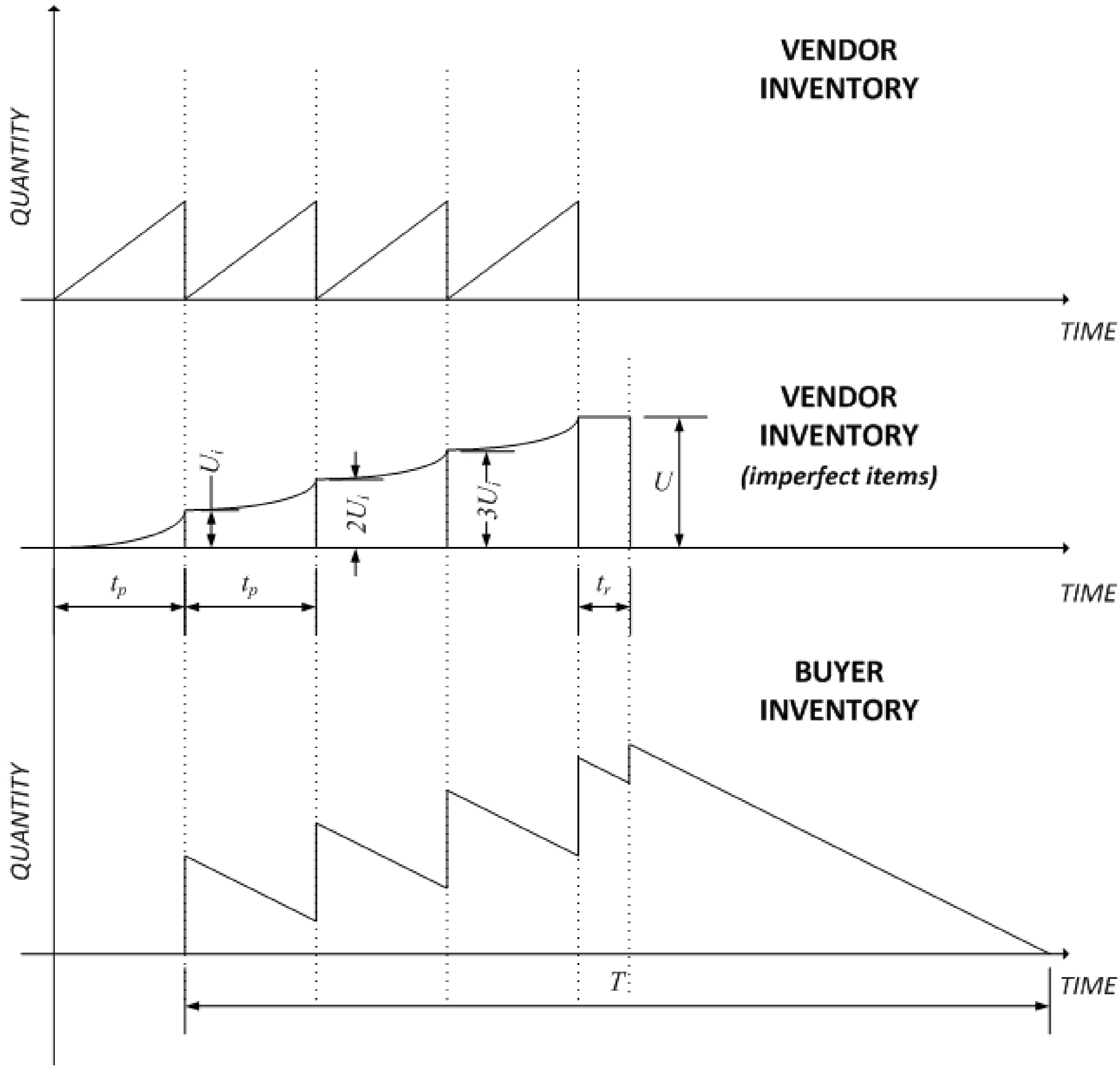

Figure 3.6 Inventory behavior for the model of Phase 3, for the comprehensive case where re-work is applied

3.2.3 Model Finalization

The objective function is to minimize the total cost of the system. However, this function is subject to a quality control constraint. It is assumed that there is a given quality control limit for each production batch. For example, a batch shipped should be at least 90% of the production batch.

Notation

Q_{CL}	minimum acceptance level (percentage) for batch production (quality control limit)	
x_L	minimum value for x such that Q_{CL} is satisfied	[items]

Mathematical Model

$$x_L = \frac{U}{n(1-Q_{CL})} \qquad [3.59]$$

The problem can now be formally stated as follows:

$$\min C = C_1 + C_2 + C_3 + C_4 + C_5 + C_6 + C_7 - C_8 \qquad [3.60]$$

Subject to:

$$x \geq x_L \qquad [3.61]$$

$$x \geq 1 \qquad [3.62]$$

$$n \geq 1 \qquad [3.63]$$

Model Programming

The model has been implemented using Microsoft Excel 2007 enhanced with Visual Basic macros. The selection of the above software tools has been made for their simplicity, flexibility and ready availability.

