Activity-Based Costing in Supply Chain Cost Management Decision Support Systems

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Abstract

Activity-Based Costing in Supply Chain Cost Management Decision

Support Systems

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Activity-based costing and management (ABC/M) is an accounting and management approach that enhances the level of understanding about business operation costs, especially the overhead costs. ABC/M generates more reliable and precise cost information compared to those of traditional cost accounting (TCA) systems. The integration of ABC/M in supply chain (SC) mathematical decision support models can elucidate the managerial aspects of ABC/M more as an accounting and management tool.

Most of the supply chain (SC) order management decision support systems (DSSs) developed so far are based mainly on the material flow and capacity constraints without considering the profitability factor. This thesis first presents a profitable-to-promise (PTP) multi-objective mixed-integer programming (MIP) model which considers profitability in order to effectively manage order acceptance decisions in supply chains, subject to capacity constraints by using ABC/M. The proposed model fulfills a desirable amount of orders completely and accepts a selective number of orders partially having the objective of minimizing the amount of residual capacity and increasing the profitability simultaneously.

Because of the common disadvantages that traditional operations research (OR) approaches have such as, complexity in modeling, impossibility of integrating qualitative factors, and inability of on-time model result analysis, the thesis presents a new generic DSS modeling methodology with system dynamics (SD) and based on ABC/M cost structure. The approach presented results a novel real-time cost monitoring and analysis system. SD is a dynamic simulation approach with learning ability to investigate the status changes in the system that correspond to the system variables' changes as well as their interactions amongst them.

Subsequently, the thesis elaborates on both models by integrating them and introducing them as hybrid (MIP-SD) decision support system. In the hybrid system, MIP model generates the order management policy and SD model monitors the cost behavior of each implemented policy during the implementation process. The main purpose is to show how ABC/M acts as a common cost accounting, information, and managerial approach to synchronize the two mentioned models and to introduce the combination as a hybrid DSS system.

In general, the approach provides the order fulfillment optimal mix aligned with the implementation strategy considering the factors such as, minimizing the residual capacity, considering the customer satisfaction level, selling price, the cost of resources incurred for each order fulfillment policy, and the share of each product and/or order from manufacturing overhead costs. Such an approach can assists management to analyzing and foreseeing the consequences and outcome of each order fulfillment strategy chosen besides finding the optimal order fulfillment combination.

Foreword
Letter of Research Originality

The current document is an extended aggregation of four journal and seven conference articles presented during Mr. Amir Khataie's Ph.D. study.

Journal Articles

1) Khataie, A. H., Bulgak, A. A., and Segovia, J. J., 2011. Activity-based costing and management applied in a hybrid decision support system for order management. *Decision Support Systems*, Conditionally Accepted on February 19, 2011.
2) Khataie, A. H., Bulgak, A. A., and Segovia, J. J., 2011. An Innovative Application of Activity-Based Costing and Management in Decision Support Modeling. *International Journal of Engineering Management and Economics*, Accepted on January 12, 2011.
3) Khataie, A. H. and Bulgak, A. A., 2011. A Review on the Role of Activity-Based Costing Information and Cost Structure Integration in Supply Chain and Operations. *International Journal of Modeling in Operations Management*, Accepted on January 9, 2011.
4) Khataie, A., Defersha, F. M., and Bulgak, A. A., 2010. A multi-objective optimization approach for order management: Incorporating Activity-Based Costing in supply chains. *International Journal of Production Research*, 48(17), 5007-5020.

Conference Articles

- Khataie, A.H., Segovia, J.J., and Bulgak A.A., 2011. The Use of System Dynamics as a Cost Management Tool. *The 17th International Conference on Information Systems Analysis and Synthesis (ISAS 2011)*.
- Khataie, A.H., Bulgak, A.A., and Segovia, J.J., 2010. Advanced decision support tool by integrating activity-based costing and management to system dynamics. *Proceeding of 10th Portland International Conference on Management of Engineering & Technology (PCIMET 2010)*.
- Khataie, A.H., Bulgak, A.A., and Segovia, J.J., 2009. A new mathematical approach in integration of activity-based costing information in supply chain order management. *Proceeding of 39th International Conference on Computers & Industrial Engineering (CIE39),* 945-950.
- Khataie, A., Bulgak, A.A., and Defersha, F.M., 2009. Integration of activity-based costing information in supply chain profit oriented decision making modeling. *Proceedings of the 29th National Operations Research and Industrial Engineering Congress (YAEM 2009)*.
- Khataie, A.H. and Bulgak, A.A., 2009. An activity based costing approach for order management in supply chains. *Proceeding of 5th International Conference on Business, Economics and Management (ICBME 2009).*
- Khataie, A., Defersha, F.M., and Bulgak, A.A., 2008. Maximizing supply chain profits by simultaneously fulfilling desirable amount of order and reducing the residual capacity, *Proceedings of 6th Annual International Symposium on Supply Chain (SCM 2008)*.

- Khataie, A., Defersha, F.M., and Bulgak, A.A., 2008. Maximizing supply chain profits with effective order management. *Proceedings of the 28th National Operations Research and Industrial Engineering Congress (YAEM 2008)*.

Mr. Kahatie as the first author of the four journal papers initially developed the research ideas and refining them through discussion with the other co-authors. His main responsibilities included the development of the models running the necessary experiments and writing the initial draft of papers. During each phase of the research he had productive discussions with the co-authors. The co-authors were giving the necessary written and mathematical comments continuously with the intention of enriching the quality of the research.

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Finally, I dedicate this dissertation to my Maman and Baba. Their love and support has always encouraged me to live in peace and happiness.

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List of Acronyms

ABC	-	Activity-Based Costing
ABC/M	-	Activity-Based Costing and Management
ATP	-	Available-to-Promise
BPR	-	Business Process Reengineering
CIMS	-	Computer Integrated Manufacturing System
CLD	-	Causal Loop Diagram
CTP	-	Capable-to-Promise
DSS	-	Decision Support System
DES	-	Discrete Event Simulation
FMADM	-	Fuzzy Multiple Attribute Decision Making
JIT	-	Just-in-Time
LA	-	Lean Accounting
LM	-	Lean Manufacturing
MAMD	-	Multiple Attribute Decision Making
MIP	-	Mixed-Integer Programming
MOH	-	Manufacturing Overhead
NVA	-	Non-Value Added
OR	-	Operations Research
PGP	-	Preemptive Goal Programming
PTP	-	Profitable-to-Promise
SC	-	Supply Chain
SCM	-	Supply Chain Management
SD	-	System Dynamics
SSM	-	Soft System Methodology

SWOT	-	Strengths, Weaknesses, Opportunities, and Threats
TA	-	Throughput Accounting
TCA	-	Traditional Cost Accounting
TOC	-	Theory of Constraints
TQM	-	Total Quality Management
VA	-	Value Added
WCM	-	World-Class Manufacturing
WGP	-	Weighted Goal Programming

Chapter 1

Introduction

Decision support systems (DSSs) play a crucial role in today's rigorous global competitive environment. DSSs help supply chains to be profitable, leaner, responsive, and agile by providing on-time and reliable decisions. DSSs also help management to foresee and analyze the consequence and impact of each decision taken on the different aspects of business. In the current business competitive environments, a powerful DSS should be able as well to monitor all the significant SC competitiveness factors on-time.

Regardless of the modeling technique applied and the application domain of the model; the DSS should be developed in such a way that it would convey the impact of the SC's financial information completely into the operations solution provided. One of the critical requirements of having a valid solution is developing the system based on an accounting cost structure which exhibits a high level of correlation with the information provided by the financial department. On the other hand, a practical DSS should respect the fundamental knowledge used by the operations department. This requires an accounting approach which unifies the operations and the financial objectives.

By 1990s non-volume related costs increased more rapidly than the volume-related costs. This brought up the need for an accounting system which can trace the non-volume related costs to the cost objects in a more accurate manner. Activity-based costing and management (ABC/M) is a relatively new cost accounting system and management approach that assigns the manufacturing overhead costs (MOH) to the cost objects through activities, instead of allocating them. ABC/M relates financial data with operational data through a detailed analysis of the activities involved in the process. In fact, ABC/M can unify the conversations between financial and operational departments.

This thesis discusses the advantages of integration of ABC/M information and costs structure integration in various SC decision support systems. The main focus of the research is on the supply chain order management area. The DSS is searching for the best possibility of accepting or rejecting the orders based on the profitability factor. It is also able to provide the detailed cost analysis of the provided operations solutions, simultaneously. The modeling approach introduced demonstrates a high level of correlation between operations and finance departments.

1.1. ABC/M Concept and Methodology

Activity-based costing and management is an accounting and cost management approach which attempts to address the deficiencies encountered with most of the current cost accounting methods. ABC begins by identifying the production process activities, and then a cost estimate is prepared for each activity individually. These cost estimates will contain all the labor, material, equipment, and the overhead costs. It results in a more accurate estimation of the overhead costs in the manufacturing processes for each product, compared to the traditional accounting systems, since the former represents a closer reflection of the real manufacturing cost. Moreover, it helps to estimate the associated costs of the production resources more precisely due to its activity oriented nature.

ABC/M or overhead costing was first developed in the 1980s by Robin Cooper and Robert Kaplan. They introduced ABC/M as a two-stage cost accounting process, (1) breaking MOH costs into different cost pools and (2) assigning MOH costs through appropriate activity cost drivers to the cost objects. The MOH costs are distributed among cost pools based on the homogeneousness with the associated cost pool activity cost driver. ABC/M is rather a cost management and accounting approach than a simple accounting method. The two-dimensional ABC/M model presented in Figure 1-1 (Hilton, 2009) depicts the relationship between the accounting and managerial sides of ABC/M. The management aspect of ABC/M involves any use of information provided by the accounting part in order to improve the organization's strategies, policies, and decisions.

The vertical dimension of the model represents the costs assignment view. As it was mentioned before, ABC/M system applies a two-stage process in order to assign the costs of resources to the cost objects. These cost objects could be products manufactured, services offered, orders fulfilled, or customers served. The horizontal dimension of the model presents the process view of an ABC/M system. The main emphasis of this dimension is on the activities. Hilton (2009) defines activities as various processes by which the work is accomplished in the organization.

The process view represents the management side of ABC/M, which consists of two sides; (1) activity analysis and (2) activity evaluation. Activity analysis is the detailed identification and description of the activities conducted in the organization. It involves identification not only of the activities but also of their root causes, the events that trigger activities and the linkages among them (Hilton, 2009). On the other hand, the evaluation of activities is made through performance measures.

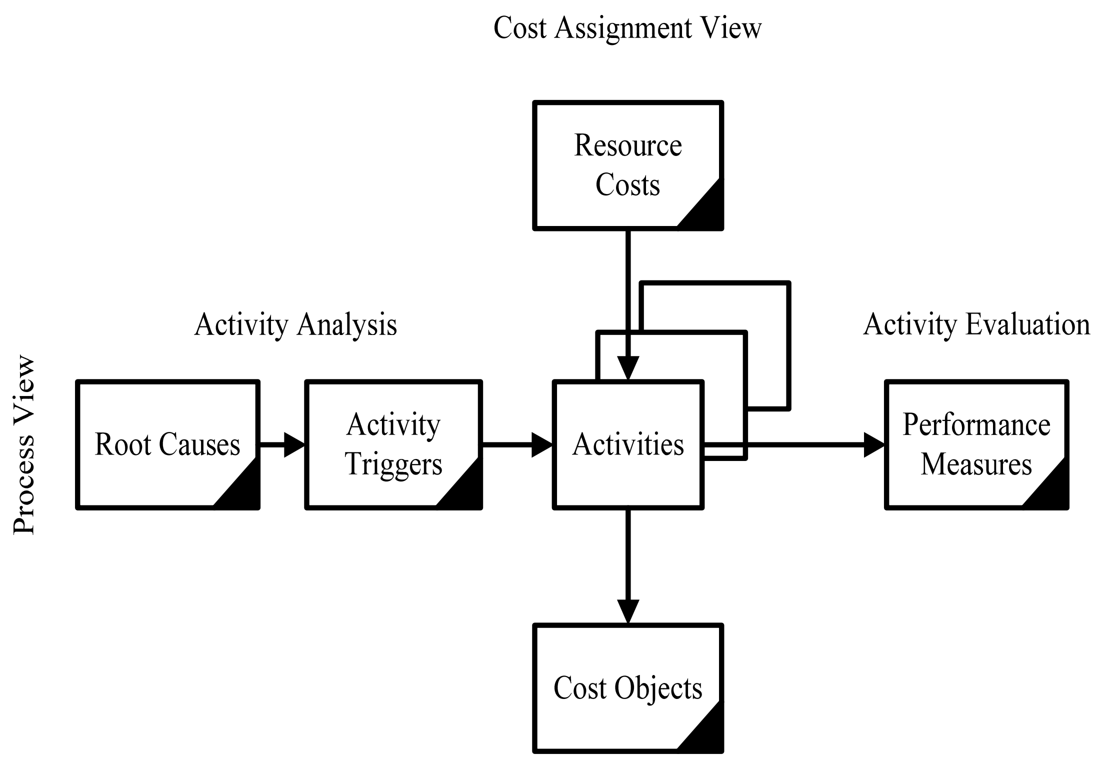

Figure 1-1: Two-dimensional ABC/M model

The traditional overhead costing systems typically emphasizes the efficient use of resources and focused on product instead of activities. In general three cost pools; labor, materials, and overhead, are taken into account. The direct labor and materials costs are incurred costs, so tracking and calculating them is straightforward while for estimating the overheads, cost drivers should be applied, such as direct labor hours and direct machinery hours based on the traditional accounting systems. All of those give a rough-cut estimation and increase the chance of having product-cost subsidies.

There are numerous examples that can be extracted from managerial accounting literature, which show how applying traditional overhead costs allocation approach results miscalculating in the financial parameters, specially, in the cases which the MOH proration is high compare to the total cost (*e.g.* Gunasekaran and Sarhadi (1998), Baykasoglu and Kaplanoglu (2008)). Consequently, it can result in an improper managerial decision at different levels and may reduce the business competitiveness ability.

In order to illustrate the differences between ABC/M overhead costs assigning approach versus the traditional allocation methodology, the following example is extracted from Hilton (2009). The result shows how traditional accounting system methodology of allocating overhead costs leads to incorrect profitability measurement of each service offered by the company.

<u>ABC/M Illustrative Example</u>

A company performs activities related to e-commerce consulting and information system in Vancouver, BC. The firm, which bills $140 per hour for services performed is in a very tight local labor market and is having difficulty finding quality help for its overworked professional staff. The cost per hour for professional staff time is $50. Selected information follows;

- Billable hours to clients for the year totaled 6,000hrs, consisting of: information systems services, 3,600hrs; e-commerce consulting, 2,400hrs.

- Administrative cost of $381,760 was (and continues to be) allocated to both services based on billable hours. These costs consist of staff support, $207,000; in–house computing, $145,000; and miscellaneous office charges, $297,860.

A recent analysis of staff support costs found a correlation with the number of clients served. In-house computing and miscellaneous office charges vary directly with the number of computer hours logged and number of client transactions, respectively. The relevant data is shown below:

	E-commerce Consulting	*Information System Services*	*Total*
Number of clients………………………………	*60*	*240*	*300*
Number of computer hours……………………..	*2,100*	*2,900*	*5,000*
Number of client transaction……………………..	*720*	*480*	*1,200*

According to the traditional cost accounting system, allocation of administrative cost should be based on billable hours. The following calculations are showing each service profitability estimation based on the traditional allocation approach. The firm uses Income billing, in order to measure the profitability of each service produced.

E-commerce consulting: 2,400 ÷ 6,000 = 40%; $381,760 x 40% = $152,704

Information systems: 3,600 ÷ 6,000 = 60%; $381,760 x 60% = $229,056

	E-Commerce Consulting	*Information Systems Services*
Billings:		
3,600 hours x $140…………		*$504,000*
2,400 hours x $140…………	*$336,000*	
Less: Professional staff cost:		
3,600 hours x $50		*(180,000)*
2,400 hours x $50	*(120,000)*	

Administrative cost……	*(152,704)*	*(229,056)*
Income……………………………	*$ 63,296*	*$ 94,944*
Income ÷ billings………………	*18.84%*	*18.84%*

Based on ABC/M system, in the first step we should define the activities. According the hints provided in the problem three activities of (1) staff support, (2) in-house computing, and (3) miscellaneous office charges are suggested. In the next step, the activity pool rates should be estimated. The following calculations estimate the applied pool rates:

Activity	*Cost*	÷	*Activity Driver*	=	*Application Rate*
Staff support	*$207,000*	÷	*300 clients*	=	*$690 per client*
In-house computing	*145,000*	÷	*5,000 computer hours (CH)*	=	*$29 per CH*
Miscellaneous office charges	*29,760*	÷	*1,200 client transactions (CT)*	=	*$24.80 per CT*

Staff support, in-house computing, and miscellaneous office charges of e-commerce consulting and information systems services according to the ABC/M system are estimated as follows;

Activity	*E-Commerce Consulting*	*Information Systems Services*
Staff support:		
240 clients x $690…………..		*$165,600*
60 clients x $690……………	*$ 41,400*	
In-house computing:		
2,900 CH x $29………………		*84,100*
2,100 CH x $29………………	*60,900*	
Miscellaneous office charges:		
480 CT x $24.80……………..		*11,904*

720 CT x $24.80……………....	*17,856*	
Total ……………………………….	*$120,156*	*$261,604*

Ultimately, the profitability e-commerce consulting and information systems services are calculated. The profitability is measured through the formula of *Income ÷ billings* for each type of service.

	E-Commerce Consulting	*Information Systems Services*
Billings:		
3,600 hours x $140……….		*$504,000*
2,400 hours x $140……….	*$336,000*	
Less: Professional staff cost:		
3,600 hours x $50		*(180,000)*
2,400 hours x $50	*(120,000)*	
Administrative cost…….	*(120,156)*	*(261,604)*
Income…………………………..	*$ 95,844*	*$ 62,396*
Income ÷ billings……………....	*28.53%*	*12.38%*

The income percentages show that e-commerce consulting provides a higher return per dollar sales than information systems services (28.53% vs. 12.38%). The result contradicts with the result provided by traditional accounting systems which allocated overhead costs based on billable hours. The incorrect product profitability measurement can result in an ineffective production strategy. The illustrative example can be expanded to estimate other financial parameters such as product/service pricing and customer profitability.

1.2. Research Objectives

ABC/M supporters highlight two principal objectives (Holmen, 1995; Sheu *et al.*, 2003): (1) providing detailed information about the costs and consumption of activities in a specific process and (2) supporting accurate information for managers to improve decisions. This has also been corroborated by Gosselin (1997) regarding a pilot and full ABC/M implementation.

Accordingly, the attention of the dissertation focus on the advantages of ABC/M system as valuable provider of information for SC order management decision making process and in modeling the related cost management system. This dissertation intends to integrate this powerful accounting system into an order management problem as a typical supply chain and operations management problem. Hence, the following objectives are established;

Research Objective 1

The use of ABC/M has been limited to a cost accounting system, rather than as a managerial technique, (Gosselin, 1997; Kaplan and Anderson, 2004; Gosseling, 2007). The first objective of this research is elaborating more the role of ABC/M as a supportive management decision making approach and as a business objective harmonizer between financial and operational departments.

Research Objective 2

The second objective is developing a mathematical multiple attribute decision support model. The new model is taking into account the fulfillment of a desirable amount of orders completely due to the importance of selective customers' satisfaction. Moreover, the new model has the possibility of satisfying the rest of the orders partially, with the objective of minimizing the residual capacity.

Research Objective 3

The ability of system dynamics (SD) in evaluating the production system status changes, and the possibility of integrating qualitative factors, introduce SD as a powerful cost monitoring and decision support tool. The third objective of the dissertation is to develop a new on-time cost monitoring approach by using SD specific attributes *i.e.* learning loops and qualitative factors.

Research Objective 4

A powerful decision support system should have the ability to predict the consequences of each decision taken. The forth objective of this dissertation is developing a hybrid DSS. ABC/M cost structure links the sub-systems and plays the role of an information unifier within the system. The DSS developed can provide the alternatives and foresee the consequence of implementation of each of the financial parameters.

Applying the ABC/M cost structure brings the possibility of introducing a novel hybrid DSS modeling approach, which in provides the optimal solution for the supply chain order management problem and can also offer on-time complementary cost analysis for the different order management appointed policies.

1.3. Research Methodology

In this section, the supply chain problem examined and the modeling approaches applied are presented in detail. It also explains the advantages of each implemented modeling approach.

1.3.1. Order Management Supply Chain Problem

A supply chain consists of different stages which are involved, directly or indirectly, in adding value to the product throughout the process. Each supply chain contains three main flows, flow of information, flow of goods, and financial flow.

The main role of information flow and financial flow is facilitating the flow of material on the opposite direction. The financial flow has the responsibility of transferring cash and credits through the physical supply chain. This involves activities such as payment estimation and payment scheduling.

In this study we are dealing with a three-stage supply chain as shown in Figure 1-2. This consists of different suppliers that can provide the raw material and the subcomponent required; the production unit, and customers. The process starts by placing an order by the customers, followed by buying a raw material and a specific part from suppliers by the producer, manufacturing and preparing the order, and shipping the final product to the required customers.

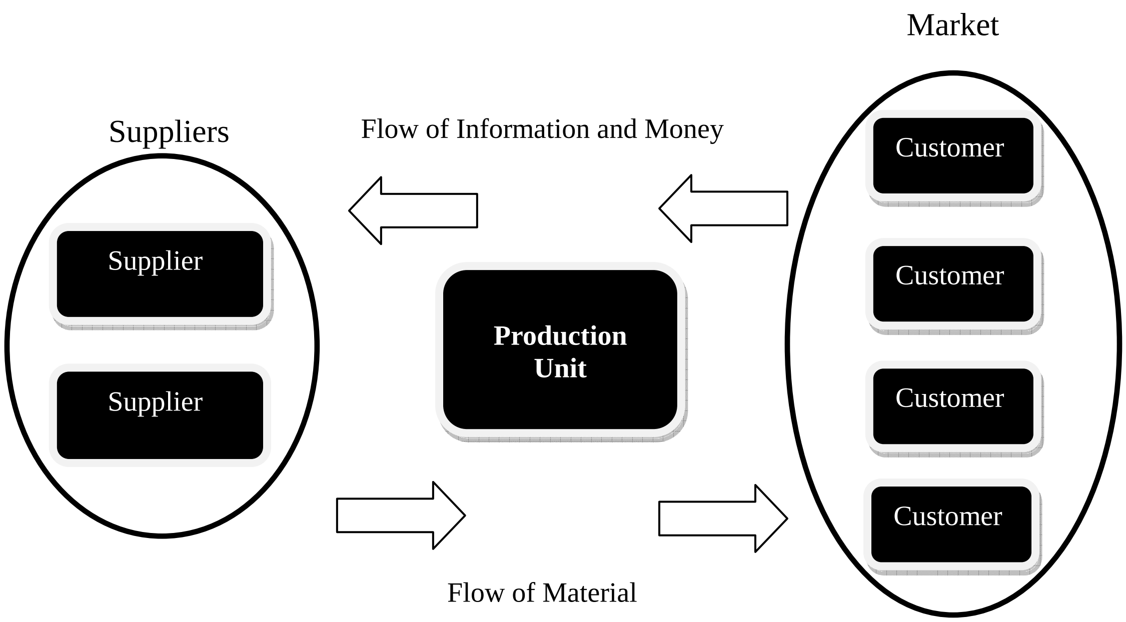

Figure 1- 2: Supply Chain Flow

Maximizing the profit of each supply chain individually does not guarantee the overall supply chain profit maximization. However, from the producer point of view, it always tries to fulfill the most profitable orders with its available capacity (choosing the most profitable customers). Additionally, it attempts to purchase the raw materials and other necessary subcomponents in the least expensive possible way. The main focus of this study is on fulfilling the set of incurred orders which maximize the profit of the production unit. Deciding which orders to accept and which orders to reject requires an understanding of exactly how profitable a particular order may be and how much capacity it requires.

1.3.2. Modeling Approach

In the supply chain order management area, decision support models can be formulated through three different theoretical modeling approaches: available-to-promise (ATP), capable-to-promise (CTP), and profitable-to promise (PTP). The first two emphasize the inventory availability and/or production capacity in order to decide whether to accept or reject an order. The PTP approach considers the opportunity cost of accepting or rejecting an order as a main decision making factor. In fact, PTP decision support models make decisions based on the possibility of assigning the available capacity not by accepting an order today to an order with higher profit margin, which is predicted to be received in the future.

The first modeling approach implemented in this dissertation is mathematical programming and specifically mixed-integer programming (MIP). Traditional optimization approach is applied in order to find the optimal combination of a set of orders which should be fulfilled. However, pursuing two goals at the same time requires a multiple attributes decision making (MADM) modeling approach. The PTP model that is introduced in the first step of this study employs weighted goal programming (WGP) technique in order to define the order fulfillment strategy which maximizes the profit and minimizes the production resources residual capacity, simultaneously.

As it was mentioned before, a powerful PTP decision making tool should be able to trace and analyze the effects of each decision on the firm's cost behavior. The other modeling approach applied is system dynamics. SD is a simulation technique that was developed in the mid 50s by J. Forrester from Massachusetts Institute of Technology to understand the dynamic behavior and status alternation of complex systems over a certain period of time with learning ability.

The last step of this study presents a hybrid modeling approach. The developed model combines the mathematical and SD models. ABC/M is the vital integration factor in developing the hybrid model. Gregoriades and Karakostas (2004) evaluated the advantages of integrating system dynamics and business objects. According to their study, the integration of SD simulation technique with the planning alternatives, provided by the mathematical model, gives the following advantages;

- *Interface perceptiveness* - The integration provides an intuitive interface to the simulation engine based on real world concepts. This is due to the nature of order fulfillment alternatives which is an abstract representative of business concepts.
- *Business-oriented modeling* – The mathematical model reduces the complexities that exist in the simulation model by presenting the user only with the information that is needed to utilize the MIP model.
- *Scalability* - The simulation models can be easily extended by attaching additional qualitative and/or quantitative parameters to the existing structure.
- *Comparative simulation* - Since the output of simulation is stored in the order fulfillment alternatives, various comparisons can be made between the results of ‘‘What if’’ scenarios.
- *Backtrack simulation* - The information related to the status of the business aspects is saved in each alternative. This information as historical data could be used to track the behavior of the organization.

1.4. Outline of Thesis

The remainder of this study is organized as follows: Chapter 2 provides an inclusive literature review on the applicability of ABC/M in developing mathematical decision support systems. Moreover, it presents a review on the SD-based decision support models applied ABC/M as a cost information system. Chapter 3 presents the mathematical model in MADM process for order management problem. The chapter includes an illustrative example to show the advantages of the new model with the older approaches. In Chapter 4, the ABC/M cost pooling structure integration, as developed by Cooper and Kaplan, with SD in order to develop a reliable and on-time decision support tool is discussed. The model is validated through a numerical example. The example presented in this chapter shows how estimating the product price based on ABC/M system results in higher profit compared to the traditional cost accounting systems. Chapter 5 introduces ABC/M as a critical integration factor to develop a hybrid (SD-MIP) decision support system. The numerical example is provided with the intention of illustrating the positive effects of the developed model. Chapter 6 contains summary, conclusion and future research guidelines. This chapter also highlights the major contributions of the research. The software programming codes and references are mentioned at the end of the dissertation.

Chapter 2

Literature Review

The significant changes in the characteristics of the business environment by the end of the 20th century magnified the competitiveness factors such as product customizations, cost controls, and competitive pricing strategy. Activity-based costing and management (ABC/M) is a relatively new accounting system that appeared at the end of the '80s as an answer to the need of an accounting system that is capable of demonstrating the business costs more accurately. ABC/M emphasizes the role of overhead costs to minimize their allocation by assigning indirect costs to the cost objects (*e.g.* product, service) through different process activities, named as activity cost drivers. Direct cost assignment increases the accuracy of product cost estimation at the supply chain level. Subsequently, it results in a more accurate product pricing strategy. Moreover, ABC is capable to measure the cost of the utilization of production resources more precisely. This introduces ABC as a powerful tool to evaluate the performance of production resources as well as human resources.

The proportion of overhead costs among other production costs has been gradually increasing in the recent years (MacArthur, 1993; Kaplan and Atkison, 1998). Sheu *et al.* (2003) consider the increase in the share of overheated costs as a consequence of increasing in product diversity, which require a variety of support activities. Another reason for this increase is the attractiveness of automation as well as the reduction of direct labor in the manufacturing process (Gunasekaran *et al.*, 1999). Hence, increases in the proportion of indirect costs have positioned ABC/M as an advantageous accounting system. Incurs

There are many studies that demonestrate the benefits of ABC/M implementation in different manufacturing/service industries. Gunasekaran and Sarhadi (1998) made a comprehensive study on the implementation issues of ABC/M in manufacturing. They showed how ABC/M helped some Finnish manufacturing companies to identify and to remove non-value added activities. The ability to identify and analyze non-value added activities positions ABC as a complementary tool for implementation of Lean Manufacturing (LM) policies.

Gunasekaran *et al.* (1999) provided four different successful examples of ABC/M implementation in some Dutch and Belgian industries. Themido *et al.* (2000) and Baykasoglu and Kaplanoglu (2008) showed the advantages of ABC/M in the transportation industry. Nachtmann and Al-Rifai (2004) examined the benefits of its implementation in an air conditioner manufacturing industry. Singer and Donoso (2006) studied the benefits in a steel manufacturer and Rezaie *et al.* (2008) in a flexible manufacturing system in a forging industry. Krishnan (2006) showed the application of ABC/M in a higher learning institution.

Some studies, Cooper (1996), Currie (1999), Cagwin and Bouwman (2002) and Cagwin and Ortiz (2005) proved the positive association between ABC/M and other supply chain management improvement strategies such as just-in-time (JIT), total quality management (TQM), and business process reengineering (BPR). Novićević and Antić (1999) introduced ABC/M as an 'enabler' to sustain improvement strategies and to optimize their effectiveness. Recently, Banker *et al.* (2008) analyzed the positive effect of ABC/M on the adoption of world-class manufacturing (WCM) components practices. Although ABC/M has been proven to be a successful accounting system, we believe that its full potential has not yet been completely utilized in industry.

The application of cost information in the management decision making process has been a key research topic in cost accounting for the last two decades (Boyd and Cox, 2002). The presented survey by Boyd and Fox (2002) results showed the importance of cost accounting information in production decision making areas such as, product pricing, product profitability, make vs. buy, and plant expansion. Among the cost accounting systems, ABC/M is a more appealing approach to supply chain management (SCM) decision making process since it provides a more detailed and a hierarchical cost structure. One possibility is integrating ABC/M cost structure and information into SCM mathematical decision support systems (DSSs). ABC/M and mathematical programming are two synergic approaches for creating data-driven models to analyze decisions about managing the firm's resources (Shapiro, 1999). Gupta and Galloway (2003) introduced ABC/M as a supportive information system in operations decision making processes such as, product planning, product design, quality management, process design, process improvement, inventory management, and investment management.

Initially, Cooper and Kaplan emphasized the capability of ABC/M in measuring and controlling the costs of resources. The activity cost drivers are not devices to allocate costs. In fact, cost drivers represent the consumption that the final product/service makes on each activity (Cooper and Kaplan, 1992). This facilitates the analysis of the performance of production resources by each product separately.

