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## Simulation modeling for integrated e-supply chain management

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**ABSTRACT**

**SIMULATION MODELING FOR  
INTEGRATED E-SUPPLY CHAIN MANAGEMENT**

by  
**Pornsarun Wirojanagud**

E-supply chain management is an emerging area of interest as companies begin to explore the Internet's potential to restructure supply chain relationships. The environmental impact of e-supply chain management is a critical issue towards sustainability. This thesis discusses and models an integrated e-supply chain network accounting for material and information flows throughout the supply chain in order to analyze the environmental implications and tradeoffs with other system characteristics. The network structure has complex interactions between various entities. In order to understand and analyze dynamic performance, a discrete-event simulation approach is utilized. An integrated tool was developed using the Arena simulation software to simulate the e-business supply chain including lifecycle stages. The modules capture general supply chain process and e-business concepts. Consequently, it can be used in wide range of applications. A case study based upon a desktop computer was modeled to illustrate the application of the simulation model, evaluate environmental performance and examine the stochastic behavior of the network.



**SIMULATION MODELING FOR  
INTEGRATED E-SUPPLY CHAIN MANAGEMENT**

**by  
Pornsarun Wirojanagud**

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Submitted to the Faculty of  
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in Partial Fulfillment of the Requirements for the Degree of  
Masters of Science in Industrial Engineering**

**Department of Industrial and Manufacturing Engineering**

**May 2001**

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## **APPROVAL PAGE**

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Caudill, R., Luo, Y., Wirojanagud, P., Zhou, M., “Exploring the Environmental Impact of eCommerce on Electronic Products: An Application of Fuzzy Decision Theory and Lifecycle Studies”, Electronic Goes Green 2000, Germany, September, 2000.

Luo, Y., Wirojanagud, P., Caudill, R., “Network-Based Optimization and Simulation of Sustainable E-Supply Chain Management”, 2001 IEEE ISEE, Denver, CO, May, 2001.

*To my beloved family*

*I have gone through  
so many different stages  
changing ideas and goals  
while searching for the  
right kind of life for me*

*You were always  
ready to help me at all times*

*It must have seemed like  
I would never follow a straight path*

*Now that I know  
what I am doing and  
where I am going*

*I can only show you  
my extreme appreciation  
for your support*

*by being true to all the ideals and values  
that you tried to teach me*

*Thank you forever  
for standing by me*

*I love and appreciate you forever*

*by Susan Polis Schutz*

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# CHAPTER 1

## INTRODUCTION

### 1.1 Background

Internet use has grown exponentially becoming a global communication and business resource. In the US, over 30 million households are currently on-line, and, by 2003 nearly 75% of all American families will be surfing the net and buying products and services directly from the manufacturer or distributor [1-2]. Internet based-business or e-business will truly affect every sector of the economy in ways that today we can only imagine.

E-business is business activities occurring over the Internet which use non-proprietary protocols connecting a mixture of information and communication technologies [3]. E-business includes those *business-to-business* (B2B) and *business-to-consumer* (B2C) practices. B2B practice uses the Internet to integrate and manage the supply chain, extending from the suppliers of raw materials and components to the final customer. Whereas, B2C commerce focuses on individual household purchases of product via internet-based electronic store fronts or web sites. The Internet and e-business extend the benefits of conventional proprietary electronic data interchange (EDI) systems to all levels of the value-added supply chain leading to reduction in procurement cycles and cost, mistaken orders and paper-based transactions, as well as shortened product development times and reduced inventories [4].

E-business also provides a direct link between the final consumer and the product manufacturer or distributor. Consequently, built-to-order and mass customization for individual consumers via the Internet have been the cornerstone of the new business strategy exploited by Dell and Cisco [5]. With electronic linkage in the supply chains,

it is possible to pass the information of buyer preferences and demands on to corporate partners and coordinate material and component procurement, a practice referred to as collaborative planning forecasting replenishment. In addition, with closer supply chain integration, the opportunity exists to exchange environmental information between businesses in response to increasing customer requests for product environmental data.

E-business is still in its infancy and its impact on the business structure such as supply chain management or the environment is uncertain and difficult to quantify with any degree of rigor or level of confidence due to incomplete data and evolving vision. Currently, some qualitative studies have been done to analyze the impact of e-commerce on supply chain management or on the environment. The principal literature support comes from the descriptions of projects of companies on how they have utilized the Internet in the management. However, no quantitative studies were accomplished.

Research work by Caudill et al [40,41] examined the lifecycle environmental impacts of e-commerce by constructing bounding scenarios and concentrating on a specific electronic product. It showed that e-commerce does have environmental impact in terms of resource, energy and environmental burdens. The result indicated that just selling products over the Internet in a single B2C practice will result in negative impact on the environment, especially if packages are shipped air express. However, if the full power of web-enabled commerce is implemented, by integrating B2B and B2C, then energy savings and environment benefits over today's business practices are achievable along with inventory and cost reduction and business competence improvement. These studies emphasized the need to further explore the environmental impact of e-business.



E-Supply Chain is an emerging business strategy that incorporates the power of e-commerce to streamline the manufacturing processes, speed the product cycles, integrate the supply chains, and better response to the customers. Integrated e-supply chain system has more complex structure than traditional supply chain system in that it embraces e-business strategy to establish information links and integrates end-of-life processes into the entire supply chain structure. Many changes will take place throughout product lifecycle stages with associated impacts on environmental performance. Methodology and approaches are needed to model and analyze these changes.

Research by Caudill et al [42], studied the e-business enabled supply chain modeled as a hyper-network structure. The physical material flow supply chain network was overlaid with the associated Internet-based information network which is playing increasingly important roles in improving supply chain effectiveness and efficiency. It identified specific changes in supply chain structure. Supply chain elements and parameters were represented as mathematical model of network. Two related networks were modeled, material flow and information networks. Fuzzy multi-objective optimization approach was presented in order to model the data uncertainty and find best possible scenario meeting multiply goals. Network optimization techniques as discussed previously only provide a single “snapshot” of the supply chain. In order to understand and analyze dynamics performance, discrete-event simulation approach was further applied.

## **1.2 Objective**

The hyper-network structure has complex interactions between different entities, simulation is thus a practical way to conduct experiments with designed models for understanding the dynamic behavior of the system. The use of simulation as a vehicle for understanding issues of organizational decision making has gained considerable attention in recent years. Many researchers used simulation to evaluate the effects of various supply chain strategies and improving performance of the supply chain in terms of objectives such as cost minimization, on-time delivery, and optimal inventory level.

The objective of this thesis is to study the environmental impact of e-commerce on the e-supply chain management and develop an integrated simulation model to capture and simulate the complex dynamics of e-business supply chain for evaluating various operation system strategies, performance analysis, decision making, as well as environmental performance.

## **1.3 Organization**

The thesis is organized as follow. In Chapter 2, literature review on supply chain management, e-commerce and environment, and simulation methods are presented. Chapter 3 illustrates a study of the lifecycle environmental study on the impact of e-business. Chapter 4 defines the integrated e-supply chain model used for developing the simulation model. The detailed design of the template and interface of the supply chain simulation tool is described in Chapter 5. In Chapter 6, a case study on a typical desktop computer supply chain is presented to illustrate the utilization of the simulation. Conclusion and further researches direction are in Chapter 7.

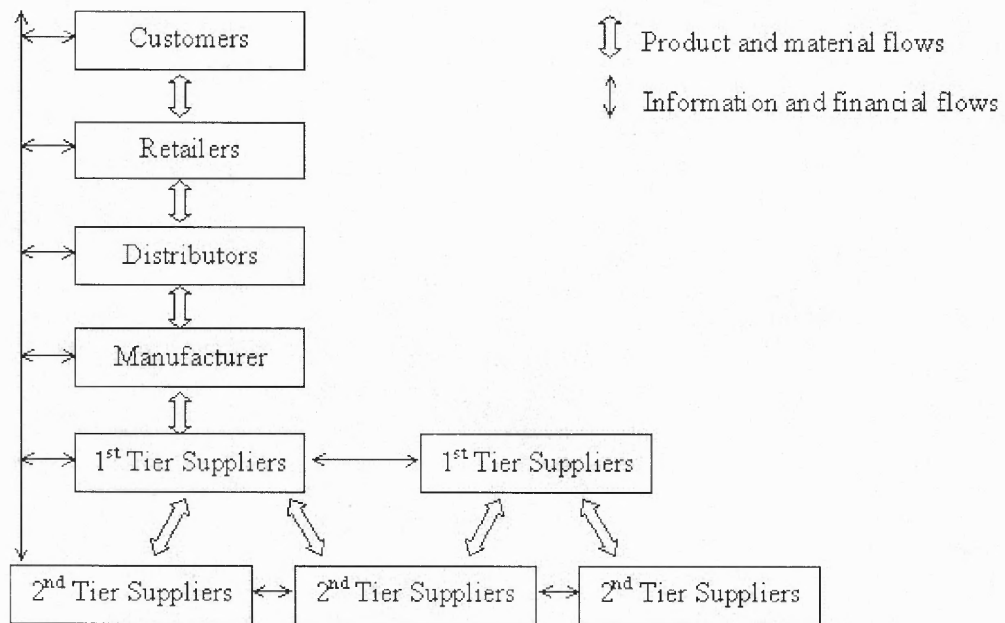
## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 Supply Chain Management**

The Supply Chain Management (SCM) literatures offer many variations when defining a supply chain. Bechtel and Jayaram [6] provided an extensive review of the literature, definitions and school of thoughts of SCM. SCM defined by The Global Supply Chain Forum is the integration of business processes from end user through original suppliers that provides products, services, and information that add value for customers [7].

SCM involves the flows of material, information, and finance in a network consisting of suppliers, manufacturers, distributors, logistics service providers, wholesalers, retailers, and customers [8,9]. Material flows include both physical product flows from suppliers to customers through the chain and reverse flows via product returns, servicing, recycling, and disposal. Information flows involve order transmission and delivery status. Financial flows include credit term, payment schedule, and consignment and title ownership arrangements. Coordination and integration of these flows are critical to effective supply chain management. Figure 2.1 illustrates the nature of supply chain management [43].



**Figure 2.1 Integrated Supply Chain Model**

### 2.1.1 Supply Chain Management and the Internet

The goals of supply chain systems are multi dimensional and include cost minimization, increased level of service, improve communication among supply chain partners. By nature, SCM deals with networks of suppliers and channel distribution. E-businesses are now providing value through the power of information network while redefining, and eliminating, activities in the physical network. The growth of Internet has presented supply chains with many significant opportunities for cost reduction and service improvement. Examples of these opportunities are the ability to track shipments, online catalogs which buyers could select and order items directly from suppliers, or the ability to notify vendors or buyers regarding to customer service problems from late delivery or stock outs. In procurement, there are opportunities for more business partners, faster turnaround, and smaller inventories.

A research by Richard [10] revealed that the most popular use of the Internet for SCM is in transportation, followed by order processing, managing vendor relationships, purchasing, procurement, and customer service. The use of Internet in each of these areas is based on the real-time information requirements needed to manage them effectively. The use of Internet in customer service, inventory management, and production planning and scheduling will become more popular as the technology develops. The Ford Motor Company uses Internet to track small quantities of spare parts shipped to customer on a daily basis. PPG Industries, Inc. utilizes the Internet to monitor the weekly route performance of carriers from its main production plants and to track long-haul deliveries across country [10].

Prominent examples of these positive effects include Dell Corporation, General Electric (GE), Wal-Mart, Digital Equipment Corporation, the personal computer supply chain, and the Hewlett-Packard Corporation [11]. Dell computer's inventory controls provide an example of how Internet supplier exchanges function. Dell has lowered its average inventory holdings from 35 days in 1993 to six days today [32]. Internet has helped Rollins Leasing Inc. reduce its supply chain costs by 5% to 15% through increased partnering with suppliers [10]. IBM has reduced inventory write-offs by \$800 millions, increase on time delivery from 90% to 98%, and reduce order commit time from two weeks to real time [33]. Since joining the trading process network, the GE Lighting unit has cut its average purchasing cycle time from 14 to 7 days. It has also reduce price paid for materials by 10 to 15 percent [43].

### 2.1.2 Supply Chain Management Modeling

Many quantitative models including optimization, simulation, stochastic models, and heuristics have been developed in order to solve supply chain management problems such issues as inventory management, supply contracts, product variety, and information flow. Analytical researches on multi-echelon inventory problem have been considerable for a long time. A multi-echelon system is one in which there are multiple tiers supply chain [15]. It can be operated on a centralized or a decentralized mode. Researchers have made efforts in modeling this under different conditions.

Axsater [17] provides a good description of models and algorithm for the analysis of continuous review policies in multi-echelon networks. Clark and Scarf [18] obtained a finite-horizon optimal policy for a serial system under centralized control with a base stock inventory policy. Federgruen and Zipkin [19] extended the model to the infinite horizon case. More recent supply chain models includes Cohen and Lee [20], Cohen and Moon [21], and Newhart, Scott, and Vasco [22], which deterministic scenarios are considered and a global optimization problem is formulated using mixed integer programs. Several papers considered a approach solving a single site inventory model repeatedly in order to recover the entire network, such as Graves [23] and Lee and Billington [24]. Garg [25] developed a supply chain modeling and analysis tool for modeling decentralized supply chain. Analytical models are good for simple situations and to grasp concepts, however, to compute number of real world situations, simulation is preferred.

Many researchers used simulation to evaluate the effects of various supply chain strategies and improving performance of the supply chain in terms of objectives such as

cost minimization, on-time delivery, and optimal inventory level. Towill, Naim, and Wiker [28] used simulation techniques to evaluate effects of various supply chain strategies on demand amplification. Swamminathan, Sadeh, and Smith [15] designed a simulation-based framework for developing customized supply chain models from a library of software components which captures generic supply chain processes and concepts. Tzafesta and Kapsiotis [31] utilized a combined analytical and simulation model to analyze supply chain. Glasserman and Tayur [29], developed a simulation based approach to obtain gradient estimation with respect to the base stock level in a multi-echelon system. Feigin et al [30] developed a supply network model to support organization decision making and utilized simulation in the performance analysis.

## **2.2 E-Commerce and the Environment**

Internet use has grown exponentially becoming a global communication and business resource. In the US alone, over 30 million households are currently on-line, and, by 2003 nearly 75% of all American families will be surfing the net and buying products and services directly from the manufacturer or distributor [34]. Electronic commerce (E-commerce) will truly affect every sector of the economy in ways that today we can only imagine. Andrew Grove, CEO of Intel, envisions a future dominated by this technology and predicted that “in five years time all companies will be Internet companies or they won’t be companies at all.” But, what will be the impact of e-commerce on production sector and the environment? Recently, researchers have begun to explore this question from many perspectives examining the growth of e-business and future trends in environment strategy.

Nevin Cohen at INFORM Inc., a national research organization, pointed out that e-commerce will have significant environmental consequences [5]. Information Revolution, Internet, and e-commerce will reshape manufacturing and distribution systems, product design, the fundamental relationship of producer to customer, and thus will alter human life and even physical landscape dramatically. The Internet and e-business have the potential to vastly improve the efficiency of business activities. Mass customization of products, and dematerialization of books and CDs, could reduce or eliminate the needs for the materials, energy, transportation and space consumed by products. With the advent of e-business, third-party shippers can have incentive to devise cost-effective take-back systems for packaging materials and products in a closed loop. E-commerce also has potential to create marketplace for secondary goods that might otherwise not have a chance at a second life. Base on all these phenomena, Cohen stated that e-commerce could be the technological foundation of an ecologically sustainable society, although the precise and long-term impacts are still impossible to predict. The author also indicated that the growth of e-commerce could have negative impacts on environment when inefficient shipping logistics and packaging are used.

David Rejeski [36], a Policy Advisor in EPA's Office of Policy, gave his insights on the electronic impacts. He explained that anything that fundamentally affects the way business is transacted can have significant environmental implication. E-business is not a stand-alone technology, but a complex and tightly coupled system. The environmental effects of this system could be much larger than anticipated. Besides some direct impacts due to changes of rates and means of transportation, and changes of consumer behaviors, the information flow in e-business connections from supply through manufacturing to the



customer is not limited to conventional pricing, ordering, and inventory messages, but could include a variety of environmentally related data. The expansion of inter-business networking provides the necessary infrastructure to support the flow of environmental information across organizational boundaries as well, creating a potential fulcrum for leveraging, and improving, the environmental performance of supply and production chains.