Chapter 4

Model Implementation (Results and Discussion)

4.1 Model Application

This chapter will illustrate the application of the model to various production cases that resemble real-world production scenarios. The model will seek to minimize the total cost under the different situations presented in Chapter 3 with an emphasis on comparing the same situation with and without minor setups for restoration. The chapter will then apply some sensitivity analysis to the comprehensive production scenario to develop some insights.

4.1.1 Production Scenarios

In order to validate the modifications made to the base model, two production scenarios will be demonstrated by the model. These are the base model, that is the model of Braglia and Zavanella (2003) and the same model when production cost and vendor profit from selling the items is considered. The common factor in these two models is that imperfect production is not considered. The ensuing production scenarios that resemble real-world production scenarios for comparisons incorporate the concept of imperfect production in its production process. These scenarios are summarized in *Table 4.1* and *Table 4.2*.

Table 4.1 summarizes the production scenarios that were considered.

Scenario Number	Description of Production Scenario
00i	Base Model without minor setups for restoration (the model of Braglia and Zavanella, 2003)
00ii	Base Model with minor setups for restoration
01i	Base Model considering production cost and considering profit made by the vendor for selling items to the buyer without minor setups for restoration
01ii	Base Model considering production cost and considering profit made by the vendor for selling items to the buyer with minor setups for restoration
A1i	Imperfect items are scrapped instantaneously at no cost (without minor setups for restoration)
A1ii	Imperfect items are scrapped instantaneously at no cost (with minor setups for restoration)
A2i	Imperfect items are scrapped instantaneously at a cost (without minor setups for restoration)
A2ii	Imperfect items are scrapped instantaneously at a cost (with minor setups for restoration)
A3i	Imperfect items are scrapped instantaneously for a marginal profit from a secondary market (without minor setups for restoration)
A3ii	Imperfect items are scrapped instantaneously for a marginal profit from a secondary market (with minor setups for restoration)
B1i	Imperfect items are held until the end of the production cycle and then scrapped at no cost (without minor setups for restoration)
B1ii	Imperfect items are held until the end of the production cycle and then scrapped at no cost (with minor setups for restoration)
B2i	Imperfect items are held until the end of the production cycle and then scrapped at a cost (without minor setups for restoration)
B2ii	Imperfect items are held until the end of the production cycle and then scrapped at a cost (with minor setups for restoration)
B3i	Imperfect items are held until the end of the production cycle and then scrapped for a marginal profit to a secondary market (without minor setups for restoration)
B3ii	Imperfect items are held until the end of the production cycle and then scrapped for a marginal profit to a secondary market (with minor setups for restoration)
C1i	Imperfect items at the end of the production are re-worked and imperfect items left scrapped at no cost (without minor setups for restoration)
C1ii	Imperfect items at the end of the production are re-worked and imperfect items left scrapped at no cost (with minor setups for restoration)
C2i	Imperfect items at the end of the production are re-worked and imperfect items left scrapped at a cost (without minor setups for restoration)
C2ii	Imperfect items at the end of the production are re-worked and imperfect items left scrapped at a cost (with minor setups for restoration)
C3i	Imperfect items at the end of the production are re-worked and imperfect items left are scrapped for a marginal profit to a secondary market (without minor setups for restoration)

Scenario Number	Description of Production Scenario
C3ii	Imperfect items at the end of the production are re-worked and imperfect items left are scrapped for a marginal profit to a secondary market (with minor setups for restoration)

Table 4.1 Summary of the production scenarios that resemble real-world cases

Table 4.2 summarizes the production scenarios and their corresponding modeling parameters.

Scenario Number	Modeling Parameters							
	P_D	H	K	R	B	λ	u_k	M
00i	0	0	0	0	0	0	0	0
00ii	0	0	0	0	0	0	0	1
01i	1	0	0	0	1	0	0	0
01ii	1	0	0	0	1	0	0	1
A1i	1	0	0	0	1	+ve	0	0
A1ii	1	0	0	0	1	+ve	0	1
A2i	1	0	1	0	1	+ve	+ve	0
A2ii	1	0	1	0	1	+ve	+ve	1
A3i	1	0	1	0	1	+ve	-ve	0
A3ii	1	0	1	0	1	+ve	-ve	1
B1i	1	1	0	0	1	+ve	0	0
B1ii	1	1	0	0	1	+ve	0	1
B2i	1	1	1	0	1	+ve	+ve	0
B2ii	1	1	1	0	1	+ve	+ve	1
B3i	1	1	1	0	1	-ve	-ve	0
B3ii	1	1	1	0	1	-ve	-ve	1
C1i	1	1	0	1	1	+ve	0	0
C1ii	1	1	0	1	1	+ve	0	1
C2i	1	1	1	1	1	+ve	+ve	0
C2ii	1	1	1	1	1	+ve	+ve	1
C3i	1	1	1	1	1	+ve	-ve	0
C3ii	1	1	1	1	1	+ve	-ve	1