The rate of activity usage subsequently identifies the rate of resource usage. By adding up the costs of all resources supplied to perform activities for an individual product/service, ABC/M estimates the costs of the resources consumed. It can approximate the costs of idle or unused resource capacity. This capability turns ABC/M into a powerful tool for solving the typical SCM decision making problems such as, product mix, vendor selection, order management, *etc*.

In order to analyze the ABC/M effectiveness at different decision making process levels, especially the order management problem, this chapter focuses on the reviewing all the work which integrates ABC/M information and cost structure in SCM mathematical decision support models at different managerial hierarchy levels (*e.g.* operational, tactical, strategic level). The remainder of this study is organized as follows; section 2.1 explains the searching methodology and provides the articles classifications for ABC/M integration in profitable-to-promise (PTP) mathematical decision support models. Section 2.2 explains the advantages of system dynamics (SD) and the possibility of using SD models as a complementary factor in developing PTP models. The conclusion and research summary are explained in the last section.

2.1. ABC/M in Mathematical Decision Support Models

Robert Kee (1995) proposed initially an ABC/M-based mixed integer programming (MIP) model to identify the optimal product mix from concurrent evaluation of the cost, physical production resources, and market demands. ABC/M was integrated to the model by applying the homogenous cost pool structure by Cooper and Kaplan (1991). According to their cost structure, the manufacturing overhead costs can be assigned to four specific homogenous cost pools; (1) unit-level (*e.g.* machining, material, direct labor), (2) batch-level (*e.g.* material handling, setup), (3) product-level (*e.g.* process engineering, manufacturing equipments maintenance, product design), and (4) facility sustaining (*e.g.* rent, utilities). The latter includes the non-volume related overhead costs which cannot be traced to a specific product or service easily. This approach results in having a higher level of control on the production resources (*e.g.* financial, human, intellectual) which can facilitate the process of planning, collecting information, and enriching the communication channels between and within supply chains.

Since then, several studies attempted to justify the usage of ABC/M in different SCM decision making domains. Ioannou and Sullivan (1999) analyzed it for investment decisions with an illustrative example for capital investment for automated material handling. Pirttila and Hautaniemi (1995) showed how ABC/M principles could be applied in distribution logistics and what relevant benefits could be achieved. Roodhooft and Konings (1996) justified the ABC/M potential benefits in supplier (vendor) selection and evaluation.

Tornberg *et al.* (2002) emphasized on the value of the cost information provided by ABC/M for product design and development. Subsequently, Ben-Arieh and Qian (2003) showed how ABC/M can improve the product development process by removing the non-value added activities and increase the company response rate to product changes.

Tsai (1996) discussed on the usefulness of ABC/M information for joint products decision making problems where the product profitability and product resource consumptions are the two main decision making factors. Lea and Fredendall (2002) elaborated the importance of ABC/M in product mix decision in a dynamic manufacturing environment where there were variations in factors such as demand and purchasing price. They also justified that a management accounting system which leads to higher short-term profits will also generate higher long-term profits. The critical point is regarding the applicability of ABC/M information and cost structure for short-term decisions (tactical/operational level decisions) versus long-term decisions (strategic decisions).

Although ABC/M opens up the possibility to apply more structural and precise planning procedures to SCM at the tactical level, it is not a suitable planning instrument at the strategic level such as portfolio or outsourcing decisions (Scheeweiis, 1998). On the other hand, Shaprio (1999) comprehensively analyzed the effectiveness of ABC/M for strategic decision making actions. He believes ABC/M can take the responsibility of extrapolating historical costs and costs relationships which is valuable for the strategic decision and planning procedures.

2.1.1. Review Methodology

A back and forth searching methodology is applied aiming to find articles within the scope of the dissertation topic. It is called back and forth technique because after finding any relevant resources, the references of the article are verified (move backward) and subsequently the citing articles are verified (move forward) to find the other relevant resources, Figure 2-1. The citing reports are extracted from *ISI Web of Knowledge* data base.

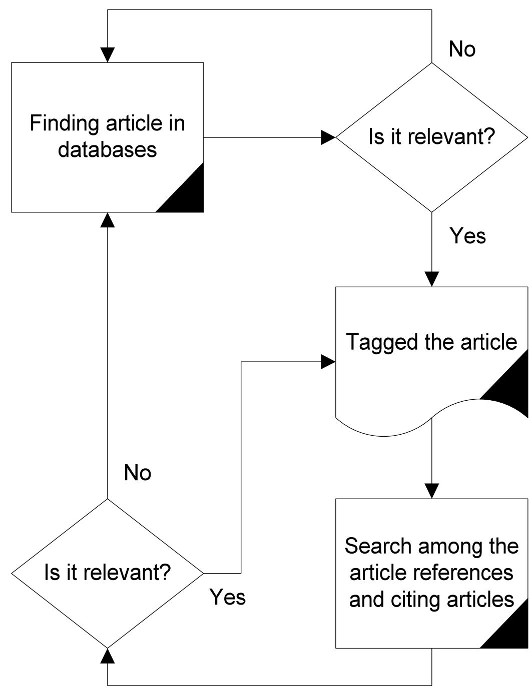

Figure 2-1: Literature searching procedure

The review search was based on the descriptors such as, ‘activity-based costing’, ‘activity-based management’, activity-based costing and supply chain management’, ‘activity-based costing and mathematical programming’, activity-based costing and decision support model’, activity-based costing and optimization’ in different academic and scholarly search engines such as, *Engineering Village*, *ProQuest*, and *Google Scholar*. The relevancy was checked and the applicable articles were tagged. The same procedure has been applied for any references and cited articles in order to find the new resources. The search methodology applied allowed us to find 50 articles in this research area, which are distributed among different publishers as can be observed on the following graph, Figure 2-2.

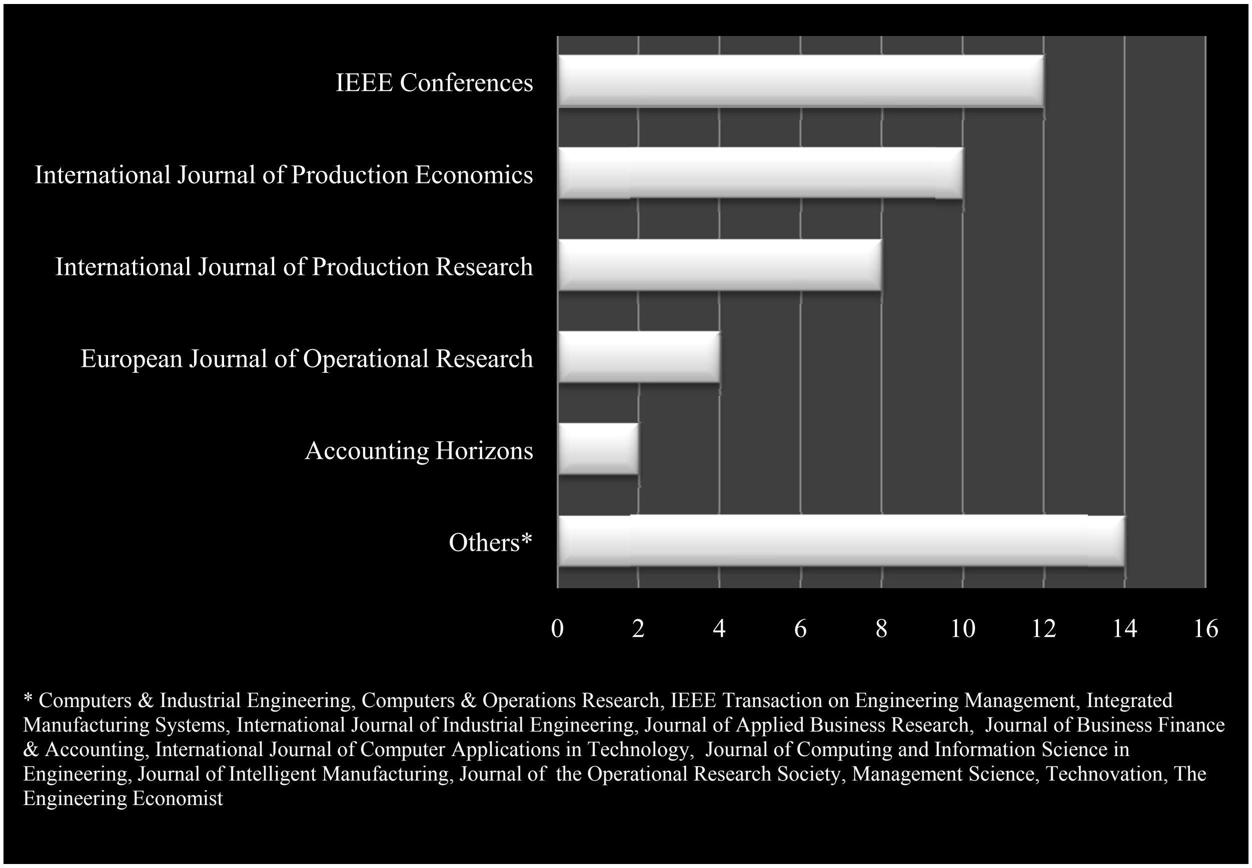

Figure 2-2: Distribution of articles by publisher

Even though not all the selected articles present an ABC/M-based mathematical decision support model, they were selected to perform a more detailed examination in order to have better understanding about the structure and scope of the subject. The subject matter is relatively a new domain of research, thus a limited number of articles have been found. The articles have been published, for the most part, in the *International Journal of Production Economics* and the *International Journal of Production Research*. There are fourteen journals that have only published one research article in this topic, are shown as *Others* in Figure 2-2.

Among these fourteen journals, seven of them, *Computers & Industrial Engineering*, *Computers & Operations Research*, *Journal of Business Finance & Accounting*, *Journal of Intelligent Manufacturing*, *Journal of the Operational Research Society*, *Management Science*, and *Technovation*, have been included in the ISI citation report published by Thomson Reuters. In addition, three journals fit within the Business and Management area, Journal of Applied Business Research, Journal of Business Finance & Accounting, and The Engineering Economist. The scope of Journals of Management Science and Technovation are closer to the Management and Business domain rather than to Industrial Engineering or Operations Research as well. Therefore, the articles published by these five journals are more conceptual than mathematical. The remnants focused their attention on Mathematical Programming; hence, the core is developing mathematical DSMs at the strategic, tactical or operational levels. Remaining twelve articles are from IEEE associated conference proceedings.

2.1.2. Literature Classifying Approach

Out of 50 articles that were selected, 44 of them have either conceptually or mathematically show the benefits of the integration of ABC/M with SCM mathematical decision support models. The articles are categorized into three groups, ABC/M direct integration, indirect integration of ABC/M, and conceptual studies. In the first group, the mathematical model is formulated according to the ABC/M cost structure. One of the most commonly observed integration approaches is applying Cooper and Kaplan (1991) costs structure (unit level, batch level, product level, and facility sustaining level). The studies in the second group, although they present a mathematical approach, ABC/M cost structure was not integrated directly to the model. The approach in this study calculates the costs based on ABC/M in the first phase and use the results as input for the mathematical model. The last group contains articles which do not provide any mathematical model but they illustrate the benefits of implementation ABC/M in a specific SCM area theoretically. Under the three categories, the articles are also sub-categorized according to the different supply chain activities in three managerial hierarchy levels, namely strategic, tactical, and operational, see Figure 2-3.

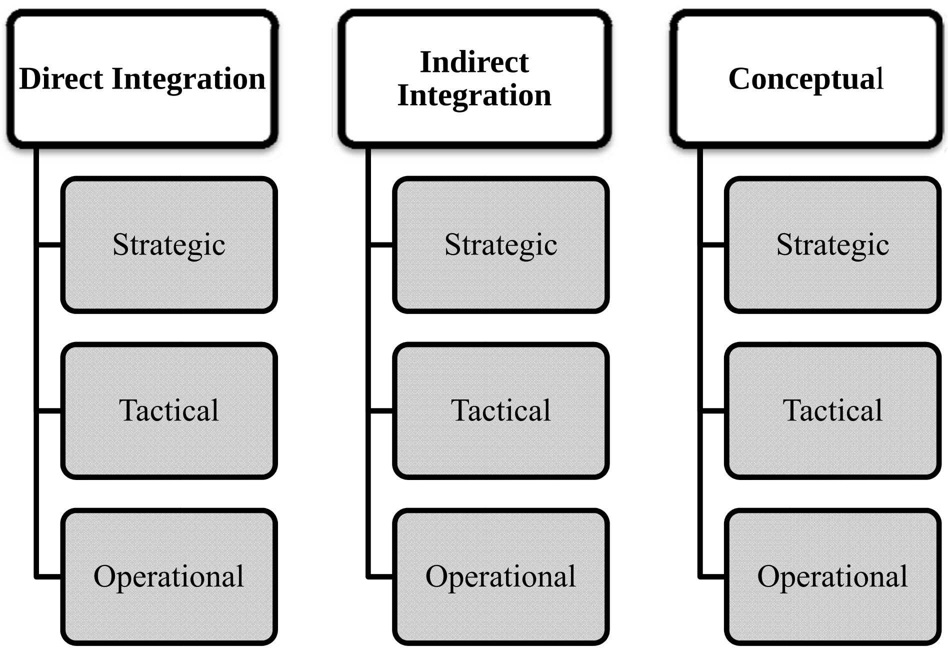

Figure 2-3: Articles classification approach

Although the difference between the tactical and operational managerial hierarchy levels is not lucid, we are making a distinction between these two groups in order to identify the pattern of the future mix ABC/M and mathematical decision support models.

Strategic Level

At the strategic level, the decision support models are focused on investment problems as well as for planning and cost control. The latter group mostly emphasizes the validity and applicability of the ABC/M-based mathematical decision support models for SCM. Shaprio (1995) affirms that the links between ABC/M and mathematical modeling are bidirectional. ABC/M can be used as a tool to identify the resources, as well as human resources, and their associated costs in order to transfer them to the mathematical model. On the other hand, mathematical models provide a template for ABC/M. Singer and Donoso (2008) showed how to implement and validate an activity-based costing optimization model. The mathematical model they suggested did not follow the ABC/M cost structure, but they used ABC/M information in order to calculate the production associated costs in the model.

Kim *et al.* (1997) presented an ABC/M-based linear programming model in the investment decision domain. The objective function was to maximize the net present value of after tax cash flow. The model also considers the opportunity costs of the residual capacity of activities (resources) consumed, in addition to the other make-to-stock decision factors. The benefits of this DSS developed were demonstrated through a robotic cellular manufacturing system example. The highly automated manufacturing process that was selected illustrated the advantages of applying ABC/M/M cost structure into the model.

Ozbararak *et al.* (2003) extended their model and applied it to an advanced manufacturing system that could be run under MRP or JIT systems. Homburg (2004) shows the applicability of ABC/M in transferring the inflexible overhead resources to the portfolio decision support mathematical models. Boonkhun *et al.* (2005), through using weighted goal programming (WGP) modeling technique, presented an ABC/M-based mathematical decision support model which pursues monetary (*e.g.* costs) and non-monetary (*e.g.* performance index) goals at the same time.

Tactical Level

At the tactical level, the models are classified into four SCM activities. The first group of studies contains models in logistics and inventory management. Yang and Liu (2008) presented ABC/M oriented inventory management decisions formulas. The new set of formulas is developed based on ABC/M cost structure instead of the traditional cost accounting. For example, in order to define the holding costs, instead of using the average amount of inventory they used warehouse required space as a cost driver. Tsai and Hung (2009b) presented a multi objective preemptive goal programming (PGP) decision support model for a reverse logistics process. The model follows environmental goals, ABC/M goals, and supply chain goals, simultaneously. ABC/M costs structure was integrated into the model by applying the homogenous cost pool developed by Cooper and Kaplan (1991).

The other group of models focuses on supplier (vendor) selection (procurement models). Initially, Roodhooft and Konings (1996) analyzed the applicability of mix ABC/M and mathematical programming for supplier selection. The idea was that ABC/M can estimate the supplier costs more accurately compared to traditional cost accounting systems. The detailed cost structure can even help to evaluate the risks associated with each supplier. Selecting the least expensive supplier can result in higher profits for the production unit as well as the whole supply chain. Integrating the ABC/M structure in supplier selection mathematical models leads to select the supplier which provides lower costs. Degraeve and Roodhooft (1998) presented an optimization model with the goal of minimizing the cost of ownership. In order to estimate the cost of ownership according to ABC/M system, they define three distinguished levels of homogenous activities, supplier level, order level, and unit level to cluster all the costs.

The justification of ABC/M benefits in order management models is very similar to the procurement models. In these models, ABC/M focuses on choosing the least expensive supplier. In order management models, ABC/M is responsible for finding the most profitable customers. In supply chain order management; Kirche *et al.* (2005) presented a MIP model for accepting or rejecting orders by implementing ABC/M homogeneous cost pool structure originally introduced by Cooper and Kaplan (1991).

The purpose of the model was to gain insight into how significant order management decisions are in maximizing profitability while the firm has insufficient production resources to satisfy all the available demand; in fact, they introduced ABC/M as a powerful tool in order management Profitable-to-Promise (PTP) approach. In PTP, besides resource availability, the order profitability is a critical factor for appointing the order fulfillment strategy. Accordingly, their mathematical objective function was based on maximizing the profit. Although the model introduced an important concept, it had some limitations such as: the restriction of fulfilling orders completely which does not help the company to use all its available capacity by partially acceptance of the orders; the inventory cost of the common part was not reflected and the overhead costs were not clearly illustrated.

These limitations bring us far from real-world situations and consequently cannot provide us with a precise and reliable final answer. Recently, Khataie *et al.* (2010) expanded the previous model, Kirche *et al.* (2005), by adding the possibility of pursuing two main different goals simultaneously, reducing the residual capacity and increasing the profitability. The mathematical model associated with an illustrative example is discussed in Chapter 3 inclusively.

The next SCM set of activities is on product development. Shorter market life span of the product is one of the main characteristics of today's business competitive environment. Ben-Arieh and Qian (2003) emphasized on the importance of shorter product development process. ABC/M has the capability to distinguish non-value added activities in the process. This helps to improve the product development process by identifying, analyzing, and removing the non-value added activities, implementing LM policy. Subsequently, it can increase the response rate to variations in customer requirements in the market.

On the other hand ABC/M is an effective tool for evaluating different design options (Tornberg *et al.*, 2002). Jiang and Hsu (2003) combined fuzzy multiple attribute decision making (FMADM) with ABC/M for activity decision space. FMADM refers to making decisions in the presence of multiple attributes, usually conflicting attributes. The method normally consists of two steps: (1) the aggregation of performance score for each alternative, (2) the ranking of the alternative according to the relevant score.

Operational Level

Product mix was the original application of ABC/M in SCM mathematical decision support models. In such problems, the key decision factor is to assign the production resources to the products in a way that maximizes the profit. Malik and Sullivan (1995) discuss the ability of ABC/M for integrating the resources idle capacity cost into SCM mathematical decision support models. They emphasized on the ABC/M advantages in long-term planning, when the role of overhead costs is most relevant, over traditional cost accounting (TCA) technique. Trough ABC/M implementation they also estimated the cost of idle capacity associated to each manufactured product. Through this integration, the cost of each type of product was estimated more accurately.

Kee (1995) integrated some aspects of theory of constraints (TOC) in ABC/M-based mixed-integer programming (MIP) modeling for the product mix problem and named it "Expanded ABC/M Model." For this purpose he utilized the Cooper and Kaplan (1991) cost framework. The model identifies the firm's optimal product mix by evaluating simultaneously the resources and product cost, the production resources availability, and the business marketing opportunities. Kee and Schmidt (2000) developed a generic MIP model for product mix problems emphasizing on the management discretionary factor. They also showed that ABC/M and TOC can provide an optimal product mix solution in scenarios which management has complete control over labor and overhead resources using a numerical example.

Tsai (1996) justified the advantages of ABC/M in joint products decisions as a more specific and complex case of product mix. Joint products are two or more products produced all together from a one material. In this case there are complex interactions among production resources and products and sequential decision considering producing joint products and their further processing (Tsai *et al.*, 2008). Tsai and Lai (2007) developed an ABC/M-based MIP model for joint products decision with options of capacity expansions or outsourcing.

The applications of ABC/M in operational level mathematical models are mostly limited to the product mix case. However, due to the increase in overhead costs, ABC/M integration with mathematical models started to expand into the other operational level SCM activities such as scheduling and quality cost control. However, these studies are still at the preliminary stages. Shao and Ke (2006) presented an ABC/M oriented mathematical/analytical approach for defining the preferable lot size and lead time. Liu *et al.* (2008) proposed an ABC/M-based cost of quality model in computer integrated manufacturing system (CIMS).

Table 2-1 demonstrates the complete classification of all articles reviewed. The table also shows that ABC/M has been mostly integrated into the tactical level decision support mathematical models, although the advantages at the strategic level have been shown trough its implementation in investment problems. There are also few studies, mostly in the product mix area, which integrate ABC/M with mathematical modeling approach at an operational level.

Table 2-1: ABC/M-based SCM decision support model classification

	SCM Activities	ABC/M direct Integration	ABC/M indirect Integration	Conceptual
Strategic	***Strategic Planning and Cost Control***	Shapiro (1999)	Singer & Donoso (2008) Liu et al. (2008)	
Strategic	***Investment Decision***	Kim *et al.* (1997) Homburg (2004) Boonkhun *et al.* (2005)	Ramdas & Sawhney (2001)	Ioannou & Sullivan (1999)
Tactical	***Logistics and Inventory Management***	Yang & Liu (2008) Tsai & Hung (2009b)	Sun *et al.* (2008) Yang (2008) Zhou & Wang (2008)	Pirttila & Hautaniemi (1995)
Tactical	***Supplier and Vendor Selection***	Degraeve & Roodhooft (1998) Degraeve & Roodhooft (1999) Degraeve & Roodhooft (2000) Tsai & Hung (2009a)		Roodhooft & Konings (1996)
Tactical	***Order Management and Customer Profitability***	Kirche *et. al* (2002) Kirche *et. al* (2005) Kirche & Srivastava (2005) Zhang *et al.* (2007) Kirche & Srivastava (2007) Khataie *et al.* (2009) Khataie *et al.* (2010)		

	SCM Activities	ABC/M direct Integration	ABC/M indirect Integration	Conceptual
	Product Development	Jinag & Hsu (2003)	Xu *et al.* (2006) Qian & Ben-Arieh (2008)	Tornberg *et al.* (2002) Ben-Arieh & Qian (2003)
Operational	***Product Mix and Joint Products Decision***	Kee (1995) Malik & Sullivan (1995) Yahya-Zadeh (1998) Kee & Schmidt (2000) Tsai & Lai (2007) Wang *et al.* (2007) Tsai *et al.* (2008) Karakas *et al.* (2010)		Tsai (1996) Lea & Fredendall (2002)
	Quality Cost Control			Liu *et al.* (2008)
	Lot Sizing and Scheduling		Shao & Ke (2006)	Fujii & Kaihara (2003)

2.2. ABC/M in System Dynamics Decision Support Models

One of the most promising soft OR approaches is system dynamics. J. Forrester (1961) defines industrial dynamics (system dynamics) as "*the study of the information feedback characteristics of industrial activity to show how organizational structure, amplification (in policies), and time delays (in decision and actions) interact to influence the success of the enterprise. It treats the interactions between the flows of information, money, orders, materials, personnel, and capital equipment in a company, an industry, or a national economy*." Although, he initially developed SD for decision making process at the operational level for manufacturing and industrial processes, but according to the literature review presented in study (Baines and Harrison; 1999), SD has been applied in service and resource management problems for the strategic level decision and analysis.

According to Tako and Robinson (2009), there are major differences between Discrete Event Simulation (DES) models and SD models. In DES models, specific entities can be followed throughout the system, system status changes occur at discrete points of time. DES models are stochastic in nature; their structure consists of a network of queues and activities. DES models are typically applied for the tactical level situations. On the other hand, in SD models specific entities cannot be followed throughout the system, system state and variables change continuously at small segments of the time. Stochastic features are rarely used in the SD models; the structure of SD models consists of a system of stocks and flows. SD models are mostly applied for strategic level situations.

The two main reasons for the popularity of SD are the complex nature of the problem and the qualitative factors such as human beings evolvement in those processes.

According to the earlier definition presented by the System Dynamics Group at MIT; “system dynamics is a method for studying the world around us. It deals with understanding how complex systems change over time. Internal feedback loops within the structure of the system influence the entire system behavior.”

Lately, system dynamics spread over numerous diverse areas of research by using the advanced generation of system dynamics simulation software. However, the survey presented by Braines and Harrison (1999) showed the limitations of system dynamics modeling in the manufacturing sector from the business and/or operational perspective. This represented a diversification from its original purpose, which was to serve as a decision support tool for manufacturing processes at the operational level. Instead, according to the survey, system dynamics have been broadly used in the modeling of resource management at national and global level decision making processes, and in the service sector at operational levels.

Gregoriades and Karakostas (2004) presented a framework (integration of business objects and SD) as a decision support modeling technique that facilitates the perdition process in today’s market-driven organizations. The study shows how SD can integrate with business objects and act as a powerful simulation approach to help organizations in pursuing their goals and mentoring their processes. On the other hand, the Supply Chain Management (SCM) optimization models cannot integrate all the qualitative factors involved in the production related decision making process effectively.

According to the taxonomy of the research developed by Angerhofer and Angelides (2000), system dynamics has been applied in the different areas of SCM including studies in inventory management, demand amplification supply chain re-engineering, supply chain design, and international SCM. SD was originally developed for modeling of manufacturing processes. Baines and Harrison (1999), through reviewing 80 research articles, showed that system dynamics has been applied mostly at the global level for resource management, which refer to the primary industry and natural resources (*e.g.* agricultural, oil). The large number of studies in the strategic and global levels is mostly in the area of ecological studies. SD has also been applied at the business level for strategic planning, marketing, and financial scenarios evaluation. The authors conclude that the main reason for the less popularity of SD in the area of operations and manufacturing modeling is due to the lack of dedicated software tools for this purpose.

Sterman (2000) emphasized on the interdisciplinary nature of system dynamics for solving real-world complex problems. He presented different successful applications of SD (*e.g.* Automobile leasing, Project management, Health industry). Although SD has been applied into different domains; the ability of this simulation approach to serve as a cost monitoring and analysis tool has not been profoundly exploited.

Abdel Hamid and Madnick (1987) applied SD simulation technique to evaluate the consequence of multi-variables changes in the model on the software development process costs. Their model, for the first time, considers the managerial qualitative functions (*e.g.* planning, staffing, controlling) and directly involved activities in the development process (*e.g.* coding, testing) concurrently.

Sachan *et al.* (2006) evaluated the total costs for grain supply chain under three different supply chain structures and three different likelihood of occurrence. SD modeling approach was implemented to analyze the dynamic interaction among key variables (*e.g.* echelons' prices, transition losses, costs) affecting grain supply chain cost.

They incorporated costs such as inventory holding costs, material handling cost, and packaging cost at different supply chain echelons. The minimum costs represented the most suitable structure for the grain supply chain.

Bianchi (2002) emphasizes on the advantage of learning ability of SD models in small and medium enterprises business planning and control, including activities such as setting goals and objectives, strategic and operational planning, goal and objective updating and adjustment. The author related the effectiveness of SD decision support models to the way of defining the decision variables. He implies that SD model must include the standardized financial variables in order to keep the financial constancy as a main characteristic of the business DSSs. The integration of the cost accounting techniques with SD can stress the harmony between the financial variables and the decision making variables. The author also presented a generic SD model embodying the traditional cost accounting technique. The model identified important aspects, which should be considered in developing cost accounting oriented decision support models. However, this modeling approach is too generic to implement and could be considered as an intermediate step in the SD modeling.

Boyd and Cox (2002) evaluated the benefits of using modern accounting techniques such as ABC/M and throughput accounting (TA), the accounting approach based on philosophy of TOC, and their compatibility with today's production environment. The study was done through a survey answered by managers of 85 companies in order to identify the most significant decisions in which cost accounting information is used. Based on the output of a simulation model, they concluded that in the production decision making process the types of accounting technique that provide better understanding about the production constraints and avoid indirect cost allocation are more reliable.

Lea and Fredendall (2002) examined the impact of management accounting techniques on the company's financial and non-financial performance. They concluded that ABC/M can achieve higher financial and non-financial performance, especially in a highly automated production system compared to the TCA techniques. An automated production system normally contains significantly high overhead costs. Their study also showed that the ABC/M accounting technique which is profitable and reliable for the short-term planning is as well suitable for the long-term planning.

Macedo *et al.* (1997) developed a preliminary real-time cost monitoring model by integrating ABC/M and SD for the reengineering process of creating a culture media, a gelatinous substance for cultivating bacteria and viruses, production at the microbiology laboratory in a hospital at Montreal. The authors establish it is necessary to employ a real-time monitoring system that notifies when the process is problematic. This is because of the high risk of failure involved normally in reengineering processes. However, the models acted as a real-time cost calculator rather than real-time cost monitoring system dynamics models. The model does not include any positive or negative feedback loops; moreover, it did not consider any qualitative factors that may be involved in a cost monitoring process.

2.2.1. Hybrid (SD-MIP) Decision Support Models

The importance and some advantages of hybrid supply chain decision support systems have been discussed shortly in a recent study presented by Martinez-Olvera (2009). He addressed a limitation in the past research in the domain of integration of supply chain DSSs by a short review study. Based on the provided review, only three studies have paid attention to some dimensions of this subject; Li and O'Brien (1999, 2001) and Sen *et al.* (2004). He also emphasized on the ability of simulation models, specifically SD, in finding the value of decision variables involved in optimizing a quantitative objective function according to certain constraints. In fact, simulation model and optimization model can work together as a DSS to facilitate the data analyzing process and improving each model compounded performance. The vital factor is how to unify these two components and facilitate the transmission of data and information between two system components.

2.3. Chapter Summary

The first part of this chapter focused on reviewing of integrating ABC/M in SCM mathematical decision support models importance. The literature review showed that there are limited numbers of studies, which have integrated directly or indirectly ABC/M within SCM mathematical decision support models at different managerial hierarchy levels.

The study also showed that, although ABC/M has been widely applied into the SCM tactical level mathematical decision support models, the effectiveness of that for certain supply chain strategic planning and decision procedures, especially investment decisions, has been elucidated in few studies. Therefore, the idea that ABC/M is not a suitable cost accounting system at the strategic level, at least contradicts with some articles. However, it can be said that ABC/M provides more applicable cost structure and information for tactical/operational level decisions. In general, ABC/M integration enhances the validity and credibility of the results provided by SCM mathematical decision support models.

The second part of the chapter mainly focused on the reviewing applicability of system dynamics as powerful modeling tool in simulating financial aspects of production processes. Most of the models used SD as a simulation tool; work as cost calculator more than a system dynamics model. Basically, the modeling approaches that have been presented so far in this domain do not apply all the advantages of system dynamics properly in developing the decision supports models.

According to the presented review, although some studies have emphasized on the advantages and credibility of modeling based on the modern accounting approaches such as throughput accounting and activity-based costing and management but, still a SD-based decision support model which has applied the advantages of SD aligned with the credibility of new accounting systems has not been presented in literature. The review study, also roughly discussed the idea of developing hybrid decision support models and the benefits and advantages that such models can have. This type of model can be a result of integrating different mathematical modeling approaches (*e.g.* hard operations research and system dynamics).

The following next three chapters contain the necessary steps that have been taken in order to develop a comprehensive decision support system for a typical order management problem in a three-echelon supply chain.