Romm, Rosenfeld, and Herrmann [37] gave specific and quantitative examples of how the Internet is affecting energy use and the environment. They found from macro-economic viewpoint that, from 1997 to 1999, there are two very remarkable, though seemingly unrelated, changes having taken place in the U.S. economy. The first is well known, the remarkable growth of the Internet. The second is that in 1997 and 1998, while the U.S. economy grew by some 8%, U.S. energy consumption hardly grew at all, about 1%. They argued that, had the historical relationship between U.S. economic growth and energy consumption been the same in those two years as it had in the previous 10 years, it might be expected 6% growth in energy consumption. This is potentially very important because the vast majority of air pollution in this country come from the production and use of energy. In particular, virtually all of the emissions of carbon dioxide, the principal greenhouse gas emitted by human activity, come from fossil fuel combustion. Indeed, U.S. emissions of greenhouse gases rose only 0.2% in 1998, the smallest rise since 1991 [38]. If the relationship between energy use and economic growth is changing, that would have profound implications for long-term economic and energy forecasting in this country. Like other dramatic shifts in commerce over the past few decades, the rise of

shopping malls, the globalization of production, Internet economy and e-commerce will have significant environmental consequences.

According to Romm's report, Internet energy efficiency gains potentially cover a broad spectrum of activity. In business-to-consumer e-commerce, for instance, retail stores could be replaced by websites and warehouses. Warehouse can contain far more products per square foot than a retail store and warehouses typically use less energy per square foot than a retail store. More important is business-to-business e-commerce, which is estimated at 5 to 10 times the size of business-to-consumer e-commerce. As traditional manufacturing and commercial companies put their supply chain on the Internet, and reduce inventories, overproduction, unnecessary capital purchases, paper transactions, mistaken orders, and the like, they achieve greater output with less energy consumption. Electronic commerce has led to a reduction in overall inventories of \$250-\$350 billion, or about a 20% to 25% reduction in current U.S. inventory levels. Few things have a larger environmental benefit than pollution prevention, especially in the energy-intensive manufacturing sector. Not making products that wouldn't have been sold or not building manufacturing plants that aren't needed is pure prevention.

Romm and his colleagues concluded that the Internet may already be reducing the energy intensity of the industrial sector, and that it holds the potential to have its most significant impact in this area. This would be the Internet's biggest impact on the environment, since this sector is responsible for a third of the nation's air pollution and the vast majority of its hazardous waste and other pollutants. In transportation sector, the Internet economy will be no worse than neutral, but could well have a large positive impact.

The issues raised by these researchers deserve far more rigorous analysis than it has been performed. Lifecycle assessment, multi-lifecycle Engineering methodology and other useful system analysis methods are appropriate to be extended and applied to analyze this changing business and production system.

### **2.3 Simulation Methods**

Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system or evaluating various strategies for the operation of the system [12]. It is used to ask “what if” questions about the real system. Its popularity is the ability to deal with very complicated models of correspondingly complicated systems.

The use of simulation as a vehicle for understanding issues of organizational decision making has gain considerable attention in recent years. The basic principles are simple. An analyst builds a model of the system, writes computer program which embodies the model and uses a computer to imitate the system’s behavior [13]. The model is built based on set of assumptions expressed in mathematical, logical, and symbolic relationships between the entities, or object of interest, of the system. Once developed and validated, the model can be used to investigate a wide variety of “what if” questions about the simulated system. Simulation modeling can be used to as an analysis tool to describe the behavior of a system, predicting the effect of changes in the system to existing systems, and as a design tool to predict the performance of new systems under varying sets of circumstances.

### 2.3.1 Modeling Concepts and Definitions

There are several concepts underlying simulation. The following are key concepts and their definitions of simulation [12,13,14].

*System:* A collection of entities, e.g. people or machines, that interact together to accomplish some stated objective.

*Model:* A representation of a group of objects or ideas in some form other than that of the entity itself. It usually contains logical and/or mathematical relationships which describe a system in terms of states, entities and their attributes, events, delays, and activities.

*Entity:* Entity represents an object that requires explicit definition. It can be any person, objects, or things whose movement through the system causes changes in the state of system.

*Attribute:* A characteristic of all entities but with a specific value in which can differ from entity to entity.

*System State:* The collection of all information needed to define what is happening within the system to a sufficient level at a given point in time.

*Variable:* A piece of information that reflects some characteristics of the system, regardless of how many of what kinds of entities might be around.

*Delays:* A delay is an indefinite duration that is caused by some combination of system conditions. When an entity joins a queue for a resource, the time that it will remain in the queue may be unknown initially since it may depend on other events that may occur.

### 2.3.2 Types of Models

Simulation models can be classified in a number of different ways. These classification refers to differences in the model and not to differences in the real system they represent.

- Static vs. Dynamic

A static simulation model is a representation of a system at a particular time or a system hat time plays no role. On the other hand, a dynamic simulation model represents a system as it evolves over time.

- Deterministic vs. Stochastic

Model that does not contain any probabilistic (i.e. random) components is called deterministic. If any random variables are present, we classify the model as a stochastic model.

- Continuous vs. Discrete

In a continuous model, the state of the system can change continuously over time; in a discrete model, change can occur only at separate points.

### 2.3.3 Advantages and Disadvantages

Simulation is a widely used and increasingly popular method for studying complex systems. Possible advantages of simulation that may account for its wide spread appeal are the following.

- Simulation allows one to estimate performance of an existing system under some projected set of operating conditions.

- Simulation enables the study of, and experimentation with, the internal interactions of a complex system which cannot be accurately described by a mathematical model that can be evaluated analytically.
- Requires fewer simplifying assumptions and thereby capture more of the true characteristics of the real system.
- By compressing or expanding time, simulation allows the operation to slow down or speed up, and thus the simulated activity could be thoroughly investigated.
- By using simulation to perform bottleneck analysis, the causes of the delays in work-in-process, information, materials, or other processes can be discovered.
- The typical cost of a simulation study is substantially less than 1% of the total amount being expended for the implementation of a design or redesign.
- Insight can be gained about which variables are most important to performance and how these variables interact.

Simulation is not without drawbacks. Some disadvantages are as follows.

- Simulation modeling and analysis can be time consuming and expensive. Skimping on resources for modeling and analysis may result in a simulation model and/pr analysis that is not sufficient to the task.
- Simulation results may be difficult to interpret. Since most simulation outputs are essentially random variables, it may be hard to determine whether an observation is a result of system interrelationships or randomness.
- Simulation cannot generate optimal solution on their own as analytic models can.
- Model building requires specialized training.

## **CHAPTER 3**

### **LIFECYCLE ENVIRONMENTAL STUDY OF THE IMPACT OF E-BUSINESS**

As discussed in Chapter 1, E-business is still in its infancy and its impact on the environment is uncertain and difficult to quantify with any degree of rigor or level of confidence, the data is incomplete and the vision is still evolving. To overcome some of these limitations, this chapter draws information from a variety of sources and case studies and examines the lifecycle environmental impacts of e-business by constructing bounding scenarios and concentrating on a specific electronic product.

The framework of the study is based on product lifecycle assessment (LCA) methodologies and tools [44-46]. Following the traditional Society of Environmental Toxicology and Chemistry (SETAC) methodology, the product lifecycle includes several stages from raw material extraction and feedstock synthesis to production, packaging, distribution, use, and end-of-life disposition. The lifecycle study identifies and evaluates product material usage, energy consumption, and environmental burdens during each stage of the product lifecycle. For the purpose of comparison, the design of the product remains fixed as the baseline for each scenario and the study focuses on the process and business practice changes associated with e-commerce and their impact on the environment.

#### **3.1 Scenario Development**

Two scenarios are postulated and modeled, a moderate scenario and an aggressive one. The baseline is the traditional commerce model for desktop computers. The manufacturer predicts demand based upon previous sales data, works with a loosely integrated supply

chain to build large lot sizes of “typical” machine configurations, and warehouses finished products waiting to ship on order to an intermediary’s who then ships to the retailer’s store. Traditional purchasers are assumed to do comparative shopping at a couple of electronics/computer retail stores, buy an available computer that most closely fits their needs, and bring the computer home in their automobile. The total warehousing time along the value chain to final purchase is approximately two months [3].

### **3.1.1 Moderate Scenario**

The moderate scenario reflects modest changes to traditional customer/business patterns representing those typical of today’s B2C commerce. The buyer visits a merchant web site, configures the desktop computer as desired, makes the purchase via electronic payment (i.e., credit card), and specifies shipping preference by air express or surface delivery (both delivery options are modeled). A back-end database keeps track of customer information and routes the order to the manufacturer (note: manufacturer and merchant could be same organization), traditional production and procurement procedures are followed to produce the “built-to-order” product. The finished product is then shipped to the distribution (or intermediary’s) warehouse by truck then drop shipped directly to the customer according to the delivery option specified.

### **3.1.2 Aggressive Scenario**

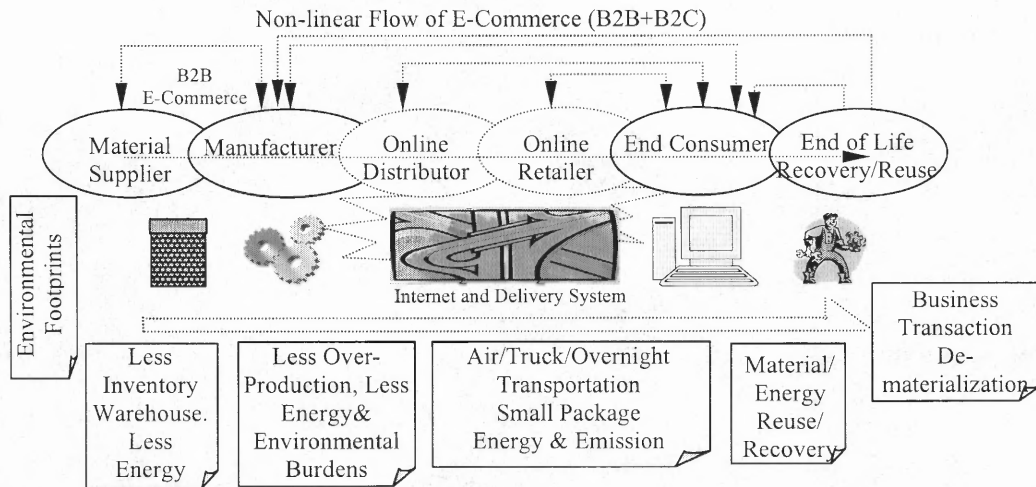
The aggressive scenario uses the same web-based B2C buyer front-end and delivery stage as the first scenario, but utilizes the customer information and product configuration data to drive a web-enabled B2B system to procure materials and components, expedite



production, assure order correctness, and coordinate shipment to the customer using a well-planned, efficient delivery system. During the product usage stage, customers can logon to the company's web site to find service information or technical support. In addition, end-of-life management of the product is integrated into the system. When the product becomes out-dated or obsolete, the customer can either resell it online using one of the existing auction sites or contact the manufacturer or a local electronic demanufacturing facility. The use of electronic product tags and "garage sale" web sites will greatly facilitate reuse and resale [47]. Collecting discarded products from the consumer may be coordinated with existing package delivery operations to improve collection efficiency and reduce energy usage. This scenario assumes recovery and reuse of all components and basic materials through disassembly and shredder operations.

### **3.2 Product Lifecycle Impact**

The lifecycle of an electronic product begins from material extraction/synthesize and product design. The product design and feedstock materials are assumed to remain the same even though e-commerce technology may allow for more efficient product innovation through closer collaboration of value chain [35]. Figure 3.1 illustrates the interconnected nature of the e-commerce process and its direct impact on product lifecycle stages.



**Figure 3.1** Impacts of E-commerce on Product Lifecycle Stages

### 3.2.1 Material Extraction and Synthesis

This stage refers to the order of raw material and components from suppliers. E-commerce technology can facilitate a company to put its supply chain onto the Internet using advanced supply chain management software. The so-called “streamlining purchases via the Internet” could save the company a lot and can bring about environmental benefits. The impacts come from five factors:

- Reduced inventory saving energy (and associated electric power generation emissions) required for warehouse construction and operation.
- Reduced mistaken orders and over-production saving material, energy and environmental burdens.
- Reduced materials such as office paper, catalogs, and manuals saving material consumption.

- Reduced transportation efficiency due to just-in-time supply increasing energy and associated environmental burden. Well-planned logistics and “spot marketing” of underutilized freight space may reduce this negative impact.
- Improved utilization of production capacity for suppliers leading to reduce production space with associated savings in construction and operation.

E-commerce can reduce inventory, storage space and energy, and potential waste of over-purchased materials. The energy consumption for commercial warehouse is 6.4 kWh per square foot [48].

### **3.2.2 Production: Component Suppliers and Assembly**

With e-commerce, manufacturers can adjust production cycles to match fluctuations in consumer demand and inventory levels. In a “build-to-order” process, trade-offs exist between production efficiency of mass production lines and flexible, just-in-time techniques. The environmental impact of these production techniques is difficult to quantify and is omitted in this study. The environmental impact included in this stage is similar to that for raw material suppliers:

- Reduced mistaken orders and over production saving material, energy and transportation.
- Reduced inventory and warehouse space saving energy and construction.
- Reduced transportation efficiency due to just-in-time delivery of components thereby increasing energy and associated environmental burden.
- Improved utilization of production space.

### **3.2.3 Package and Distribution**

In this stage, products are typically packaged and placed in lot sizes, skidded and wrapped for warehousing onsite or at an intermediate distribution facility. If individual products are shipped directly to the customer, secondary packaging should not be needed, thereby, saving materials such as cardboard paper and plastic. Shippers themselves have an incentive to reduce one of their principal cost, post-consumer recycled shipping materials and reusable package will be vastly used [37]. If there is a significant growth in the delivery of packages to residences, it seems likely that more retailers and shippers will explore reusable packaging.

The most significant consideration affecting environmental impact at this lifecycle stage is the transportation mode selected to the product from the manufacturer to the customer. An earlier LCA study of textile products has shown that if overnight air express is used as opposed to standard trucking, then transportation energy becomes a significant portion of the lifecycle energy consumption of the product. In general, however, some of the distribution impact is offset if the product is shipped directly from the manufacturer to the customer bypassing at least one stage of bulk shipment to the retailer's warehouse.

### **3.2.4 Marketing and Sale**

While not typically considered in LCA as one of the lifecycle stages of the product, marketing and sales becomes important for two primary reasons: First, web-based marketing of products reduces or even eliminates the need for printed catalogs and traditional advertising materials. This will save consumption of paper, printing cost and

distribution costs. It is estimated that e-commerce may lead to 15% reduction in paper for catalogs [45]. Second shopping on the web may lead to a reduced need for retail store space for display and inventory. Some estimate that the potential exists for significant changes in future land-use for malls and shopping centers, predicting future commercial retail building will decline to 12.5% [5]. Both of which can bring about large resource and energy savings.

### **3.2.5 Product Delivery**

Although a non-traditional lifecycle stage, product delivery will be directly affected by e-commerce. This stage is the final transportation link delivering the product from an intermediate warehouse or transfer point (for air express or small package shipments) to the customer. If more efficient package delivery by truck could replace at least in part the inefficient personal driving to malls, supermarkets, bookstores and the like, then the environmental impact of small package direct delivery would be offset.

### **3.2.6 Use**

For this study, the product is the same for each of the e-commerce scenarios; consequently, the use stage generates no difference. However, there may be significant changes in the web-based technical support and maintenance services offered to customers. The cyber-home with intranets and major appliances connected to the web are now being developed and may have major impact in the future.

### **3.2.7 End-of-Life Recovery & Reuse for Multi-lifecycle**

Considerable attention has been given to recovery and reuse of discarded electronic products through demanufacturing. The potential exists to expand the collection infrastructure and extend the secondary markets for reuse and material recovery through various Internet-enabled outlets [47]. Today, many demanufacturers are web-active conducting resale via their own sites and commercial auction sites. In addition, e-commerce can help manufacturers track the location and condition of the products. Through coordination of delivery, the logistics system can also function as reverse logistics, making discarded product collection more efficient. Frequently, high collection costs prohibit recycling and reuse of materials; consequently, e-commerce may lead to greater recovery at lower cost.