Key: +ve = a positive value
-ve = a negative value

Table 4.2 Summary of the modeling parameters for various production scenarios considered

In consistency with the model of Braglia and Zavanella (2003), the following values are used:

$A_1 = 400$ [$/setup]

$A_2 = 25$ [$/batch order]

$D = 1000$ [items/year]

$P = 3200$ [items/year]

$h_1 = 4$ [$/item · year]

$h_2 = 5$ [$/item · year]

The following is also assumed:

$u_p = 10$ [$/item]

$u_k = 1$ [$/item] when considered positive (10% of u_p)

$u_k = -1$ [$/item] when considered negative (10% of u_p)

$\lambda = 0.15$ when considered positive

$Q_{CL} = 0.9$

$\alpha = 0.5$

$\beta = 0.05$

$\gamma = 0.05$

$\mu = 0.01$

$\phi = 0.05$

$b_1 = 0.25$

4.1.2 Results and Discussion

The results for the various production scenarios aforementioned are presented in *Table 4.3*.

Scenario Number	CASE i (without minor setups for restoration)				CASE ii (with minor setups for restoration)			
	C	T	x	n	C	T	x	n
A1	-160.13	0.38	195.66	2	-259.96	0.48	160.39	3
A2	-141.61	0.38	194.05	2	-252.43	0.48	159.84	3
A3	-178.81	0.39	197.30	2	-267.52	0.48	160.94	3
B1	-155.60	0.38	194.88	2	-257.70	0.48	160.06	3
B2	-137.16	0.38	193.30	2	-250.18	0.48	159.52	3
B3	-174.20	0.38	196.49	2	-265.24	0.48	160.61	3
C1	-332.03	0.42	210.28	2	-483.21	0.58	141.82	4
C2	-312.50	0.42	208.41	2	-476.73	0.58	141.40	4
C3	-351.74	0.42	212.20	2	-489.73	0.58	142.25	4
01	-465.15	0.49	122.86	4	-259.96	0.48	160.39	3
00	2034.85	0.49	122.86	4	2163.62	0.49	164.85	3

Table 4.3 Results for the various production scenarios that resemble the real world

The result for Case 00i yields the exact same results as presented in Braglia and Zavanella (2003). Case 00ii is the same model but with the application of minor setups for restoration. It can be clearly seen that this model is less optimal (of a higher cost) when the minor setups for restoration are applied. This is because there is an additional cost for the minor setups; however, there is no benefit gained from the restoration of the process as there are no imperfect items and hence no associated costs.

Case 01i and Case 01ii indicate a negative cost which is in essence a profit made by the system as the profit made by the vendor is taken into consideration. The values for x and n in case 01i are the same as those in case 00i as there is no change in the policy, only a change in the incorporation of production cost and the consideration of vendor profit. Again, it can be seen that there is no benefit from minor restorations as evident from the reduced profit shown (a less negative cost). Once again, this is attributed to the fact no costs for imperfect items are considered. For this reason, it is vital the imperfect production be considered in future consignment stock models.

In all the other scenarios, an imperfect production process is considered and it is clearly seen there is a benefit from applying the minor restorations to restore the process. It is also notable, that the highest increase from the application of minor restorations is in the cases where re-work is considered. The different scenarios that consider scrapping at a cost, or no cost, or sold for a marginal profit to a secondary market have a small impact on the total cost of the system.

4.2 Sensitivity Analysis

Case C2i and C2ii represent the most comprehensive case of the different production scenarios. It shall be these cases in which the model shall be tested for different values of D, u_p, and λ . When changing the values of u_p, the value for u_k will always be 10% off that value.

4.2.1 Variation of Demand

In this experiment, the values used are the exact values of Case C2i and C2ii as presented earlier in Section 4.1.1, however, the value of the demand shall be altered to vary from 1000 to 3000 by every 100. There is no need to vary the demand beyond 3000 units as it the maximum production capacity is limited to 3200 units per year as given by Braglia and Zavanella (2003).

Table 4.4 presents the results of the model when for the various demands.