Chapter 3

ABC/M-Based Multi-Objective Optimization Approach for Order Management

A business can greatly benefit from a dynamic approach that can determine how the orders should be treated. This can be reached through a decision support model that considers profitability and capacity usage of each order concurrently. Controlling the profitability requires a complete understanding of the production cost. The production cost is a function of external factors, such as the inflation rate and raw material costs, as well as internal parameters such as the rate of automation and the utilization rate of the production unit. There are several essential aspects that such a model should consider in order to provide a constructive solution for the order management problem; short-term profitability, long-term stability, and customer loyalty.

One of the important criteria is the short-term profitability. This approach normally utilizes less capacity for the revenue offered, and allows the acceptance of further orders once the current order is fulfilled and the capacity is freed. Basically, enterprises prefer to produce a product and accept an order which generate a higher profit margin by consuming fewer amounts of resources in the shortest possible time. In this approach, calculating the right production cost and assigning a proper selling price play a crucial role. For instance, such a policy could be typified in job shops and other short run production facilities, where clients and products change frequently due to variations in the market demand.

The second parameter is the long-term stability. Long-term stability means that the chosen order is the one that provides a guaranteed profit over a longer period of time. Basically, the preferences of companies are on producing and investing on the products that make money for the business for a longer duration. This goal could be archived through offering a type of product that has a long-term demand. In other words, despite the fact that the profit potential is not as high as that in the short term profitability criterion (since the capacity is not freed up as quickly), there is less risk for the production facility to be standing idle due to the lack of orders.

Customer loyalty is the third vital factor. The critical issue here is to provide a product with specific requirements and attributes which could motivate customers to continue the business with the company. The idea behind this is that a loyal customer is generally more profitable over a one-time customer. However, any single contract that preserves the business relationship has a value of its own since this could be changed to a long-term relationship if both sides are satisfied with the business.

In this chapter, we show how activity-based costing (ABC/M) integration in supply chain (SC) order management mixed-integer programming (MIP) model can assist the model to support the business in perusing its short and long term objectives indicated. The new model is taking into account the fulfillment of a desirable amount of orders completely due to the importance of selective customers' satisfaction and the possibility of satisfying the rest of the orders partially, with the objective of minimizing the residual capacity. This chapter is organized as follows: Section 3.1 discusses the applied cost structure. In section 3.2 and 3.3, the model and numerical examples are presented respectively. Section 3.4 contains chapter summary and conclusions.

3.1. ABC/M Cost Structure

The manufacturing or factory overhead costs refer to all indirect costs that are incurred to keep the factory operational. Costs such as the utilities that are consumed by the production unit, any kind of depreciation on equipment and building, and factory personnel (excluding direct labor) can be considered as typical examples of overhead costs. Calculating those costs and finding the consumption of each per unit of product is one of the big challenges for the companies. ABC/M assigns the overhead costs to the products through the required production and manufacturing activities. This provides a more accurate estimation of production and manufacturing costs per unit of each product. Cooper and Kaplan (1991) presented a framework for manufacturing cost which assigns the overhead costs to four specific cost pools:

- Unit-level activities (machining time, material, direct labor, *etc.*) costs that vary directly with the number of units produced.
- Batch-level activities (planning and tactical management, material handling, setup, *etc.*) costs which are invoked whenever a batch is processed.

- Product-level activities (process engineering, design, *etc.)* costs which come into play whenever a particular product is manufactured.
- Facility sustaining activities costs such as rent, utilities, maintenance, and facility management.

This approach helps to show and clarify the role and source of each overhead costs in a production and manufacturing processes. According to the manufacturing environment presented as well as Cooper and Kaplan's (1991) framework; overhead costs are distributed among unit-level, batch-level, and product-level. The following section contains the mathematical model developed.

3.2. The ABC/M–based Mixed Integer Programming Model

In this chapter, the ABC/M based mixed-integer programming model developed will be presented and analyzed. The ABC/M cost structure is integrated into the MIP model by linking order fulfillment rate decisions with detailed unit, batch, and order-level costs to maximize the overall profitability and minimize the residual capacity, similar to the studies of Kirche *et al.* (2005) and Kirche and Srivastava (2005). The generic model has been developed based on the following assumptions:

- Processing times are deterministic.
- Transit time between cells is considered negligible.
- Each product is manufactured in equal-sized batches under a pull system.
- Demand for each type of product per order is deterministic.
- Each order consists of just one type of product.

- No possibility for increasing the production activities capacity.
- There is a possibility to satisfy the orders partially, completely, or even reject them.
- A desirable amount of orders should be fulfilled completely.
- The overhead costs are distributed among three levels of activities (Unit-level, Batch-level, and Product-level).

The m_i represents the preference coefficients for the model different objectives. The other assumption for this model is $m_1 > m_2$ which indicates that the capacity stretching policy is more expensive than not using the capacity completely; in fact, there is not any possibility for enlarging the capacity in this problem. Moreover, $m_4 > m_3$ shows that the goal of minimizing the residual capacity is more significant than making profit. The exact amount of m_i and the other coefficients will be discussed in the next section.

The new approach presented allows orders to be fulfilled partially, which allows the company to minimize the residual capacity. The model also has the possibility of indicating the amount of orders that need to be fulfilled completely based on the company's policies and customer relationships. This makes the model more customer-oriented by allowing us to make a decision based on customers' credentials. Accordingly, the mathematical model developed, using weighted goal programming (WGP) modeling technique, follows two goals simultaneously; to maximize the profit margin and to minimize the residual capacity. The model notation followed by the objective function and constraints are indicated below.

Notation

i *product index*

t	*period index*
r	*raw material index*
v	*supplier index*
j	*activities at Unit- level index*
k	*activities at Batch- level index*
l	*activities at Order- level index*
o	*order index*
d_l^+	*amount of over capacity production (capacity surplus variable)*
d_l^-	*amount of under capacity production (capacity slack variable)*
x_j	*cost rate of performing Unit- level activity j*
a_k	*cost rate of performing Batch- level activity k*
y_l	*cost rate of performing Order- level activity l*
c_{rv}	*unit cost of material r from supplier v*
g_{ir}	*required amount of resource r to produce product i*
h_i	*holding cost of product i per period*
cph	*Holding cost of common part*
q_{ij}	*required amount of time to perform activity j for product i*
u_{ijk}	*required amount of time to perform activity k at batch- level related to activity j at Unit- level for product i*
f_{il}	*required amount of time to perform activity l for product i*
b_{ij}	*batch size of product i at activity j*
p_i	*sales price of product i*
m_1	*cost of stretching the production capacity*
m_2	*cost of not using whole capacity*
m_3	*preference coefficient of maximizing profit*
m_4	*preference coefficient of minimizing residual capacity*
M	*The big M*
O	*desirable full order amount*
R_{rvt}	*supplier capacity of raw material r in period t*
D_{iot}	*demand quantity of product i in order o due in period t*

Q_{jt}	*total available time to perform activity j in period t*
U_{kt}	*total available time to perform activity k in period t*
F_l	*total available time to perform activity l*
I_{it}	*Inventory amount of product I in period t*
CPI_t	*common part inventory amount in period t*
P_{ijt}	*amount of product i produced in period t in machine j*
S_{iot}	*quantity of product i in accepted order o in period t*
B_{ijtk}	*number of batches of product i produced in machine j by applying setup k in period t*
Y_{iotl}	*The proportion of accepted order o from product i in period t by applying production line of l*
$YNew_{iotl}$	*The binary form of Y_{iotl}*

The Model

$Max\ z = m_3 \times (\sum_t \sum_o \sum_i p_i \times S_{iot}$ $\quad revenue$

$- \sum_t \sum_i \sum_v \sum_r \sum_{j=2} g_{ir} \times c_{rv} \times P_{ijt}$ $\quad raw\ material\ cost$

$- \sum_t \sum_i \sum_j x_j \times q_{ij} \times P_{ijt}$ $\quad unit\ level\ costs$

$- \sum_t \sum_i \sum_j \sum_k a_k \times u_{ijk} \times B_{ijtk}$ $\quad batch\ level\ costs$

$- \sum_t \sum_o \sum_i \sum_l y_l \times f_{il} \times Y_{iotl}$ $\quad order\ level\ costs$

$- \sum_i \sum_t h_i \times I_{it}$ $\quad inventory\ cost$

$- \sum_t cph \times CPI_t\ )$ $\quad common\ part\ inventory\ cost$

$-m_4 \times (\sum_l m_1 d_l^+ + m_2 d_l^-\ )$ $\ minimizing\ the\ capacity\ variation \qquad (3-1)$

Subject to:

Raw material constraints

$$\sum_i \sum_j g_{ir} \times P_{ijt} \leq \sum_v R_{rvt} \qquad \forall r, t \qquad (3-2)$$

Unit- level activities constraints

$$\sum_i q_{ij} \times P_{ijt} + \sum_i \sum_k u_{ijk} \times B_{ijtk} \ \leq Q_{jt} \qquad \forall j, t \qquad (3-3)$$

Batch- level activities constraints

$$P_{ijt} = b_{ij} \times \sum_k B_{ijtk} \qquad \forall i,j,t \qquad (3-4)$$

$$\sum_i u_{ijk} \times B_{ijtk} \le U_{kt} \qquad \forall j,k,t \qquad (3-5)$$

Order- level activities constraints

$$S_{iot} = D_{iot} \times \sum_l Y_{iotl} \qquad \forall i,o,t \qquad (3-6)$$

$$\sum_i \sum_o \sum_t f_{il} \times Y_{iotl} - d_l^+ + d_l^- = F_l \qquad \forall l \qquad (3-7)$$

$$\sum_l Y_{iotl} \le 1 \qquad \forall i,o,t \qquad (3-8)$$

$$\sum_i \sum_o \sum_t \sum_l YNew_{iotl} \ge O \qquad (3-9)$$

$$Y_{iotl} \ge YNew_{iotl} \qquad \forall i,o,t,l \qquad (3-10)$$

$$D_{iot} > \sum_l Y_{iotl} \qquad \forall i,o,t \qquad (3-11)$$

Inventory balance constraints

$$I_{i0} = 0 \qquad \forall i \qquad (3-12)$$

$$I_{i(t-1)} + \sum_{j=2} P_{ijt} - I_{it} = \sum_o S_{iot} \qquad \forall i, t \ge 1 \qquad (3-13)$$

Inventory balance constraints for common part

$$CPI_0 = 0 \qquad (3-14)$$

$$\sum_i \sum_{j=2} P_{i1t} - P_{ijt} + CPI_{t-1} = CPI_t \qquad \forall t \ge 1 \qquad (3-15)$$

Binary and non-negativity constraints

$$P_{ijt} \ge 0 \qquad \forall i,j,t \qquad (3-16)$$

$$B_{ijtk} \ge 0 \qquad \forall i,j,t,k \qquad (3-17)$$

$$0 \le Y_{iotl} \le 1 \qquad \forall i,o,t,l \qquad (3-18)$$

$$YNew_{iotl} = 0 \ \ or \ \ 1 \qquad \forall i,o,t,l \qquad (3-19)$$

The objective function consists of two parts which are required to pursue the two goals previously described; increasing the profit margin and decreasing the residual capacity. The first part of the objective function consists of seven mathematical terms. The first term calculates the revenue which is the multiplication of sales by the product price. The next six terms calculate the process costs including the cost of work in process (WIP) inventory. The second part of the objective function serves to minimize the residual capacity. According to this term any violation from the available capacity has a certain penalty cost. In order to decrease the residual capacity, the possibility of accepting the orders partially is added to the model by replacing the acceptance and rejection binary decision variable in the previous versions (Y_{iot}) with proportion fulfillment decision variables (Y_{iotl}). This decision variable can take any value between 0 and 1 which represents the proportion of order fulfillment.

The first set of constraints is established to limit the consumption of the raw material and the subcomponent to the available quantities that can be purchased. Constraints (3-3) and (3-5) ensure that the available Unit-level and Batch-level capacity, respectively, are not exceeded. Constraints (3-4) allow the variety in batch sizes to exist, the constraints (3-6) make sure that the production quantity meets the order commitments, and constraints (3-7) are the capacity variation constraints. Constraints (3-8) to (3-11) define the amount of desirable orders which should be fulfilled completely based on the company's policy. Finally, constraints (3-12) to (3-15) calculate the amount of inventory for the final products and for the common part or WIP at the end of each period. The rest of the constraints are self explanatory.

3.3. An Illustrative Numerical Example

The defined problem consisting of 14 orders from 4 different types of product in 14 periods is presented in order to compare the model with the possibility of acceptance of partial orders with the previous models that are developed based on accepting or rejecting orders completely. The related operational and financial parameters are also presented.

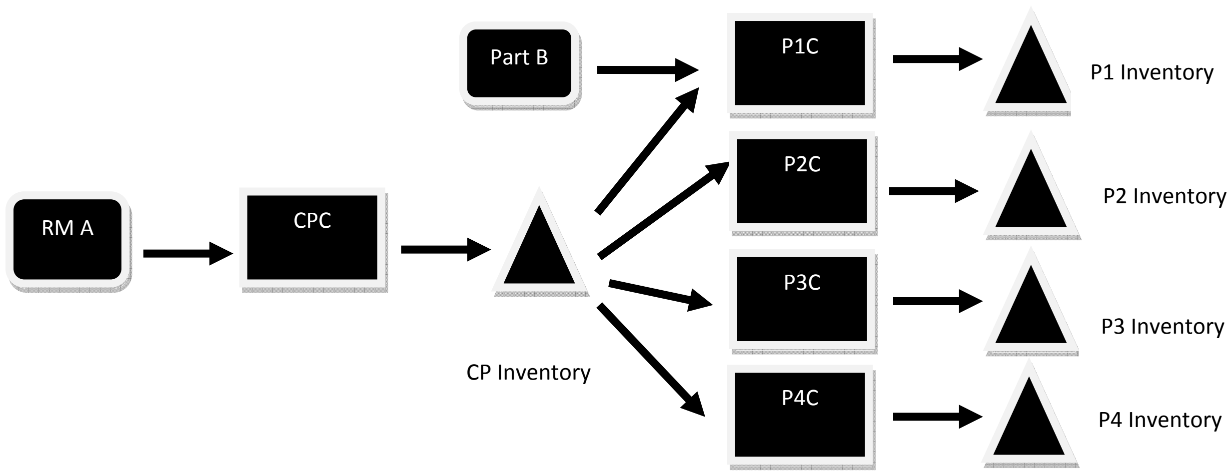

Figure 3-1: Manufacturing Process Flow

This study uses a pull production system which consists of two different types of suppliers, supplier of part A and supplier of part B who are trading directly with the producer. Each supplier has the capacity to provide 25 units of raw material "A" and 25 units of sub-component "B". The producer is manufacturing four different types of product (P1 to P4). It is also assumed that there are no delays in transporting the parts or/and raw material along the supply chain and between cells. This example is originating from the article of O'Brien and Sivaramakrishnan (1996) and has been also discussed in Umble *et al.* (2001) and Kiriche *et al.* (2005).

In order to manufacture the products, each unit has to go through the production cells; which are formed by a common cell followed by four product-specific cells. Figure 3-1 illustrates the manufacturing process, which begins by injecting the raw material "A" into the common part cell, the outcome is defined as common part (CP). Those common parts then transfer to each of their respective product-specific cells. There are four production lines, each one dedicated to one type of product. The only exception is product number one (P_1) which requires an extra part, named Part "B" in addition to "CP" to be completed. The production process finishes by storing the end products in their related warehouse; subsequently, the proper products are shipped to the related customers at the right moment. The related operational parameters such as total available production time, batch sizes, and required setup time which is originally from Yang and Jacobs (1999) are shown in Table 3-1. The product pricing parameters as well as the relevant cost data are shown in the

Table 3-2: Financial parameter are obtained from Kiriche *et al.* (2005).

Table 3-1: Operational parameters

			Product		
Activities	*CP*	*P1*	*P2*	*P3*	*P4*
Mean run time per unit(h)	0.25	0.25	0.25	0.25	0.25
Batch size(units)	4	4	4	4	4
Batch set-up time(h)	0. 500	0.333	0.333	0.333	0.333
Total available capacity in each cell per period(h)	9	8	8	7.5	7.5
Utilization rate in each cell	0.667	0.750	0.750	0.800	0.800

Table 3-2: Financial parameters

			Product		
	CP	*P1*	*P2*	*P3*	*P4*
Order-level Costs ($)		123.21	82.14	41.07	41.07
Batch-level Costs($)	14.28	9.58	9.58	7.19	7.19
Unit-level Costs($)	7.08	3.67	3.67	1.77	1.77
Sales Price($)	-	111.00	75.00	80.00	65.00
Inventory Costs($)	1.30	2.80	1.90	1.60	1.60

The Order specifications of the problem that have been developed to clarify the advantages of the improved model are shown in Table 3-3. The objective is to evaluate the 14 orders and provide a decision within 14 units of time (14 weeks). It is also assumed that for each unit of product P_1 to P_4, we need one unit of raw material "A" and for each unit of P_1, one unit of sub-component "B" is consumed. The model applied to the nine different scenarios by using the software Lingo Version 10;

- Without partial order acceptance
- With partial order acceptance
- Fulfilling the different desirable number of orders completely

Table 3-3: Order specifications

Order Number	Product Type	Period	Quantity	Order Number	Product Type	Period	Quantity
1	P1	1	40	8	P1	8	35
2	P2	2	57	9	P2	9	40
3	P1	2	50	10	P1	10	68
4	P3	4	45	11	P3	11	30
5	P1	5	65	12	P4	12	25
6	P1	5	95	13	P4	13	30
7	P3	7	50	14	P3	14	80

In order to give a higher preference rate to the goal of minimizing the residual capacity compared to maximizing the profit as well as diminishing the impact of preference coefficients on the objective function profit calculation; the amount of m_1 to m_4 are assumed equal to 1, 0.5, 1, and 2, respectively. In fact, this combination allows the model to calculate the precise amount of profit ($) in each scenario by reducing the effect of the preference coefficients in the calculation. The related outputs are shown in Tables 3-4 and 3-5.

Table 3-4: Planned order in with and without partial order acceptance

	Without Partial Order Acceptance					With Partial Order Acceptance				
	Product Type									
Period	*P1*	*P2*	*P3*	*P 4*	*CP*	*P1*	*P2*	*P3*	*P 4*	*CP*
1	0	0	12	0	12	0	4	8	0	20
2	0	0	8	0	16	0	24	4	0	20
3	0	0	16	0	20	0	0	16	0	20
4	0	0	16	0	20	0	0	16	0	20
5	0	0	16	0	20	12	0	16	0	20
6	0	0	16	0	20	0	0	16	0	20
7	0	12	16	0	20	0	0	16	0	20
8	0	16	12	0	20	0	4	16	0	20
9	0	12	16	0	20	0	24	4	0	20
10	0	0	16	0	16	4	0	16	0	20
11	0	0	16	0	16	0	0	16	0	20
12	0	0	16	0	16	0	0	16	8	20
13	0	0	16	0	16	0	0	16	4	20
14	0	0	16	0	16	0	0	16	0	16

By comparing the outputs in Table 3-4, it is clear that the utilization rate of our common part cell, which is in fact, the bottleneck of the process, increases significantly if the possibility of partial order acceptance is applied. Based on the operational parameter, the maximum capacity of the common part cell to manufacture CP is equal to 20 units per period which has been used completely with the exception of period 14. This gives the total residual capacity value of 4; while in the case of only rejecting or accepting the orders completely, the amount is equal to 32 for the 14 weeks of the planning period.

The results of applying the model to the different scenarios, with or without partial order acceptance and with desirable number of orders that should be fulfilled completely are shown in Table 3-5. The benefit of decreasing residual capacity by accepting the orders partially is illustrated by showing the increment in the profit margin *(Optimum Value)* by $1,053.48 when compared to the one without partial order acceptance. This also represents a 15% positive increase in the profit margin. The optimal solution is satisfying two orders completely and eight orders partially with different ratios of fulfillment. This yields a profit of $8,147.57. The model also demonstrates the value of the profit if there is a constraint on the number of orders that should be completely satisfied. The profit decreases as the number of orders that should be satisfied completely is greater than one, since the binding constraint is getting tighter. The model also gives an infeasible solution when it is required to satisfy more than six orders completely, due to a violation of the total available capacity constraints. The related software codes can be found in Appendix 1, ABC/M-based MIP order management model.

Table 3-5: Comparison table for fulfilling rate

	Without Partial Order	With Partial Order	*Minimum desirable amount of orders which should be satisfied completely*						
			1	2	3	4	5	6	7
Order	*Fulfilling Rate (%)*	*Fulfilling Rate (%)*	*Fulfilling Rate (%)*	*Fulfilling Rate (%)*	*Fulfilling Rate (%)*	*Fulfilling Rate (%)*	*Fulfilling Rate (%)*	*Fulfilling Rate (%)*	*Fulfilling Rate (%)*
1	-	-	-	-	-	-	-	-	No Feasible Solution
2	-	49%	49%	49%	42%	42%	42%	14%	
3	-	-	-	-	-	-	-	-	
4	100%	98%	98%	98%	100%	100%	100%	100%	
5	-	-	-	-	-	-	-	-	
6	-	13%	13%	13%	13%	13%	13%	1%	
7	100%	96%	96%	96%	100%	100%	100%	100%	
8	-	-	-	-	-	-	-	100%	
9	100%	70%	70%	100%	70%	1000%	100%	100%	
10		6%	6%	6%	6%	6%	-	-	
11	100%	100%	100%	100%	100%	100%	100%	100%	
12	-	32%	32%	32%	32%	32%	100%	8%	
13	-	13%	13%	13%	13%	13%	23%	100%	
14	100%	88%	88%	73%	89%	74%	54%	44%	
Profit $	$7094.09	$8147.57	$8147.57	$8144.16	$8137.10	$8133.70	$7884.73	$7468.52	

3.4. Chapter Summary

In this chapter, we presented a customer-oriented SC mathematical decision support model which considers the profitability issue in addition to capacity constraints by applying the goal programming modeling approach as well as integrating the ABC/M methodology in the mixed-integer programming. Integrating ABC/M cost structure enhances the accuracy of model output. In the model presented, the facility-sustaining activities are not included, although later, Chapter 5, it will be added to the model and discussed exclusively.

The developed decision support MIP model achieves its three main goals: (1) satisfy a desirable amount of orders completely according to the management determination, (2) it reduces the residual capacity (with the possibility of accepting the orders partially) in order to improve the process efficiency, and (3) maximize the amount of profit as one of the main goals of any businesses. Subsequently, the numerical results verified the presented model and illustrated the advantages of it over the previous ones that does not consider the possibility of fulfilling the orders partially and does not include the management discretionary factor.

Although the model can provide the optimal solution within an adequate time scale, it does not have the capability to present a comprehensive financial analysis on the solutions provided. A comprehensive model should also be able to consider the effects of factors such as interior customer liability, opportunity cost, the market environment, and enterprise market position in decision making process. The next chapter contains a resolution methodology for the inadequacies stated.

Chapter 4

An Activity-Oriented Cost Management Decision Support Model: Integration of SD and ABC/M

Operations research (OR) involves mathematical modeling approaches to find the optimal solution. However, all the aspects of an actual situation may not be integrated into an optimization model due to the high level of complexity. It may not be feasible to transfer all the variables and factors involved in the process into a mathematical model. Incorporating of certain details into the model could result in building very complex models and significantly increased computational time.

On the other hand, simplifying the problem through integrating reasonable assumptions may have an effect on the validity of the model output. In addition, implementing an optimal solution normally is a complicated and time consuming process, which requires spending a significant amount of resources. A long implementation time may invalidate the model's solution due to the possible changes in the status of the business environment.

As a result, doubts have arisen about the effectiveness of traditional optimization decision making and decision support modeling approaches for solving complex problems in today's competitive business environment. Therefore, management prefers a resolution problem solving scenario over an optimal solution, especially, if the former includes factors that are easy and fast to be modeled and implemented. This popularized the soft operations research modeling techniques like; SWOT (strengths, weaknesses, opportunities, and threats) analysis, decision trees, soft system methodology (SSM), and system dynamics (SD). Heyer (2004) states that these problem solving approaches, as opposed to the traditional OR hard methods, employ predominantly qualitative, rational, interpretative and structured techniques to interpret, define, and explore various perspectives of the problems under scrutiny. One of the most promising soft OR techniques is SD.

As noted before, Forrester (1961) defines industrial dynamics (system dynamics) as "*the study of the information feedback characteristics of industrial activity to show how organizational structure, amplification (in policies), and time delays (in decision and actions) interact to influence the success of the enterprise. It treats the interactions between the flows of information, money, orders, materials, personnel, and capital equipment in a company, an industry, or a national economy*". The two main reasons for the popularity of SD are the ability to model the complex nature of the problem, and to integrate qualitative factors, such as the human being involvement, in those processes into the model.

In recent years, due to different factors such as technology improvement, automation, product diversity, and product customization, the percentage of indirect costs as part of the total manufacturing costs has increased significantly. Activity-based costing and management (ABC/M) is a managerial accounting technique with the capability to estimate more precisely the manufacturing overhead (MOH) costs. ABC/M instead of allocating the MOH costs; it assigns them to the activities and estimates the consumption of MOH costs by each product through the level of activity usage. As it was discussed before, Cooper and Kaplan (1991) developed a generic cost structure for the overhead costs involved in the manufacturing process. According to their system, the MOH costs are incurred at a unit-level, batch-level, product-level, and facility-level homogenous cost pools. MOH costs are assigned to a cost pool according to the main incurred reason.

In this chapter, a general approach of integrating ABC/M to the SD modeling in order to develop a precise on-time cost monitoring and analysis tool for an order management problem is presented. The model will be able to calculate the real-time selling price and adjust cost pool rates in each period of time based on the execution of the previous management policies and decisions. The remaining of this chapter is organized as follows: Section 4.1 shows the generic SD cost monitoring model. Section 4.2 incorporates a specific illustrative example developed according to the generic approach. The chapter summary is presented in section 4.3.

4.1. Generic System Dynamics Model

Introducing a generic system dynamics model requires developing a causal loop diagram (CLD) as the first step. CLD guides the model customization and simplifies the model adaptation for each specific scenario. A causal diagram consists of variables by arrows denoting the causal influences among the variables (Sterman, 2000). In fact, CLD represents the model general structure schematically and identifies the main feedback loops involved in the process. Developing CLD is also helpful in the model improvement and modification process. Figure 4-1 shows the CLD for a general production problem emphasizing on the manufacturing unit and without the possibility of backlog.

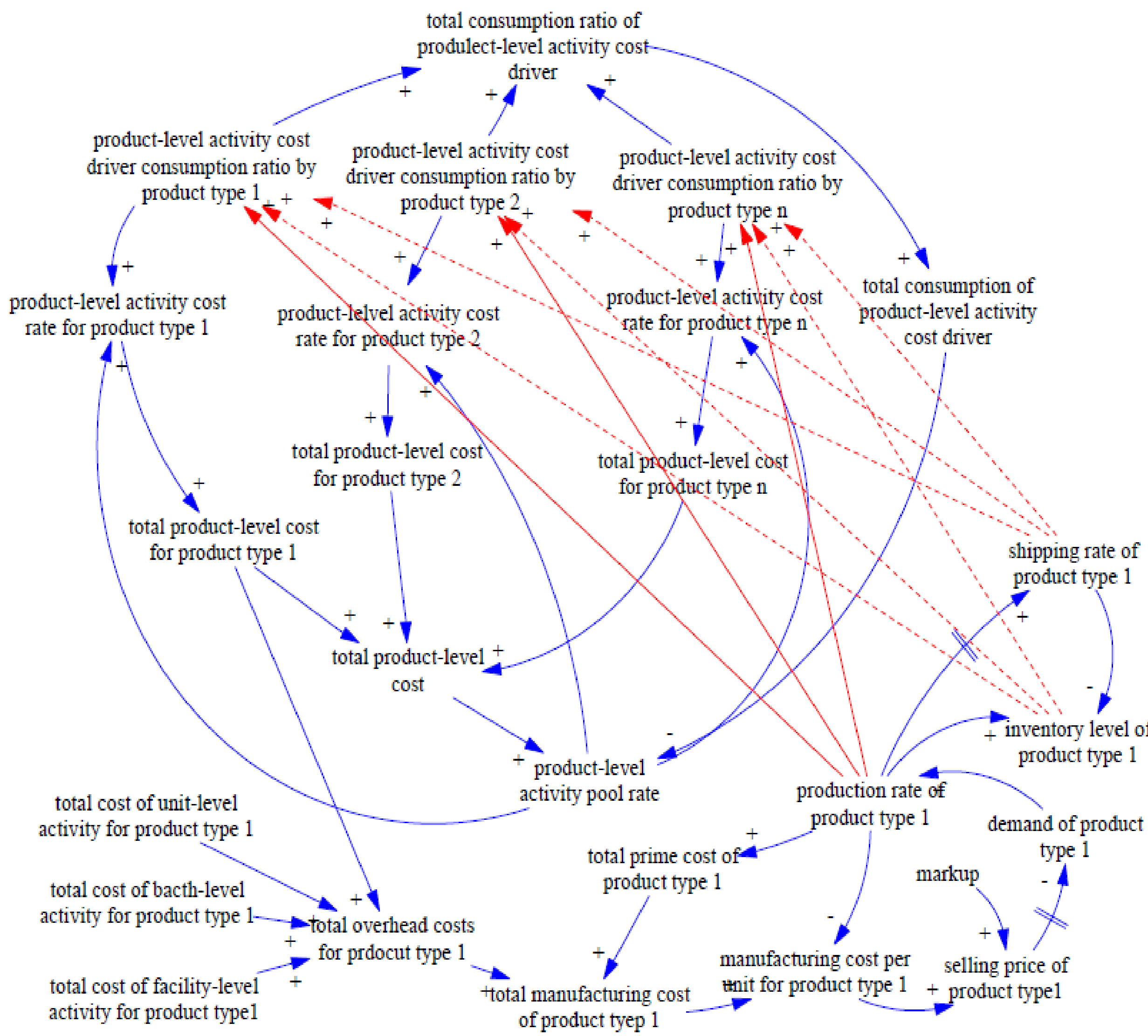

Figure 4-1: Generic model causal loop diagram

The causal loop diagram developed shows three main groups of feedback loops; (1) product manufacturing costs estimation, (2) activity-level (e.g. unit-level, batch-level, etc.) pool rates adjustment, and (3) product demand prediction. In this study it is assumed that there is no work-in-process at the end of each planning period, which means that the total manufacturing cost is equal to the cost of goods manufactured. The CLD presented will be used in the next section as a foundation for developing the system dynamics cost monitoring and analysis tool under a specific scenario.

Product Cost Estimation Loops

The total product cost, as well as the manufacturing overhead costs, is estimated through the first main group of loops called product cost estimation loop. The loop starts with a production rate, which is a function of demand and management policy. The shipping rate at each period is defined based on the production rate with a constant delay; the outflow is equal to the inflow by the constant delay time. This can represent the manufacturing process length. This type of delay is also known as pipeline delay; any pulse in inflow, the outflow gets it exactly delay time units later (Sterman, 2000).

The inventory level at the end of each period is equal to the difference of the production rate and the shipping rate for that period. The activity-level cost driver consumption ratios could be defined based on the production rates, shipping rates or inventory levels based on the cost nature. For example, costs related to the batch-level activities such as setup, are mostly estimated through the production rates, and costs related to the product-level activities like engineering design changes are estimated through the shipping rates.

The cost consumption ratios define the activity-level overhead cost for producing a specific product. The total overhead cost in any activity-level is equal to the summation of that cost for all type of products. The total manufacturing overhead cost amount is equal to the aggregation of all overhead costs. By adding the total prime cost to that, we can estimate the total manufacturing cost under a specific production planning policy. By knowing the total manufacturing cost and the total production amount we can estimate the manufacturing cost per unit of product. The selling price is defined based on the manufacturing cost per unit, which has direct impact on the demand and the production rate.