## **3.3 Case Study on Desktop Computer**

A typical desktop computer system is used as a case study which consisting of the computer, monitor, keyboard and mouse. Table 3.1 gives the material inventory for the product and the energy intensity associated with raw material extraction and synthesis. The two scenarios are used to establish the type of changes which are expected to occur in selling, producing and delivering the desktop computer to an individual customer. Various sources of data, may not sector or product specific, were used to study the material, energy and environmental impact of these scenarios. In addition, several assumptions, as stated in this and previous sections, have been made in order to quantify and help to understand which lifecycle stages are most important and need further detailed consideration and evaluation.

**Table 3.1** Material/Energy Inventory of  
Desktop Computer, Monitor, Keyboard & Mouse

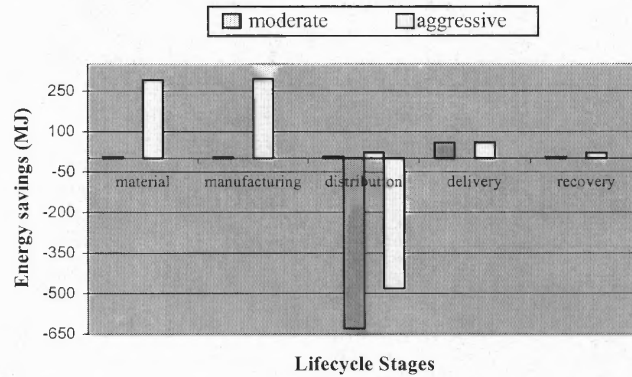
Material	Weight (kg)	Energy Intensity (MJ/kg)	Energy (MJ)
Plastic	7.3	120	876
CRT Glass	9.9	15	148
Aluminum	4.5	300	1350
Steel	6.5	23	149
Copper	2.2	150	330
Circuit Bds	0.5	120	60
Other	<1		
Total			2913

Table 3.2 gives the detailed analysis assumptions and results in terms of energy savings due to e-commerce over lifecycle stages. Figure 3.2 indicates the energy saving and Figure 3.3 indicates the CO<sub>2</sub> equivalent emission saving over lifecycle stages.

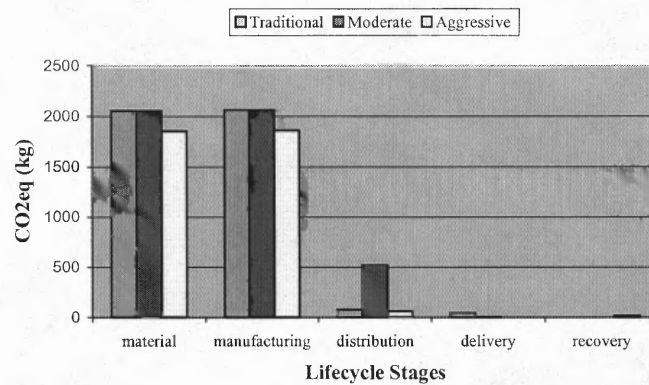
**Table 3.2** Energy Saving due to E-commerce over Product Lifecycle

	Traditional Model Energy Consumption (MJ)	Major Reference/Assumption	Energy Saving in Aggressive Scenario (MJ)		Energy Saving in Moderate Scenario (MJ)	
<b>Material</b>	2913	20% reduction of over/mistaken production, 50% of which can be reused. The material saving is 10%.	291		0	
<b>Manufacturing</b>	Energy use for warehouse floor space for one product 2	1. 20% reduction of inventory warehouse. 2. Energy intensity is 6.4kWh/ft <sup>2</sup> for warehouse. 3. 1 unit of computer is 3*2*2 ft <sup>3</sup> , 1 stack 6*6*6 ft <sup>3</sup> contains 18 units, 4 levels high of stack in one column. Warehouse turnover is 6 times/year. The warehouse floor space for one computer is 0.083ft <sup>2</sup> /unit-year.	0.4		0	
	Production energy 2920	20% reduction of mistaken/over production due to mistaken order, 50% of which can be reused. The production energy saving is 10%.	292		0	
<b>Distribution</b>	Transportation energy from manufacturer to distributor, and from distributor to retailer 105	1. Transportation from manufacturer to distributor 1000 miles, from distributor to retailer 100 miles. 2. Energy intensity for truck transportation is 3MJ/ton-mile. 3. Energy intensity for air transportation is 21MJ/ton-mile. 4. 20% energy saving in aggressive scenario due to reduction of mistaken order. 5. Traditional model always uses truck, but e-commerce has 2 modes, air (overnight) and truck.	Air -482	Truck 21	Air -629	Truck 0
	Energy use in retail building for one unit 4	1. There is 12.5% reduction of wholesale and retail building. 2. Energy intensity for retail building 12 kWh/ft <sup>2</sup> .	0.5		0.5	
<b>Delivery</b>	Transportation energy from retail building to home, one round-trip-shopping 60	1. There is 20% transportation energy saving in aggressive scenario due to reduction of mistaken order. 2. Average shopping length is 11.2 mile. 3. Car energy intensity is 5.4 MJ/mile. 4. 20 miles from local delivery site to home.	58		57	
<b>Reuse/recovery</b>	No energy is recovered 0	1. 50% of End-Of-Life (EOL) computers can be reused. 2. 50% of EOL computers can be recovered. 3. Part shredding needs 24 MJ/kg for typical electronic products. 4. Plastics contain significant amount of embedded energy, 111MJ/kg energy.	21		0	
<b>Total Energy and Saving</b>	6004		181	684	-572	58
<b>Energy Saving Percentage</b>			3%	11%	-9%	1%





**Figure 3.2** Energy Savings Over Lifecycle



**Figure 3.3** CO2 Equivalent Emission Savings

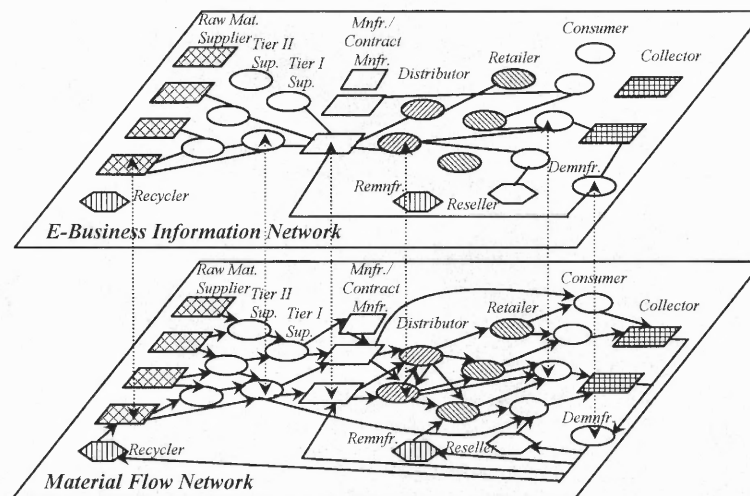
The environment lifecycle study shows that the emerging e-commerce does have environmental impact in terms of resource, energy and environmental burdens. The study indicates that just selling products over the Internet in a single B2C practice will result in negative impact on the environment up to 10%, especially if packages are shipped air express. However, if the full power of web-enabled commerce is implemented, by integrating B2B and B2C, then energy savings and environment benefits, exceeding 10% improvement over today's business practices, are achievable. The detailed results are considered as approximations and insights for further study as opposed to definitive conclusions.

## **CHAPTER 4**

### **INTEGRATED E-SUPPLY CHAIN MANAGEMENT MODEL**

As discussed in Chapter 2, supply chain management is concerned with the flows of products and information between the supply chain member organizations (i.e. suppliers, customers, manufacturers). E-supply chain is an emerging business strategy that incorporates the power of e-commerce to streamline the manufacturing processes, speed the product cycles, integrate the supply chains, and better response to the customers. Integrated e-supply chain system has more complex structure than traditional supply chain system in that it embraces e-business strategy to establish information links and integrates end-of-life processes into the entire supply chain structure.

An Integrated E-Supply Chain (IESC) network is defined as a hyper-network of material flows overlaid with an e-business information network. The material flow network contains autonomous or semi-autonomous business entities collectively responsible for the full lifecycle of the product, from raw material extraction and processing to component suppliers, manufacturing, distribution and customer use, to end-of-life product collection, demanufacturing, material and component recovery, and remanufacturing. In this network, e-business strategies are combined to build e-relationship between business entities and streamline the material and information flow efficiently and effectively. The manufacturer is the focal point in this network framework. Figure 4.1 illustrates an example of the integrated e-supply chain network.



**Figure 4.1** Integrated E-Supply Chain Network

The IESC contains eight supply chain stages: raw material supply, tier II supplier, tier I supplier, manufacturer, distributor, retailer, customer use, and demanufacturer in which is not considered in traditional supply chain as shown in Figure 2.1. After the demanufacturer stage, recovered material or components will feedback to suitable supply chain stages. Such feedback is not seen in traditional model either.

In e-supply chain networks, transportation link are between two partners. However, multiple links are allowed between two nodes to model different transportation modes. Information link is e-business relationship between business entities for streamlining the material flow efficiently and effectively. It can speed up the communication process and thus reduce the response time affecting such measures as cost, productivity and energy use of partners, and links in the material flow network. Information link can also be used by a company to select its suppliers and service providers.

E-supply chains can bring about a more cooperative business environment, especially between manufacturer and service providers. Some modular components of a product such as the monitor and keyboard can be shipping directly from a supplier to a consumer without passing through the manufacturer. The elements in IESC network are involved in production, warehousing and transportation activities. Placement and selection of these elements are related to the supply chain configuration and e-business scenario developed.

From the IESC network, specific supply chain activities that are possible for developing the simulation modules (discussed in Chapter 5) include:

- Suppliers
- Manufacturer
- Distributor
- Retailer
- Consumer
- Demanufacturer
- Recycler

## CHAPTER 5

### SIMULATION MODELING AND TEMPLATE DESIGN

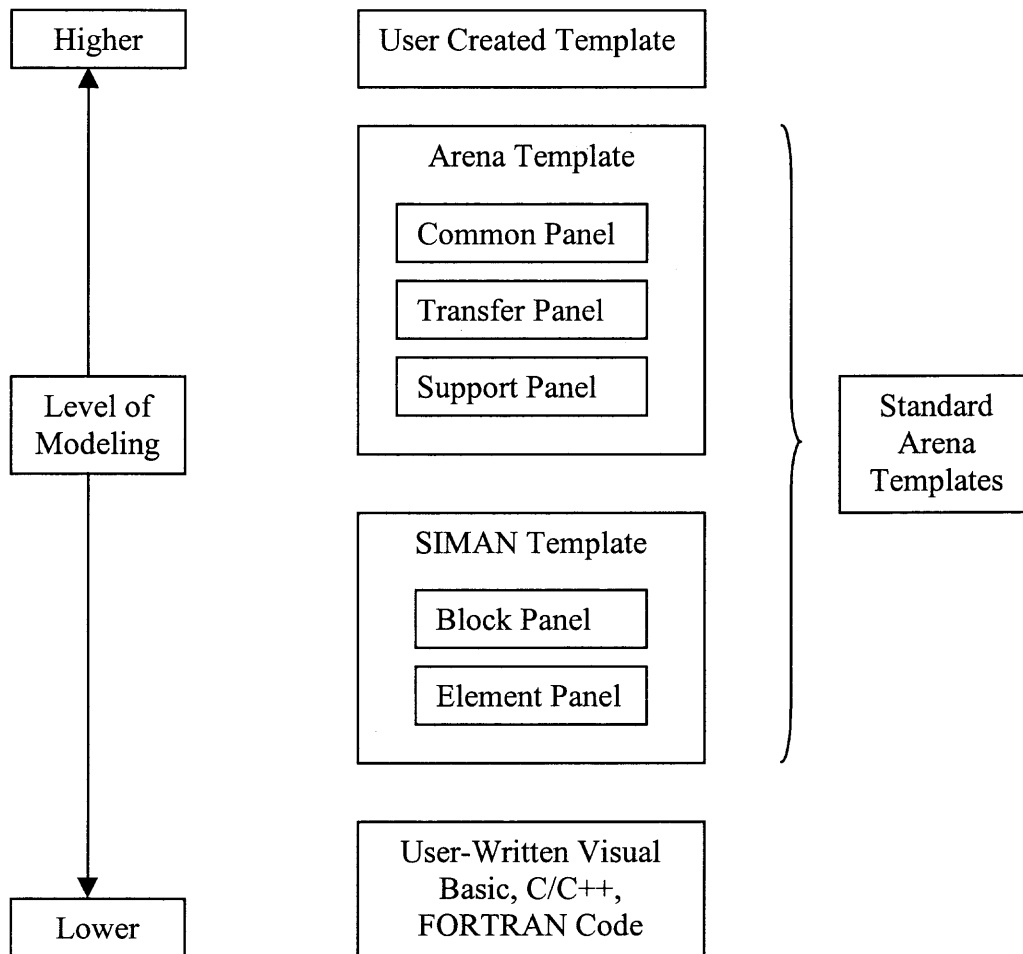
#### 5.1 Overview of Arena

Arena software employs an object-oriented design for entirely graphical model development, and uses SIMAN as its simulation engine. To animate simulation models, Arena's core modeling structures are accompanied by CINEMA. Arena software is selected for this research because of its object oriented approach, user defined customized templates and integration with Windows application.

Arena application combines module structure with the flexibility of simulation languages from general-purpose procedural language like the Microsoft Visual basic, FORTRAN, or C to higher level user-created templates. Figure 5.1 shows the hierarchical structure of Arena. The supply chain template utilized the modules mainly from three abstraction levels, i.e., Common, Support, and Transfer.

A template is a panel consisting of a group of objects called modules. A module is a single construct that may be selected from a template panel and placed in a model or can be built from the combination of existing modules in other template panels [26]. The information about the module is stored in the *Template Files (\*.tpl)*, which is referred to as module definition. The information contained in the module definition is condensed to *template panel object file (\*.tpo)*, which is used by end users to build their own model. A module definition is created by working with five windows as follow: model logic, operand, panel icon, switch, and user view window.

*Operand window:* Operand is the key source that performs the user-friendly interface and provides user input information.



**Figure 5.1** Arena's Hierarchical Structure

*Logic window:* Logic window provides the actual logic to be performed during the simulation run. The execution and performance of the simulation is defined in this window.

*User view:* This window defines the default animation feature and also the handle of a specific module. When a modeler places an instance of a module in a model window, the graphic objects that are added to the window are referred to as the user view window.

*Panel icon:* As an attached template, the picture of a module displayed on the template panel is referred to as the module's panel icon.

*Switch*: Individual objects in the user view, operand, and logic window may be selected to be included only if a particular condition is true. Switch is used to define these behaviors.

## 5.2 Template Design

The template for supply chain simulation includes modules that perform specific supply chain activities and gather the operational data from simulation. The modules are developed based on the activities in the integrated supply chain management structure discussed in Chapter 4. Following modules are identified for supply chain template:

- Supplier
- Manufacturer
- Distributor
- Retailer
- Customer
- Demanufacturer
- Recycle

Additional modules developed in order to improve the flexibility of the simulation tool are as follow:

- Raw material
- Group
- Queue
- Match
- Split
- Depart

- Signal
- Attribute Names
- Simulate
- Transport

### 5.2.1 Supplier Module Design

Figure 5.2 shows the operand window and logic window of supplier module. Operand window defines the performance of the user interface and input information for the module and has embedded connection with logic window that transfer the user input to logic module.