D	CASE C2i				CASE C2ii				PROFIT SAVED FOR APPLYING $M = 1$
	C	T	x	n	C	T	x	n	
1000	-312.50	0.41	208.41	2	-476.73	0.58	141.40	4	164.23
1100	-449.81	0.39	217.96	2	-673.51	0.56	151.25	4	223.70
1200	-591.34	0.38	227.01	2	-879.69	0.55	161.24	4	288.35
1300	-736.52	0.36	235.60	2	-1103.47	0.58	147.48	5	366.95
1400	-884.92	0.35	243.80	2	-1338.78	0.58	157.22	5	453.86
1500	-1036.17	0.33	251.63	2	-1590.83	0.62	149.01	6	554.65
1600	-1189.98	0.32	259.13	2	-1857.25	0.66	144.65	7	667.27
1700	-1348.87	0.33	188.69	3	-2143.81	0.67	155.19	7	794.95
1800	-1511.57	0.32	193.90	3	-2451.39	0.72	154.23	8	939.81
1900	-1676.40	0.31	198.94	3	-2784.16	0.82	146.71	10	1107.76
2000	-1843.16	0.30	203.83	3	-3148.61	0.89	151.67	11	1305.45
2100	-2011.72	0.29	208.57	3	-3551.93	1.02	152.01	13	1540.22
2200	-2181.94	0.29	213.18	3	-4006.36	1.20	150.41	16	1824.42
2300	-2353.71	0.28	217.67	3	-4526.62	1.45	148.67	20	2172.92
2400	-2526.92	0.27	222.04	3	-5132.02	1.77	147.68	25	2605.10
2500	-2701.49	0.27	226.30	3	-5846.48	2.18	147.93	31	3144.99
2600	-2877.33	0.26	230.45	3	-6700.18	2.71	147.12	39	3822.85
2700	-3054.37	0.26	234.51	3	-7734.29	3.42	147.13	49	4679.91
2800	-3232.55	0.25	238.48	3	-9010.30	4.41	146.05	63	5777.75
2900	-3411.80	0.25	242.36	3	-10630.90	5.93	145.28	83	7219.13
3000	-3592.06	0.24	246.16	3	-12789.80	8.36	164.06	100	9197.76

Table 4.4 Results for production scenarios C2i and C2ii when the demand is varied

In consistency with the results presented in section 4.1.2 there is always a larger profit made (or lower cost) when minor setups for restoration are applied. As the demand is increased, the extra profit made by the application of minor setups is even more. Hence, the larger the demand, the more beneficiary it is to apply minor setups for restoration. What is noticeable is that in the case of applying minor setups for restoration the number of shipments and minor setups are increased whereas the number of items per shipment is considered relatively in the same range. So even though there are additional costs for minor setups and for the shipments made, yet the savings are considerable larger. It should be noted that, for the last run where the demand was set to be 3000 units per year, the number of required shipments made when applying minor setups for restoration is 100. This is the maximum number of shipments permitted and is considered a programming limitation of the model.

4.2.2 Variation of Unit Production Cost

Again, in this experiment, the values used are the exact values of Case C2i and C2ii as presented earlier in section 4.1.1, however, the unit price shall be altered to vary between 10 and 60 dollars per unit. The results are presented in *Table 4.5*.

u_p	CASE C2i				CASE C2ii				PROFIT SAVED FOR APPLYING $M = 1$
	C	T	x	n	C	T	x	n	
10	-312.50	0.41	208.41	2	-476.73	0.58	141.40	4	164.23
11	-556.64	0.41	207.85	2	-745.66	0.58	142.62	4	189.02
12	-800.80	0.41	207.30	2	-1014.76	0.59	143.88	4	213.96
13	-1044.97	0.41	206.75	2	-1284.02	0.59	145.17	4	239.04
14	-1289.16	0.41	206.20	2	-1553.44	0.60	146.49	4	264.28
15	-1533.37	0.41	205.66	2	-1823.04	0.60	147.85	4	289.67
16	-1777.59	0.41	205.13	2	-2092.82	0.61	149.24	4	315.23
17	-2021.83	0.41	204.60	2	-2362.77	0.62	150.66	4	340.94
18	-2266.08	0.41	204.07	2	-2635.39	0.67	130.48	5	369.31
19	-2510.34	0.41	203.55	2	-2908.67	0.68	131.94	5	398.33
20	-2754.62	0.40	203.03	2	-3182.20	0.68	133.44	5	427.58
21	-2998.92	0.40	202.51	2	-3455.99	0.69	134.99	5	457.08
22	-3243.23	0.40	202.00	2	-3730.05	0.70	136.58	5	486.83
23	-3487.55	0.40	201.50	2	-4004.39	0.71	138.23	5	516.84
24	-3731.89	0.40	200.99	2	-4279.81	0.77	124.10	6	547.92
25	-3976.24	0.40	200.49	2	-4557.42	0.78	125.80	6	581.18
26	-4220.61	0.40	200.00	2	-4835.39	0.79	127.56	6	614.78
27	-4464.99	0.40	199.50	2	-5113.73	0.80	129.39	6	648.75
28	-4709.38	0.40	199.02	2	-5392.47	0.81	131.28	6	683.09
29	-4953.79	0.40	198.53	2	-5672.71	0.87	120.81	7	718.92
30	-5198.21	0.39	198.05	2	-5954.83	0.89	122.78	7	756.62
31	-5442.64	0.39	197.57	2	-6237.45	0.90	124.82	7	794.80
32	-5687.09	0.39	197.10	2	-6520.59	0.92	126.96	7	833.50