Pool Rates Adjustment Loops

The other group of loops is in charge of adjusting the pool rates based on the applied production policies and the incurred costs for that particular pool in the previous periods. The number of these loops at each activity-level, product-level in Figure 4-1, is equal to the number of product types that are using that particular activity. The general formula in ABC/M for calculating overhead cost for each product at specific activity-level is equal to the multiplication of pool rate and activity-level cost driver consumption ratio.

Basically, the pool rate defines the cost generation rate for each type of product using that activity (resource), and the multiplication of the pool rate and the consumption ratio gives the related MOH. The summation of those MOH costs for all types of product using the activity gives the total cost of that activity-level. The pool rate is calculated from the related activity-level total cost and the total activity consumption until the current period. The total consumption equals to the summation of the consumption ratios of all products from that activity during a defined amount of time. As it was discussed before, the activity-level cost driver consumption ratio could be a function of the production rate, the shipping rate, or the inventory level.

Product Demand Estimation Loops

The product demand estimation loops are the other main feedback loops of the diagram. These loops start with the manufacturing cost per unit. The selling prices are defined based on the manufacturing cost per unit and the desirable markup for each product type. The initial amount for the selling prices, called budget selling prices, is assigned by management according to the budgeted manufacturing costs and desirable markups. Each product selling price with a constant delay defines that product demand. The demand is estimated according to the following equation given by Boyd and Cox (2002) for each type of product:

$$Demand = ((SP / BSP-1) * PEoD + 1) * Expected\ Demand$$

Where

SP: *selling price*

BSP: *budgeted selling price*

PEoD: *price elasticity of demand*

The production rates are chosen according to the demand and management production policy. In this study, it is assumed that the management policy is satisfying all the incurred demand in all periods. Therefore, the demand for a particular product is equal to the production rate for that product. It is also assumed that the company already has flexibility in its capacity to absorb the demand fluctuations. Thus, the model presented does not incorporate constraints regarding the availability of resources or activities. Production rates, according to the first group of loops, define the production costs and ultimately define the manufacturing cost per unit.

The causal loop diagram presented in Figure 4-1 is limited to the particular number of variables for one activity-level, product-level, and only for one type of product, product type 1. The similar structure should be replicated for the other products and other activity-levels in order to develop the entire CLD. The following example further illustrates more the presented generic modeling approach.

4.2. An Illustrative Numerical Example

In order to validate and to illustrate the advantages of the approach presented, we are using the example called Knickknack Inc. case study, which was extracted from Hilton (2008). According to the case study, the goal is to estimate the products manufacturing cost and the products price employing the two different accounting systems, ABC/M and TCA, via the basic managerial accounting techniques. Here, it is shown how the SD approach can provide an inclusive solution aligned with a comprehensive analysis for the case study. The objective is to monitor the MOH costs in 12 months under each accounting technique, TCA or ABC/M, and to foresee the effects on the company's profit, on the products' selling price, and on the MOH costs behavior using a system dynamics model as a real-time cost monitoring tool, which was presented in the previous section.

The company manufactures two types of product, Odds model and Ends model. Each product's consumption of manufacturing overhead costs is estimated through Activity-Based Costing/Management, and by using a plant wide rate. The MOH costs are assigned to each product manufactured based on four different costs pools namely, unit-level, batch-level, product-level, and facility-level activity cost pool based on ABC/M technique. In the case of TCA technique, the plant-wide rate allocates the MOH costs based on the direct labor hours. The problem specifications presented in Table 4-1 and 4-2, are exactly the same as in the case study.

Table 4-1: Knickknack Inc. production cots information

	Cost / Unit ($)	
Manufacturing Costs	Odds	Ends
Direct material	$ 160.00	$ 240.00
Direct labor	$ 120.00 (4* × $30)	$ 180.00 (6**×$ 30)
Manufacturing overhead	$ 384.00 (4 × $96)	$ 576.00 (6×$96)
Budgeted Manufacturing overhead		
Machine-related costs	$ 1,800,000.00	
Setup and inspection	$ 720,000.00	
Engineering	$ 360,000.00	
Plant-related cost	$ 384,000.00	

* Machining hours for Odds model

**Machining hours for Ends model

Table 4-2: Knickknack Inc. ABC/M cost structure

				Cost Driver / Unit ($)	
Activity	Activity-level	Activity Cost Driver	Activity Cost Driver (Pool) Rate	Odds	Ends
Machine-related costs	Unit-level	Machine hours	$ 100.00	$ 800.00	$ 200.00
Setup and inspection	Batch-level	Number of production runs	$ 9,000.00	$ 360.00	$ 72.00
Engineering	Product-level	Engineering change order	$ 1,800.00	$ 270.00	$ 18.00
Plant-related cost	Facility-level	Square footage of space	$ 100.00	$ 307.20	$ 15.36

In general, a system dynamics model structure contains three different groups of variables; level variables, rate variables, and auxiliary variables. All of those groups are related to each other with in and out flows. The flows are presented by arrows and in case that a flow involves a delay the "||" is added to the arrow. The first group of variables is level or stock which is symbolized by rectangle. This type of variables represents the status of under examined element (*e.g.* amount of product or money) in the system at any particular time. A combination of all level variables is a representation of the system status at a specific time. The pace of change in level variables is controlled by rate variables.

The rate variables, which are shown by valves, control the rate of flows in the model. The third group is auxiliary variables which makes the model easy to understand and is shown with clear boxes. The source and sink nodes for the flows are presented by clouds. The clouds are showing flows to/from the outside boundary of the model. The variables denoted in between single left and right-pointing angle quotes are the shadow variables. They are substitute of other types of variables in order to keep the flow easily understandable. The models are developed in Vensim software environment with the similar legends discussed in Sterman (2000), Figure 4-2. The main objective of the model is to calculate a real-time selling price and adjust cost pool rates and demand for each month according to the previous selling price.

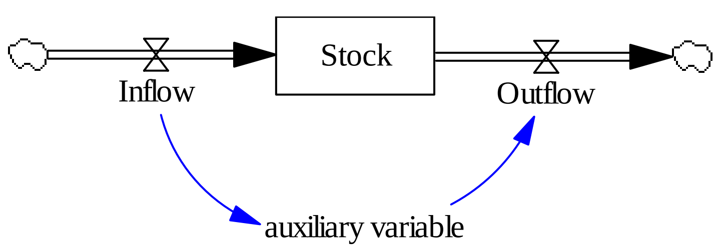

Figure 4-2: System dynamics model diagramming notation

The ABC/M based model includes five parts; the main part calculates the total manufacturing costs, prices, and demands; the other four parts adjust the pool rates. For modeling purposes, it is assumed that there is no final product, or work-in-process inventories meaning that the shipping rate is equal to the production rate. Therefore, all the activity-level cost drives consumption ratios are defined based on the production rates. The entire loops that determine and adjust the pool rates are shown in Figure 4-3. For example, for the batch-level (setup and inspection), the loops are *batch-level cost rate for the odds model → total batch-level- cost for odds model → total batch-level cost → batch-level pool rate → batch-level cost rate for the odds model* and the same loop for ends model. The batch-level pool rate in each period is adjusted based on the setup and inspection activity resource consumption in the previous periods. The batch sizes for odds and ends model are 25 and 125, respectively. The average number of units per order received for each type of product manufactured indicated in Figure 4-4 is also equal to the product batch size.

The cost of goods manufactured, selling price, and demand for each product type are determined in Figure 4-4. The cost of goods manufactured because of not having any work-in-process inventory is equal to the manufacturing cost. The manufacturing cost for each type of product is equal to the summation of the prime cost and MOH cost. The prime cost is calculated based on the production rate and direct labor cost rate according to the approach explained in the case study. The MOH cost for each model is equal to the summation of all the manufacturing overhead costs at unit, batch, product, and facility level for the particular product.

The selling price *((1+markup) × cost of goods manufactured per unit)* defines the product demand according to the formula explained. The price elasticity of demand for both products is equal to -1 which means an *x%* increase (decrease) in the selling prices will result *x%* decrease (increase) in demand quantities. The assigned selling prices for each product per period are indeed a lower bound for the products selling price. In fact, if management is willing to achieve the desirable 20% markup, the customer should be charged not less than the calculated selling prices for each product unit sold in that period. The difference between the product prices in different periods is the result of the adjustment of the pool rates by model.

The problem could be modeled in a similar way using the TCA technique. The only difference is that in TCA model there is only one cost rate adjustment loop. This loop defines the MOH according to the direct labor hours involved in the manufacturing process of each product.

The comparison between the two models indicates that the ABC/M technique yields higher profit, $972,811.00, for the company compared to the TCA technique, $825,162.00 in the 12 months planning period. However, the comparison is based on a products' price elasticity of -1. Figure 4-5 shows the profit amount per period for the two different cost accounting techniques. The profit is equal to the differences of sales revenue and total costs of goods manufactured. The assigned prices under each cost accounting techniques are shown in Table 4-3. Table 4-4 displays the average MOH costs per unit of each manufactured product till certain periods under the two cost accounting techniques.

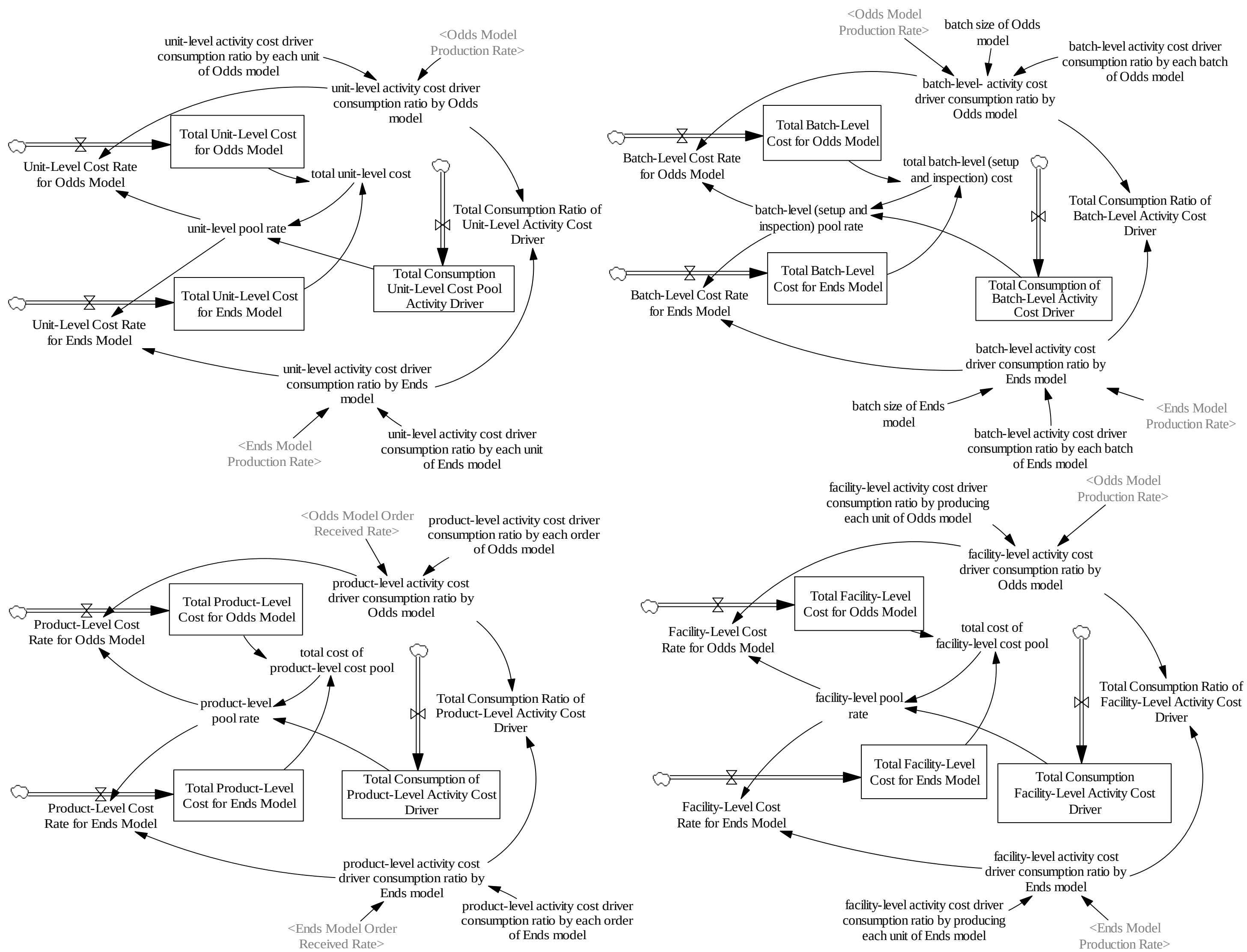

Figure 4-3: Pool rate adjustment loops

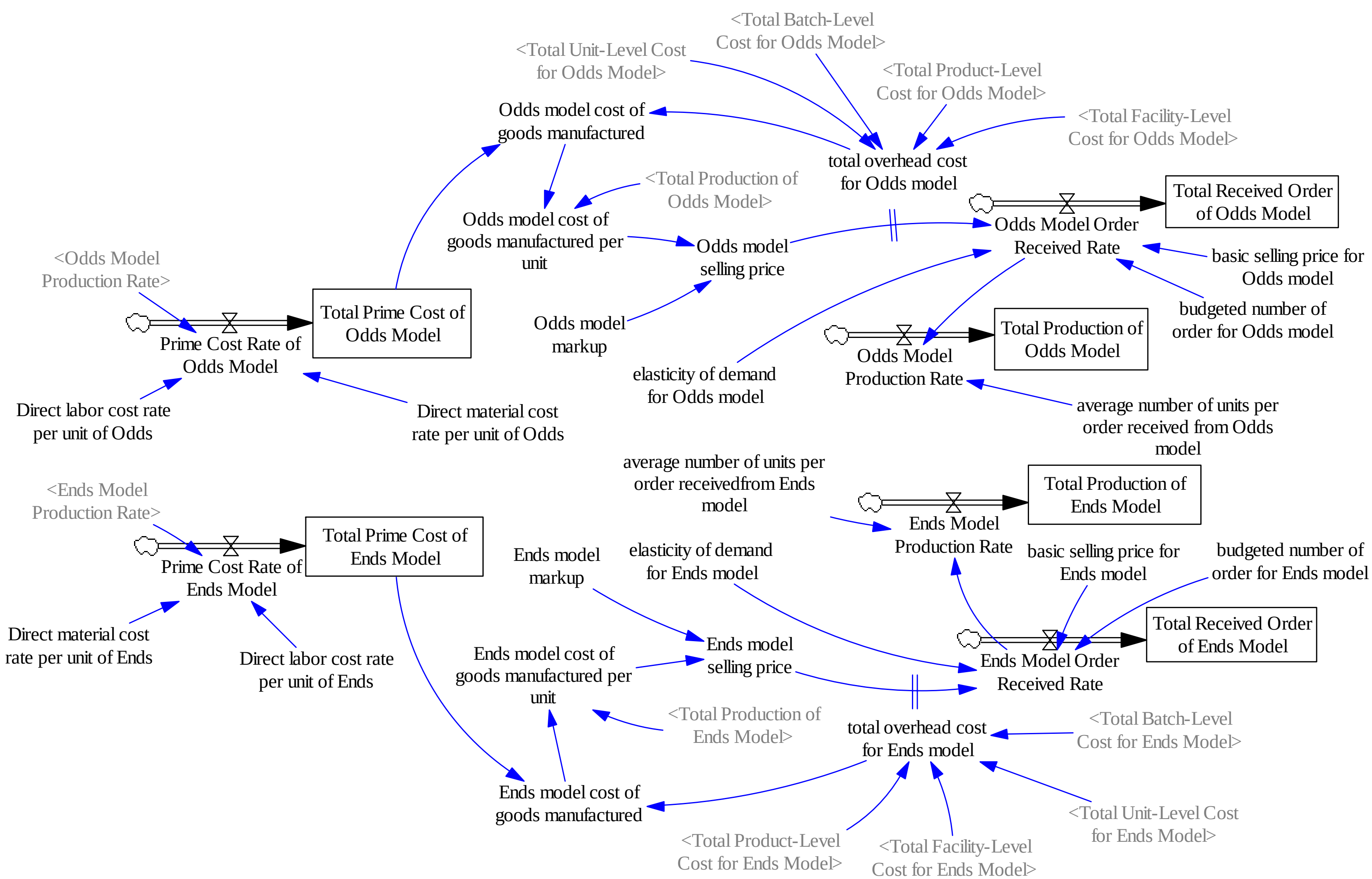

Figure 4-4: Manufacturing cost, selling price, and demand estimation

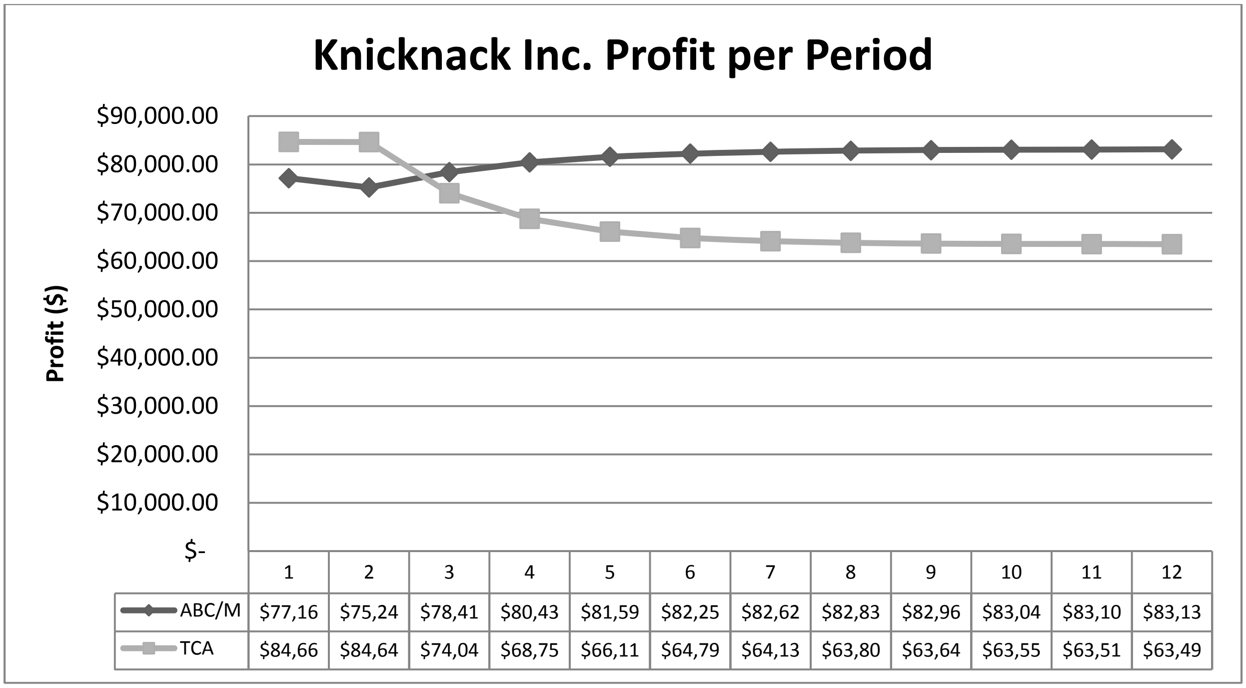

Figure 4-5: Knicknack Inc. profit per period

Table 4-3: Desirable selling price per period

	ABC/M Selling Price $		TCA Selling Price $	
Period	Odds	Ends	Odds	Ends
1	$ 2,420.64	$ 750.43	$ 796.80	$ 1,195.20
2	$ 2,378.53	$ 743.49	$ 796.71	$ 1,195.06
3	$ 2,364.49	$ 741.08	$ 796.67	$ 1,195.03
4	$ 2,357.43	$ 739.88	$ 796.66	$ 1,195.01
5	$ 2,353.18	$ 739.17	$ 796.65	$ 1,194.99
6	$ 2,350.35	$ 738.71	$ 796.64	$ 1,194.98
7	$ 2,348.33	$ 738.38	$ 796.64	$ 1,194.98
8	$ 2,346.82	$ 738.14	$ 796.64	$ 1,194.97
9	$ 2,345.65	$ 737.96	$ 796.63	$ 1,194.97
10	$ 2,344.71	$ 737.81	$ 796.63	$ 1,194.97
11	$ 2,343.95	$ 737.69	$ 796.63	$ 1,194.96
12	$ 2,343.31	$ 737.60	$ 796.63	$ 1,194.96

Table 4-4: Average MOH costs per unit till certain period

	ABC/M MOH Costs $		TCA MOH Costs $	
Period	Odds	Ends	Odds	Ends
1	$ 1,737.20	$ 205.36	$ 384.00	$ 576.00
2	$ 1,702.11	$ 199.58	$ 383.93	$ 575.89
3	$ 1,690.41	$ 197.56	$ 383.90	$ 575.85
4	$ 1,684.52	$ 196.56	$ 383.88	$ 575.84
5	$ 1,680.98	$ 195.97	$ 383.87	$ 575.83
6	$ 1,678.62	$ 195.59	$ 383.87	$ 575.82
7	$ 1,676.94	$ 195.32	$ 383.87	$ 575.82
8	$ 1,675.68	$ 195.12	$ 383.86	$ 575.81
9	$ 1,674.71	$ 194.96	$ 383.86	$ 575.81
10	$ 1,673.93	$ 194.84	$ 383.86	$ 575.81
11	$ 1,673.29	$ 194.73	$ 383.86	$ 575.80
12	$ 1,672.76	$ 194.66	$ 383.86	$ 575.80

The TCA technique assigned the average selling price of $796.66 and $1195.01 for odds and ends models, respectively. The ABC/M sets the average price of $2358.12 for odds model and $740.03 for ends model. In fact, the ends model is overpriced and odds model is underpriced when using TCA. This indicates that a portion of the odds model MOH costs is subsidized by the ends model, which results in inaccurate pricing.

As previously mentioned, the above results consider both price elasticity amounts equal to -1. In order to show the model usefulness in analyzing the effect of the different accounting systems on the firm's financial performance, various price elasticity combinations are used. Subsequently, in both TCA and ABC/M models, the product price elasticity amounts are generated randomly by normal distribution with the average of -1 and the standard deviation of 0.5, $N(-1, 0.25)$.

The applied distribution generates most of the random numbers (99.73%) within the interval of [-2.5, 0.5]. Although any continuous distribution could be used, the random numbers generated by the defined normal distribution are in concordance with the price elasticity of different products in North American countries. In order to make sure the simulation reaches the steady state situation, 1000 runs are applied for each case, ABC/M and TCA. The sensitivity graphs of net profit provided by different models are shown in Figure 4-6 and 4-7 respectively.

In the ABC/M case the average net profit is equal to $972,100, whereas in TCA is $821,970. Moreover, the net profits generated by ABC/M system vary between $900,855 and $1,074,000, whereas in TCA net profits vary between $461,818 and $1,112,000. This shows less variance in the net profit generated by ABC/M considering different price elasticity scenarios as compared to TCA. In fact, the ABC/M accounting system has a steady performance and assigns better product price in different cases compared to the TCA accounting system.

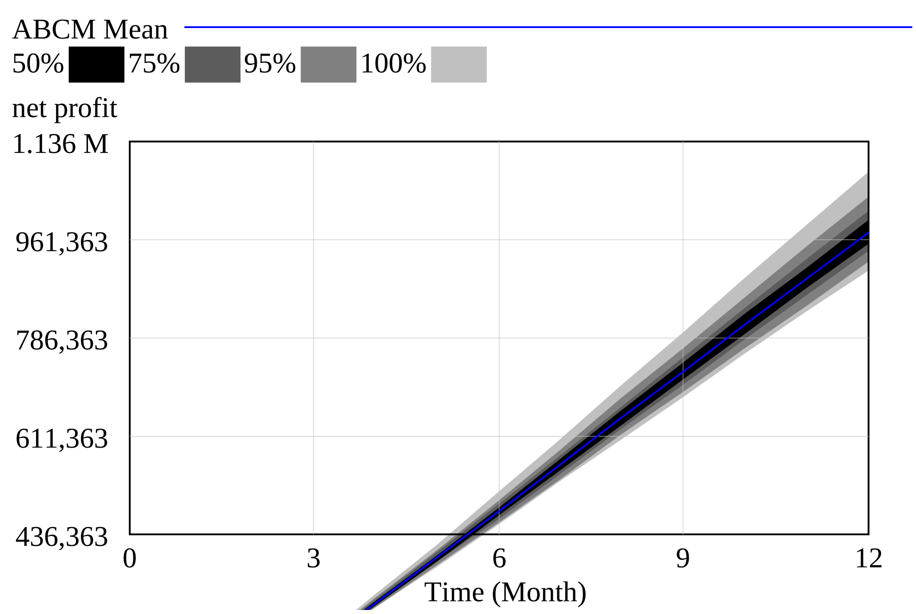

Figure 4-6: Sensitivity graph for ABC/M system

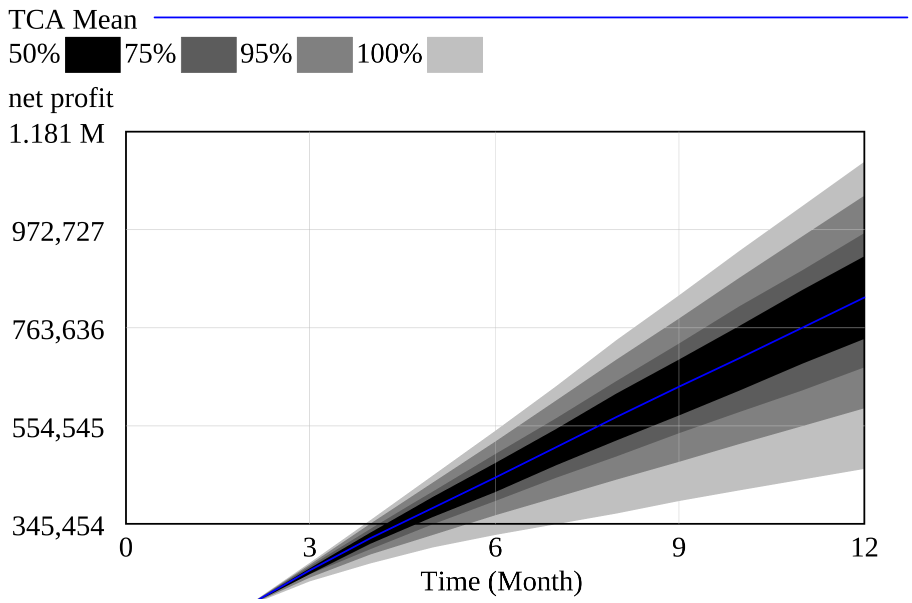

Figure 4-7: Sensitivity graph for TCA system

All the associated equations and mathematical relationships between decision variables can be extracted easily from Appendix 2, ABC/M-based system dynamics cost monitoring model and Appendix 3 for TCA system dynamics cost monitoring model. The decision variables and model parameters all are in alphabetic format.

4.3. Chapter Summary

When analyzing a production situation, the managements are often confronted by a situation in which the question as to whether or not it is necessary to find an optimal solution, or if an acceptable feasible solution (resolution), is satisfactory arises. This statement brought the attention of management into the soft operations research modeling techniques. In view of that, this chapter contains a novel ABC/M-based decision support model that monitors the cost of a particular production process. The model emphasizes on the advantages of ABC/M as a precise cost measurement accounting system. The numerical result exemplifies the ability of the developed model by demonstrating the advantages of using ABC/M over TCA in determining product prices for a particular manufacturing facility and with different product price elasticity combinations.

The result generated by SD model shows how the model gradually estimates the new product price based on adjusting the pool rates and previous periods demand. The typical static approach presented in the refereed case study cannot exhibit the impact of a correct price calculation on the profit during a period of time. Instead, the generic SD model presented can foresee the further effect of ABC/M adaptation on a company's financial performance. Implementing ABC/M instead of TCA results in a more precise and reliable product cost estimation which ultimately generates higher profit for the company.

Integrating ABC/M cost structure into the model enhances the model sensitiveness to the costs changes and improves the accuracy of the decision. Moreover, the integration provides a better understanding and control of the production resources costs, which can lead to processes performance improvement.

The modeling approach presented could be used by business students in developing decision making skills, as well as by business managers, as an aid in the decision making process in the real business world. The next chapter of thesis explains how this model and the MIP model presented in Chapter 3 can work together as a powerful decision support system. Such a system, besides of suggesting order management policies, can help management to have a more advanced sight about the implemented policy costs behavior.

Chapter 5

ABC/M Integrated into a Hybrid (SD-MIP) Modeling Approach for Order Management

The available-to-promise (ATP) and capable-to-promise (CTP) are the two common and popular approaches in order management supply chain (SC) decision making and decision support modeling. ATP models make decisions regarding the acceptance or rejection of orders based on the product inventory availability; whereas CTP models make decisions based on production capacity availability. However, foreseeing the available production capacity or inventory level contains some significant errors which are the result of some out of control variables and factors; such as machining breakdown or workers' performance.

In order management decision making problem, profitable-to-promise (PTP) based decision support systems (DSSs) consider profitability as a main decision factor instead of focusing only on capacity or inventory availability. Considering profitability as a main decision factor requires a tool that can precisely estimate the relevant cost of each decision. Otherwise the results provided will not be reliable and precise.

As it was discussed before, product manufacturing incurs three different costs: direct labor, direct material, and manufacturing overhead costs (MOH). The first two are categorized as direct costs, which are traceable to a specific service or product. The latter represent a mixture of both direct and indirect costs, which causes a difficulty to assign them to a specific product or service.

The traditional cost accounting approach allocates MOH costs either by using a plant-wide rate or departmental rates; either case does not provide a good estimation of the orders fulfillment costs. Especially in a case where there is a highly customized and low volume production process. Therefore, PTP decision support models and cost-based decision support models, which use the traditional cost accounting system, cannot provide reliable answers since they apply an impractical cost estimation method.

Unrealistic cost estimation, which leads to mispricing, generally compromise the firm's growth and profitability. Activity-based costing and management (ABC/M) is an accounting approach which assigns, instead of allocating, MOH costs. Although, the application of ABC/M does not eliminate MOH allocation; it can reduce it to some facility-level costs. This significantly decreases, MOH costs allocation errors and leads to a better understanding of the companies' indirect expenses, providing more accurate orders profitability estimation, and finally resulting in a more reliable and comprehensive decision.

In this chapter, we presented how the last two approaches explained in the previous chapters, can be integrated and utilized as a powerful tool to develop a hybrid mixed-integer programming (MIP)-based order management decision support and system dynamics (SD)-based cost monitoring and controlling decision support model. The remnant of this chapter is organized as follows: in section 5.1 we elaborate the general order management problem. In section 5.2 we incorporate the adapted MIP decision support model and the related numerical results for the MIP model. The SD cost monitoring decision support system and the outcomes all are explained exclusively in section 5.3 and in section 5.4 the summary and relevant conclusion is explained.

5.1. General Illustrative Problem

A flexible machining system is selected as a pilot production facility in a simplified three-echelon SC including supplier, producer, and customers. The system can setup two different production processes or models; basic and deluxe. The raw material is similar for both types of models and there is no restriction for supplying the raw material. The manufacturing process, Figure 5-1, starts by injecting the common raw material to the system. Second, the manufacturing system alternates between two types of setup based on the assigned production plan. Lastly, the final products are stored for shipping to the customers.