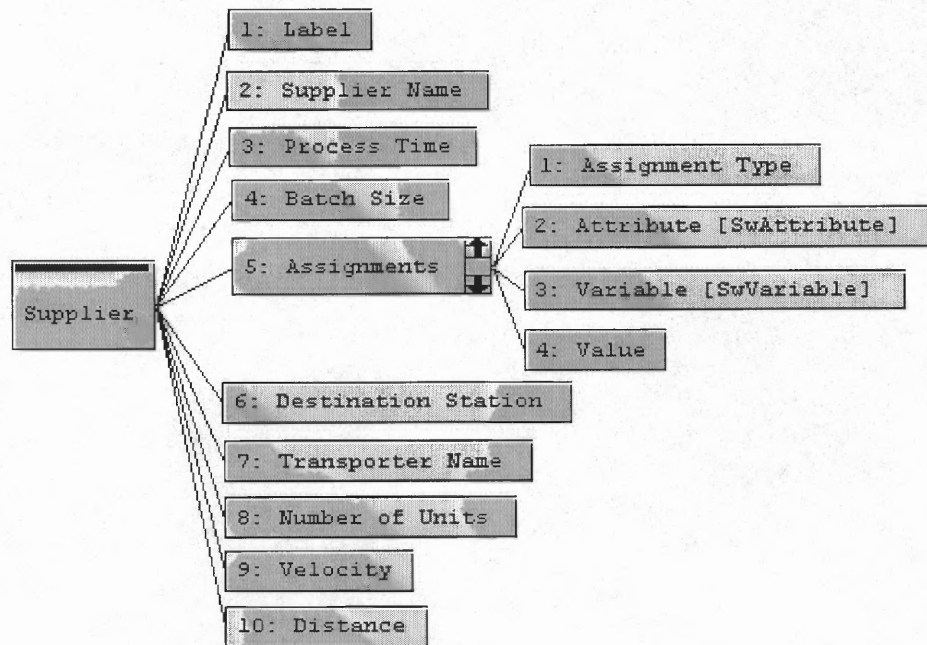


Figure 5.2 (a) Operand Window



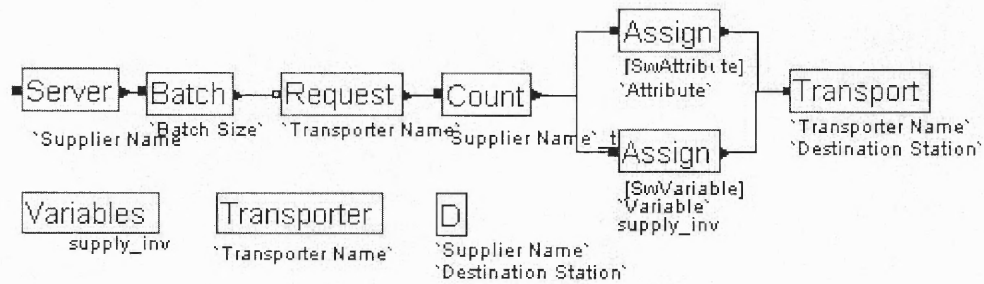


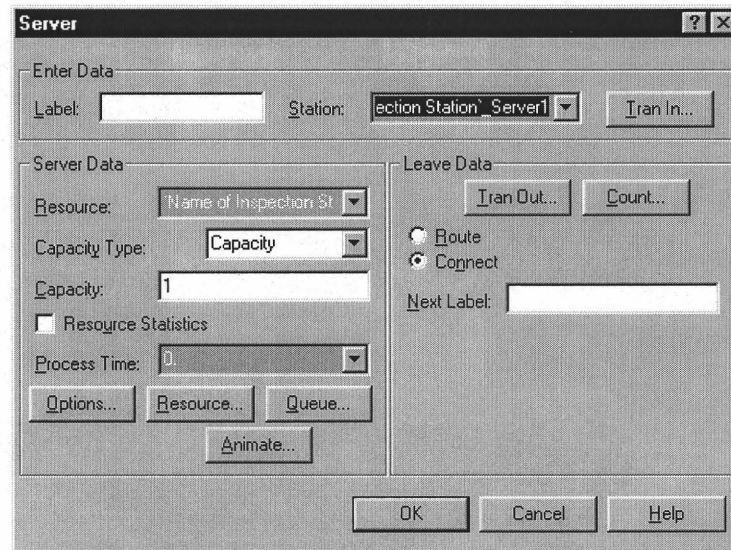
Figure 5.2 (b) Logic Window

**Figure 5.2** Template Design for Supplier Module

The logic window acts as a source code for execution of the module. In this logic window, the following embedded modules are used:

- **Server Module**

A *Server* module from a Common template represents the machine, including the resource, its queue, and the processing time required. It is used to be an active processor. Figure 5.3 shows its user screen of *Server* module. In *Server* module, an entity enters a station, seizes a resource, experiences a processing delay, and is transferred to another station or module. An entity can be transferred to a *Server* module in one of three ways. First, by referencing the station associated with the *Server* module, then routing, conveying, or transporting to that station. Second, by using graphical connection. Third, an entity can be redirected to the *Label* associated with the *Server* module. The *Enter Data* area keeps information on *Resource* name and *Trans-in* option to free the transfer resource. The *Server Data* section holds the information about a processing activity. After entering the server, the entity waits in the associated queue until the server resource is available. Once the unit of resource is available, the entity seizes the server.

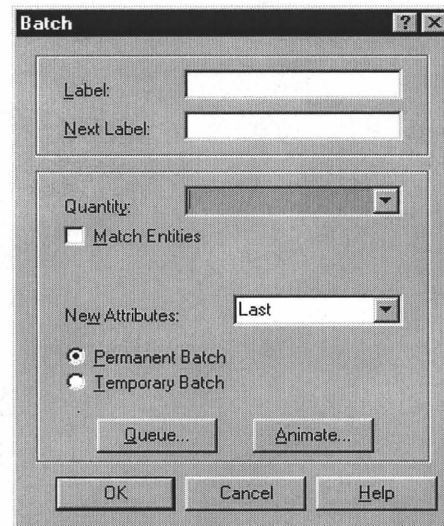


**Figure 5.3** Server Module

- **Batch Module**

A *Batch* module from a Support template collects entities to form a single batch for transportation activities in the supply chain template. Figure 5.4 shows the user screen of a *Batch* module. Entities arriving at the *Batch* module are placed in a queue, if specified, until the required number of entities is reached. After this, one new representative entity is created. There are two types of batch methods: temporary batch or permanent batch. The attribute values of the batched entity are assigned values of the entities that form the batch based on the New Attributes option. When a batch is temporarily formed, the entities forming the batch are removed from the queue, and the original component entities may be recovered later using a *Split* module. If the entities are formed permanently, the entities forming the batch are disposed, and the original component entities are not recovered. *Quantity* field defines the number of entities to batch permanently or temporarily which could be

used in the supply chain template as the batch size for transportation. The *Batch Method* determines if the batching of the entities is permanent or temporary.



**Figure 5.4** Batch Module

- **Request Module**

A *Request* module from a Transfer template is used to assign a transporter to an entity or batch and move the transporter to the entity's station location. Figure 5.5 shows the user screen for a *Request* module. When the entity arrives at the *Request* module, it is allocated a transporter if available. The entity leases the request module when transporter unit reaches the entity's destination station. *From Station* field defines the station location of the requesting entity. If not specified, the entity's current station location is used. *Transporter* field defines the name of the transporter to request. *Unit Number* field determines the specific transporter unit in the transporter set to request. *Velocity* field specifies the temporary velocity at which the transporter moves toward the entity's station location. *Priority* field defines the priority used to request transporter units among competing modules when entities are waiting for the same

transporter. *Storage* field defines the name of the storage at which the entity waits while the transporter is moved to the entity's station. The entity is automatically removed from the storage when the transporter arrives at the station.

**Figure 5.5** Request Module

- **Count Module**

The *Count* module from a Support template is used to calculate the entities passing through. Figure 5.6 represents the user screen of this module. *Counter Name* specifies the counter to change. It could be an individual counter, a set of counters, a value of static, an attribute of entity or an expression. The value may be specified as a constant or an expression that is truncated to an integer. In the Supplier module, the counter is used to count the amount of trips of transportation.



**Figure 5.6** Count Module

- **Assign Module**

An *Assign* module from a Support template assigns a value to a user-defined variable, continuous rates or levels, entity attribute or picture, model status variable, or a resource state. Multiple assignments may be made by a single *Assign* module. When an entity arrives at an *Assign* module, the assignment value or state is evaluated and assigned to the variable or resource specified. If an attribute or picture is specified, the arriving entity's attribute or picture is assigned a new value. For the Supplier module, the assign is used for assigning inventory levels.

- **Transport Module**

A *Transport* module from a Transfer template transfers both the controlling entity and the transporter unit from one station to another. The user screen of *Transport* module is shown in Figure 5.7. *Transport* field defines the name of the transporter to be transported. *Unit Number* field determines which of the transporter unit in the

transporter set to transport. *Destination Station* determines the method for specifying the entity's destination.

The screenshot shows a 'Transport' dialog box with the following elements:

- Title Bar:** 'Transport' with a help icon (?) and a close icon (X).
- Label:** A text input field.
- Transporter:** A dropdown menu.
- Unit Number:** A dropdown menu.
- Entity Destination Station:** A group of four radio buttons:
  - ☐ Sequential
  - ☒ Station Name
  - ☐ Attribute
  - ☐ Static Name
- Station:** A dropdown menu.
- Velocity:** A text input field.
- Transporter Destination:** A group of three radio buttons:
  - ☐ Station
  - ☒ Intersection
  - ☐ Link
- Intersection:** A dropdown menu, located to the right of the 'Intersection' radio button.
- Buttons:** 'OK', 'Cancel', and 'Help' at the bottom.

**Figure 5.7** Transport Module

- **Transporter Module**

A *Transporter* module allows the definition of a transporter device for entity movement from one station location to another. This module creates a single transporter set. Multiple sets of transporters may be defined by placing the Transporter module multiple times.

- **Distance Module**

The *Distance* module defines the distance between two stations in the distance set. The *Beginning Station*, *Ending Station*, and *Distance* are used to create an appropriate distance set, which is used during the simulation run by the transporter moving between the specified stations.

- **Variable Module**

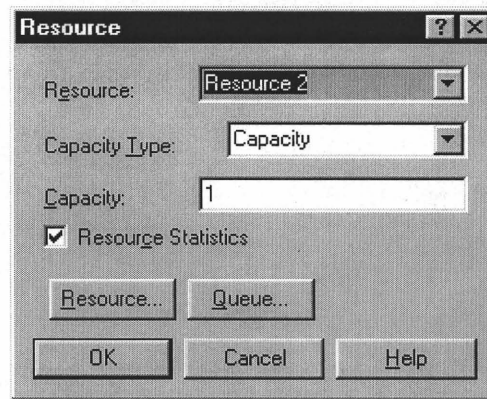
A *Variable* module from a Common template specifies user-defined global variables and their initial values. Variables are referenced in the model by using their name.

### 5.2.2 Manufacturer, Distributor, Retailer, Customer, Demanufacturer, and Recycle Module Design

The operations within manufacturer, distributor, retailer, demanufacturer and recycle are comparable therefore the module design are very similar. The differences are only the embedded names relating the operand window to the logic window and some logics in the logic window. Modules and operands used to create manufacturer, distributor, retailer, customer, demanufacturer and recycle modules are listed below:

- **Resource Module**

The *Resource* module selected from a Common template, defines the characteristics of the resources, including the resource names and initial capacities. Figure 5.8 shows the screen for this module. In the manufacturer module, a resource module represents the manufacturer and its capacity.



**Figure 5.8** Resource Module

- **Station Module**

A *Station* module from a Support template defines a station corresponding to a physical or logical location where processing occurs. *Station Name* determines which type of station is being defined. *Station* defines the symbol name of the station that is associated with this entrance point. *Station* modules in the supply chain template are presented at various locations such as manufacturer, distributor, retailer, and customer. The user screen of *Station* module is shown in Figure 5.9.

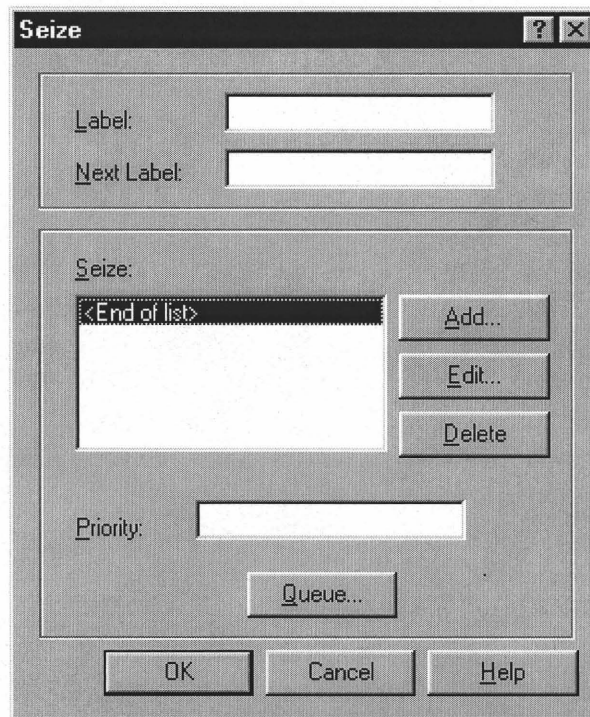


**Figure 5.9** Station Module



- **Seize Module**

A *Seize* module is in a Support template and used to allocate units of one or more resources to an entity. Figure 5.10 shows the user screen of *Seize* module. The *Seize* module may be used to seize units of a particular resource, a member of a resource set, or a resource as defined by an alternative method, such as a static or attribute. When an entity enters *Seize* module, it waits in a queue (if specified) until all specified resources are available. *Seize* repeat group is used to define one or more resources to be allocated to an entity. If multiple resources are specified, the entity must wait in the queue (internal or external) until all the specified resource units are available. The *Resource Name* which appears when clicking the *add* button besides repeat group determines what type of data defines the resource to be seized. The types of a resource include Resource, Resource Set, Specific Member, Static Name, Attribute, and Expression Resource. Resource field is visible only if Resource Name is Resource. This field defines the symbol name of the resource.



**Figure 5.10** Seize Module

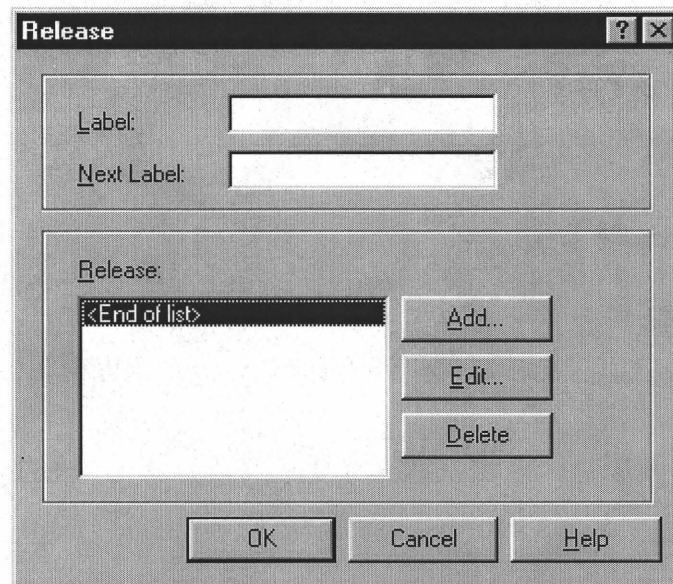
- **Delay Module**

The *Delay* module from a Support template delays an entity in the system by a specified amount of time. When an entity arrives at a *Delay* module, the time delay expression is evaluated and the entity remains in the module for the resulting time period. The *Delay Type* is specified by three ways: Expression, Static Name, and Attribute. User can input a mathematical expression whose value will be used as the entity delay time. *Expression* allows a general expression to be entered. The value of the *expression* is the delay time for the entity. The delayed entities are stored in the storage field. Storage field defines the storage name associated with the delay. Figure 5.11 shows the user screen for *Delay* module.

**Figure 5.11** Delay Module

- **Release Module**

A *Release* module is an object from a Support template used to release units of a resource that an entity previously seized. For each resource to be released, its name and quantity are specified. When the entity enters a Release module, it gives up control of the specified resource(s). Any entities waiting in queues for those resources gain control of the resources immediately. Figure 5.12 shows the user screen of a *Release* module.