u_p	CASE C2i				CASE C2ii				PROFIT SAVED FOR APPLYING $M = 1$
	C	T	x	n	C	T	x	n	
33	-5931.55	0.39	196.62	2	-6805.90	0.99	118.90	8	874.34
34	-6176.03	0.39	196.16	2	-7092.60	1.01	121.13	8	916.57
35	-6420.51	0.39	195.69	2	-7379.96	1.03	123.46	8	959.44
36	-6665.01	0.39	195.23	2	-7669.49	1.10	117.09	9	1004.48
37	-6909.53	0.39	194.77	2	-7960.59	1.12	119.52	9	1051.07
38	-7154.06	0.39	194.32	2	-8252.77	1.20	114.38	10	1098.72
39	-7398.59	0.39	193.87	2	-8547.73	1.23	116.92	10	1149.14
40	-7643.15	0.39	193.42	2	-8843.62	1.25	119.59	10	1200.48
41	-7887.71	0.38	192.97	2	-9142.47	1.34	115.35	11	1254.76
42	-8132.29	0.38	192.53	2	-9442.53	1.42	111.82	12	1310.24
43	-8376.88	0.38	192.09	2	-9745.66	1.45	114.58	12	1368.78
44	-8622.37	0.36	361.35	1	-10050.50	1.54	111.58	13	1428.12
45	-8871.52	0.36	361.22	1	-10358.00	1.58	114.44	13	1486.43
46	-9120.68	0.36	361.10	1	-10667.90	1.67	111.85	14	1547.22
47	-9369.83	0.36	360.97	1	-10980.10	1.76	109.62	15	1610.24
48	-9618.99	0.36	360.84	1	-11295.20	1.81	112.51	15	1676.19
49	-9868.15	0.36	360.71	1	-11612.90	1.90	110.52	16	1744.74
50	-10117.30	0.36	360.59	1	-11933.10	1.99	108.77	17	1815.81
51	-10366.50	0.36	360.46	1	-12256.00	2.05	111.65	17	1889.56
52	-10615.60	0.36	360.33	1	-12581.90	2.15	110.03	18	1966.31
53	-10864.80	0.36	360.20	1	-12910.50	2.24	108.58	19	2045.71
54	-11113.90	0.36	360.08	1	-13241.70	2.34	107.26	20	2127.81
55	-11363.10	0.36	359.95	1	-13575.70	2.44	106.06	21	2212.62
56	-11612.30	0.36	359.82	1	-13912.50	2.50	108.75	21	2300.24
57	-11861.40	0.36	359.70	1	-14252.10	2.60	107.58	22	2390.70
58	-12110.60	0.36	359.57	1	-14594.40	2.70	106.49	23	2483.85
59	-12359.70	0.36	359.45	1	-14939.40	2.80	105.49	24	2579.69
60	-12608.90	0.36	359.32	1	-15287.10	2.90	104.55	25	2678.19

Table 4.5 Results for production scenarios C2i and C2ii when the unit price is varied

Again, the application of minor setups for restoration is always more cost saving (yields better profits) than in the case where it is not applied. This is the case for all values of unit price of each item. Furthermore, as the unit cost per item is increased, the benefit from the application of minor setups for restoration is more and more. It is noticed that in the case of no application of minor setups, as the unit price increases, the number of shipments decreases to yield optimum results; however, in the case of the application of minor setups for restoration, the number of shipments increases (reminder: there is a minor setup performed at each shipment).

4.2.3 Variation in Probability Factor for Imperfect Production

Again, in this experiment, the values used are the exact values of Case C2i and C2ii as presented earlier in section *4.1.1*, however, the λ parameter used in the approximation of the number of defective items resulting from an imperfect production process shall be altered to vary between 0.15 and 1.14. The results are presented in the *Table 4.6*.

λ	CASE C2i					CASE C2ii					PROFIT SAVED FOR APPLYING $M = 1$
	C	T	x	n	U	C	T	x	n	U	
0.15	-312.50	0.41	208.41	2	8.06	-476.73	0.58	141.40	4	3.74	164.23
0.16	-306.79	0.41	207.88	2	8.55	-488.41	0.58	141.95	4	4.02	181.63
0.17	-301.09	0.41	207.37	2	9.04	-500.08	0.58	142.49	4	4.30	198.98
0.18	-295.41	0.41	206.85	2	9.52	-511.71	0.59	143.04	4	4.58	216.29
0.19	-289.75	0.41	206.34	2	9.99	-523.31	0.59	143.58	4	4.88	233.56
0.20	-284.09	0.41	205.83	2	10.46	-534.88	0.59	144.12	4	5.17	250.79
0.21	-278.45	0.41	205.33	2	10.92	-546.43	0.59	144.65	4	5.47	267.97
0.22	-272.83	0.41	204.83	2	11.38	-557.94	0.60	145.18	4	5.77	285.11
0.23	-267.21	0.41	204.34	2	11.83	-569.42	0.60	145.71	4	6.07	302.21
0.24	-261.61	0.40	203.84	2	12.28	-580.86	0.60	146.23	4	6.38	319.26
0.25	-256.01	0.40	203.35	2	12.72	-592.28	0.61	146.75	4	6.69	336.26
0.26	-250.43	0.40	202.87	2	13.16	-603.66	0.61	147.26	4	7.01	353.23
0.27	-244.87	0.40	202.38	2	13.59	-615.01	0.61	147.77	4	7.32	370.14
0.28	-239.31	0.40	201.90	2	14.02	-627.22	0.66	126.60	5	6.97	387.91
0.29	-233.76	0.40	201.43	2	14.44	-640.00	0.66	127.06	5	7.27	406.24
0.30	-228.23	0.40	200.95	2	14.86	-652.73	0.67	127.52	5	7.58	424.51
0.31	-222.70	0.40	200.48	2	15.28	-665.42	0.67	127.97	5	7.88	442.72
0.32	-217.20	0.40	200.02	2	15.69	-678.06	0.67	128.41	5	8.19	460.87
0.33	-211.69	0.40	199.55	2	16.09	-690.66	0.68	128.85	5	8.50	478.97