The management follows pull production strategy; therefore, it develops the aggregate production plan based on the received orders per month. Not all the orders can be fulfilled completely due to the restriction in the available machine hours per period; as a result, the firm's management has to choose the fulfillment rate of each order. The order management policy is fulfilling completely or partially or rejecting the orders according to the production system availability and orders profitability factors. In order to facilitate the modeling process in the step of defining a cost structure and relevant data, we borrowed a managerial accounting educational business case study known as "Willow Company" from Hansen *et al.* (2001).

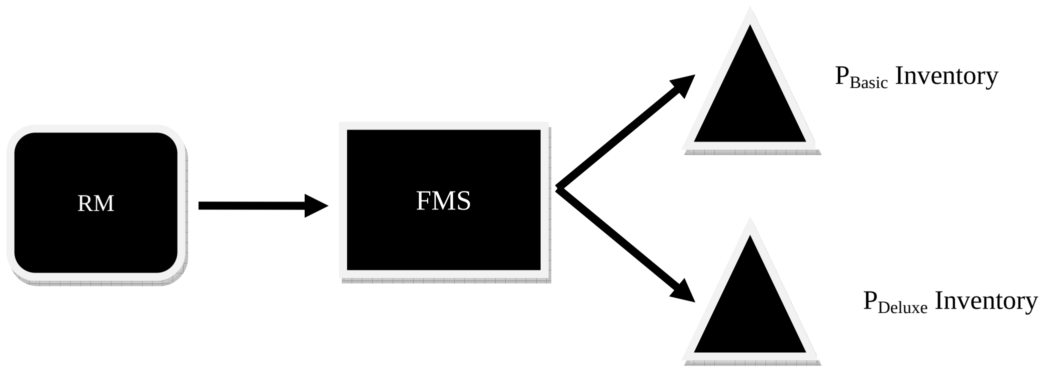

Figure 5-1: Production process flow

According to the problem extracted, the production costs have been split into two groups; prime costs (which include Direct Materials and Direct Labour) and overhead costs. The latter is divided into five homogeneous cost pools with a particular activity cost driver for each one. It is also assumed that the overhead unit-level costs are completely traceable and are included in the prime costs. This is not an unrealistic assumption because this group of overhead costs is normally related directly to each unit of products and are also known as direct overhead costs. There are two different batch-level cost pools introduced in the case study; material handling and setup being the activity cost driver the number of moves and the number of setups, respectively. The case also presents two product-level or order-level costs pools; administrative cost pool with activity cost driver of number of orders and engineering supports cost pool with activity cost driver of maintenance hours. The last pool is facility-level which has a unit-level activity cost driver, machining hours, based on the hint given in the case study. Figure 5-2 shows the activity-based cost flow down diagram for Willow Company.

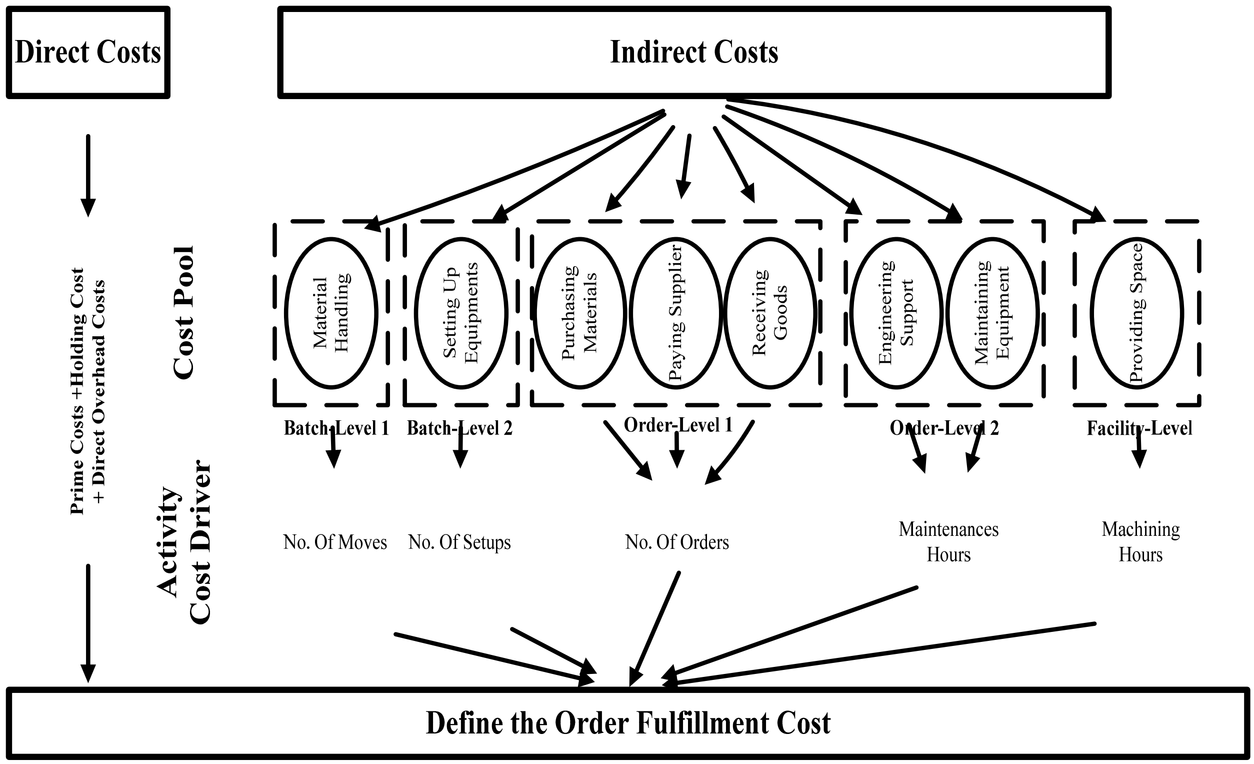

Figure 5-2: Activity-based cost flow diagram of Willow Company

5.2. Hybrid Decision Support System – MIP Model

In the developing decision support model the goal is to find the most profitable and optimal combination of the fulfilling ratio of the received orders by taking into account the orders profitability, the production resources productivity and availability. For the purpose of modeling, we implemented the modeling technique that was initially presented in Chapter 3, solving the order management problem by integrating the activity-based costing and management (ABC/M) and mixed integer programming optimization techniques.

In developing the mathematical order management decision support model, we pursue two goals: maximizing the profit and minimizing the residual capacity. There two goals are incorporated into the model by applying weighted goal programming (WGP) techniques. Like the previous MIP decision support model, the general objective function is maximizing the profit *(sales revenue – production resources costs – holding costs)* and minimizing the residual capacity simultaneously, subject to different constraints like; production resources constraints, order commitment constraints, management discretionary constrains, and inventory constraints. The management discretionary factor is also added to the model by using a constraint that fulfills a certain number of orders completely.

The generic model is developed based on the following assumptions; processing times are deterministic, each product is manufactured in equal-sized batches under a pull system, and each order consists of just one type of product. There is a possibility to satisfy the orders partially, completely, or even reject them. In this chapter, the general homogenous costs pooling structure which has been discussed exclusively in Chapter 3, is replaced by a more detailed homogeneous costs pooling structure. In fact, instead of grouping all the batch-level activities in one cost pool, we are dealing with two different batch-level overhead cost pools, similar for order-level activities. The facility-level overhead costs pool is also added to the model which has been omitted in the previous chapter. As it was mentioned before, for the Willow Company case study, the unit-level overhead activities resources and costs are integrated into the prime costs. The applied notations are as follows:

i	*product index*
t	*period of time index*
o	*order index*

j	*activities at unit-level index*
k	*activities at batch-level index*
l	*activities at order-level index*
r	*activity at facility-level index*
d_l^+	*amount of over capacity production (capacity surplus variable)*
d_l^-	*amount of under capacity production (capacity slack variable)*
pr_i	*prime cost of product i*
a_k	*batch-level k pool rate*
y_l	*order-level l pool rate*
c_r	*facility-level r pool rate*
h_i	*holding cost of product i per period*
q_{ijr}	*consumption rate of performing activity r at facility-level related to activity j at unit-level for product i*
u_{ijk}	*consumption rate of performing activity k at batch-level related to activity j at unit-level for product i*
f_{il}	*consumption rate of performing activity l for product i*
b_{ij}	*batch size of product i at activity j*
p_i	*sales price of product i*
m_1	*cost of stretching the production capacity*
m_2	*cost of not using whole capacity*
m_3	*preference coefficient of maximizing profit*
m_4	*preference coefficient of minimizing residual capacity*
O	*number of orders which should be fulfilled completely*
D_{iot}	*demand quantity of product i in order o due in period t*
Q_{jt}	*total available time to perform activity j in period t*
U_{kt}	*total available time to perform activity k in period t*
F_l	*total available time to perform activity l*
I_{it}	*inventory level of product i in period t*
P_{it}	*amount of product i produced in period i*
S_{iot}	*quantity of product i from order o sold in period t*
B_{ijt}	*number of batches of product i produced in machine j in period t*

Y_{iot}	*The proportion of accepted order o from product i in period t*
YB_{iot}	*The binary form of Y_{iot}*

In order to develop the multi objective function we used WGP technique. The equation (5-1) represents the objective function, which consists of two parts that pursue two different goals of the decision support model. The m_i represents each goal's significance or management preference coefficient for each goal. The first part calculates the profit, which is the revenue (*multiplication of sales by the product price*) minus the production process costs. The production process costs is the addition of the prime costs, overhead costs (*batch-level, order-level, facility-level*) and product's holding costs. The second part of the objective function minimizes the residual capacity. According to this term any violation from the available order fulfillment capacity has a certain penalty cost.

$$\text{Max } z = m_3 \times (\sum_t \sum_o \sum_i p_i \times S_{iot} - \sum_t \sum_i pr_i \times P_{it} - \sum_t \sum_i \sum_j \sum_k a_k \times u_{ijk} \times B_{ijt} - \sum_t \sum_o \sum_i \sum_l y_l \times f_{il} \times Y_{iot} - \sum_t \sum_o \sum_i \sum_j \sum_r c_r \times q_{ijr} \times S_{iot} - \sum_i \sum_t h_i \times I_{it}) - m_4 \times (\sum_l m_1 d_l^+ + m_2 d_l^-) \quad (5\text{-}1)$$

Constraints (5-2) and (5-3) ensure that the available order fulfillment resource capacity at unit-level and batch-level capacity, respectively, are not exceeded. Constraints (5-4) allow the diversity in batch sizes to exist.

$$\sum_i q_{ijr} \times P_{it} \leq Q_{jt} \qquad \forall j, r, t \qquad (5\text{-}2)$$

$$\sum_i \sum_j u_{ijk} \times B_{ijt} \leq U_{kt} \qquad \forall k, t \qquad (5\text{-}3)$$

$$P_{it} = b_{ij} \times B_{ijt} \qquad \forall i, j, t \qquad (5\text{-}4)$$

Constraints (5-5) make sure that the production quantity meets the sales commitments of each order. Constraints (5-6) are the order-level activities capacity variation constraints.

They ensure that we accept the orders considering the order-level activities available capacity. The ratio of order fulfillment is represented with the proportion fulfillment decision variables (Y_{iotl}). These decision variables can take any real number between 0 and 1, which represents the acceptance portion of each order.

$$S_{iot} = D_{iot} \times Y_{iot} \qquad \forall i, o, t \qquad \text{(5-5)}$$

$$\sum_i \sum_o \sum_t f_{il} \times Y_{iot} - d_l^+ + d_l^- = F_l \qquad \forall l \qquad \text{(5-6)}$$

Constraints (5-7) incorporate the management discretionary factor into the model, which represents the number of orders (O) that management decides to fulfill completely. Constraints (5-8) ensure that if a specific order is selected to be fulfilled completely then the relevant fulfillment ratio (Y_{iot}) is equal to 100%. Constraints (5-9) make sure that the feasible area only includes the orders that exist. Accordingly, if the demand of a certain order from certain product at certain period (D_{iot}) is equal to 0 then Y_{iot} of that order must be equal to zero.

$$\sum_i \sum_o \sum_t YB_{iot} \geq O \qquad \text{(5-7)}$$

$$Y_{iot} \geq YB_{iot} \qquad \forall i, o, t \qquad \text{(5-8)}$$

$$D_{iot} \geq Y_{iot} \qquad \forall i, o, t \qquad \text{(5-9)}$$

Constraints (5-10) and (5-11) determine the inventory level for each product type at the end of each period of time.

$$I_{i0} = 0 \qquad \forall i \qquad \text{(5-10)}$$

$$I_{i(t-1)} + P_{it} - I_{it} = \sum_o S_{iot} \qquad \forall i, t > 1 \qquad \text{(5-11)}$$

Finally, constraints (6-12) to (6-14) are the non-negativity constraints, and constraints (6-15) are the binary constraints.

$$P_{it} \geq 0 \qquad \forall i, t \qquad \text{(5-12)}$$

$$B_{ijt} \geq 0 \qquad \forall i, j, t \tag{5-13}$$

$$0 \leq Y_{iot} \leq 1 \qquad \forall i, o, t \tag{5-14}$$

$$YB_{iot} = 0 \;\; or \;\; 1 \qquad \forall i, o, t \tag{5-15}$$

The expanded model, besides of having all the advantages of the previous MIP order management decision support models, has an illustrative emphasis on the effect of overhead costs in the decision making process by adding the facility-level activities overhead cost pool and replacing the homogenous order and batch-level overhead costs pool with a more detailed and activity oriented overhead cost pools. In fact, the model elaborates on how the significant role of overhead costs are in the procedure of order management decision making in a better way compared to the previous MIP order management models. In the following section the model is validated by using a numerical example.

The objective is to find the optimal combination of order fulfillment ratio, the combination that maximizes the profit and minimizes the residual capacity for the system. The discussed flexible manufacturing system should take decisions regarding sixteen incurred orders in the next twelve periods of time (month). Each order consists of only one type of product, deluxe or basic model. The list of the received orders and their specifications are shown in Table 5-1. All the required financial and operational parameters are extracted from the Willow Company case study.

Even though the Willow Company case study does not include holding costs, we decided that such a variable is important in a realistic scenario. Therefore, a holding cost has been assigned to each product. An applicable holding cost (h_i) is assumed to be equal to 5% of the ABC/M-based unit manufacturing cost as indicated in Hansen *et al.* (2001). Therefore, the amounts used in the MIP model are 4.22 and 9.06 for the Basic and the

Deluxe models, respectively, in dollar/unit/month. A further elaboration of holding costs requires incorporating inventory-related activities into the model structure.

Table 5-1: Order specifications

Order Number	Product Type	Period Due	Quantity
1	Basic	1	3500
2	Basic	2	4600
3	Deluxe	2	2500
4	Basic	2	3000
5	Deluxe	3	2500
6	Basic	5	3200
7	Basic	5	4700
8	Deluxe	5	1900
9	Deluxe	6	4000
10	Basic	8	4500
11	Deluxe	9	3000
12	Basic	10	3500
13	Basic	11	3000
14	Basic	12	5000
15	Deluxe	12	2700
16	Deluxe	12	5000

The manufacturing facility can produce the basic and deluxe model in batch sizes of 100 and 170 units, respectively, based on the given projected production amount and the number of setups for each product. The resources' annual capacity at different level has been determined based on the cumulative forecasted annual resource consumption given in the case study for producing the projected amount for each product. The preference coefficients (m_1 to m_4) are equal to 1, 0.5, 1, and 2, respectively, similar to Chapter 3. According to this combination the goal of minimizing the residual capacity has higher significance compared to the profit maximization goal. The model is coded with the optimization software Lingo Version 10 and applied to the different scenarios, different desirable number of orders (*O*) which should be satisfied completely, on a 3.00GHz Pentium-4 processor with 1GB of RAM. The model Lingo codes are presented in Appendix 4, hybrid system (MIP model). The average computational time for the presented model is less than five seconds. Table 5-2 shows the outcome of each scenario.

As it was discussed before, the goal is to find the optimal combination of fulfilling ratio of the received orders by taking into account the production resources capacity availability and profitability factor of each one. According to the results shown in Table 5-2, the optimal value is $3,694,067.00 which considers all the costs including the facility-level costs (fixed overhead cost) by relaxing the constraint of fulfilling the certain number of orders completely.

The related optimal solution is fulfilling five orders completely and six orders partially. The table also demonstrates the effect of integrating the management discretionary factor into the model where a certain number of orders have to be fulfilled completely. Management strategy for reaching higher customer satisfaction may require more number of orders to be fulfilled completely. According to the results, demanding more than five completely fulfilled orders from management diminishes the optimal value, company's profit. In fact, management would sacrifice the short-term profit for having a higher customer satisfaction level and long-term profit. The policy of fulfilling ten or more number of orders completely does not have a feasible optimal solution. This is the consequence of having the set of constraints (5-7) as a binding constraint.

By integrating the ABC/M information into the mathematical order management decision support model, the PTP decision support system (DSS) developed elaborates more on the role of costs and especially overhead costs in the order management process compared to the more traditional CPT and ATP models. Illustrating the role of overhead costs in the order management process presents a superior understanding of the production resources and operations expenses, a more accurate approximation about the profitability factor of each order, and finally, leads to a more consistent and reliable order management decision.

However, the MIP model presented solely cannot provide an on-time detailed cost analysis for the different Order Fulfillment scenarios because of its static nature. In fact, it does not take advantage of all the information generated by applying ABC/M cost structure. Therefore, there is a need for a complementary decision support model.

Table 5-2: Comparison table for fulfilling rates

	Minimum desirable amount of orders which should be satisfied completely					
Order	5 or less Fulfilling Rate %	6 Fulfilling Rate %	7 Fulfilling Rate %	8 Fulfilling Rate %	9 Fulfilling Rate %	10 Fulfilling Rate %
1	86	86	86	60	31	No Feasible Solution
2	65	-	-	-	-	
3	14	14	14	14	8	
4	-	100	100	100	100	
5	27	27	6	27	-	
6	72	72	72	100	100	
7	100	100	100	100	100	
8	45	45	100	30	100	
9	17	17	17	-	-	
10	100	100	100	100	100	
11	68	68	68	100	100	
12	100	100	100	100	100	
13	100	100	100	100	100	
14	100	100	100	100	100	
15	-	-	-	-	-	
16	20	20	20	20	20	
Profit $	3,694,067.00	3,693,925.00	3,681,280.00	3,650,092.00	3,614,196.00	

The integration of ABC/M in the order management decision support modeling also provides trustworthy information for the decision expenditure analysis. However, the MIP model solely cannot provide a deep cost analysis for the different scenarios due to its static nature. This means not taking all the benefits of ABC/M information integration into the decision making process and it justifies the need for a powerful decision support model. A model like this can be used as a cost monitoring and analyzing tool with the ability to evaluate and foresee the effects of each taken decision on the system status alternation. The next steps explain how the output of the MIP decision support model can be used as an input of the system dynamics-based decision support and cost analysis model and how ABC/M is used as a common approach to link these two models.

5.3. Hybrid Decision Support System – SD Model

The main advantage of system dynamics is its ability to effectively update the system status after each decision is taken and provides more reliable data based on the new status for further decisions. We believe the ability of SD in on-time evaluation of the system status can be used in system cost monitoring process. The remainder of this chapter is focused on presenting a pioneer cost monitoring system for order management problem based on the approach presented in Chapter 4 and its relationship with the developed MIP decision support model.

The model is developed based on the earlier variables defined in the optimization decision support model and with respect to the similar applied ABC/M structure. This represents ABC/M as a common approach between the MIP decision support model and SD decision support model. These two models are linked through a spreadsheet generated by the MIP model. The combination of these two models creates the hybrid decision support system. Figure 5-3; dashed lines, show the flow of information. The main objective of the developed system is to calculate real-time selling price and adjust cost pool rates in each month based on the execution of the previous months order fulfillment policy.

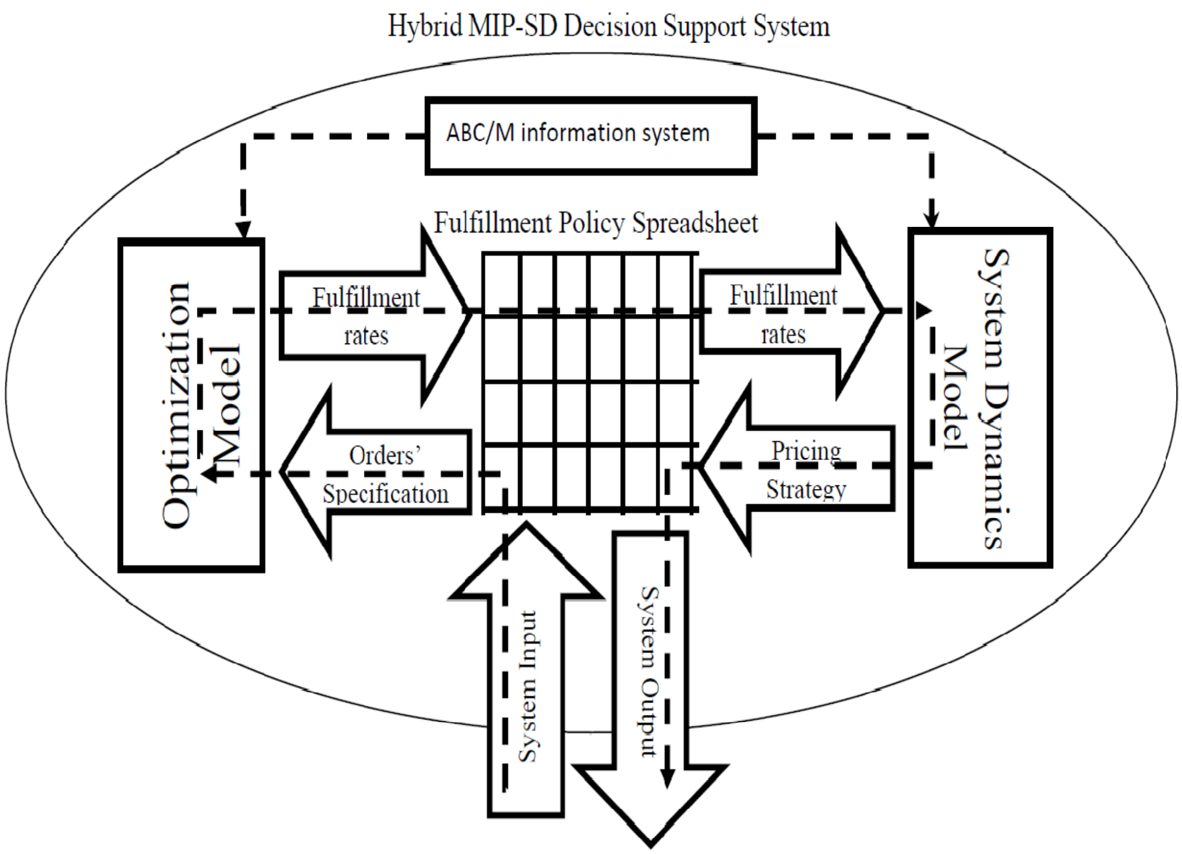

Figure 5-3: Hybrid Order Management Decision Support System

Basically, management decides about the scenario of the order fulfillment, number of orders that should be fulfilled completely, and the decision support model provides the optimal solution for the desirable scenario; this includes the order fulfillment rates for each order, as can be observed in Table 5-2. In the next step, the output of MIP decision support model is used as the input for SD model in order to have the possibility of on-time monitoring of related costs and to define the minimum products' selling price in each period regarding the previous decisions and desirable markup.

The SD model structure contains level variables, rate variables, and auxiliary variables which all are related to each other with in and out flows. Level or stock variables are represented by rectangles and they show the level of discussed unit (*e.g.* products or money) in the system at different periods of time. The combination of level variables normally defines the status of the system at different times. Rate variables control the pace of change in a specific level variable and are represented by valves in the model; in fact, they determine the flow. The auxiliary variables, which are shown with clear boxes, simplify the model and make it easier to understand. The clouds play the role of source and sink nodes for the in and out flows. This means the flow comes from or goes to outside boundaries of the model. The variables within single left and right-pointing angle quotes are shadow variables. They are substitute of any level, rate, or auxiliary variables in order to make the model less crowded. The model is developed in Vensim software environment with the similar legends discussed in Chapter 4. It includes six distinguished parts which are discussed separately.

First Part

The first part of the model, Figure 5-4, calculates the total holding cost of each product separately by getting the exact level of inventory for each type of product in each period and the related holding fractional ratio for each case. The holding cost fractional ratios are estimated based as 5% of the cost of goods manufactured per unit for each product. The production rates and shipping rates are extracted from the output of MIP decision support model. The model reads the amounts from separate spreadsheets which have been automatically generated by Lingo.

Second to Sixth Part

All the five learning loops that determine and adjust the pool rates are shown in Figures 5-5a to 5-5e. The pool rates adjustment loops help the model to define the selling price based on the actual Order Fulfillment costs. For the batch-level-1 (material handling), Figure 5-5a, the loops are *batch-level-1 cost rate for the Deluxe model → total bacth-level-1 cost for Deluxe model → total batch-level-1 cost → batch-level-1 pool rate* and the same loop for the Basic model. These two loops adjust the batch-level-1 pool rate in each period based on the material handling activity resource consumption in the previous periods. The batch level-1 pool rate is also related to the total consumption of batch-level-1 cost pool activity driver. This level variable is estimated via batch level-1 activity cost driver consumption ratio for the Basic and Deluxe models, which eventually depends on the products' batch size, production rate, and batch-lelvel-1activity consumption ratio.

Figure 5-5b shows the relations for the batch-level-2 (Setup). The pool rate adjustment loops are similar to the batch-level-1 loops. The total consumption of bacth-level-2 cost pool activity driver is estimated in each period of time via the product's production rate, batch size, and batch-level-2 activity driver consumption ratio, which is similar to the previous cost pool.

The relations for order-level-1, which is a homogenous cost pool, contains there different MOH costs; procurement material, paying supplier, and receiving goods; it is presented in Figure 5-5c. In this case the pool rate adjustment loops are *order-level-1 cost rate for Deluxe model → total order-level-1 cost for Deluxe model → total cost of order-level-1cost pool → cost-level-1 pool rate* and the same loop for the Basic model. In the order-level-1 cost pool, the MOH costs are estimated via order fulfillment rates for the

Deluxe and Basic models and order-level-1 activity cost driver consumption ratio.

For the order-level-2 homogeneous cost pool, engineering and maintenance, the relations between variables are presented in Figure 5-5d. The relevant adjustment loops are designed similar to the order-level-1 MOH costs for the Basic and Deluxe models. The total consumption of order-level-2 cost pool activity driver is estimated through order fulfillment rates for each product model and the order-level-2 activity cost driver consumption ratio.

Figure 5-5e presents the relations between variables involved estimating the facility-level MOH cost. The pool rate adjustment loops are similar to the previous cost pools. We are considering the facility-level activity cost driver consumption ratio and the orders' shipping rates in order to estimate the total consumption of the related activity cost driver.

Seventh Part

The prime cost, overhead cost, cost of goods manufactured, and selling price for each product type are determined in Figure 5-6. The prime costs are calculated based on the production rates and fractional production ratios which are the same as the prime costs per unit projected in the Willow Company case study. The overhead cost for each model is equal to the summation of all the overhead costs at batch, product, and facility level for the specific product. Adding this amount to the related holding cost and prime cost provides the cost of goods manufactured. The selling price for each product is estimated by adding the specific markup for each product to the related cost of goods manufactured per unit for that product. All the initial pool rates and the other related constants (*e.g.* batch sizes, markups) are similar to the MIP decision support model. The related equations to the SD model variables are presented in alphabetic order in Appendix 5, hybrid system (SD model).