**Figure 5.12** Release Module

- **Chance Module**

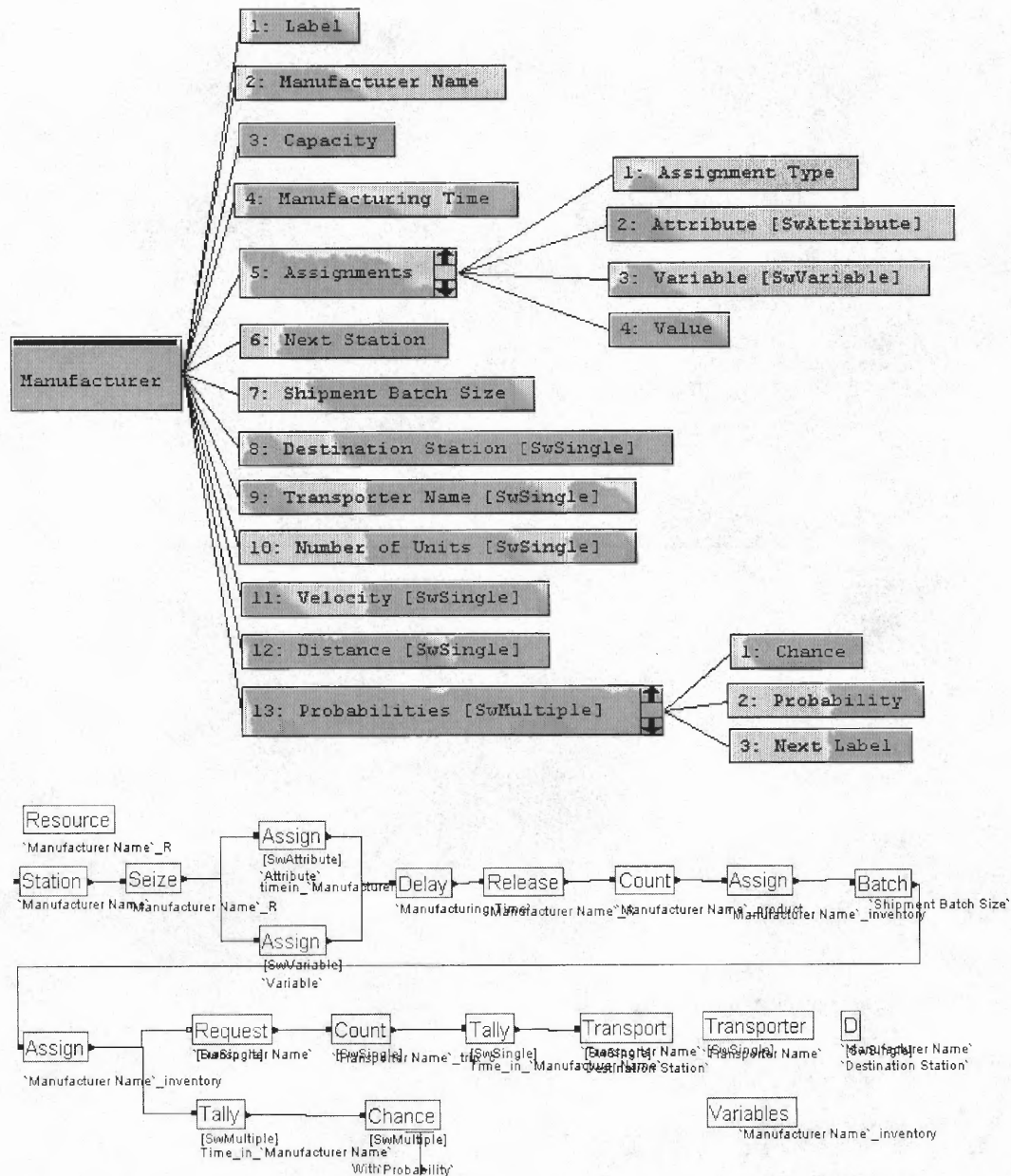
A *Chance* module from a Support template provides branching based on the *With* probability rule and the *Else* deterministic rule. Entity destinations for each defined branch are specified by a graphical connection or by the *Next Label* prompt. When an entity arrives at a Chance module, it determines which probability branches, if any, will be taken based on the probabilities of the *With* statements specified. If the sample falls outside of the cumulative probability range representing the *With* probability branches, the *Else* branch is taken. If the *Else* branch has not been defined, the arriving entity is disposed. In the manufacturer module, this *Chance* module is used if the products have more than one destination.

- **Tally Module**

A *Tally* module records observations to a specified tally. The observation is defined either as an expression or one of two special functions, Interval or Between. The Interval records the time between a previous event and current simulated time for the

entity arriving at the Tally. The *Between type of Statistics* stores the time between arrivals of entities to this *Tally* module. We use *Tally* module in logic to record the product's time in system.

The others modules used are Assign, Count, Batch, and Request. The operand windows and logic windows for manufacturer module are shown in Figure 5.13.



**Figure 5.13** Template Design for Manufacturer Module

### 5.2.3 Raw Material Module Design

Raw material module consists of five modules in the logic design, create, wait, assign, leave, and variables.

- **Create Module**

The *Create* model from a Support template is the “Birth” node for arrival of entities into the model from outside by creating the modeling entities representing the various parts and products in the supply chain system. The module is divided into two areas as shown in Figure 5.14. In the first area, *Next label* describes the next module connected with this one. In the second area, *Batch Size* is a field defining the number of entities in each creation. *First Creation* describes the time triggering the operation of the whole model. *Time Between* defines the time between each batch creation. *Mark Time Attribute* gives the current simulated time an attribute name. This is typically used to track the amount of time an entity spends in all or a specific part of the model. Assignments repeat group is used to specify all attribute and variable assignments that occurs when each entity is created. Picture option determines the type, if any, of initial picture assignment for an entity when it is created.



**Create**

Next Label:

Batch Size:

First Creation:

Time Between:  ▼

Max Batches:

Mark Time Attribute:  ▼

Assignments:

<End of list>

Add...

Edit...

Delete

☒ Picture
 ☐ Picture Set
 ☐ None

Initial Picture:  ▼

OK Cancel Help

**Figure 5.14** Create Module

- **Wait Module**

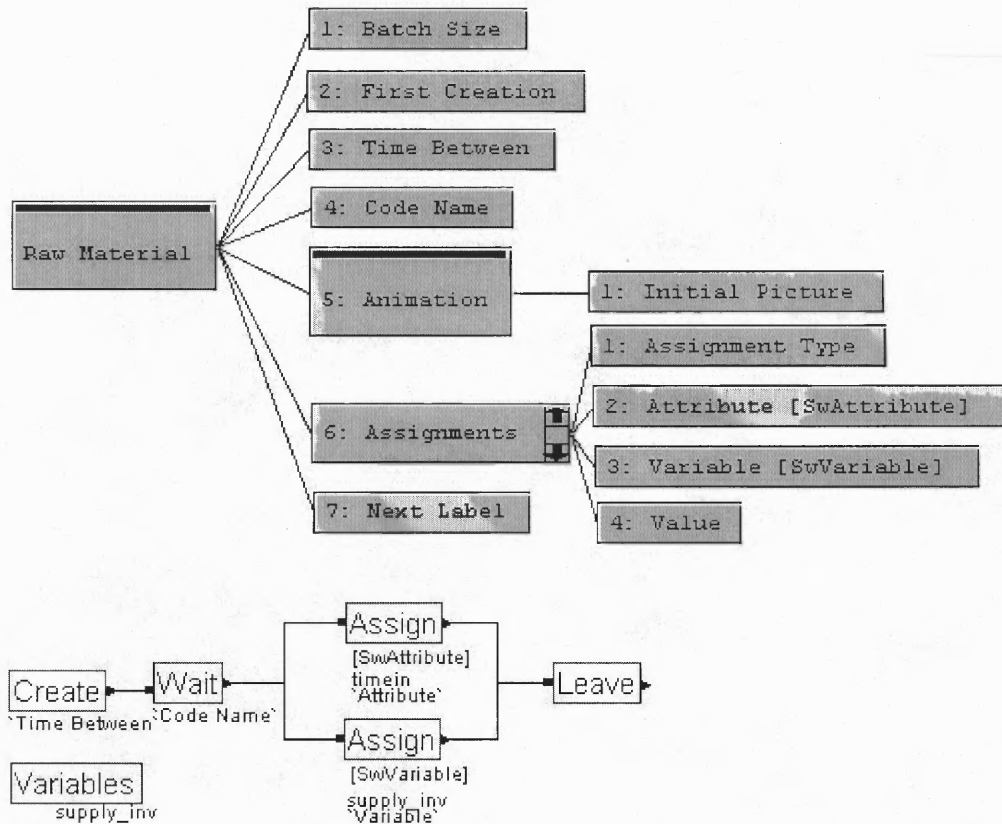
Entities arriving at the *Wait* module are placed in a queue until a signal sent by a *Signal* module is received. When the signal is received, entities are released from the queue to the next module. The quantity of entities is specified in *Release Limit* area. The *Wait* module is used to hold the parts or products and wait for a signal from the destination station such as from manufacturer. The signal is sent when the manufacturer or customer places order.

- **Leave Module**

The *Leave* module from Common template is used to transfer an entity to a station or module. An entity may be transferred in one of three ways, it can be transferred to a module that defines a station by referencing the station and routing, conveying, or transporting to that station, a graphical connection can be used to transfer an entity to another module, and an entity can be redirected to a module by referencing the module's Label in a Next Label field.

**Figure 5.15** Leave Module





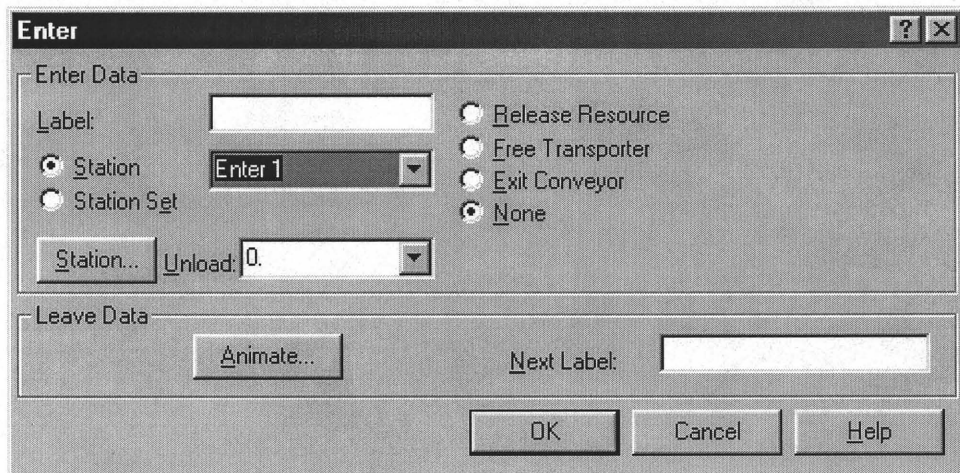
**Figure 5.16** Template Design for Raw Material Module

### 5.2.4 Group Module Design

Group module is used to group parts and components for a product. Arena modules used are Enter, Split, Assign, and Choose.

- **Enter Module**

The *Enter* module defines a station corresponding to a physical or logical location where processing occurs. If the *Enter* module defines a station set, it is effectively defining multiple processing locations. *Station* defines the symbol name of the station that is associated with this entrance point. When an entity arrives at an *Enter* module, an “unloading” delay may occur and any transfer device used to transfer the entity to the Enter module’s station may be released.



**Figure 5.17** Enter Module

- **Split Module**

A *Split* module from a Support template terminates a temporary representative entity that is formed at a *Batch* module and recovers the original entities that form the group. The entities proceed sequentially from the *Split* module in the same order in which they are originally added to the group.

- **Choose Module**

A *Choose* module provides entity branching based on the If conditional rule in conjunction with the deterministic *Else* and *Always* rules. Branch destinations are defined by graphical connections or by specifying a label destination. When an entity arrives at the *Choose* module, it examines each of the defined branch options and sends the original arriving entity to the destination of the first branch whose condition is satisfied. If no branches are taken, the arriving entity is disposed. The *Choose* module is used in the Match module to separate the parts into individual queues for matching operation.

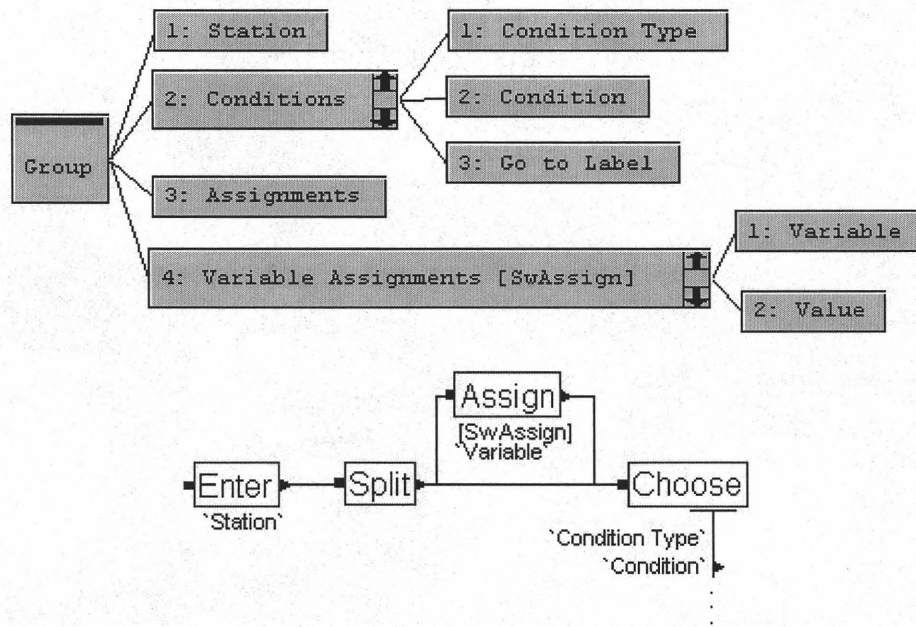


Figure 5.18 Group Module Design

### 5.2.5 Queue Module Design

Three modules are in the logic window for this module, Queue, Queues, and Tally.

Figure 5.19 shows the operand window and logic window.

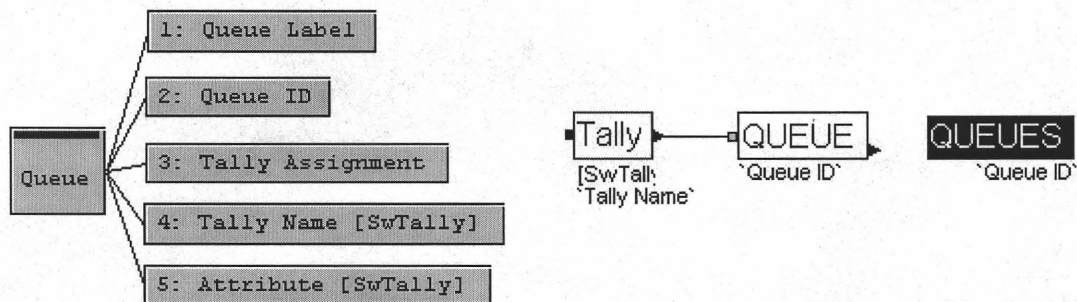


Figure 5.19 Template Design for Queue Module

- **Queue Module**

The *QUEUE* module from Block template is used to model a waiting space until another Arena modeling construct removes them. However, it is used as a detached queue in this module. Detached queue means that the queue is not directly linked to a

downstream module. It will hold entities until your model logic determines that's it's time to remove them. In this case, it is used to separate the entities according to their attribute, preparing to be matched together. The link between the Group and Queue module is by module labels.

- **Queues Module**

*QUEUES* module from Element template specifies the total number of queues along with their names, ranking criterion, and associated model *QUEUE* block.

### 5.2.6 Match Module Design

Match module is used for assembling components for parts or products. It consists of three modules, match, batch, and leave as shown in Figure 5.20.

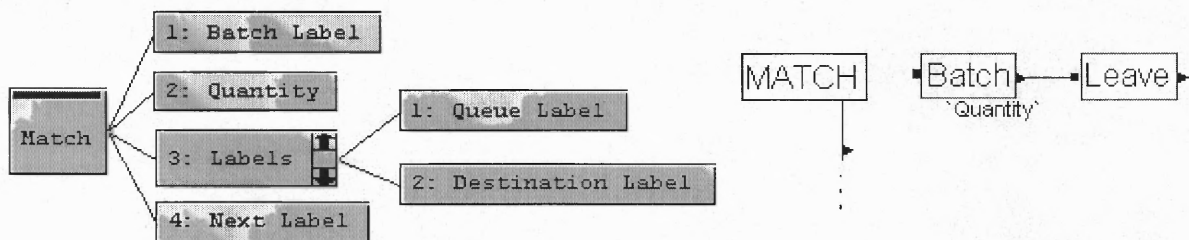


Figure 5.20 Template Design for Match Module

- **Match Module**

The *MATCH* from block template synchronizes the advance of two or more entities located in different, detached queues. Two or more detached queues, each with its own *Queue Label*, are used in conjunction with the *MATCH* block. When an entity arrives at one of these detached queues, SIMAN assigns the value of Match Attribute as the entity's match code. When all detached queues associated with a *MATCH* block have one or more entities with the same match code, these entities are released

to the *Destination Label* corresponding to each *Queue Label*, or are disposed if no *Destination Label* is specified. When a match occurs, only one entity is released from each queue. Other entities with a valid match code remain in the queues until the next match occurs.