λ	CASE C2i					CASE C2ii					PROFIT SAVED FOR APPLYING $M = 1$
	C	T	x	n	U	C	T	x	n	U	
0.34	-206.19	0.39	199.09	2	16.49	-703.21	0.68	129.28	5	8.82	497.01
0.35	-200.71	0.39	198.63	2	16.89	-715.71	0.68	129.71	5	9.14	515.00
0.36	-195.24	0.39	198.17	2	17.28	-728.16	0.69	130.13	5	9.46	532.92
0.37	-189.78	0.39	197.72	2	17.67	-740.56	0.69	130.55	5	9.78	550.78
0.38	-184.32	0.39	197.27	2	18.06	-752.91	0.69	130.96	5	10.10	568.59
0.39	-178.88	0.39	196.82	2	18.44	-765.21	0.70	131.36	5	10.43	586.34
0.40	-173.44	0.39	196.37	2	18.82	-777.46	0.70	131.76	5	10.76	604.02
0.41	-168.02	0.39	195.93	2	19.19	-789.66	0.70	132.15	5	11.09	621.65
0.42	-162.60	0.39	195.49	2	19.56	-801.81	0.71	132.53	5	11.43	639.21
0.43	-157.19	0.38	195.05	2	19.92	-814.25	0.75	116.85	6	10.92	657.05
0.44	-151.79	0.38	194.61	2	20.28	-827.30	0.76	117.18	6	11.24	675.51
0.45	-146.40	0.38	194.17	2	20.64	-840.29	0.76	117.50	6	11.55	693.89
0.46	-141.02	0.38	193.74	2	20.99	-853.21	0.76	117.81	6	11.87	712.20
0.47	-135.64	0.38	193.31	2	21.34	-866.08	0.77	118.12	6	12.19	730.43
0.48	-130.28	0.38	192.88	2	21.69	-878.87	0.77	118.42	6	12.51	748.60
0.49	-124.92	0.38	192.46	2	22.03	-891.61	0.77	118.71	6	12.83	766.69
0.50	-119.57	0.38	192.03	2	22.37	-904.27	0.78	119.01	6	13.15	784.70
0.51	-114.23	0.38	191.61	2	22.71	-916.88	0.78	119.29	6	13.48	802.65
0.52	-108.89	0.38	191.19	2	23.04	-929.41	0.78	119.56	6	13.80	820.52
0.53	-103.57	0.38	190.78	2	23.37	-941.88	0.79	119.83	6	14.13	838.32
0.54	-98.24	0.37	190.36	2	23.69	-954.29	0.79	120.10	6	14.46	856.04
0.55	-92.93	0.37	189.95	2	24.01	-966.63	0.79	120.35	6	14.78	873.69
0.56	-87.63	0.37	189.53	2	24.33	-978.90	0.79	120.60	6	15.11	891.27
0.57	-82.33	0.37	189.12	2	24.65	-991.10	0.80	120.85	6	15.44	908.77
0.58	-77.04	0.37	188.72	2	24.96	-1003.24	0.80	121.08	6	15.77	926.20
0.59	-71.75	0.37	188.31	2	25.27	-1015.31	0.80	121.32	6	16.10	943.56
0.60	-66.48	0.37	187.91	2	25.57	-1027.45	0.85	108.72	7	15.36	960.98
0.61	-63.02	0.35	350.81	1	22.69	-1040.04	0.85	108.90	7	15.66	977.02
0.62	-61.11	0.35	350.49	1	23.01	-1052.55	0.85	109.08	7	15.97	991.44
0.63	-59.19	0.35	350.17	1	23.33	-1064.99	0.86	109.25	7	16.27	1005.79
0.64	-57.28	0.35	349.85	1	23.64	-1077.35	0.86	109.42	7	16.58	1020.07
0.65	-55.36	0.35	349.52	1	23.95	-1089.64	0.86	109.58	7	16.89	1034.28
0.66	-53.44	0.35	349.20	1	24.27	-1101.85	0.86	109.74	7	17.19	1048.41
0.67	-51.53	0.35	348.88	1	24.58	-1113.99	0.87	109.89	7	17.50	1062.46
0.68	-49.61	0.35	348.55	1	24.88	-1126.05	0.87	110.03	7	17.80	1076.45
0.69	-47.69	0.35	348.23	1	25.19	-1138.04	0.87	110.17	7	18.11	1090.36
0.70	-45.76	0.35	347.91	1	25.49	-1149.96	0.87	110.31	7	18.41	1104.20
0.71	-43.84	0.35	347.58	1	25.80	-1161.80	0.88	110.44	7	18.71	1117.96