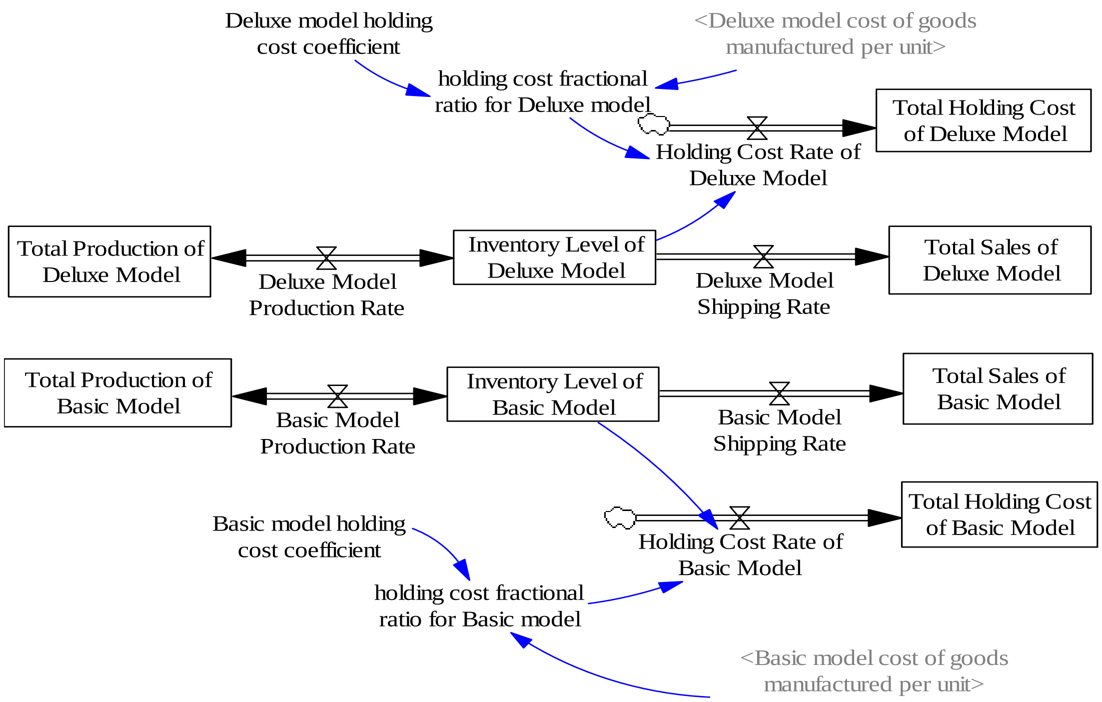

Figure 5-4: Inventory level and holding cost approximation

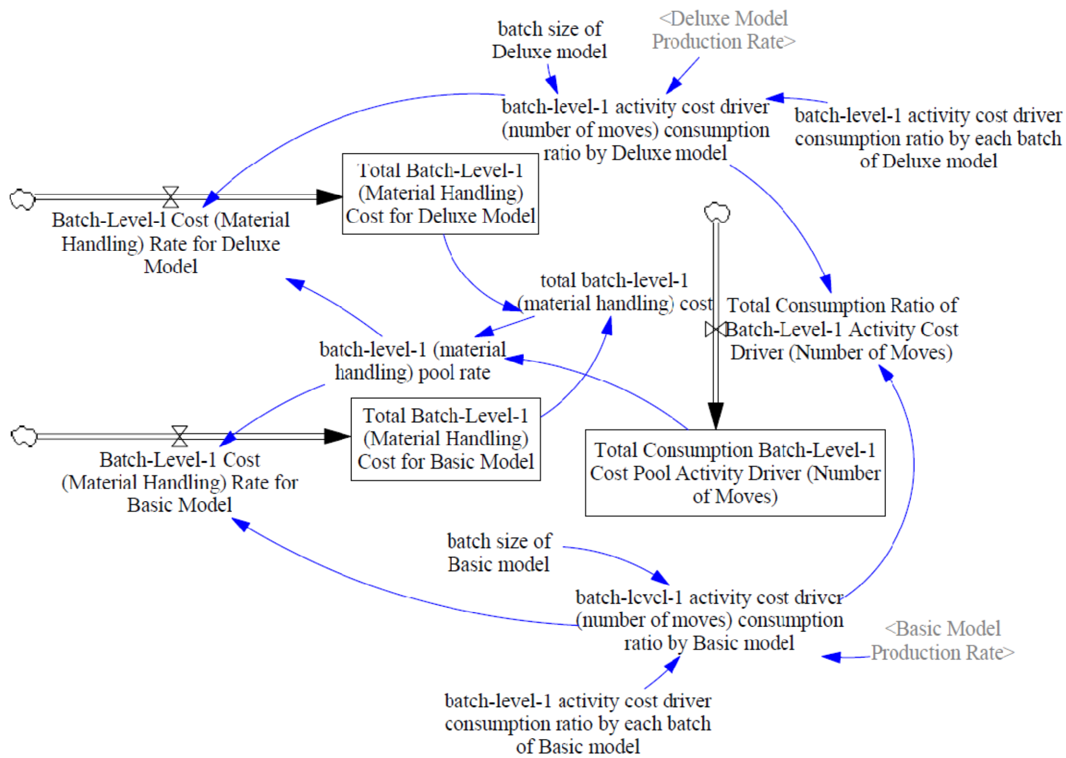

Figure 5-5a: Batch-level-1 pool rates adjustment loops

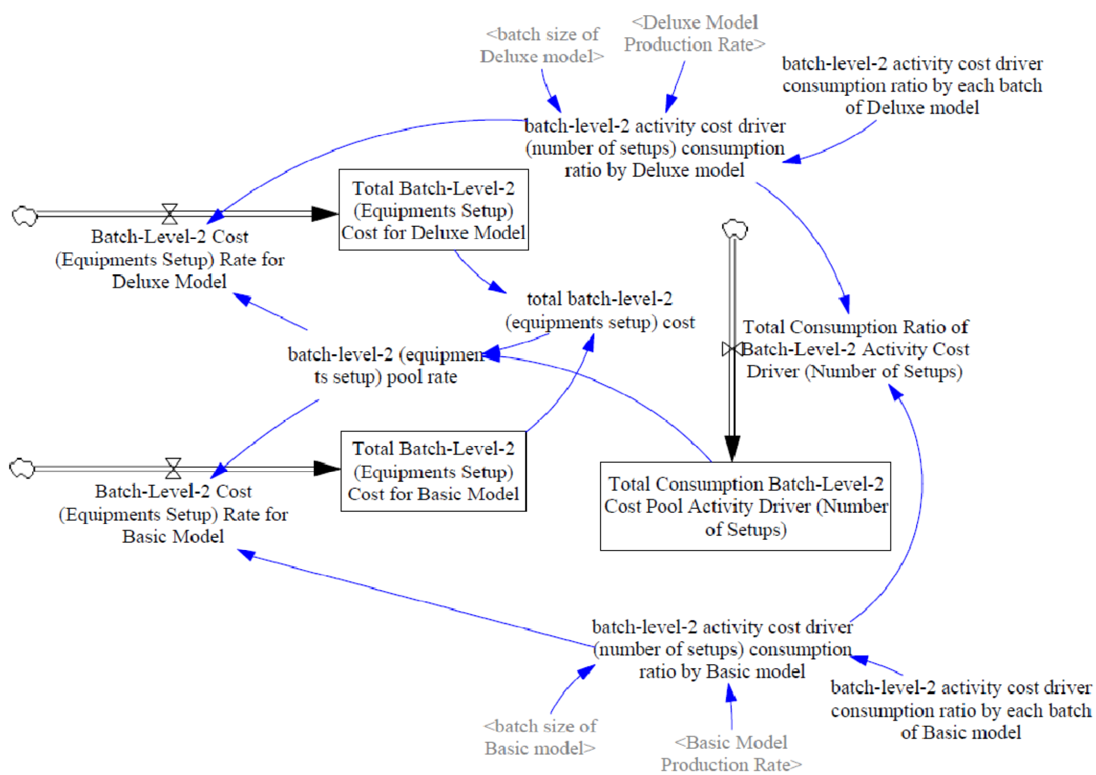

Figure 5-5b: Batche-level-2 pool rates adjustment loops

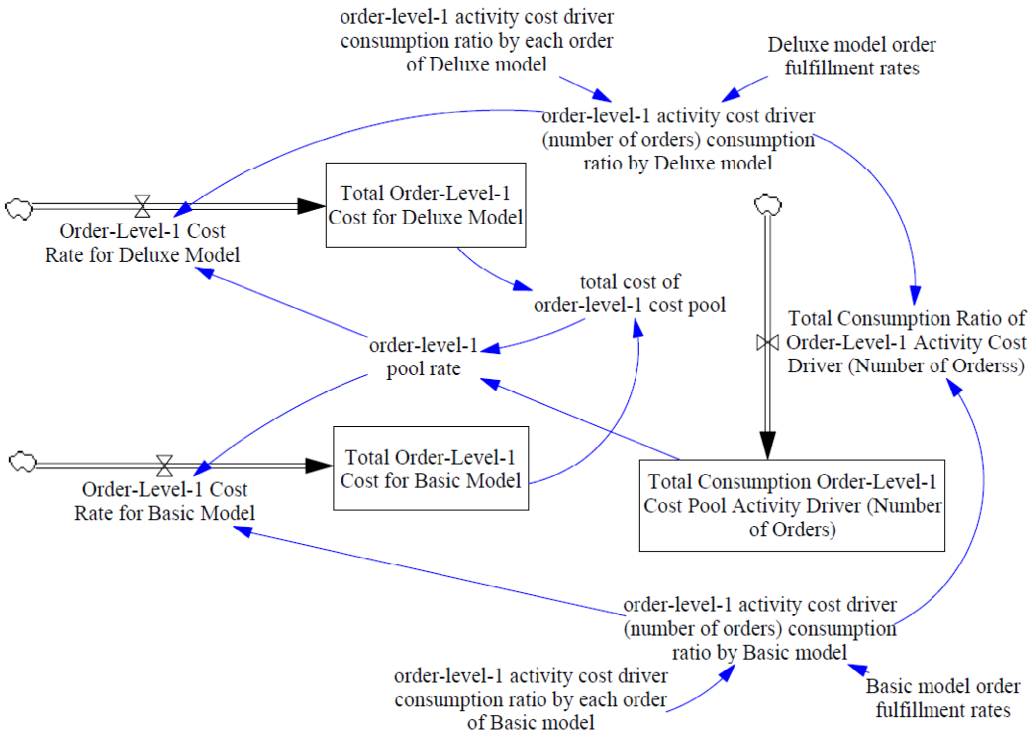

Figure 5-5c: Order-level-1 pool rates adjustment loops

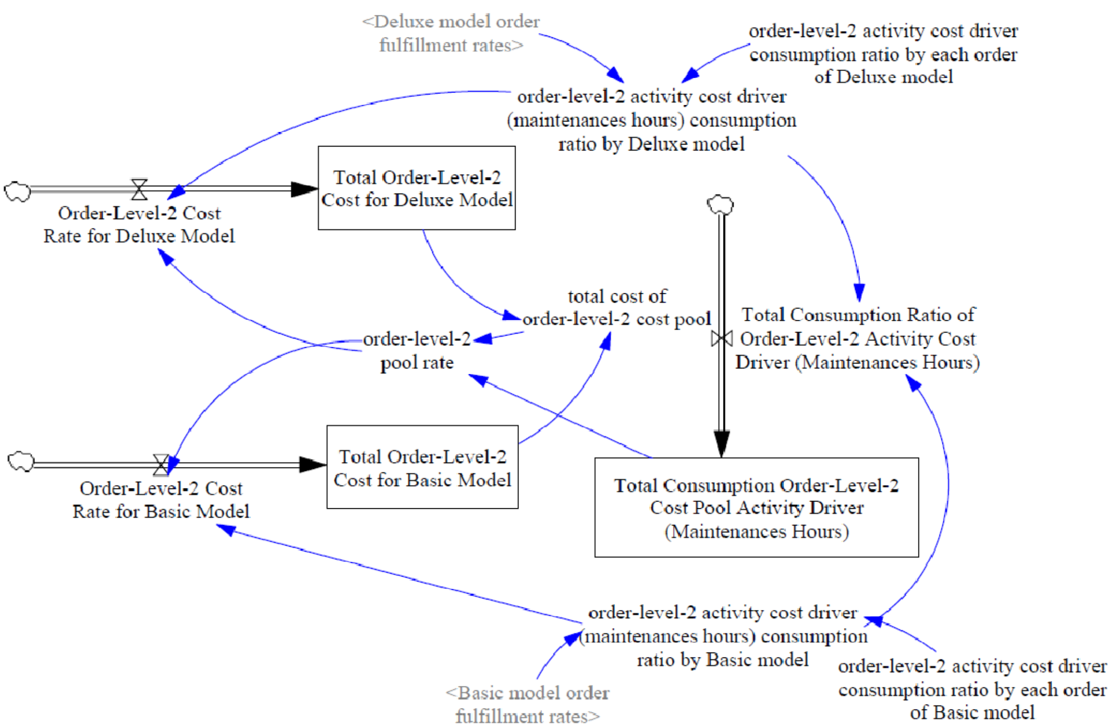

Figure 5-5d: Order-level-2 pool rates adjustment loops

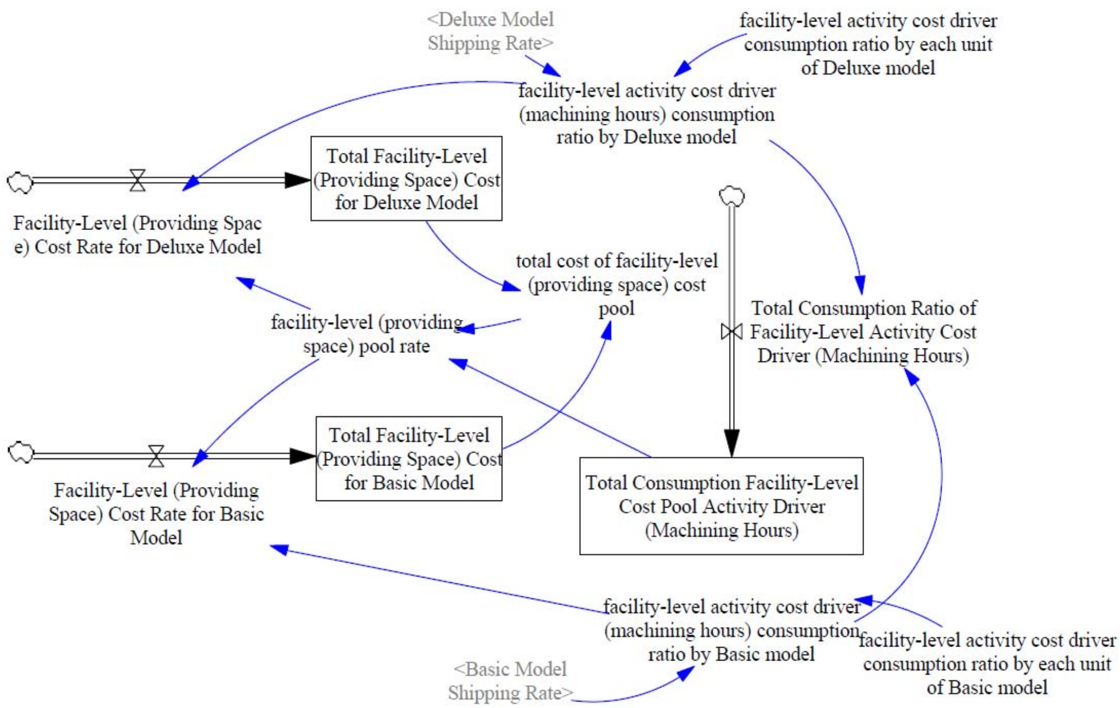

Figure 5-5e: Facility-level pool rates adjustment loops

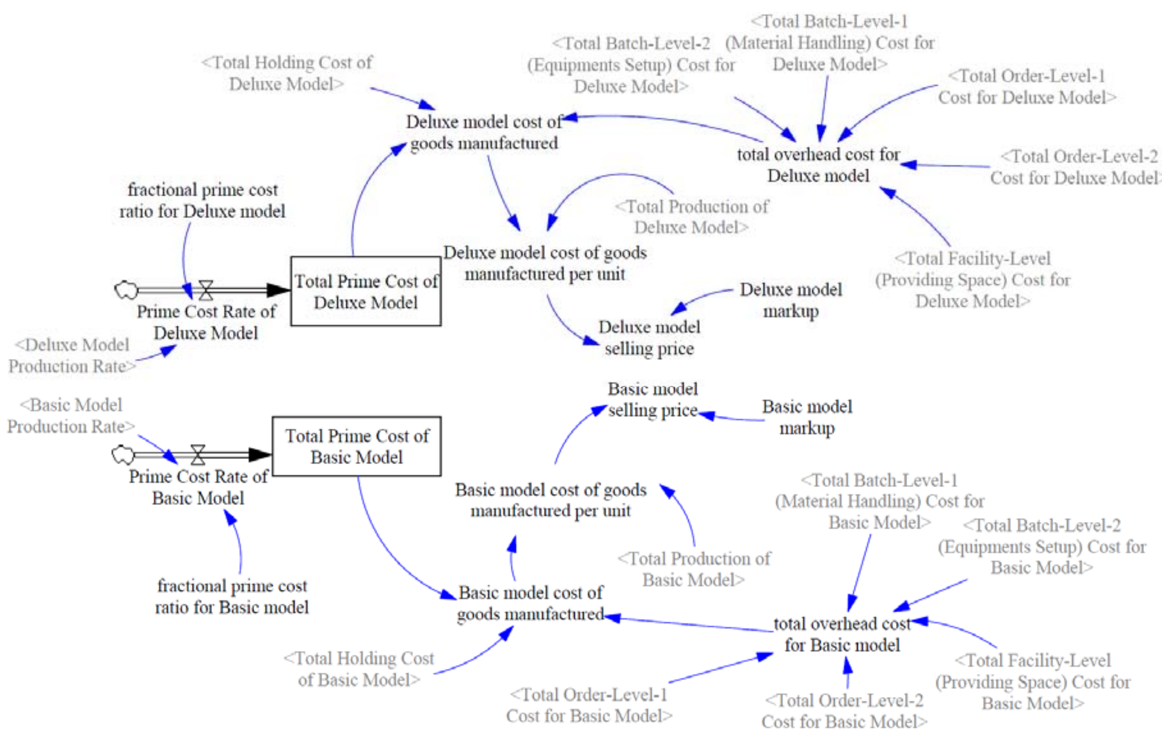

Figure 5-6: Selling price and product cost estimation

The model can be applied to the different order fulfillment scenarios in order to appraise the attributes of each order fulfillment policy and evaluate the effect of the management discretionary factor on the manufacturing cost and subsequently on the selling price *(selling price = (1+markup) × cost of goods manufactured per unit)*. The variation in the selling price based on the number of orders that should be fulfilled completely is shown in Table 5-3. The indicated prices in period one are the prices used by the MIP model.

The selling prices estimated by the SD model are calculated through the actual manufacturing cost. The estimated prices are used as a reference price in implementing the Order Fulfillment policy, instead of the selling price used by MIP model. The calculated selling prices for each product per period are indeed a lower limit for the products selling price. Thus, if management is willing to achieve the desirable projected profit, it should charge the customer no less than the calculated selling price per period for each type of product. According to the SD model output, Table 5-3, fulfilling more orders completely would require to increase the average selling price.

The rise in the average products' selling price, Figure 5-7, could be the consequence of an increase in the total cost of goods manufactured (that could be the result of changes in the total overhead costs, total prime costs, and/or total holding costs) and/or an increase in the manufacturing system residual capacity (this could be the result of changes in the production rate).Table 5-4 exhibits the total cost of goods manufactured for each model. Table 5-5 shows the related production amount and Table 5-6 displays the total overhead costs for each product type. Similar tables can be extracted from the model output for the other variables.

The variations in the cost amounts are because of the selected order fulfillment policy, which defines the inventory policy and the production rates. For example, in the case of 6 orders to be completely fulfilled, the total production amount according to the Table 5 for the Deluxe model is 4930 units and for the cases of 7 and 8 orders to be completely fulfilled are 5440 and 4930 units respectively. Therefore, the increases in both MOH and the manufacturing costs from 6 to 7 as well as the decreases from 7 to 8 can be justified.

However, the production amount is not the only reason in cost variations. The other reason is due to the changes in the pool rates. The model adjusts the pool rates after each run. This justifies the difference between the MOH costs for the Basic model from the case of 5 to the case of 6, although the total production amount remains the same. The other reason for the cost changes is due to the inventory cost which is different for each order fulfillment policy.

The model also has the ability to adjust the pool rates. Figure 5-8 reveals the adjustment for the order-level activities pool rates in different Order Fulfillment scenarios. The disparity between the order-level pool rates under different fulfillment scenarios is because of the correlation between the Order Fulfillment ratios and the order-level activities. In contrast, in Figure 5-9 there is no correlation between batch-level and facility-level activities pool rates and the Order Fulfillment scenario. Accordingly, the pool rates have not changed for those activities at different Order Fulfillment scenarios.

Table 5-3: Selling price variation

	Minimum desirable amount of orders which should be satisfied completely									
	5 or less Selling Price $		6 Selling Price $		7 Selling Price $		8 Selling Price $		9 Selling Price $	
Period	Basic	Deluxe	Basic	Deluxe	Basic	Deluxe	Basic	Deluxe	Basic	Deluxe
1	180.000	360.000	180.000	360.000	180.000	360.000	180.000	360.000	180.000	360.000
2	178.755	347.461	178.755	347.461	178.755	347.461	178.361	347.461	177.923	347.461
3	178.429	356.987	178.461	356.987	178.461	356.987	179.591	356.955	180.829	356.999
4	178.051	350.247	178.075	350.247	178.075	349.049	179.933	350.215	181.999	350.852
5	179.361	349.443	179.378	349.443	179.624	352.819	181.482	349.415	184.531	356.819
6	183.081	350.344	183.096	350.344	182.746	361.395	185.620	349.962	188.559	366.354
7	182.259	349.392	182.272	349.392	181.913	358.145	184.460	350.457	186.896	363.199
8	182.703	348.386	182.715	348.386	182.426	355.685	184.658	354.435	186.817	364.481
9	184.298	350.759	184.309	350.759	184.138	356.718	186.064	360.160	188.079	368.187
10	184.254	356.031	184.263	356.031	184.106	360.747	185.858	368.390	187.668	374.675
11	184.859	355.623	184.867	355.623	184.756	360.227	186.271	367.541	187.871	373.705
12	185.142	355.856	185.150	355.856	185.061	360.302	186.403	367.384	187.828	373.380

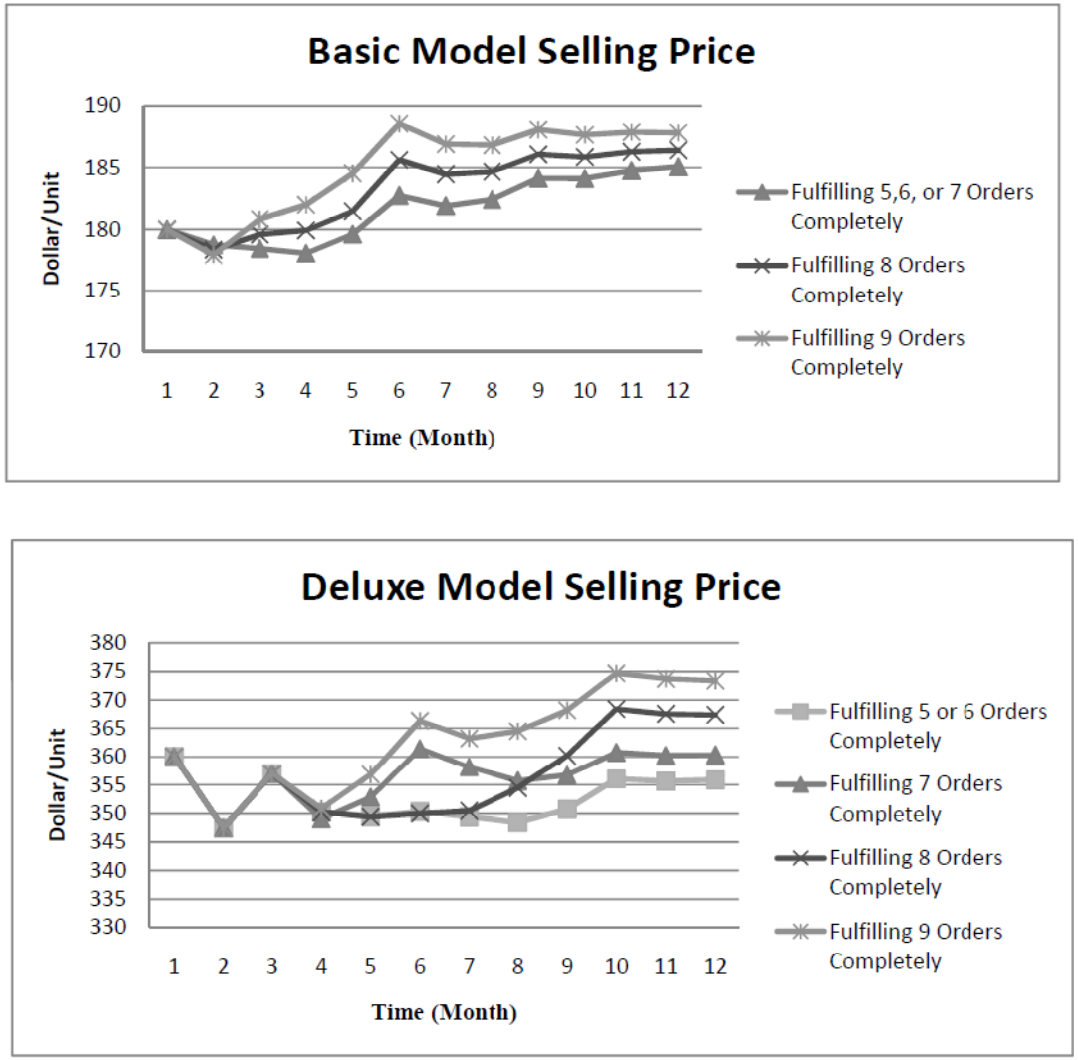

Figure 5-7: Products selling price variation

Table 5-4: Total cost of goods manufactured per model

	Minimum desirable amount of orders which should be satisfied completely				
	5 or less	6	7	8	9
Product	Cost of Goods Manufactured $	Cost of Goods Manufactured $	Cost of Goods Manufactured $	Cost of Goods Manufactured $	Cost of Goods Manufactured $
Basic	2,343,900.00	2,344,000.00	2,256,110.00	2,359,860.00	2,289,830.00
Deluxe	883,103.00	883,103.00	986,631.00	911,711.00	1,022,440.00

Table 5-5: Total production per model

	Minimum desirable amount of orders which should be satisfied completely				
	5 or less	6	7	8	9
Product	Total Production Unit	Total Production Unit	Total Production Unit	Total Production Unit	Total Production Unit
Basic	27000	27000	26000	27000	26000
Deluxe	4930	4930	5440	4930	5440

Table 5-6: Total overhead cost per model

	Minimum desirable amount of orders which should be satisfied completely				
	5 or less	6	7	8	9
Product	Total Overhead Cost $	Total Overhead Cost $	Total Overhead Cost $	Total Overhead Cost $	Total Overhead Cost $
Basic	94,247.20	94,338.00	90,696.40	94,114.10	90,173.30
Deluxe	71,830.60	71,830.60	79,327.80	71,762.50	79,090.50

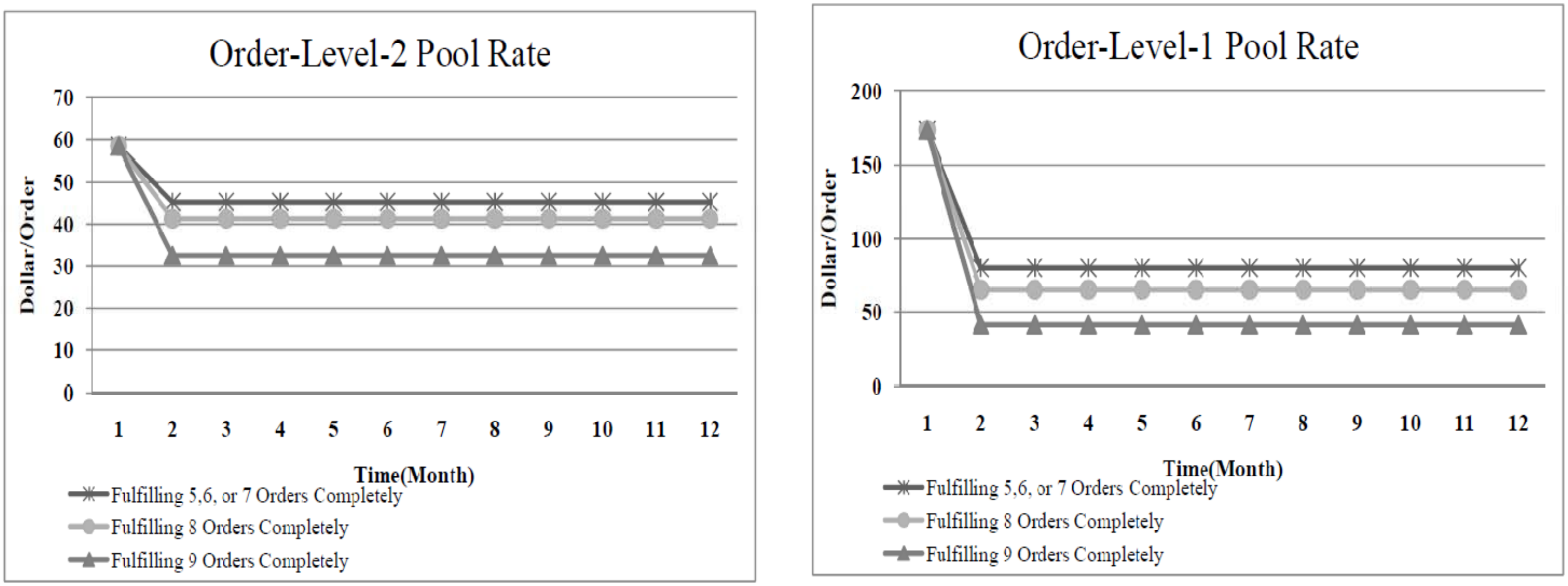

Figure 5-8: Order-level activities pool rates

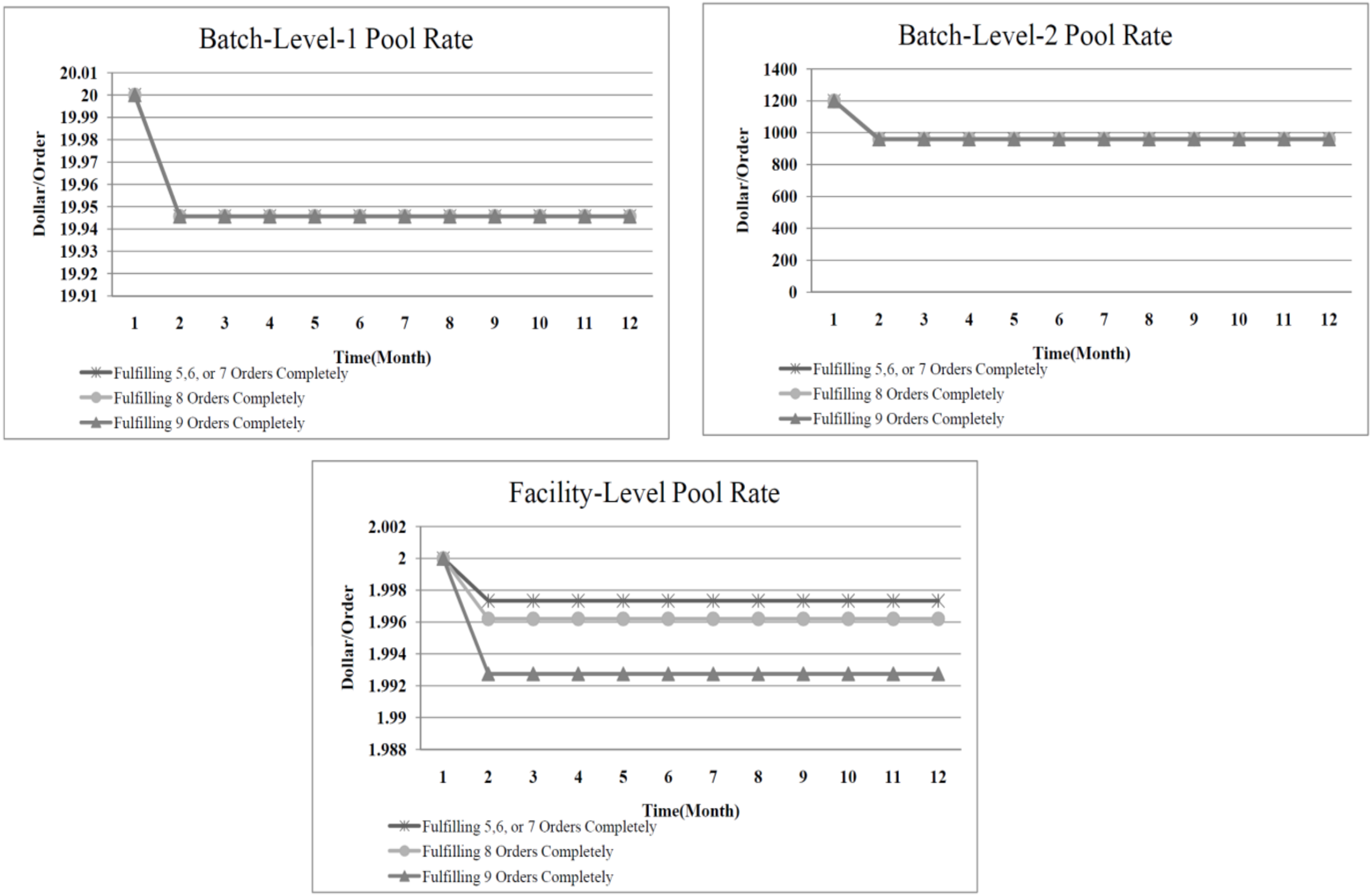

Figure 5-9: Batch-level and facility-level activities pool rates

5.4. Chapter Summary

This chapter presents a novel modeling approach in integrating SD and optimization in order to develop a powerful hybrid profitable-to-promise DSS tool for a SC order management problem. The DSS system developed assists management in monitoring, analyzing and foreseeing the consequences and outcomes of each decision and monitors their business competitiveness factors. In the first step, we developed a decision support model based on the ABC/M cost structure. In the new MIP model, the general homogeneous cost pools structure, applied in Chapter 4, is replaced with a more detailed and activity oriented cost structure. Moreover, the facility-level activity cost pool is added to the model that has been omitted in the previous models. These changes help the new model to assign the overhead costs more accurately, which ultimately increases the precision of the profitability estimation of each order and generates a more reliable order management decision.

As a second step, the ABC/M-based system dynamics model developed adds a supportive powerful tool to the MIP model. This model can identify the interconnections and correlations between the order management decision making variables. The SD model can help management to investigate and examine the further consequences of executing the different order fulfillment decision scenarios expansively. The model can define the on-time selling price based on the management financial policy and can also serve as a cost monitoring tool with the purpose of checking the costs behavior at different levels and for different products. ABC/M as a common modeling approach unifies two models and makes them work together as a powerful hybrid decision support system.