### 5.2.7 Split Module Design

Split module is used to terminate a temporary representative entity that was formed at a Batch module and recovers the original entities that formed the group. Figure 5.21 shows the operand window and logic window which includes three modules, *Enter*, *Tally*, and *Split*.

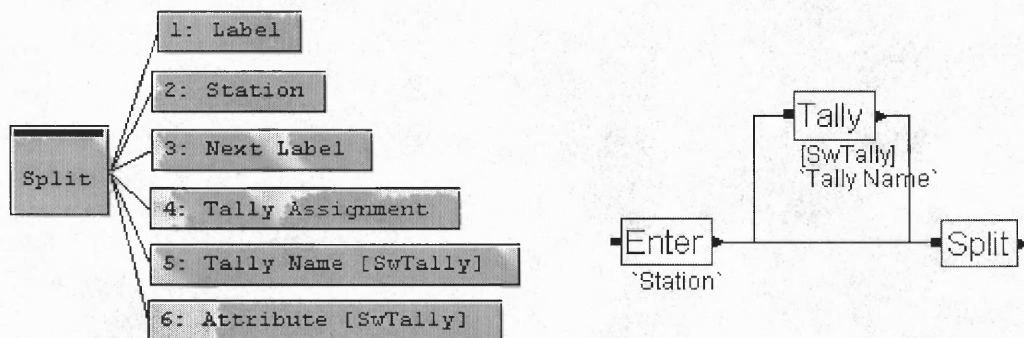


Figure 5.21 Template Design for Split Module

### 5.2.8 Depart Module Design

Depart module used *Enter*, *Split*, *Count*, and *Dispose* in the logic window shown in Figure 5.22.

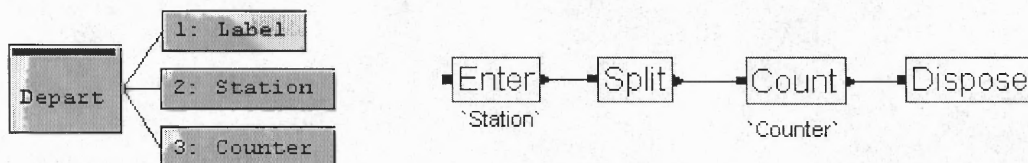


Figure 5.22 Template Design for Depart Module



- **Dispose Module**

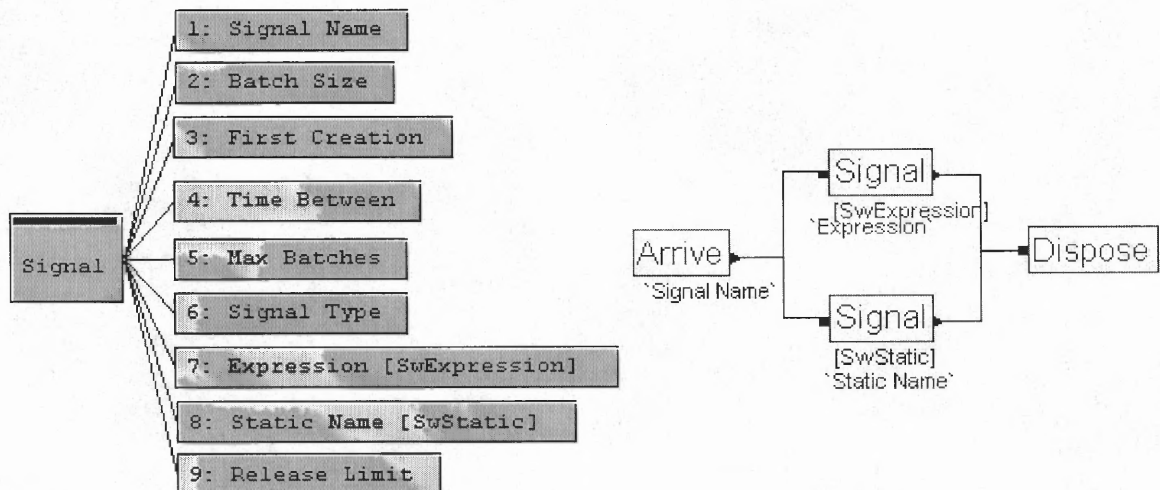
A *Dispose* module immediately disposes of an arriving entity. The disposed entity is removed from the system.

### 5.2.9 Signal Module Design

Signal module is designed to represent the request of components and parts. Modules used are *Arrive*, *Signal*, and *Dispose*.

- **Signal Module**

A *Signal* module sends a signal value to each *Wait* module in the model and releases the specified number of entities. When an entity arrives at a *Signal* module, the signal is evaluated and the signal code is sent. At this time, entities at *Wait* modules that are waiting for the same signal are removed from their queues. The operand window and logic window design is shown in Figure 5.23.



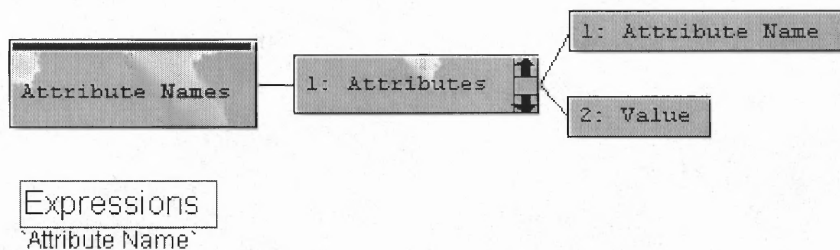
**Figure 5.23** Template Design for Signal Module

### 5.2.10 Attribute Name Module Design

Attribute Name module used the Expressions module from common panel. It is used for defining the attributes used in the simulation such as specifying the name of the parts and components.

- **Expressions Module**

This module defines expressions and their associated values. Expressions are referenced in the model by using their names.



**Figure 5.24** Template Design for Attribute Name Module

### 5.2.11 Transport Module Design

Figure 5.25 shows the operand and logic window for *Transport* module. The modules of Arena template used are *Request*, *Count*, *Transport*, *Transporter*, and *Distance*. This module is used to transfer product from station to station. Generally, all the module design for supply chain template includes transport within the module when single destination is defined. Therefore, this module is used in the case when there are more than one destination station.

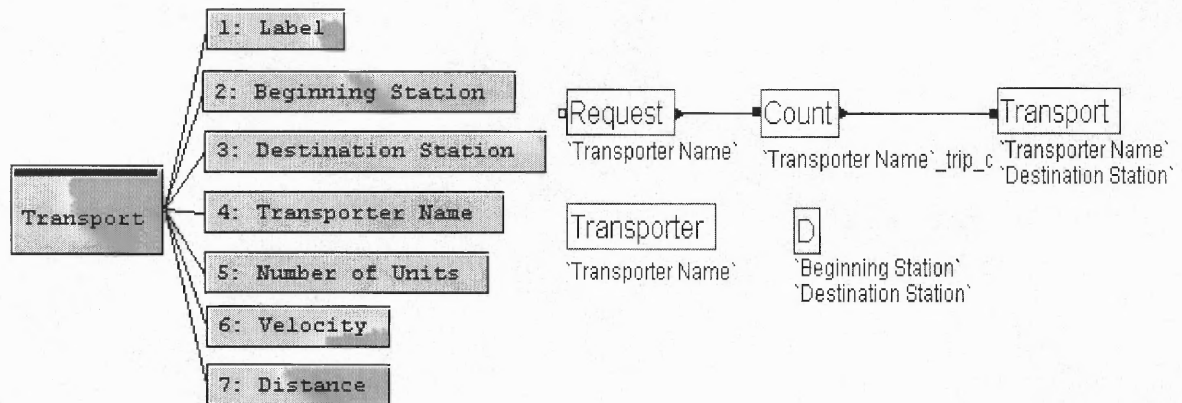


Figure 5.25 Template Design for Transport Module

### 5.2.12 Simulate Module Design

Simulate module is design for specifying simulation running time, variable definition, and statistics collection. Modules used in logic window are *Simulate*, *Statistics*, and *Variables* from Common template. Figure 5.26 shows the Simulate module design.

- Simulate Module

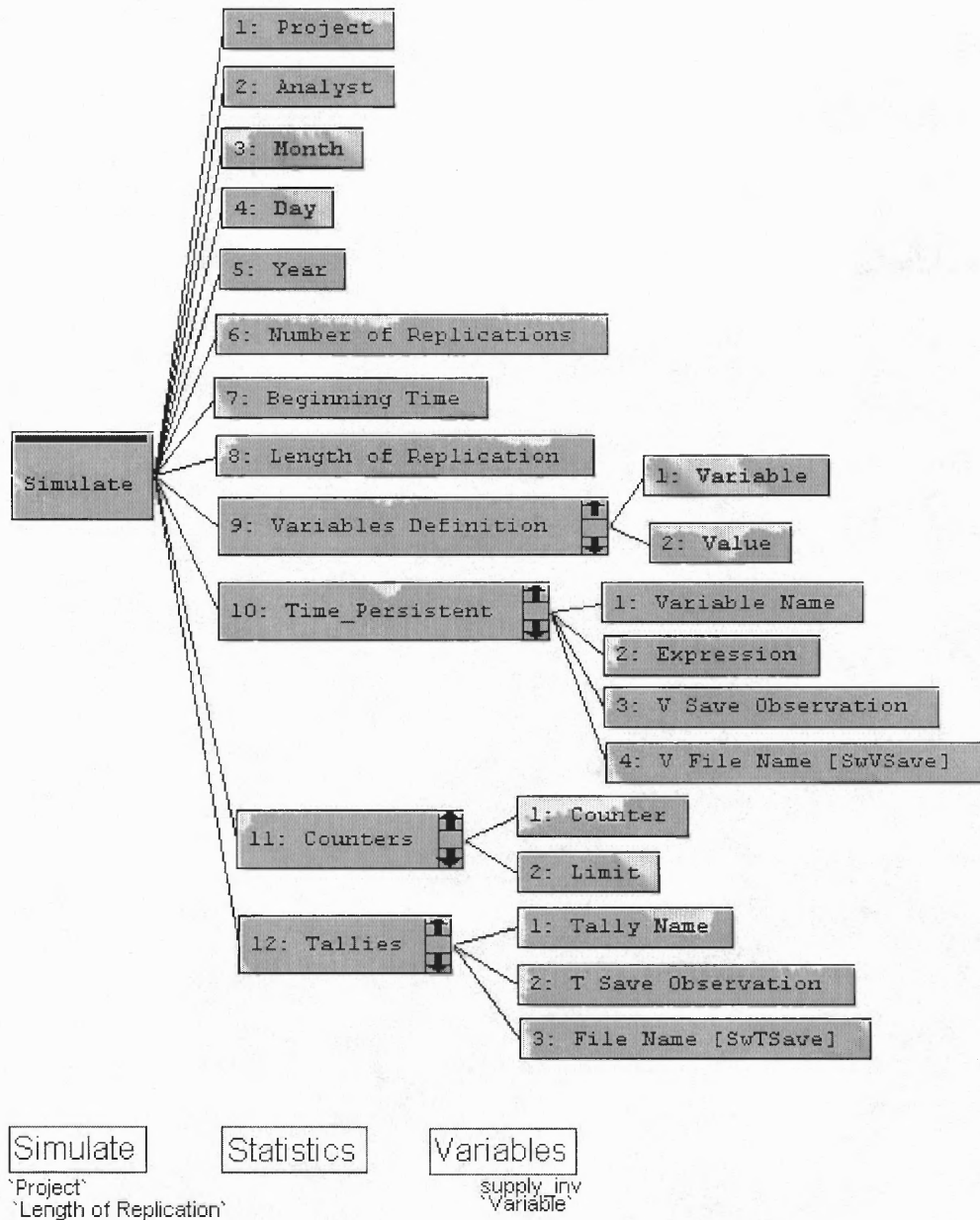
The *Simulate* module specifies the number of simulation replications to be performed; the beginning time of the first replication; the maximum length or terminating condition for each replication; the type of initialization to be performed between replications; Finally, it allows the association of entity pictures with the simulation model.

- Statistics Module

The *Statistics* module is used to define statistics that are to be collected during the simulation and to specify output data files to which statistical observations are written for use with the Arena Output Analyzer. *Time Persistent* is used to obtain time-persistent statistics such as utilization of resources, length of queues, and inventory



levels. *Tallies* is used to obtain observational statistics such as time duration spent in the entire modeled system. *Counters* is used to obtain count-based statistics.



**Figure 5.26** Template Design for Simulate Module

### 5.3 User Interface Design

In order to perform a simulation, user has to enter information into the modules. A user friendly interface is designed for each module by using the advanced Arena Customization of Template technology.

#### 5.3.1 Simulate Module Interface Design

To run the simulation, run length and number of replications has to be specified. The simulate interface is designed for information gathering. It consists of three areas as follow:

1. Project Area: which contains description about the simulation project, i.e. project name, analyst, and date.
2. Replications area

This is the important part. Simulation run length is entered in *Length of Replication*.

Numbers of replications and beginning time are also specified in this area.

3. Definitions Area:

Variable definition sub-window contains the name of variables used in the simulation model. Time Persistent, Counters, and Tallies sub-window are used for user to identify the statistics collection that would be shown in the summary report or save as an observation file for further analysis.

**Simulate**

**Project**  
 Project: Supply Chain Base Case  
 Analyst: MERC  
 Date:

**Replications**  
 Number of Replications: 1  
 Beginning Time: 0  
 Length of Replication: 120

**Variables Definition:**  
 manu\_inv, 0  
 supplier\_inv, 0  
 <End of list>  
 Add...  
 Edit...  
 Delete

**Time\_Persistent:**  
 manu\_inv, manu\_inv  
 supplier\_inv, supplier\_inv  
 <End of list>  
 Add...  
 Edit...  
 Delete

**Counters:**  
 depart\_c,  
 <End of list>  
 Add...  
 Edit...  
 Delete

**Tallies:**  
 Time in System, No  
 <End of list>  
 Add...  
 Edit...  
 Delete

OK Cancel Help

**Figure 5.27** Simulate Module User Interface

### 5.3.2 Raw Material Interface Design

Raw Material module is the starting point of the simulation. Entities for the supply chain simulation are created from this module. The *Arrival Data* area contains the information of arrival entities. *Time Between* and *Code Name* is required. Code holds the entity until it receives a signal which is order from the downstream activities. The entity can be redirected to a module by referencing the module's Label in a *Next Label* field or by a graphical connection to another module.

**Figure 5.28** Raw Material User Interface

### 5.3.3 Supplier Module Interface Design

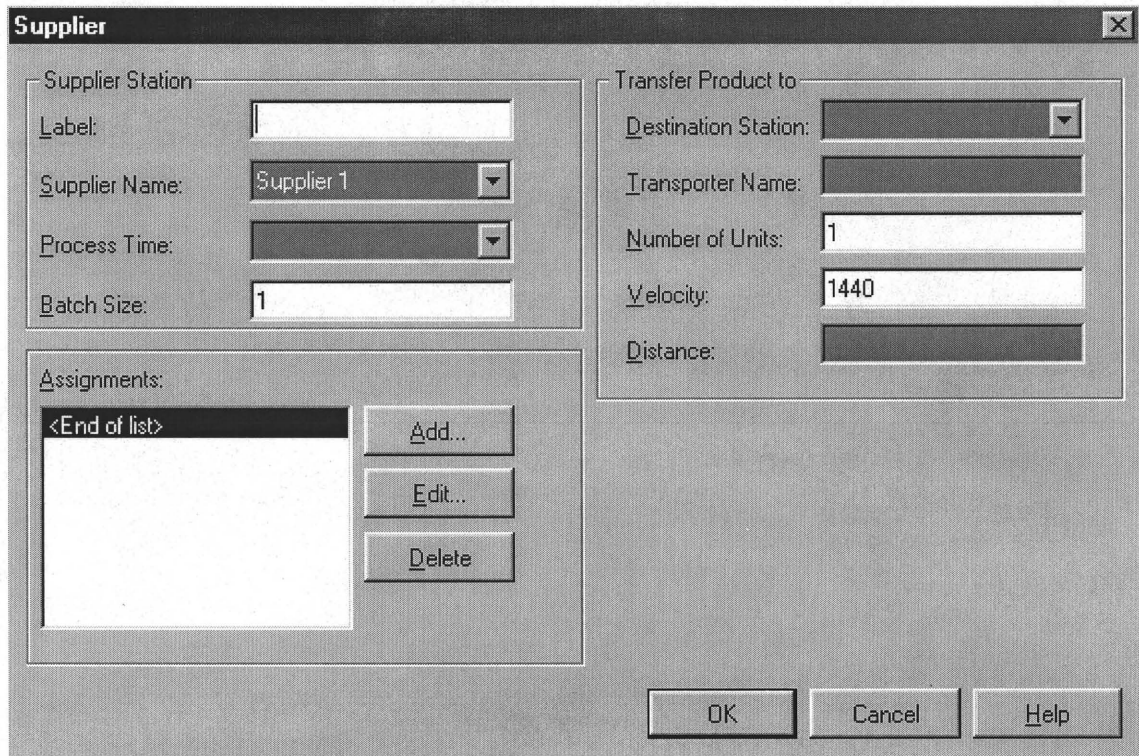
This module is designed to represent the supplier production operation in the supply chain.