λ	CASE C2i					CASE C2ii					PROFIT SAVED FOR APPLYING $M = 1$
	C	T	x	n	U	C	T	x	n	U	
0.72	-41.92	0.35	347.26	1	26.10	-1173.57	0.88	110.57	7	19.02	1131.66
0.73	-39.99	0.35	346.93	1	26.40	-1185.27	0.88	110.69	7	19.32	1145.28
0.74	-38.06	0.35	346.61	1	26.70	-1196.90	0.88	110.80	7	19.62	1158.83
0.75	-36.13	0.35	346.28	1	26.99	-1208.45	0.89	110.91	7	19.92	1172.31
0.76	-34.20	0.35	345.95	1	27.29	-1219.93	0.89	111.02	7	20.22	1185.73
0.77	-32.27	0.35	345.63	1	27.58	-1231.34	0.89	111.12	7	20.52	1199.07
0.78	-30.34	0.35	345.30	1	27.87	-1242.67	0.89	111.22	7	20.82	1212.34
0.79	-28.40	0.34	344.97	1	28.16	-1253.94	0.89	111.32	7	21.12	1225.54
0.80	-26.46	0.34	344.65	1	28.45	-1265.13	0.90	111.41	7	21.42	1238.67
0.81	-24.53	0.34	344.32	1	28.74	-1276.26	0.90	111.49	7	21.72	1251.73
0.82	-22.58	0.34	343.99	1	29.02	-1287.38	0.94	100.91	8	20.61	1264.80
0.83	-20.64	0.34	343.66	1	29.31	-1298.75	0.94	100.97	8	20.88	1278.11
0.84	-18.70	0.34	343.33	1	29.59	-1310.05	0.94	101.03	8	21.15	1291.35
0.85	-16.75	0.34	343.00	1	29.87	-1321.27	0.94	101.08	8	21.42	1304.52
0.86	-14.80	0.34	342.67	1	30.15	-1332.41	0.94	101.13	8	21.69	1317.61
0.87	-12.85	0.34	342.34	1	30.43	-1343.49	0.95	101.17	8	21.96	1330.64
0.88	-10.90	0.34	342.01	1	30.70	-1354.49	0.95	101.21	8	22.23	1343.59
0.89	-8.95	0.34	341.68	1	30.97	-1365.42	0.95	101.25	8	22.49	1356.47
0.90	-6.99	0.34	341.35	1	31.25	-1376.28	0.95	101.28	8	22.76	1369.29
0.91	-5.03	0.34	341.01	1	31.52	-1387.07	0.95	101.32	8	23.02	1382.03
0.92	-3.07	0.34	340.68	1	31.79	-1397.78	0.96	101.35	8	23.28	1394.71
0.93	-1.11	0.34	340.35	1	32.05	-1408.43	0.96	101.37	8	23.54	1407.32
0.94	0.85	0.34	340.02	1	32.32	-1419.01	0.96	101.40	8	23.80	1419.86
0.95	2.82	0.34	339.68	1	32.58	-1429.52	0.96	101.42	8	24.06	1432.34
0.96	4.79	0.34	339.35	1	32.85	-1439.96	0.96	101.44	8	24.32	1444.75
0.97	6.76	0.34	339.01	1	33.11	-1450.33	0.96	101.45	8	24.58	1457.09
0.98	8.74	0.34	338.68	1	33.37	-1460.64	0.97	101.47	8	24.84	1469.37
0.99	10.71	0.34	338.34	1	33.62	-1470.88	0.97	101.48	8	25.09	1481.59
1.00	12.70	0.34	337.15	1	33.72	-1481.05	0.97	101.49	8	25.34	1493.75
1.01	14.84	0.33	333.82	1	33.38	-1491.16	0.97	101.49	8	25.60	1506.00
1.02	17.20	0.33	330.54	1	33.05	-1501.20	0.97	101.50	8	25.85	1518.40
1.03	19.75	0.33	327.33	1	32.73	-1511.17	0.97	101.50	8	26.10	1530.93
1.04	22.51	0.32	324.19	1	32.42	-1521.09	0.97	101.50	8	26.35	1543.59
1.05	25.45	0.32	321.10	1	32.11	-1530.94	0.98	101.50	8	26.60	1556.39
1.06	28.58	0.32	318.07	1	31.81	-1540.72	0.98	101.49	8	26.84	1569.30
1.07	31.89	0.31	315.10	1	31.51	-1550.44	0.98	101.49	8	27.09	1582.33
1.08	35.37	0.31	312.18	1	31.22	-1560.11	0.98	101.48	8	27.33	1595.48
1.09	39.03	0.31	309.32	1	30.93	-1569.70	0.98	101.47	8	27.58	1608.73