The hybrid DSS output indicates that fulfilling more orders actually decreases the company’s profit (MIP part output), and requires adjusting the product selling price (SD part output). Depending on the product type and applied Order Fulfillment scenario, the selling price could be decreased or increased compared to the initial selling price used in the MIP model. Reducing the selling price can give more satisfaction to the customer if the level of order fulfillment remains the same. However, increasing the selling price may result in a lower or higher customer satisfaction level. This depends on the customer’s understanding and the value given to a better order fulfillment service. Thus, it should be considered that the result of fulfilling more orders completely actually may conflict with the original intention of increasing customer satisfaction.

Chapter 6

Summary, Discussion, Conclusion, and Future Research

The dissertation focuses on developing a new systematic approach for cost management, cost control, and cost analysis in the order fulfillment process. The approach presented aims not only at maximizing the profit, but also at how to improve the utilization rate, and how to implement the most appropriate order fulfillment strategy. Using activity-based costing and management (ABC/M) as the cost structure gives ABC/M a critical role in the modeling process while increasing the validity of the model output.

6.1. Summary

The importance of integrating ABC/M in supply chain management (SCM) mathematical decision support models as one of the elements of ABC/M evolution is reviewed in Chapter 2. The literature review provided depicts the importance and suitability of ABC/M information and cost structure integration into mathematical decision support models at different managerial hierarchy levels. The supply chain (SC) activity oriented literature classification provides a descriptive perspective for this matter. It shows how ABC/M oriented mathematical decision support models are mostly focused on the tactical level. However, few studies have shown ABC/M integration into strategic level decision support models especially in investment related decisions.

At the operational level, the integration of ABC/M in SCM decision support models recently started to attract more attention. Developing ABC/M oriented cost of quality controls models, cost-based scheduling, and inventory control models all are novel topics in the area of developing SCM decision support models which have not been considered in literature.

6.1.1. Contribution to ABC/M-based Mathematical Decision Support Model

In Chapter 3 the new approach of integrating ABC/M cost structure in mathematical decision support models for order management problems is introduced. The new profitable-to-promise (PTP) model integrates the option of fulfilling the orders partially by applying weighted goal programming (WGP) techniques in order to reduce the residual capacity and increase profitability at the same time.

The mixed-integer programming (MIP) model developed also incorporates the concept of management discretionary factor. The model is able to fulfill a desirable amount of orders completely according to the managers’ preferences with the possibility of satisfying the rest of the orders partially, with the objective of minimizing the residual capacity.

6.1.2. Contribution to ABC/M-based System Dynamics Decision Support Model

Current system dynamics (SD) cost monitoring models act as a real-time cost calculator rather than as a system dynamics model. They do not contain positive or negative feedback loops; moreover they do not consider any qualitative factors for the cost monitoring process. The model presented in Chapter 4 benefits from SD's main characteristic, *i.e.*, the integration of learning loops. Through the illustrative example, the advantage of ABC/M over traditional cost accounting (TCA) systems is exemplified.

Furthermore, using ABC/M integrates a more comprehensive cost structure into the model. This enhances the model reliability and preciseness. The integration of ABC/M helps the model to track the costs and analyze the implemented strategy in terms of cost behavior in a more detailed way. The SD model developed has also the ability to define the product's selling price. The recommended prices help companies to remain competitive and earn profits, simultaneously.

6.1.3. Contribution to ABC/M-based Hybrid Decision Support Model

Although the MIP model presented brought up several important concepts, it still has some limitations such as manufacturing overhead (MOH) costs indistinctness due to the implementation of the extremely general homogeneous cost pools, high level of mathematical and optimization complexity, and lack of a tool that can provide an on-time reliable decision support analysis.

The ABC/M integration opens the possibility of linking the two decision support models presented. A novel hybrid decision support model by integrating the ABC/M cost structure with MIP and SD to improve the business performance in the order fulfillment management process is presented in Chapter 5. Integration of ABC/M due to its main characteristic, it assignees the overhead costs instead of allocating them (*e.g.* by using a specific plant-wide rate), results in a more reliable and precise cost monitoring tool. Adopting ABC/M in both models also demonstrates the advantage of it by linking the information between SD simulation modeling and MIP mathematical model. The model also illustrates the role of overhead costs by defining a more specific cost structure and by adding the facility-level costs pool to the initial model presented in Chapter 3.

In general, Chapters 3 to 5 presented the three steps required in developing the hybrid (MUP-SD) decision support system (DSS). In Chapter 3, the MIP model which defines the optimal order management customer oriented policy is discussed. In Chapter 4, the SD modeling part is presented. The SD model can track the cost behavior of each order management policy chosen. In Chapter 5 the two models developed integration by using ABC/M as a common cost structure approach is elaborated. The combination is introduces as a hybrid DSS which assists management to select and implement the most appropriate order management strategy.

6.2. Discussion and Conclusion

ABC/M is being evolved from a cost accounting approach to a managerial and cost accounting system. The ABC/M application in supply chain management decision support modeling, along with its proven positive effect on the other SC improvement strategies (*e.g.* Total Quality Management, Just-in-Time), emphasizes more on ABC/M managerial aspects. Theses also emerge the positional advantages of ABC as a supporting tool for lean manufacturing (LM).

LM focuses on the methodologies and approaches that can help an enterprise to reduce the waste factors in its processes. The traditional cost accounting is a transaction oriented approach, but a LM process requires an activity oriented cost information. ABC/M because of its activity oriented nature can provide useful information to identify the cost effect of each value added (VA) and non-value added (NVA) process activities. This introduces ABC as a lean accounting (LA) approach that can help to analyze each process from LM perspective.

Accordingly, the hybrid activity oriented modeling approach presented in this dissertation can work as a supporting tool to track the effect of the changes in the integrated activity costs (*i.e.* VA and NVA activities) by incorporating the necessary adjustments. For example, in the quality control process generally we deal with four different homogenous cost pools named, prevention, appraisal, internal failure, and external failure. Each cost pool involved different VA and NVA activities. The hybrid modeling approach can be used to develop a model which can suggest a LM oriented quality control policy which relatively involved less NVA activity costs. In addition, it can help to adjust the policy based on the LM performance indicators during the implementation phase.

6.3. Recommendation for Future Research

The thesis presented is in a relatively new research area, it shows the significance of ABC/M managerial aspects and it elucidates the advantages of ABC/M integration into SCM decision supports models. However, this study still can be expanded from different aspects.

- The integration of ABC/M information and cost structure at operational level management decision support mathematical models according to the explained approach in literature review.
- This research can also be used as a platform for developing educational modeling tools for MBA and management students.

The suggested amounts for m_i coefficients in the MIP part of the hybrid model are chosen by trial and error, in order to find an appropriate combination, more investigation is necessary. This can be done by developing a new model through other modeling techniques for the similar problem and comparing the results.

- Verifying the effectiveness of the selected m_i at the MIP part of hybrid model.

This research can also be expanded by including the role of additional factors, such as product quality and/or other market competitors' price, as part of the demand fluctuation. The current system considers the demand as a function of the price and the price elasticity only. However, the integration requires reliable information to confirm a systematic relation between the supplementary variables and demand.

- Adding qualitative factors to the SD part of hybrid model which make the model more realistic.

The model can be expanded at the supply chain level by integrating the process costs that are controlled by the other supply chain members such as; raw material purchasing cost, raw material holding costs, and transportation costs. The expansion can also be made at the operational level by integrating the factors that are controlled by company such as adding the possibility of having backlog.

- Illustrating the role of raw material suppliers and raw material inventory into the hybrid model.
- Integrating the cost of backlog among the decision making factors in the hybrid model.

The above mentioned approaches can be considered with the purpose of enhancing the model's legitimacy level or as a general instruction to apply a similar modeling approach in the other supply chain and operations management decision support domains.

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Appendices

A.1. ABC/M-based MIP Order Management Model

```
SETS:
Product /P1,P2,P3,P4/: h,p1;              !i;
Order /O1..O14/;                          !o;
RawMaterial /A,B/;                        !r;
Supplier /SUP1,SUP2/;                     !v;
Period /T1..T14/;                         !t;
UnitLevel /j1..j5/:x;                     !j;
BatchLevel /k1..k5/:a;                    !k;
OrderLevel /l1..l4/:y1,d1,d2,F;           !l;

LINK1 (Product,Order,Period):S,D;
LINK2 (Product,Period):In,CPIn;
Link3 (Product,UnitLevel,Period):P;
Link4 (Product,UnitLevel,Period, BatchLevel):B2;
LINK5 (LINK2,UnitLevel, BatchLevel): Y2;
LINK6 (Product,Order,Period, OrderLevel):Y,Ynew;
Link7 (Product,UnitLevel):q1,b1;
Link8 (Product,UnitLevel,BatchLevel):u1;
Link9 (Product,OrderLevel):f1;
Link11(UnitLevel,Period):Q;
Link12(BatchLevel,Period):U;
Link13(Period,Product,Supplier,RawMaterial);
Link14(Period,Product,UnitLevel);
Link15(Period,Product,UnitLevel,BatchLevel);
Link16(Period,Order,Product,OrderLevel);
Link17(Product,BatchLevel);
Link18(RawMaterial,Supplier,Period):RC;
Link19(Product,RawMaterial):g;
Link20(RawMaterial,Supplier):c;

ENDSETS
```

```
!OBJECTIVE FUNCTION;

MAX = M3*(@SUM(Link1(i, o, t): p1(i)*S(i,o,t))
- @SUM(Link13(t, i, v, r):g(i,r)*c(r,v)*
@SUM(UnitLevel(j)|j#GE#2:P(i,j,t)))
- @SUM(Link14(t, i, j):x(j)*q1(i,j)*P(i,j,t))
- @SUM(Link15(t,i, j,k):a(k)*u1(i,j,k)*B2(i,j,t, k))
- @SUM(Link16(t,o,i,l): y1(l)*f1(i,l)*Y(i,o,t, l))
- @SUM(Link2(i,t):h(i)*In(i,t))
- @SUM(Link2(i,t):CPh*CPIn(i,t)))
- M4*(@Sum(Orderlevel(l):M1*d1(l)+M2*d2(l)));

!Raw Material Constraint;
@FOR(RawMaterial(r):
@FOR(Period(t):[const2]
@SUM(Product(i):g(i,r)*@SUM(UnitLevel(j):P(i,j,t))) <=
@SUM(Supplier(v):RC(r,v,t)))
);

!Unit Level Balance Constraint;
@FOR(UnitLevel(j):
@FOR(Period(t): [const3]
     @SUM(Product(i):q1(i,j)*P(i,j,t))+
@SUM(Link17(i,k):u1(i,j,k)*B2(i,j,t,k))  <=Q(j,t))
);

!Batch Level Balance Constraints;
@FOR(UnitLevel(j):
@FOR(Period(t):
@FOR(Product(i):[const4]
     P(i,j,t)= b1(i,j) * @sum(BatchLevel(k): B2(i,j,t,k))))
);

@For(BatchLevel(k):
@FOR(Period(t):
@FOR(UnitLevel(j): [const5]
     @Sum(Product(i): u1(i, j, k)*B2(i, j, t, k))<=U(k,t)))
);

!Order Level Balance Constraints;
@FOR(Product(i):
@FOR(Order(o):
@For(Period(t): [const6]
     S(i,o,t)=D(i,o,t)*@sum(orderlevel(l):Y(i,o, t, l)) ))
);

@FOR(OrderLevel(l): [const7]
     @SUM(Link1(i,o,t):f1(i,l)*Y(i,o,t, l)- d1(l) + d2(l)) = F(l)
);

@FOR(Product(i):
@FOR(Order(o):
@For(Period(t):
     @sum(orderlevel(l):Y(i,o, t, l)) <= 1 ))
);

@SUM(Link6(i,o,t,l):Ynew(i,o,t,l))>= 0;
```

```
@For(Link6(i,o,t,l):Y(i,o,t,l)>= Ynew(i,o,t,l)
);
@For(Link1(i,o,t):
D(i,o,t)>@Sum(OrderLevel(l):Y(i,o,t,l))
);

!Inventory Balance Constraint;
@FOR(LINK2(i,t)|t #EQ# 1:
      @SUM(UnitLevel(j)|j#GE# 2: P(i,j,t))-In(i,t) =
@sum(order(o):S(i,o,t))
);

@FOR(LINK2(i,t)|t #GE# 2: [const9]
      In(i,t-1)+ @SUM(UnitLevel(j)| j#GE#2 :P(i,j,t))-In(i,t)=
@sum(order(o):S(i,o,t))
);

!Inventory Balance Constraints For Common Parts;
@FOR(Period(t)|t #GE# 2:
     CPIn(1,t)= P(1,1,t)-P(1,2,t)+ CPIn(1,t-1)
);

@FOR(Period(t)|t #GE# 2:
     CPIn(2,t)= P(2,1,t)-P(2,3,t) + CPIn(2,t-1)
);

@FOR(Period(t)|t #GE# 2:
     CPIn(3,t)= P(3,1,t)-P(3,4,t) + CPIn(3,t-1)
);

@FOR(Period(t)|t #GE# 2:
     CPIn(4,t)= P(4,1,t)-P(4,5,t) + CPIn(4,t-1)
);

@FOR(Period(t)|t #EQ# 1:
     CPIn(1,t)= P(1,1,t)-P(1,2,t)
);

@FOR(Period(t)|t #EQ# 1:
     CPIn(2,t)= P(2,1,t)-P(2,3,t)
);

@FOR(Period(t)|t #EQ# 1:
     CPIn(3,t)= P(3,1,t)-P(3,4,t)
);

@FOR(Period(t)|t #EQ# 1:
     CPIn(4,t)= P(4,1,t)-P(4,5,t)
);

!Other Constraints;
@FOR(LINK6(i,o,t,l): Y(i,o,t,l)<= 1);

@FOR(LINK6: @BIN(Ynew)
);

@FOR(LINK5:
```

```
      @BIN(Y2));

@FOR(LINK3:
      @GIN(P));

@FOR(LINK4:
      @GIN(B2));

DATA:

M1=1;

M2=0.5;

M3=1;

M4=2;

O =7;

x= 7.08, 3.67, 3.67, 1.77, 1.77;

c= 30, 10, 30, 10;

a= 14.38,9.58,9.58,7.19,7.19;

y1= 123.21,82.14,41.07,41.07;

h= 2.8,1.9,1.6,1.6;

CPh= 1.3;

g= 1,1,
   1,0,
   1,0,
   1,0;

RC= 25,25,25,25,25,25,25,25,25,25,25,25,25,25,
    25,25,25,25,25,25,25,25,25,25,25,25,25,25,
    25,25,25,25,25,25,25,25,25,25,25,25,25,25,
    25,25,25,25,25,25,25,25,25,25,25,25,25,25;

q1= 0.25,0.25,10000,10000,10000,
    0.25,10000,0.25,10000,10000,
    0.25,10000,10000,0.25,10000,
    0.25,10000,10000,10000,0.25;

u1= 0.5,10000,10000,10000,10000,
    10000,0.333,10000,10000,10000,
    10000,10000,10000,10000,10000,
    10000,10000,10000,10000,10000,
    10000,10000,10000,10000,10000,
    0.5,10000,10000,10000,10000,
    10000,10000,10000,10000,10000,
    10000,10000,0.333,10000,10000,
    10000,10000,10000,10000,10000,
    10000,10000,10000,10000,10000,
    0.5,10000,10000,10000,10000,
    10000,10000,10000,10000,10000,
    10000,10000,10000,10000,10000,
    10000,10000,10000,0.333,10000,
    10000,10000,10000,10000,10000,
    0.5,10000,10000,10000,10000,
```

```
     10000,10000,10000,10000,10000,
     10000,10000,10000,10000,10000,
     10000,10000,10000,10000,10000,
     10000,10000,10000,10000,0.333;

b1=  4,4,10000,10000,10000,
     4,10000,4,10000,10000,
     4,10000,10000,4,10000,
     4,10000,10000,10000,4;

p1=  111.00,75.00,80.00,65.00;

f1=  1.5,10000,10000,10000,
     10000,1.5,10000,10000,
     10000,10000,1.5,10000,
     10000,10000,10000,1.5;

D=  40,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,50,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,65,0,0,0,0,0,0,0,0,0,
    0,0,0,0,95,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0
    0,0,0,0,0,0,0,35,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,68,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,

    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,57,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,40,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,

    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,45,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,50,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,30,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,
```

```
   0,0,0,0,0,0,0,0,0,0,0,0,0,80,
   0,0,0,0,0,0,0,0,0,0,0,0,0,0,
   0,0,0,0,0,0,0,0,0,0,0,0,0,0,
   0,0,0,0,0,0,0,0,0,0,0,0,0,0,
   0,0,0,0,0,0,0,0,0,0,0,0,0,0,
   0,0,0,0,0,0,0,0,0,0,0,0,0,0,
   0,0,0,0,0,0,0,0,0,0,0,0,0,0,
   0,0,0,0,0,0,0,0,0,0,0,0,0,0,
   0,0,0,0,0,0,0,0,0,0,0,0,0,0,
   0,0,0,0,0,0,0,0,0,0,0,0,0,0,
   0,0,0,0,0,0,0,0,0,0,0,0,0,0,
   0,0,0,0,0,0,0,0,0,0,0,0,0,0,
   0,0,0,0,0,0,0,0,0,0,0,25,0,0,
   0,0,0,0,0,0,0,0,0,0,0,0,30,0,
   0,0,0,0,0,0,0,0,0,0,0,0,0,0;

Q= 9,9,9,9,9,9,9,9,9,9,9,9,9,9,
   8,8,8,8,8,8,8,8,8,8,8,8,8,8,
   8,8,8,8,8,8,8,8,8,8,8,8,8,8,
   7.5,7.5,7.5,7.5,7.5,7.5,7.5,7.5,7.5,7.5,7.5,7.5,7.5,7.5,
   7.5,7.5,7.5,7.5,7.5,7.5,7.5,7.5,7.5,7.5,7.5,7.5,7.5,7.5;

U=2.997,2.997,2.997,2.997,2.997,2.997,2.997,2.997,2.997,2.997,2.997,2.9
97,2.997,2.997,
   2,2,2,2,2,2,2,2,2,2,2,2,2,2,
   2,2,2,2,2,2,2,2,2,2,2,2,2,2,
   1.5,1.5,1.5,1.5,1.5,1.5,1.5,1.5,1.5,1.5,1.5,1.5,1.5,1.5,
   1.5,1.5,1.5,1.5,1.5,1.5,1.5,1.5,1.5,1.5,1.5,1.5,1.5,1.5;

F= 112,112,105,105;

ENDDATA
```

A.2. ABC/M-based System Dynamics Cost Monitoring Model

(01) average number of units per order received from Odds model=
25
Units: Unit/Order

(02) average number of units per order received from Ends model=
125
Units: Unit/Order

(03) basic selling price for Ends model=
870.43
Units: Dollar/Unit

(04) basic selling price for Odds model=
2420.64
Units: Dollar/Unit

(05) batch size of Ends model=
125
Units: Unit/Batch

(06) batch size of Odds model=
25
Units: Unit/Batch

07) "batch-level (setup and inspection) pool rate"=
IF THEN ELSE("total batch-level (setup and inspection) cost">0, "total batch-level (setup and inspection) cost"
/"Total Consumption of Batch-Level Activity Cost Driver" , 9000)
Units: Dollar/Setup

(08) "batch-level activity cost driver consumption ratio by each batch of Ends model"
=
1
Units: Setup/Batch

(09) "batch-level activity cost driver consumption ratio by each batch of Odds model"
=
1
Units: Setup/Batch

(10) "batch-level activity cost driver consumption ratio by Ends model"=
Ends Model Production Rate/batch size of Ends model*"batch-level activity cost driver consumption ratio by each batch of Ends model"
Units: Setup/Month

(11) "Batch-Level Cost Rate for Ends Model"=
"batch-level activity cost driver consumption ratio by Ends model"*"batch-level (setup and inspection) pool rate"
Units: Dollar/Month

(12) "Batch-Level Cost Rate for Odds Model"=
"batch-level (setup and inspection) pool rate"*"batch-level- activity cost driver consumption ratio by Odds model"
Units: Dollar/Month

(13) "batch-level- activity cost driver consumption ratio by Odds model"=
Odds Model Production Rate/batch size of Odds model*"batch-level activity cost driver consumption ratio by each batch of Odds model"
Units: Setup/Month

(14) budgeted number of order for Ends model=
3
Units: Order/Month

(15) budgeted number of order for Odds model=
3
Units: Order/Month

(16) Direct labor cost rate per unit of Ends=
180
Units: Dollar/Unit

(17) Direct labor cost rate per unit of Odds=
120
Units: Dollar/Unit

18) Direct material cost rate per unit of Ends=
240
Units: Dollar/Unit

(19) Direct material cost rate per unit of Odds=
160
Units: Dollar/Unit

(20) elasticity of demand for Ends model=
-1
Units: Dmnl

(21) elasticity of demand for Odds model=
-1

Units: Dmnl

(22) Ends model cost of goods manufactured per unit=
IF THEN ELSE(Ends model cost of goods manufactured>0,Ends model cost of goods manufactured
/Total Production of Ends Model , 725.36)
Units: Dollar/Unit

(23) Ends model cost of goods manufactured=
total overhead cost for Ends model+Total Prime Cost of Ends Model
Units: Dollar

(24) Ends model markup=
0.2
Units: Dmnl

(25) Ends Model Order Received Rate=
DELAY1(((Ends model selling price/basic selling price for Ends model-1)*elasticity of demand for Ends model
+1)*budgeted number of order for Ends model , 2)
Units: **undefined**

(26) Ends Model Production Rate=
average number of units per order received from Ends model*Ends Model Order Received Rate
Units: Unit/Month

(27) Ends model selling price=
(1+Ends model markup)*Ends model cost of goods manufactured per unit
Units: Dollar/Unit

(28) "facility-level activity cost driver consumption ratio by Ends model"=
Ends Model Production Rate*"facility-level activity cost driver consumption ratio by producing each unit of Ends model"
Units: SquareFeetUsage/Month

(29) "facility-level activity cost driver consumption ratio by Odds model"=
"facility-level activity cost driver consumption ratio by producing each unit of Odds model"

(30) "facility-level activity cost driver consumption ratio by producing each unit of Ends model"
=
0.1536
Units: SquareFeetUsage/Unit

(31) "facility-level activity cost driver consumption ratio by producing each unit of Odds model"
=
3.072
Units: SquareFeetUsage/Unit

(32) "Facility-Level Cost Rate for Ends Model"=
"facility-level pool rate"*"facility-level activity cost driver consumption ratio by Ends model"
Units: Dollar/Month

(33) "Facility-Level Cost Rate for Odds Model"=
"facility-level pool rate"*"facility-level activity cost driver consumption ratio by Odds model"
Units: Dollar/Month

(34) "facility-level pool rate"=
IF THEN ELSE("total cost of facility-level cost pool">0, "total cost of facility-level cost pool"
/"Total Consumption Facility-Level Activity Cost Driver" , 100)
Units: Dollar/SquareFeetUsage

(35) FINAL TIME = 12
Units: Month
The final time for the simulation.

(36) INITIAL TIME = 0
Units: Month
The initial time for the simulation.

(37) Odds model cost of goods manufactured=
total overhead cost for Odds model+Total Prime Cost of Odds Model
Units: Dollar

(38) Odds model cost of goods manufactured per unit=
IF THEN ELSE(Total Production of Odds Model>0,Odds model cost of goods manufactured
/Total Production of Odds Model , 2017.2)
Units: Dollar/Unit

(39) Odds model markup=
0.2
Units: Dmnl

(40) Odds Model Order Received Rate=
DELAY1(((Odds model selling price/basic selling price for Odds model-

1)*elasticity of demand for Odds model
+1)*budgeted number of order for Odds model ,2)
Units: Order/Month

(41) Odds Model Production Rate=
average number of units per order received from Odds model*Odds Model Order Received Rate
Units: Unit/Month

(42) Odds model selling price=
(1+Odds model markup)*Odds model cost of goods manufactured per unit
Units: Dollar/Unit

(43) Prime Cost Rate of Ends Model=
Ends Model Production Rate*(Direct labor cost rate per unit of Ends+Direct material cost rate per unit of Ends
)
Units: Dollar/Month

(44) Prime Cost Rate of Odds Model=
Odds Model Production Rate*(Direct labor cost rate per unit of Odds+Direct material cost rate per unit of Odds
)
Units: Dollar/Month

(45) "product-level activity cost driver consumption ratio by each order of Ends model"
=
1.25
Units: EngineeringChange/Order

(46) "product-level activity cost driver consumption ratio by each order of Odds model"
=
3.75
Units: EngineeringChange/Order

(47) "product-level activity cost driver consumption ratio by Ends model"=
Ends Model Order Received Rate*"product-level activity cost driver consumption ratio by each order of Ends model"
Units: EngineeringChange/Month

(48) "product-level activity cost driver consumption ratio by Odds model"=
Odds Model Order Received Rate*"product-level activity cost driver consumption ratio by each order of Odds model"
Units: EngineeringChange/Month

(49) "Product-Level Cost Rate for Ends Model"=
"product-level activity cost driver consumption ratio by Ends model"*"product-level pool rate"
Units: Dollar/Month

(50) "Product-Level Cost Rate for Odds Model"=
"product-level activity cost driver consumption ratio by Odds model"*"product-level pool rate"
Units: Dollar/Month

(51) "product-level pool rate"=
IF THEN ELSE("total cost of product-level cost pool">0, "total cost of product-level cost pool"
/"Total Consumption of Product-Level Activity Cost Driver" , 1800)
Units: Dollar/EngineeringChange

(52) SAVEPER =
TIME STEP
Units: Month [0,?]
The frequency with which output is stored.

(53) TIME STEP = 1
Units: Month [0,?]
The time step for the simulation.

(54) "total batch-level (setup and inspection) cost"=
"Total Batch-Level Cost for Ends Model"+"Total Batch-Level Cost for Odds Model"
Units: Dollar

(55) "Total Batch-Level Cost for Ends Model"= INTEG (
"Batch-Level Cost Rate for Ends Model",
0)
Units: Dollar

(56) "Total Batch-Level Cost for Odds Model"= INTEG (
"Batch-Level Cost Rate for Odds Model",
0)
Units: Dollar

(57) "Total Consumption Facility-Level Activity Cost Driver"= INTEG (
"Total Consumption Ratio of Facility-Level Activity Cost Driver",
1)
Units: SquareFeetUsage

(58) "Total Consumption of Batch-Level Activity Cost Driver"= INTEG (
"Total Consumption Ratio of Batch-Level Activity Cost Driver",
1)
Units: Setup

(50) "Total Consumption of Product-Level Activity Cost Driver"= INTEG (
"Total Consumption Ratio of Product-Level Activity Cost Driver",
1)
Units: EngineeringChange

(60) "Total Consumption Ratio of Batch-Level Activity Cost Driver"=
"batch-level activity cost driver consumption ratio by Ends model"+"batch-level- activity cost driver consumption ratio by Odds model"
Units: Setup/Month

(61) "Total Consumption Ratio of Facility-Level Activity Cost Driver"=
"facility-level activity cost driver consumption ratio by Ends model"+"facility-level activity cost driver consumption ratio by Odds model"
Units: SquareFeetUsage/Month

(62) "Total Consumption Ratio of Product-Level Activity Cost Driver"=
"product-level activity cost driver consumption ratio by Ends model"+"product-level activity cost driver consumption ratio by Odds model"
Units: EngineeringChange/Month

(63) "Total Consumption Ratio of Unit-Level Activity Cost Driver"=
"unit-level activity cost driver consumption ratio by Ends model"+"unit-level activity cost driver consumption ratio by Odds model"
Units: Unit/Month

(64) "Total Consumption Unit-Level Cost Pool Activity Driver"= INTEG (
"Total Consumption Ratio of Unit-Level Activity Cost Driver",
1)

(65) "total cost of facility-level cost pool"=
"Total Facility-Level Cost for Ends Model"+"Total Facility-Level Cost for Odds Model"
Units: Dollar

(66) "total cost of product-level cost pool"=
"Total Product-Level Cost for Ends Model"+"Total Product-Level Cost for Odds Model"
Units: Dollar

(67) "Total Facility-Level Cost for Ends Model"= INTEG (
"Facility-Level Cost Rate for Ends Model",

0)
Units: Dollar

(68) "Total Facility-Level Cost for Odds Model"= INTEG (
"Facility-Level Cost Rate for Odds Model",
0)
Units: Dollar

(69) total overhead cost for Ends model=
"Total Batch-Level Cost for Ends Model"+"Total Facility-Level Cost for Ends Model"
+"Total Product-Level Cost for Ends Model"+"Total Unit-Level Cost for Ends Model"
Units: Dollar

(70) total overhead cost for Odds model=
"Total Batch-Level Cost for Odds Model"+"Total Facility-Level Cost for Odds Model"
+"Total Product-Level Cost for Odds Model"+"Total Unit-Level Cost for Odds Model"
Units: Dollar

(71) Total Prime Cost of Ends Model= INTEG (
Prime Cost Rate of Ends Model,
0)
Units: Dollar

(72) Total Prime Cost of Odds Model= INTEG (
Prime Cost Rate of Odds Model,
0)
Units: Dollar

(73) "Total Product-Level Cost for Ends Model"= INTEG (
"Product-Level Cost Rate for Ends Model",
0)
Units: Dollar

(74) "Total Product-Level Cost for Odds Model"= INTEG (
"Product-Level Cost Rate for Odds Model",
0)
Units: Dollar

(75) Total Production of Ends Model= INTEG (
Ends Model Production Rate,
0)
Units: Unit

(76) Total Production of Odds Model= INTEG (
Odds Model Production Rate,
0)
Units: Unit

(77) Total Received Order of Ends Model= INTEG (
Ends Model Order Received Rate,
0)
Units: Order

(78) Total Received Order of Odds Model= INTEG (
Odds Model Order Received Rate,
0)
Units: Order

(79) "Total Unit-Level Cost for Ends Model"= INTEG (
"Unit-Level Cost Rate for Ends Model",
0)
Units: Dollar

(80) "Total Unit-Level Cost for Odds Model"= INTEG (
"Unit-Level Cost Rate for Odds Model",
0)
Units: Dollar

(81) "total unit-level cost"=
"Total Unit-Level Cost for Ends Model"+"Total Unit-Level Cost for Odds Model"
Units: Dollar

(82) "unit-level activity cost driver consumption ratio by each unit of Ends model"
=
1
Units: Setup/Batch

(83) "unit-level activity cost driver consumption ratio by each unit of Odds model"
=
8
Units: MachiningHr/Unit

(84) "unit-level activity cost driver consumption ratio by Ends model"=
Ends Model Production Rate*"unit-level activity cost driver consumption ratio by each unit of Ends model"
Units: MachiningHr/Month

(85) "unit-level activity cost driver consumption ratio by Odds model"=
Odds Model Production Rate*"unit-level activity cost driver consumption ratio by each unit of Odds model"
Units: MachiningHr/Month

(86) "Unit-Level Cost Rate for Ends Model"=
"unit-level activity cost driver consumption ratio by Ends model"*"unit-level pool rate"
Units: Dollar/Month

(87) "Unit-Level Cost Rate for Odds Model"=
"unit-level pool rate"*"unit-level activity cost driver consumption ratio by Odds model"
Units: Dollar/Month

(88) "unit-level pool rate"=
IF THEN ELSE("total unit-level cost">0, "total unit-level cost"/"Total Consumption Unit-Level Cost Pool Activity Driver"
, 100)
Units: Dollar/MachiningHr

A.3. TCA-based System Dynamics Cost Monitoring Model

(01) average number of unit per order received from Odds model=
25
Units: Unit/Order

(02) average number of unit per order received from Ends model=
125
Units: Unit/Order

(03) basic selling price for Ends model=
870.43
Units: Dollar/Unit

(04) basic selling price for Odds model=
2420.64
Units: Dollar/Unit

(05) budgeted number of order for Ends model=
3
Units: Order/Month

(06) budgeted number of order for Odds model=
3
Units: Order/Month

(07) Direct labor cost rate per unit of Ends=
180
Units: Dollar/Unit

(08) Direct labor cost rate per unit of Odds=
120
Units: Dollar/Unit

(09) Direct material cost rate per unit of Ends=
240
Units: Dollar/Unit

(10) Direct material cost rate per unit of Odds=
160
Units: Dollar/Unit

(11) elasticity of demand for Ends model=
-1
Units: Dmnl

(12) elasticity of demand for Odds model=
-1
Units: Dmnl

(13) Ends model cost of goods manufactured per unit=
IF THEN ELSE(Ends model cost of goods manufactured>0,Ends model cost of goods manufactured
/Total Production of Ends Model , 725.36)
Units: Dollar/Unit

(14) Ends model cost of goods manufactured=
Total Manufacturing Overhead Cost for Ends Model+Total Prime Cost of Ends Model
Units: Dollar

(15) Ends model markup=
0.2
Units: Dmnl

(16) Ends Model Order Received Rate=
DELAY1(((Ends model selling price/basic selling price for Ends model-1)*elasticity of demand for Ends model
+1)*budgeted number of order for Ends model , 2)
Units: **undefined**

(17) Ends Model Production Rate=
average number of unit per order received from Ends model*Ends Model Order Received Rate
Units: Unit/Month

(18) Ends model selling price=
(1+Ends model markup)*Ends model cost of goods manufactured per unit
Units: Dollar/Unit

(19) FINAL TIME = 12
Units: Month
The final time for the simulation.