#### 1. Supplier Station Area

Supplier information is defined in this area. The required data are the *Supplier name* and *Process time*. *Batch size* indicates the batch size of parts leaving from the supplier.

#### 2. Transfer Product to Area

This area defines the destination station for the entities or parts. Required input data are the *Destination Station*, *Transporter Name*, *Velocity* and *Distance*.



The image shows a 'Supplier' dialog box with the following fields and controls:

- Supplier Station:**
  - Label: [Text Field]
  - Supplier Name: [Dropdown Menu, currently showing 'Supplier 1']
  - Process Time: [Dropdown Menu]
  - Batch Size: [Text Field, currently showing '1']
- Assignments:**
  - [List Box containing '<End of list>']
  - Add...
  - Edit...
  - Delate
- Transfer Product to:**
  - Destination Station: [Dropdown Menu]
  - Transporter Name: [Text Field]
  - Number of Units: [Text Field, currently showing '1']
  - Velocity: [Text Field, currently showing '1440']
  - Distance: [Text Field]
- Buttons:** OK, Cancel, Help

**Figure 5.29** Supplier User Interface

### 5.3.4 Manufacturer, Distributor, Retailer, Customer, Demanufacturer, and Recycle Module Interface Design

These modules represent process and time consumed in each activity of the supply chain.

#### 1. Station Name Area

The station name and the processing time are required.

#### 2. Assignments Area

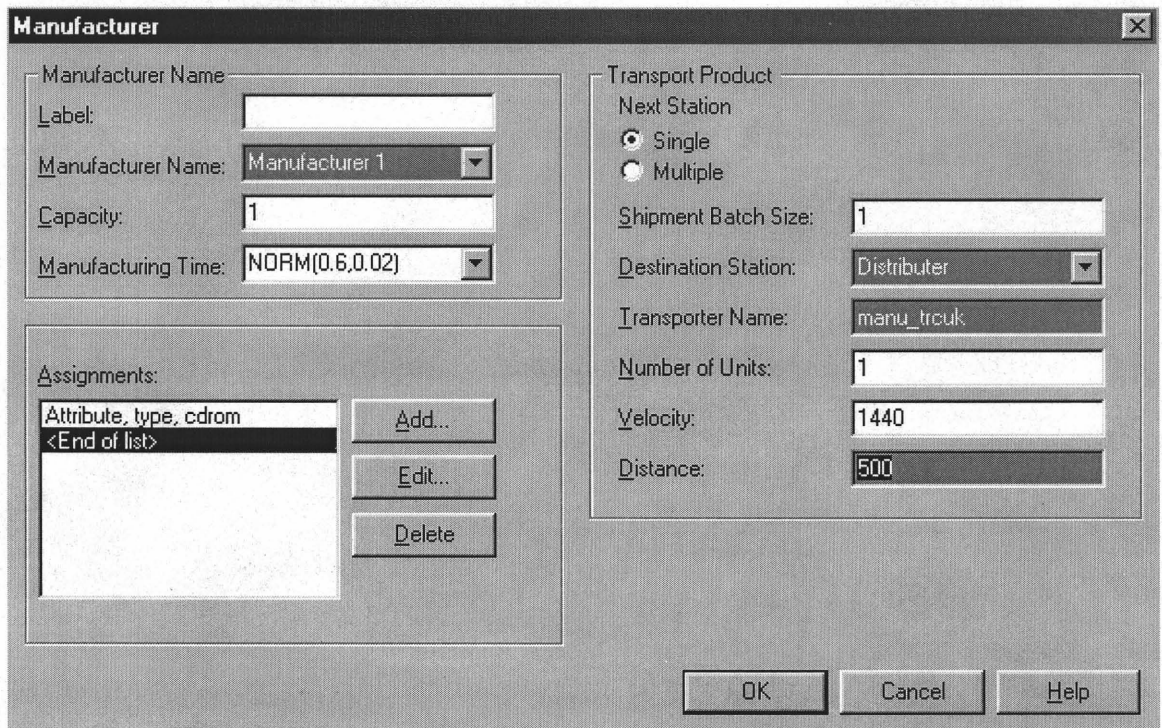
This area is for assigning names for the parts or products leaving the module. Names are assigned for the purpose of grouping and matching.

#### 3. Transport Area

This area defines the destination station for the entities or parts. Two types of transportation, single or multiple destination. For single destination, required input



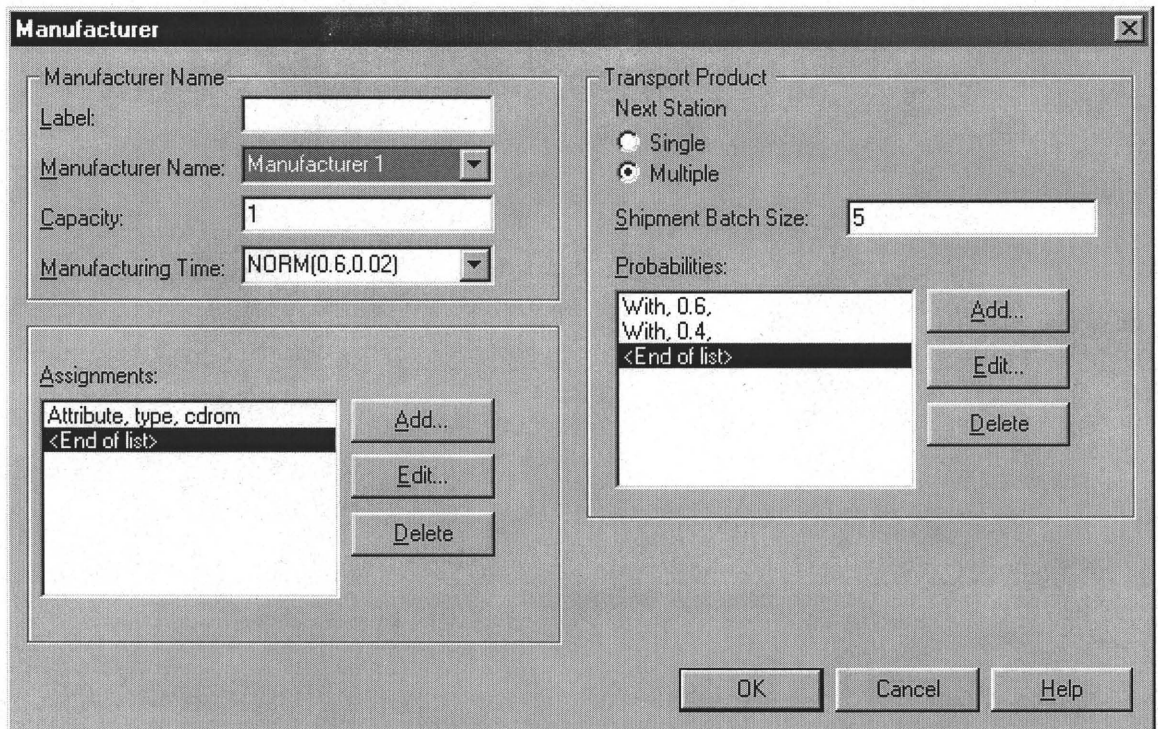
data are the *Destination Station*, *Transporter Name*, *Velocity* and *Distance*. In multiple destination, probabilities are assign for each destination. The manufacturer user interface for single and multiple destinations are shown in Figure 5.30 and 5.31 respectively.



The image shows a Windows-style dialog box titled "Manufacturer". It is divided into several sections for data entry:

- Manufacturer Name Section:** Contains a "Label:" text box, a "Manufacturer Name:" dropdown menu (currently showing "Manufacturer 1"), a "Capacity:" text box (containing "1"), and a "Manufacturing Time:" dropdown menu (showing "NORM(0.6,0.02)").
- Assignments Section:** Features a list box with the header "Attribute, type, cdrom" and the entry "<End of list>". To the right of the list box are three buttons: "Add...", "Edit...", and "Delete".
- Transport Product Section:** Includes a "Next Station" group box with two radio buttons, "Single" (which is selected) and "Multiple". Below this are several text boxes: "Shipment Batch Size:" (containing "1"), "Destination Station:" (a dropdown menu showing "Distributor"), "Transporter Name:" (containing "manu\_truck"), "Number of Units:" (containing "1"), "Velocity:" (containing "1440"), and "Distance:" (containing "500").
- Buttons:** At the bottom right of the dialog are three buttons: "OK", "Cancel", and "Help".

**Figure 5.30** Manufacturer User Interface (Single Destination)



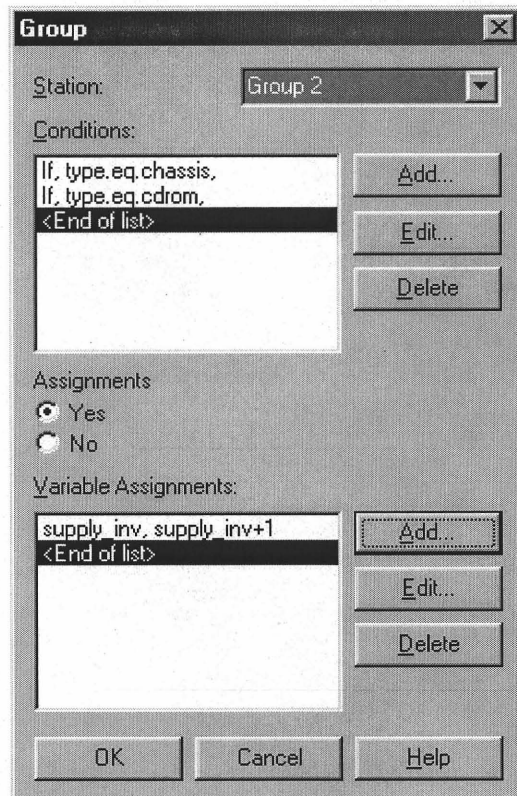
The image shows a software dialog box titled "Manufacturer". It is divided into several sections for configuring a manufacturer's settings.

- Manufacturer Name Section:** Contains a "Label:" text box, a "Manufacturer Name:" dropdown menu currently showing "Manufacturer 1", a "Capacity:" text box with the value "1", and a "Manufacturing Time:" dropdown menu showing "NORM(0.6,0.02)".
- Assignments Section:** Features a list box with "Attribute, type, cdrom" and "<End of list>". To the right of the list are three buttons: "Add...", "Edit...", and "Delete".
- Transport Product Section:** Includes a "Next Station" section with radio buttons for "Single" and "Multiple" (the "Multiple" option is selected). Below this is a "Shipment Batch Size:" text box with the value "5".
- Probabilities Section:** Contains a list box with "With, 0.6,", "With, 0.4,", and "<End of list>". To the right are three buttons: "Add...", "Edit...", and "Delete".
- Bottom Section:** Contains three standard buttons: "OK", "Cancel", and "Help".

**Figure 5.31** Manufacturer User Interface (Multiple Destination)

### 5.3.5 Group Module Interface Design

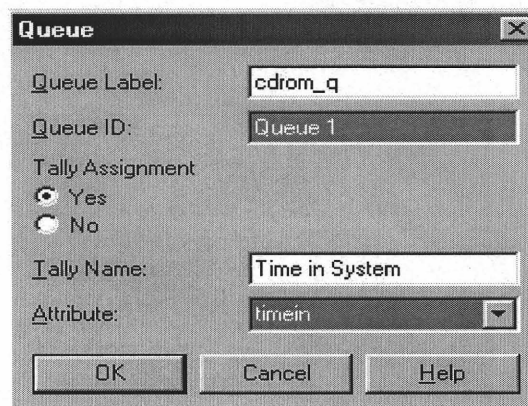
Group module is used to separate entities according to their types or names preparing the entities to enter its individual queues. Therefore, *Group* module has to be followed by *Queue* module. Station name and conditions are required. *Conditions* is used to separate the entities according to the condition entered. *Variable Assignments* is used for assign variables, if preferred.



**Figure 5.32** Group User Interface

### 5.3.6 Queue Module Interface Design

Queue module is used for matching the parts together, it has to be followed by *Match* Module. *Queue Label* and *Queue ID* are required. Tally is optional and used if statistical values are collected.



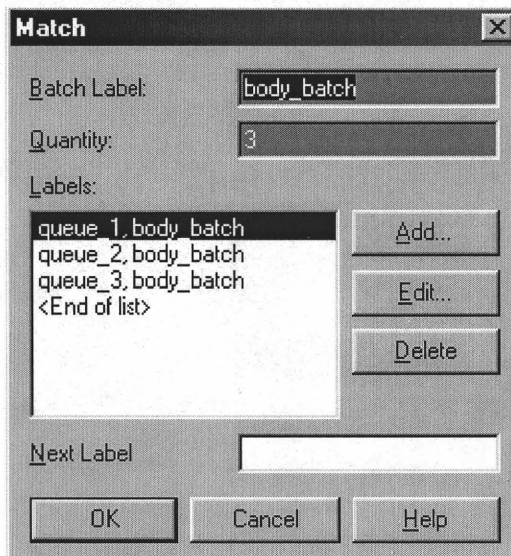
**Figure 5.33** Queue User Interface



### 5.3.7 Match Module Interface Design

The Match module is designed to synchronize two or more entities located in different detached queues. For example, a product consists of three components. Before entering any processes such as manufacturer, those components have to be match together instead of individually entering the process.

Figure 5.34 shows the Match user interface. *Batch Label* is required for specifying the destination for the queues. *Quantity* is the number of components that are being matched. *Labels* define the queues containing components to be matched. The entity can be redirected to a module by referencing the module's Label in a *Next Label* field or by a graphical connection to another module.



**Figure 5.34** Match User Interface

### 5.3.8 Split Module Interface Design

Entities might be batch while transporting. Split module is used to terminate a temporary batch that was form.



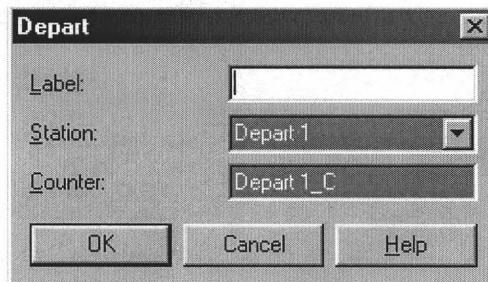
The 'Split' dialog box contains the following fields and controls:

- Label:** A text input field.
- Station:** A dropdown menu with 'Split 1' selected.
- Next Label:** A text input field.
- Tally Assignment:** Radio buttons for 'Yes' (selected) and 'No'.
- Tally Name:** A text input field containing 'Time in manufacturer'.
- Attribute:** A dropdown menu with 'time\_in\_manu' selected.
- Buttons:** 'OK', 'Cancel', and 'Help' at the bottom.

**Figure 5.35** Split User Interface

### 5.3.9 Depart Module Interface Design

The Depart module is an exit of the system. Numbers of entity departing from the system at this module is collected.