λ	CASE C2i					CASE C2ii					PROFIT SAVED FOR APPLYING $M = 1$
	C	T	x	n	U	C	T	x	n	U	
1.10	42.85	0.31	306.50	1	30.65	-1579.24	0.98	101.46	8	27.82	1622.09
1.11	46.83	0.30	303.74	1	30.37	-1588.72	0.98	101.44	8	28.06	1635.55
1.12	50.97	0.30	301.03	1	30.10	-1598.14	0.98	101.43	8	28.30	1649.11
1.13	55.26	0.30	298.37	1	29.84	-1607.49	0.98	101.41	8	28.54	1662.76
1.14	59.71	0.30	295.75	1	29.57	-1616.79	0.99	101.39	8	28.78	1676.50

Table 4.6 Results for production scenarios C2i and C2ii when the $\boldsymbol{\lambda}$ parameter for the quality approximation is varied

As with the previous results, the application of minor setups for restoration always yields a better profit (more cost efficient) than the case without minor setups. Moreover, as the parameter for the number of defective items increases, the number of defective items increases and correspondingly the larger the benefit from the application of minor setups for restoration. However, it should be noted that, as the parameter for λ reaches increases, the difference in the number of imperfect items from the two different scenarios is not that different. In fact, they approach similar values, which may lead to the consideration of limiting the model at a certain value for λ. Furthermore, in the case of no application of minor setups, once λ has a value of 0.94 and above, the system is actually operating and not yielding any profit even at an optimum production scenario.

Chapter 5

Conclusion

5.1 Conclusion

This chapter will summarize the thesis and conclude presenting findings and further recommendations for future research.

5.1.1 Summary of the Thesis

The thesis has covered a variety of topics with regards to supply chain coordination, imperfect production processes, and consignment stock policy. The thesis provided a brief introduction to supply chain highlighting key definitions and concepts. It further introduces supply chain performance metrics and provides an overview on supply chain coordination discussing the bull-whip effect, supply-chain data and information, collaborative planning, forecasting, and replenishment. The topics of consignment stock policy and the issue of imperfect production were also discussed. Furthermore, a literature review is presented thoroughly illustrating and discussing supply chain coordination, the issue of imperfect production quality in supply chains and finally consignment stock coordination as a strategic policy.

The thesis then defines the problem and provides a clear conceptualization of the scope of the model and the model rationale. The conceptual design is then translated into an actual mathematical model as presented by the thesis through a detailed step-by-step construction process. The construction was demonstrated through a build-up of phases clearly presenting the reasons behind its development. Finally, the model has been applied and tested under various circumstances that resemble real-world scenarios and under various changing conditions to further understand the behavior of the model to develop insights. The results were discussed and presented.

5.1.2 Conclusions

A mathematical model representing real-world scenarios has been developed that further expands the work of Braglia and Zavanella (2003) with regards to the consignment stock model to incorporate imperfect production and various managerial decisions that may surface as a result of the imperfect production.

In response to the objectives of the thesis, the following can be stated:

- A flexible model that resembles the real-world production scenario is developed that applies a consignment stock policy. The model…:
    - … incorporates imperfect production processes
    - … allows for holding of imperfect items
    - … allows for imperfect items to be scrapped
    - … allows for imperfect items to be re-worked
    - … can apply minor setups for restoration
- The model can be applied as a decision tool for management to determine production policies for different production scenarios based on data input from management
- A comparison of the application of minor setups for restoration is presented with regards to a consignment stock policy

The results show that when considering imperfect production, the proposed model of Braglia and Zavanella (2003) is not applicable and needs to be modified as has been achieved in this thesis. Numerous production scenarios that resemble real-world cases were considered, and in all considered production cases the application of minor setups for restoration has shown reduced costs (yielded better profits). Scrapping imperfect items either at no cost, or a cost, or sold for a marginal profit is considered minor relative to the benefits from re-work or applying minor setups for restoration.

5.2 Future Work

Although seen as a successful exploration of the consignment stock policy, the proposed model is not without some limitations. Such limitations may be programmable or conceptual and include:

- The model is deterministic
- The number of shipments per cycle may not exceed 100 shipments
- Items re-worked shall only be re-worked once
- The holding cost of imperfect items is considered equal to that of imperfect items
- Minor setups for restoration are performed when a shipment is made

For further investigations, the above assumptions can be relaxed. Moreover, there are a number of different lines of approach subject to further exploration and study. Such lines of approach include, but are not limited to:

- Programming
    - Providing a more formal software, ready-to-use and user friendly for management
    - Allow for faster calculations and processing time
- Imperfect Production
    - Include more than one re-work process
    - Consider the production process with a stochastic nature
    - Allow for minor setups for restoration in between delivery shipments
- Consignment Stock
    - Consider a stochastic market demand
    - Consider a three-level or multi-level supply chain coordination network
    - Consider a multi-product supply chain scenario
    - Consider the possibility of machine breakdowns for manufacturing
    - Relax the assumption that setups and minor setups are instantaneous

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