(20) INITIAL TIME = 0
Units: Month
The initial time for the simulation.

(21) manufacturing overhead consumption ratio by Odds model=
manufacturing overhead consumption ratio by producing each unit of Odds model

*Odds Model Production Rate
Units: DLhr/Month

(22) manufacturing overhead consumption ratio by producing each unit of Odds model
=
4
Units: DLhr/Unit

(23) manufacturing overhead cost driver consumption ratio by producing each unit of Ends model
=
6
Units: DLhr/Unit

(24) Manufacturing Overhead Cost Rate for Ends Model=
plantwide overhead rate*manufacturing overhead cost ratio by Ends model
Units: Dollar/Month

(25) Manufacturing Overhead Cost Rate for Odds Model=
plantwide overhead rate*manufacturing overhead consumption ratio by Odds model
Units: Dollar/Month

(26) manufacturing overhead cost ratio by Ends model=
Ends Model Production Rate*manufacturing overhead cost driver consumption ratio by producing each unit of Ends model
Units: DLhr/Month

(27) Odds model cost of goods manufactured=
Total Manufacturing Overhead Cost for Odds Model+Total Prime Cost of Deluxe Model
Units: Dollar

(28) Odds model cost of goods manufactured per unit=
IF THEN ELSE(Total Production of Odds Model>0,Odds model cost of goods manufactured
/Total Production of Odds Model , 2017.2)
Units: Dollar/Unit

(29) Odds model markup=
0.2
Units: Dmnl

(30) Odds Model Order Received Rate=
DELAY1(((Odds model selling price/basic selling price for Odds model-

1)*elasticity of demand for Odds model
+1)*budgeted number of order for Odds model ,2)
Units: Order/Month

(31) Odds Model Production Rate=
average number of unit per order received from Odds model*Odds Model Order Received Rate
Units: Unit/Month

(32) Odds model selling price=
(1+Odds model markup)*Odds model cost of goods manufactured per unit
Units: Dollar/Unit

(33) plantwide overhead rate=
IF THEN ELSE(total manufacturing overhead cost>0, total manufacturing overhead cost
/"Total Consumption Facility-Level Activity Cost Driver" , 96)
Units: Dollar/DLhr

(34) Prime Cost Rate of Ends Model=
Ends Model Production Rate*(Direct labor cost rate per unit of Ends+Direct material cost rate per unit of Ends
)
Units: Dollar/Month

(35) Prime Cost Rate of Odds Model=
Odds Model Production Rate*(Direct labor cost rate per unit of Odds+Direct material cost rate per unit of Odds
)
Units: Dollar/Month

(36) SAVEPER =
TIME STEP
Units: Month [0,?]
The frequency with which output is stored.

(37) TIME STEP = 1
Units: Month [0,?]
The time step for the simulation.

(38) "Total Consumption Facility-Level Activity Cost Driver"= INTEG (
Total Consumption Ratio of Manufacturing Overhead Cost,
1)
Units: DLhr

(39) Total Consumption Ratio of Manufacturing Overhead Cost=

manufacturing overhead cost ratio by Ends model+manufacturing overhead consumption ratio by Odds model
Units: DLhr/Month

(40) total manufacturing overhead cost=
Total Manufacturing Overhead Cost for Ends Model+Total Manufacturing Overhead Cost for Odds Model
Units: Dollar

(41) Total Manufacturing Overhead Cost for Ends Model= INTEG (
Manufacturing Overhead Cost Rate for Ends Model,
0)
Units: Dollar

(42) Total Manufacturing Overhead Cost for Odds Model= INTEG (
Manufacturing Overhead Cost Rate for Odds Model,
0)
Units: Dollar

(43) Total Prime Cost of Deluxe Model= INTEG (
Prime Cost Rate of Odds Model,
0)
Units: Dollar

(44) Total Prime Cost of Ends Model= INTEG (
Prime Cost Rate of Ends Model,
0)
Units: Dollar

(45) Total Production of Ends Model= INTEG (
Ends Model Production Rate,
0)
Units: Unit

(46) Total Production of Odds Model= INTEG (
Odds Model Production Rate,
0)
Units: Unit

(47) Total Received Order of Ends Model= INTEG (
Ends Model Order Received Rate,
0)
Units: Order

(48) Total Received Order of Odds Model= INTEG (
Odds Model Order Received Rate,

0)
Units: Order

A.4. Hybrid System (MIP Model)

```
SETS:
Product /Basic,Deluxe/: h,p1,pr;                  !i;
Order /O1..O16/;                                  !o;
Period /T1..T12/;                                 !t;
UnitLevel /j1/;                                   !j;
BatchLevel /k1,k2/: a;                            !k;
OrderLevel /l1,l2/:y1,d1,d2,F;                    !l;
FacilityLevel /r1/:c1,C;                          !r;

Link1 (Product,Order,Period):S,D,Y,Ynew;
Link2 (Product,Period):P,In;
Link3 (Product,UnitLevel,Period):B;
Link4 (UnitLevel,Period):Q;
Link5 (Product,Order,Period);
Link6 (Product,UnitLevel, FAcilityLevel):q1;
Link7 (Product,UnitLevel):b1;
Link8 (Product,UnitLevel,BatchLevel):u1;
Link9 (Product,OrderLevel):f1;
Link10(Period,Order,Product,UnitLevel,FacilityLevel);
Link12(BatchLevel,Period):U;
Link15(Period,Product,UnitLevel,BatchLevel);
Link16(Period,Order,Product,OrderLevel);

ENDSETS

!OBJECTIVE FUNCTION;

MAX = M3 * (@SUM(Link1(i, o, t): p1(i) * S(i,o,t))
- @SUM(Link2(i, t): pr(i) * P(i,t))
- @SUM(Link15(t,i, j,k): a(k) * u1(i,j,k) * B(i,j,t))
- @SUM(Link16(t,o,i,l): y1(l) * f1(i,l) * Y(i,o,t))
- @SUM(Link10(t,o,i,j,r): c1(r) *q1(i,j,r)* S(i,o,t))
- @SUM(Link2(i,t): h(i) * In(i,t)))
- M4 * (@Sum(Orderlevel(l): M1*d1(l) + M2*d2(l)));

!Unit Level Balance Constraints;
@FOR(UnitLevel(j):
@FOR(FacilityLevel(r):
@FOR(Period(t):
     @SUM(Product(i):q1(i,j,r) * P(i,t))<= Q(j,t)))
);

!Batch Level Balance Constraints;
@FOR(UnitLevel(j):
@FOR(Period(t):
@FOR(Product(i):
     P(i,t) =  b1(i,j) * B(i,j,t)))
);

@FOR(BatchLevel(k):
@FOR(Period(t):
     @SUM(Link7(i,j): u1(i, j, k) * B(i, j, t)) <= U(k,t))
);
```

```
!Order Level Balance Constraints;
@FOR(Product(i):
@FOR(Order(o):
@FOR(Period(t):
     S(i,o,t) = D(i,o,t) * Y(i,o, t)) )
);

@FOR(OrderLevel(l):
     @SUM(Link1(i,o,t): f1(i,l) * Y(i,o,t)- d1(l) + d2(l)) = F(l)
);

@SUM(Link1(i,o,t): Ynew(i,o,t)) >= 0;

@FOR(Link1(i,o,t): Y(i,o,t) >= Ynew(i,o,t)
);

@FOR(Link1(i,o,t):
     D(i,o,t) > Y(i,o,t)
);

!Inventory Balance Constraints;
@FOR(Link2(i,t)|t #EQ# 1:
     P(i,t) - In(i,t) = @SUM(order(o): S(i,o,t))
);

@FOR(Link2(i,t)|t #GE# 2:
     In(i,t-1) + P(i,t) - In(i,t) = @SUM(order(o): S(i,o,t))
);

!Other Constraints;
@FOR(Link1(i,o,t): Y(i,o,t) <= 1
);

@FOR(Link1: @BIN(Ynew)
);

@FOR(Link2: @GIN(P)
);

@FOR(Link3: @GIN(B)
);


DATA:

M1=1;

M2=0.5;

M3=1;

M4=2;

O =5;

pr = 80.00, 160.00;

a= 20,1200;
```

```
y1= 173.33,58.50;

c1= 2;

h= 4.22,9.06;

q1= 0.25,0.5;

u1= 100,1,66.67,1;

f1= 1,4,1,6;

b1= 1000,170;

p1= 180.00,360.00;

D= 3500,0,0,0,0,0,0,0,0,0,0,0, !1;
   0,4600,0,0,0,0,0,0,0,0,0,0, !2;
   0,0,0,0,0,0,0,0,0,0,0,0,    !3;
   0,3000,0,0,0,0,0,0,0,0,0,0, !4;
   0,0,0,0,0,0,0,0,0,0,0,0,    !5;
   0,0,0,0,3200,0,0,0,0,0,0,0, !6;
   0,0,0,0,4700,0,0,0,0,0,0,0, !7;
   0,0,0,0,0,0,0,0,0,0,0,0,    !8;
   0,0,0,0,0,0,0,0,0,0,0,0,    !9;
   0,0,0,0,0,0,0,4500,0,0,0,0, !10;
   0,0,0,0,0,0,0,0,0,0,0,0,    !11;
   0,0,0,0,0,0,0,0,0,3500,0,0, !12;
   0,0,0,0,0,0,0,0,0,0,3000,0, !13;
   0,0,0,0,0,0,0,0,0,0,0,5000,  !14;
   0,0,0,0,0,0,0,0,0,0,0,0,    !15;
   0,0,0,0,0,0,0,0,0,0,0,0,    !16;

   0,0,0,0,0,0,0,0,0,0,0,0,    !1;
   0,0,0,0,0,0,0,0,0,0,0,0,    !2;
   0,2500,0,0,0,0,0,0,0,0,0,0, !3;
   0,0,0,0,0,0,0,0,0,0,0,0,    !4;
   0,0,2500,0,0,0,0,0,0,0,0,0, !5;
   0,0,0,0,0,0,0,0,0,0,0,0,    !6;
   0,0,0,0,0,0,0,0,0,0,0,0,    !7;
   0,0,0,0,1900,0,0,0,0,0,0,0, !8;
   0,0,0,0,0,4000,0,0,0,0,0,0, !9;
   0,0,0,0,0,0,0,0,0,0,0,0,    !10;
   0,0,0,0,0,0,0,0,3000,0,0,0, !11;
   0,0,0,0,0,0,0,0,0,0,0,0,    !12;
   0,0,0,0,0,0,0,0,0,0,0,0,    !13;
   0,0,0,0,0,0,0,0,0,0,0,0,    !14;
   0,0,0,0,0,0,0,0,0,0,0,2700, !15;
   0,0,0,0,0,0,0,0,0,0,0,5000; !16;

Q= 850,850,850,850,850,850,850,850,850,850,850,850;

U= 500,500,500,500,500,500,500,500,500,500,500,500,
7,7,7,7,7,7,7,7,7,7,7,7;

F= 750,4000;

ENDDATA
```

A.5. Hybrid System (SD Model)

(001) Basic model cost of goods manufactured=
total overhead cost for Basic model+Total Prime Cost of Basic Model+Total Holding Cost of Basic Model
Units: Dollar

(002) Basic model cost of goods manufactured per unit=
IF THEN ELSE(Total Production of Basic Model>0,Basic model cost of goods manufactured
/Total Production of Basic Model , 84.4)
Units: Dollar/Unit

(003) Basic model holding cost coefficient=
0.05
Units: 1/Month

(004) Basic model markup=
1.1327
Units: Dmnl

(005) Basic model order fulfillment rates:=
GET XLS DATA('FB.xls' , 'Sheet1' , '1' , 'B3')
Units: Order/Month

(006) Basic Model Production Rate:=
GET XLS DATA('PB.xls' , 'Sheet1' , '1' , 'B3')
Units: Unit/Month

(007) Basic model selling price=
(1+Basic model markup)*Basic model cost of goods manufactured per unit
Units: Dollar/Unit

(008) Basic Model Shipping Rate:=
GET XLS DATA('SB.xls' , 'Sheet1' , '1' , 'B3')
Units: Unit/Month

(009) batch size of Basic model=
1000
Units: Unit/Batch

(010) batch size of Deluxe model=
170
Units: Unit/Batch

(011) "batch-level-1 (material handling) pool rate"=
IF THEN ELSE("total batch-level-1 (material handling) cost">0, "total batch-level-1 (material handling) cost"
/"Total Consumption Batch-Level-1 Cost Pool Activity Driver (Number of Moves)"
, 20)
Units: Dollar/Move

(012) "batch-level-1 activity cost driver (number of moves) consumption ratio by Basic model"
=
Basic Model Production Rate/batch size of Basic model*"batch-level-1 activity cost driver consumption ratio by each batch of Basic model"
Units: Move/Month

(013) "batch-level-1 activity cost driver (number of moves) consumption ratio by Deluxe model"
=
Deluxe Model Production Rate/batch size of Deluxe model*"batch-level-1 activity cost driver consumption ratio by each batch of Deluxe model"
Units: Move/Month

(014) "batch-level-1 activity cost driver consumption ratio by each batch of Basic model"
=
100
Units: Move/Batch

(015) "batch-level-1 activity cost driver consumption ratio by each batch of Deluxe model"
=
66.67
Units: Move/Batch

(016) "Batch-Level-1 Cost (Material Handling) Rate for Basic Model"=
"batch-level-1 activity cost driver (number of moves) consumption ratio by Basic model"
*"batch-level-1 (material handling) pool rate"
Units: Dollar/Month

(017) "batch-level-2 (equipments setup) pool rate"=
IF THEN ELSE("total batch-level-2 (equipments setup) cost">0, "total batch-level-2 (equipments setup) cost"
/"Total Consumption Batch-Level-2 Cost Pool Activity Driver (Number of Setups)"
, 1200)

Units: Dollar/Setup

(018) "batch-level-2 activity cost driver (number of setups) consumption ratio by Basic model"
=
Basic Model Production Rate/batch size of Basic model*"batch-level-2 activity cost driver consumption ratio by each batch of Basic model"
Units: Setup/Month

(019) "batch-level-2 activity cost driver (number of setups) consumption ratio by Deluxe model"
=
Deluxe Model Production Rate/batch size of Deluxe model*"batch-level-2 activity cost driver consumption ratio by each batch of Deluxe model"
Units: Setup/Month

(020) "batch-level-2 activity cost driver consumption ratio by each batch of Basic model"
=
1
Units: Setup/Batch

(021) "batch-level-2 activity cost driver consumption ratio by each batch of Deluxe model"
=
1
Units: Setup/Batch

(022) "Batch-Level-2 Cost (Equipments Setup) Rate for Basic Model"=
"batch-level-2 (equipments setup) pool rate"*"batch-level-2 activity cost driver (number of setups) consumption ratio by Basic model"
Units: Dollar/Month

(023) "Batch-Level-2 Cost (Equipments Setup) Rate for Deluxe Model"=
"batch-level-2 (equipments setup) pool rate"*"batch-level-2 activity cost driver (number of setups) consumption ratio by Deluxe model"
Units: Dollar/Month

(024) "Batch-Level-l Cost (Material Handling) Rate for Deluxe Model"=
"batch-level-1 (material handling) pool rate"*"batch-level-1 activity cost driver (number of moves) consumption ratio by Deluxe model"
Units: Dollar/Month

(025) Deluxe model cost of goods manufactured=
total overhead cost for Deluxe model+Total Prime Cost of Deluxe Model+Total Holding Cost of Deluxe Model

Units: Dollar

(026) Deluxe model cost of goods manufactured per unit=
IF THEN ELSE(Total Production of Deluxe Model>0,Deluxe model cost of goods manufactured
/Total Production of Deluxe Model , 181.21)
Units: Dollar/Unit

(027) Deluxe model holding cost coefficient=
0.05
Units: 1/Month

(028) Deluxe model markup=
0.9866
Units: Dmnl

(029) Deluxe model order fulfillment rates:=
GET XLS DATA('FD.xls' , 'Sheet1' , '1' , 'B3')
Units: Order/Month

(030) Deluxe Model Production Rate:=
GET XLS DATA('PD.xls' , 'Sheet1' , '1' , 'B3')
Units: Unit/Month

(031) Deluxe model selling price=
(1+Deluxe model markup)*Deluxe model cost of goods manufactured per unit
Units: Dollar/Unit

(032) Deluxe Model Shipping Rate:=
GET XLS DATA('SD.xls' , 'Sheet1' , '1' , 'B3')
Units: Unit/Month

(033) "Facility-Level (Providing Space) Cost Rate for Basic Model"=
"facility-level (providing space) pool rate"*"facility-level activity cost driver (machining hours) consumption ratio by Basic model"
Units: Dollar/Month

(034) "Facility-Level (Providing Space) Cost Rate for Deluxe Model"=
"facility-level (providing space) pool rate"*"facility-level activity cost driver (machining hours) consumption ratio by Deluxe model"
Units: Dollar/Month

(035) "facility-level (providing space) pool rate"=
IF THEN ELSE("total cost of facility-level (providing space) cost pool">
0, "total cost of facility-level (providing space) cost pool"/"Total Consumption

Facility-Level Cost Pool Activity Driver (Machining Hours)"
, 2)
Units: Dollar/MachiningHr

(036) "facility-level activity cost driver (machining hours) consumption ratio by Basic model"
=
Basic Model Shipping Rate*"facility-level activity cost driver consumption ratio by each unit of Basic model"
Units: MachiningHr/Month

(037) "facility-level activity cost driver (machining hours) consumption ratio by Deluxe model"
=
Deluxe Model Shipping Rate*"facility-level activity cost driver consumption ratio by each unit of Deluxe model"
Units: MachiningHr/Month

(038) "facility-level activity cost driver consumption ratio by each unit of Basic model"
=
0.25
Units: MachiningHr/Unit

(039) "facility-level activity cost driver consumption ratio by each unit of Deluxe model"
=
0.5
Units: MachiningHr/Unit

(040) FINAL TIME = 12
Units: Month
The final time for the simulation.

(041) fractional prime cost ratio for Basic model=
80
Units: Dollar/Unit

(042) fractional prime cost ratio for Deluxe model=
160
Units: Dollar/Unit

(043) Holdeing Cost Rate of Deluxe Model=
holding cost fractional ratio for Deluxe model*Inventory Level of Deluxe Model
Units: Dollar/Month

(044) holding cost fractional ratio for Basic model=
Basic model holding cost coefficient*Basic model cost of goods manufactured per unit
Units: Dollar/(Unit*Month)

(045) holding cost fractional ratio for Deluxe model=
Deluxe model holding cost coefficient*Deluxe model cost of goods manufactured per unit
Units: Dollar/(Month*Unit)

(046) Holding Cost Rate of Basic Model=
holding cost fractional ratio for Basic model*Inventory Level of Basic Model
Units: Dollar/Month

(047) INITIAL TIME = 1
Units: Month
The initial time for the simulation.

(048) Inventory Level of Basic Model= INTEG (
Basic Model Production Rate-Basic Model Shipping Rate,
0)
Units: Unit

(049) Inventory Level of Deluxe Model= INTEG (
Deluxe Model Production Rate-Deluxe Model Shipping Rate,
0)
Units: Unit

(050) Prime Cost Rate of Basic Model=
Basic Model Production Rate*fractional prime cost ratio for Basic model
Units: Dollar/Month

(051) Prime Cost Rate of Deluxe Model=
Deluxe Model Production Rate*fractional prime cost ratio for Deluxe model
Units: Dollar/Month

(052) "order-level-1 activity cost driver (number of orders) consumption ratio by Basic model"
=
Basic model order fulfillment rates*"order-level-1 activity cost driver consumption ratio by each order of Basic model"
Units: Order/Month

(053) "order-level-1 activity cost driver (number of orders) consumption ratio by

Deluxe model"
=
Deluxe model order fulfillment rates*"order-level-1 activity cost driver consumption ratio by each order of Deluxe model"
Units: Order/Month

(054) "order-level-1 activity cost driver consumption ratio by each order of Basic model"
=
1
Units: Dmnl

(055) "order-level-1 activity cost driver consumption ratio by each order of Deluxe model"
=
1
Units: Dmnl

(056) "Order-level-1 Cost Rate for Basic Model"=
"order-level-1 pool rate"*"order-level-1 activity cost driver (number of orders) consumption ratio by Basic model"
Units: Dollar/Month

(057) "Order-level-1 Cost Rate for Deluxe Model"=
"order-level-1 activity cost driver (number of orders) consumption ratio by Deluxe model"
*"order-level-1 pool rate"
Units: Dollar/Month

(058) "order-level-1 pool rate"=
IF THEN ELSE("total cost of order-level-1 cost pool">0,"total cost of order-level-1 cost pool"
/"Total Consumption Order-level-1 Cost Pool Activity Driver (Number of Orders)"
, 173.33)
Units: Dollar/Order

(059) "order-level-2 activity cost driver (maintenances hours) consumption ratio by Basic model"
=
Basic model order fulfillment rates*"order-level-2 activity cost driver consumption ratio by each order of Basic model"
Units: MaintenanceHr/Month

(060) "order-level-2 activity cost driver (maintenances hours) consumption ratio by Deluxe model"

=

"order-level-2 activity cost driver consumption ratio by each order of Deluxe model"

*Deluxe model order fulfillment rates

Units: MaintenanceHr/Month

(061) "order-level-2 activity cost driver consumption ratio by each order of Basic model"

=

4

Units: MaintenanceHr/Order

(062) "order-level-2 activity cost driver consumption ratio by each order of Deluxe model"

=

6

Units: MaintenanceHr/Order

(063) "Order-level-2 Cost Rate for Basic Model"=

"order-level-2 activity cost driver (maintenances hours) consumption ratio by Basic model"

*"order-level-2 pool rate"

Units: Dollar/Month

(064) "Order-level-2 Cost Rate for Deluxe Model"=

"order-level-2 activity cost driver (maintenances hours) consumption ratio by Deluxe model"

*"order-level-2 pool rate"

Units: Dollar/Month

(065) "order-level-2 pool rate"=

IF THEN ELSE("total cost of order-level-2 cost pool">0, "total cost of order-level-2 cost pool"

/"Total Consumption Order-level-2 Cost Pool Activity Driver (Maintenances Hours)"

, 58.5)

Units: Dollar/MaintenanceHr

(066) SAVEPER =

TIME STEP

Units: Month

The frequency with which output is stored.

(067) TIME STEP = 1

Units: Month

The time step for the simulation.

(068) "Total Batch-Level-1 (Material Handling) Cost for Basic Model"= INTEG
(
"Batch-Level-1 Cost (Material Handling) Rate for Basic Model",
0)
Units: Dollar

(069) "Total Batch-Level-1 (Material Handling) Cost for Deluxe Model"= INTEG
(
"Batch-Level-l Cost (Material Handling) Rate for Deluxe Model",
0)
Units: Dollar

(070) "total batch-level-1 (material handling) cost"=
"Total Batch-Level-1 (Material Handling) Cost for Basic Model"+"Total Batch-Level-1 (Material Handling) Cost for Deluxe Model"
Units: Dollar

(071) "Total Batch-Level-2 (Equipments Setup) Cost for Basic Model"= INTEG
(
"Batch-Level-2 Cost (Equipments Setup) Rate for Basic Model",
0)
Units: Dollar

(072) "Total Batch-Level-2 (Equipments Setup) Cost for Deluxe Model"= INTEG
(
"Batch-Level-2 Cost (Equipments Setup) Rate for Deluxe Model",
0)
Units: Dollar

(073) "total batch-level-2 (equipments setup) cost"=
"Total Batch-Level-2 (Equipments Setup) Cost for Basic Model"+"Total Batch-Level-2 (Equipments Setup) Cost for Deluxe Model"
Units: Dollar

(074) "Total Consumption Batch-Level-1 Cost Pool Activity Driver (Number of Moves)"
= INTEG (
"Total Consumption Ratio of Batch-Level-1 Activity Cost Driver (Number of Moves)"
,
1)
Units: Move

(075) "Total Consumption Batch-Level-2 Cost Pool Activity Driver (Number of Setups)"

= INTEG (
"Total Consumption Ratio of Batch-Level-2 Activity Cost Driver (Number of Setups)"
,
1)
Units: Setup

(076) "Total Consumption Facility-Level Cost Pool Activity Driver (Machining Hours)"
= INTEG (
"Total Consumption Ratio of Facility-Level Activity Cost Driver (Machining Hours)"
,
1)
Units: MachiningHr

(077) "Total Consumption Order-level-1 Cost Pool Activity Driver (Number of Orders)"
= INTEG (
"Total Consumption Ratio of Order-level-1 Activity Cost Driver (Number of Orders)"
,
1)
Units: Order

(078) "Total Consumption Order-level-2 Cost Pool Activity Driver (Maintenances Hours)"
= INTEG (
"Total Consumption Ratio of Order-level-2 Activity Cost Driver (Maintenances Hours)"
,
1)
Units: MaintenanceHr

(079) "Total Consumption Ratio of Batch-Level-1 Activity Cost Driver (Number of Moves)"
=
"batch-level-1 activity cost driver (number of moves) consumption ratio by Basic model"
+"batch-level-1 activity cost driver (number of moves) consumption ratio by Deluxe model"
Units: Move/Month

(080) "Total Consumption Ratio of Batch-Level-2 Activity Cost Driver (Number of Setups)"
=
"batch-level-2 activity cost driver (number of setups) consumption ratio by Basic model"

+"batch-level-2 activity cost driver (number of setups) consumption ratio by Deluxe model"
Units: Setup/Month

(081) "Total Consumption Ratio of Facility-Level Activity Cost Driver (Machining Hours)"
=
"facility-level activity cost driver (machining hours) consumption ratio by Basic model"
+"facility-level activity cost driver (machining hours) consumption ratio by Deluxe model"
Units: MachiningHr/Month

(082) "Total Consumption Ratio of Order-level-1 Activity Cost Driver (Number of Orders)"
=
"order-level-1 activity cost driver (number of orders) consumption ratio by Basic model"
+"order-level-1 activity cost driver (number of orders) consumption ratio by Deluxe model"
Units: Order/Month

(083) "Total Consumption Ratio of Order-level-2 Activity Cost Driver (Maintenances Hours)"
=
"order-level-2 activity cost driver (maintenances hours) consumption ratio by Basic model"
+"order-level-2 activity cost driver (maintenances hours) consumption ratio by Deluxe model"
Units: MaintenanceHr/Month

(084) "total cost of facility-level (providing space) cost pool"=
"Total Facility-Level (Providing Space) Cost for Basic Model"+"Total Facility-Level (Providing Space) Cost for Deluxe Model"
Units: Dollar

(085) "total cost of order-level-1 cost pool"=
"Total Order-level-1 Cost for Basic Model"+"Total Order-level-1 Cost for Deluxe Model"
Units: Dollar

(086) "total cost of order-level-2 cost pool"=
"Total Order-level-2 Cost for Basic Model"+"Total Order-level-2 Cost for Deluxe Model"
Units: Dollar

(087) "Total Facility-Level (Providing Space) Cost for Basic Model"= INTEG
(
"Facility-Level (Providing Space) Cost Rate for Basic Model",
0)
Units: Dollar

(088) "Total Facility-Level (Providing Space) Cost for Deluxe Model"= INTEG
(
"Facility-Level (Providing Space) Cost Rate for Deluxe Model",
0)
Units: Dollar

(089) Total Holding Cost of Basic Model= INTEG (
Holding Cost Rate of Basic Model,
0)
Units: Dollar

(090) Total Holding Cost of Deluxe Model= INTEG (
Holding Cost Rate of Deluxe Model,
0)
Units: Dollar

(091) total overhead cost for Basic model=
"Total Batch-Level-1 (Material Handling) Cost for Basic Model"+"Total Batch-Level-2 (Equipments Setup) Cost for Basic Model"
+"Total Facility-Level (Providing Space) Cost for Basic Model"+"Total Order-level-1 Cost for Basic Model"
+"Total Order-level-2 Cost for Basic Model"
Units: Dollar

(092) total overhead cost for Deluxe model=
"Total Batch-Level-1 (Material Handling) Cost for Deluxe Model"+"Total Batch-Level-2 (Equipments Setup) Cost for Deluxe Model"
+"Total Facility-Level (Providing Space) Cost for Deluxe Model"+"Total Order-level-1 Cost for Deluxe Model"
+"Total Order-level-2 Cost for Deluxe Model"
Units: Dollar

(093) Total Prime Cost of Basic Model= INTEG (
Prime Cost Rate of Basic Model,
0)
Units: Dollar

(094) Total Prime Cost of Deluxe Model= INTEG (
Prime Cost Rate of Deluxe Model,
0)

Units: Dollar

(095) "Total Order-level-1 Cost for Basic Model"= INTEG (
"Order-level-1 Cost Rate for Basic Model",
0)
Units: Dollar

(096) "Total Order-level-1 Cost for Deluxe Model"= INTEG (
"Order-level-1 Cost Rate for Deluxe Model",
0)
Units: Dollar

(097) "Total Order-level-2 Cost for Basic Model"= INTEG (
"Order-level-2 Cost Rate for Basic Model",
0)
Units: Dollar

(098) "Total Order-level-2 Cost for Deluxe Model"= INTEG (
"Order-level-2 Cost Rate for Deluxe Model",
0)
Units: Dollar

(099) Total Production of Basic Model= INTEG (
Basic Model Production Rate,
0)
Units: Unit

(100) Total Production of Deluxe Model= INTEG (
Deluxe Model Production Rate,
0)
Units: Unit

(101) Total Sales of Basic Model= INTEG (
Basic Model Shipping Rate,
1)
Units: Unit

(102) Total sales of Deluxe Model= INTEG (
Deluxe Model Shipping Rate,
1)
Units: Unit