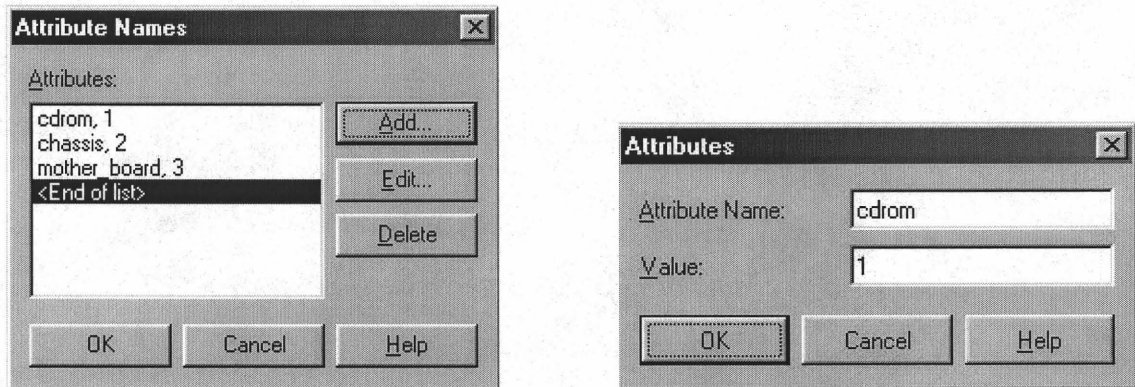
The 'Depart' dialog box contains the following fields and controls:

- Label:** A text input field.
- Station:** A dropdown menu with 'Depart 1' selected.
- Counter:** A text input field containing 'Depart 1\_C'.
- Buttons:** 'OK', 'Cancel', and 'Help' at the bottom.

**Figure 5.36** Depart User Interface

### 5.3.10 Attribute Names Module Interface Design

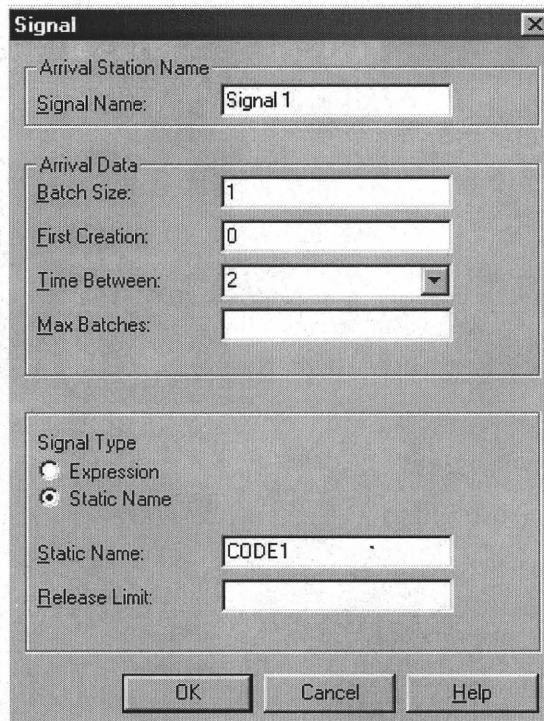
Attribute Name Module is used for defining the attributes assigned in the simulation model. When double click on *add*, the Attributes interface appears. *Attribute name* and *Value* is required. The value for each attribute should be different.



**Figure 5.37** Attribute Name User Interface

### 5.3.11 Signal Module Interface Design

Signal Module is used to inform the supplier to ship parts to the destination station. Signal could be orders requested from manufacturer, distributor, retailer, or customer. The information required for this module is the *Time Between*, *Signal Type*, *Static Name*, and *Release Limit*. Static Name is referred to in the Code Name in Raw Material Module.



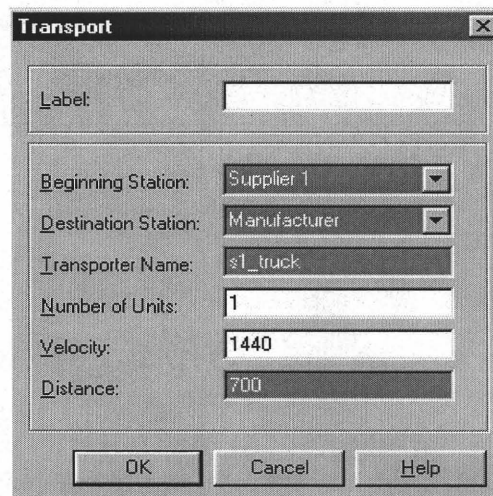
The **Signal** dialog box is used to configure signal parameters. It contains the following fields and controls:

- Arrival Station Name:** A text field labeled "Signal Name:" containing the text "Signal 1".
- Arrival Data:** A group box containing:
  - Batch Size:** A text field containing "1".
  - First Creation:** A text field containing "0".
  - Time Between:** A text field containing "2" with a dropdown arrow on the right.
  - Max Batches:** An empty text field.
- Signal Type:** Two radio buttons: "Expression" (unselected) and "Static Name" (selected).
- Static Name:** A text field containing "CODE1".
- Release Limit:** An empty text field.
- Buttons:** "OK", "Cancel", and "Help" buttons at the bottom.

**Figure 5.38** Signal User Interface

### 5.3.12 Transport Module Interface Design

Transport module is used when multiple destinations are selected. Entities are transported from station to station. The information required in this module is the *Beginning Station*, *Destination Station*, *Transporter Name*, *Velocity*, and *Distance*.



The **Transport** dialog box is used to configure transport parameters. It contains the following fields and controls:

- Label:** An empty text field.
- Beginning Station:** A dropdown menu showing "Supplier 1".
- Destination Station:** A dropdown menu showing "Manufacturer".
- Transporter Name:** A text field containing "\$1\_truck".
- Number of Units:** A text field containing "1".
- Velocity:** A text field containing "1440".
- Distance:** A text field containing "700".
- Buttons:** "OK", "Cancel", and "Help" buttons at the bottom.

**Figure 5.39** Transport User Interface

## 5.4 Software Application

Steps to perform simulation for a supply chain model are specified in this section.

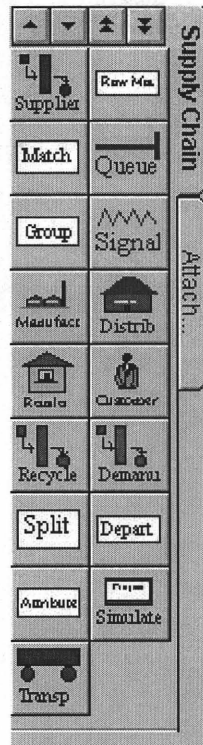
Step 1: Start Arena software by double clicking the Arena icon.

Step 2: Open a new model window by File/New.

Step 3: Attach the panel(s) required to build model. In supply chain model, only the supply chain template is needed. Attach the template by clicking on the Attach panel tab in the Templates toolbar. This opens the Attach Template Panel dialog, where you open supply chain panel (file name with extension *.tpo*).

The attached panel will appear displaying the icons representing each of the modules in this panel as shown in Figure 5.40. The buttons in this form of module display are 17 kinds of modules. To add a module to screen, click on its icon in the panel window, move mouse to the location in the model window where you want to position the chosen module, and then click to “drop” it there. This places an instance of the module in the workspace. The placed module always consists of at least a module handle, the box that contains module name and the animation feature or a default name. Add data to a module by double clicking in its handle to “open it up”. This causes the dialog for that module to open as the screen as described previously.

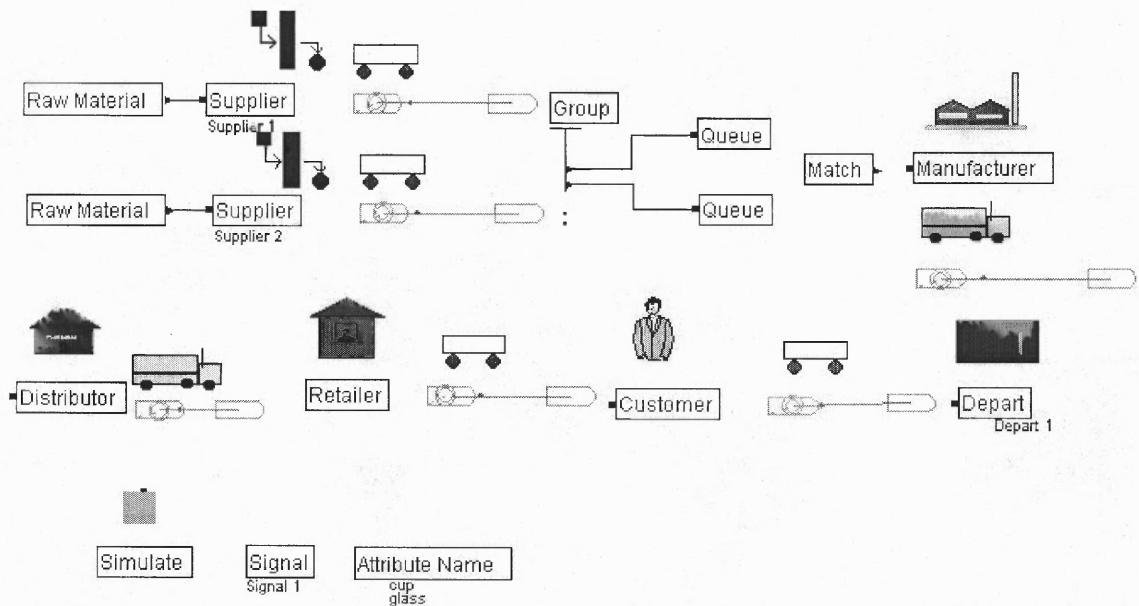




**Figure 5.40** Supply Chain Template Panel

From Step 1-3, the basic simulation environment is established. The next steps are to build a simulation model to demonstrate how to utilize the simulation tool. For the purpose of illustration, the supply chain model is simplified contain two suppliers, one manufacturer, one distributor, one retailer, and one customer.

Step 4: Put the required modules on the screen. Two raw materials, two suppliers, one manufacturer, one distributor, one retailer, one customer, one simulate, one group, two queue, one match, one depart, one signal, and one attribute name. Figure 5.41 illustrates the supply chain model window with the required modules.



**Figure 5.41** Supply Chain Model Window

Step 5: Open Raw Material module by double click on its name. Enter the time between, code, and assign name for the parts leaving this module.

Step 6: In supplier, the information for station name and process time is required to input. Also identify the destination which is Group name, the transporter name, velocity, and distance.

Step 7: In Group, enter the conditions for separating the parts for entering queue by referring to the parts name. Drag connection line between group and queue.

Step 8: Input a name in “Queue Label” and Queue ID in the queue module.

Step 9: Enter batch label, quantity, and labels in match module. Since there are two parts enter the match, the quantity is two and two labels are assign.

Step 10: In Manufacturer, enter the manufacturer name and processing time. Assign the name of parts leaving the manufacturer. Identify the destination, transporter name, velocity, and distance.

Step 11: Enter the data similar to manufacturer in distributor, retailer, and customer.

Step 12: Enter all the attributes assign in the model in the Attributes name module.

Step 13: In Signal module, enter the time between, static name, and release limit.

Step 14: Open simulate module, specify the number of replications, beginning time, and length of replication. Enter the variables assigned in the model in the variable definition. If there are any statistic values collected, assign in time persistent, counters, or tallies.

Step15: Now the simulation is ready to run. Normally there are three ways to run the simulation: Use the Go button on the run toolbar or the Run/Go option. When the simulation runs to completion, a dialog pops up and asks if users want to see the result. If user selects yes, they should get a window of the summary report of the simulation.

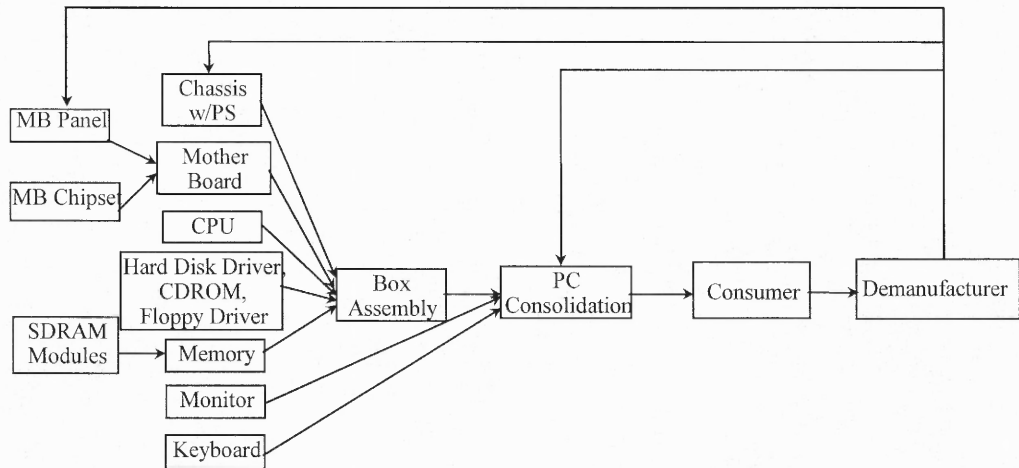


## CHAPTER 6

### CASE STUDY

#### 6.1 Introduction

In this Chapter, a desktop computer supply chain system consisting of computer, monitor, and keyboard is modeled using the simulation tool developed. The data of material and energy inventory are in Appendix. The integrated supply chain model for the desktop computer consists of two tiers suppliers, box assembly, PC consolidation, consumer, and demanufacturer as shown in Figure 6.1. This model was adapted from reference [39] and extended to demanufacturing stage.



**Figure 6.1** Integrated PC Supply Chain

The supplier and manufacturing time are estimates on what the minimum, most likely, and maximum times are for. Time units are in day. The data are shown in Table 6.1 [39]. The final assembly has the capacity for producing 25,000 computers per month. All the suppliers have the capacity for providing the subassemblies to meet the production needs.

## 6.2 Constructing the Model

Internet has been identified as important technological that effects supply chain performance in a significant manner. Thus, the simulation model is constructed to study and compare the performances of two scenarios: Case 1 assuming traditional business practices and Case 2 for the e-supply chain network which implements the Internet effects into the model.

**Table 6.1** Supplier and Manufacturing Times

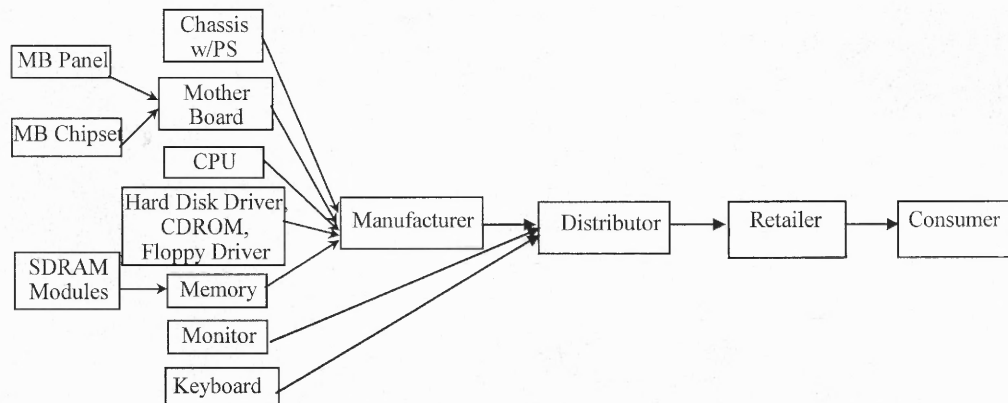
	Manufacturing Time (days)		
	Min	Most Likely	Max
MB Panel	6	8	10
MB Chipset	20	25	30
SDRAM	18	20	22
Chassis	20	25	30
Mother board	2	3	4
CPU	22	25	28
Hard disk drive	20	25	30
Memory	3	5	7
Monitor	10	13	16
Keyboard	4	5	6
Manufacturer	0.5	1	1.5
Distributor	1	1	1

- Case 1: Traditional supply chain

The concept is that the manufacturer produces products according to the production plan. It will send order to the suppliers upstream periodically. When supplier receives order, they start to produce product and send to manufacturer. Once the products are produced they will be stored in manufacture's warehouse. Customer will request for products from retailer. When the inventory level in the retailer reaches the reorder level, retailer will request products from distributor. In the same manner, when the inventory level of distributor reaches the minimum level, products will be requested

to the manufacturer. In this case the products are consolidated in distribution center.

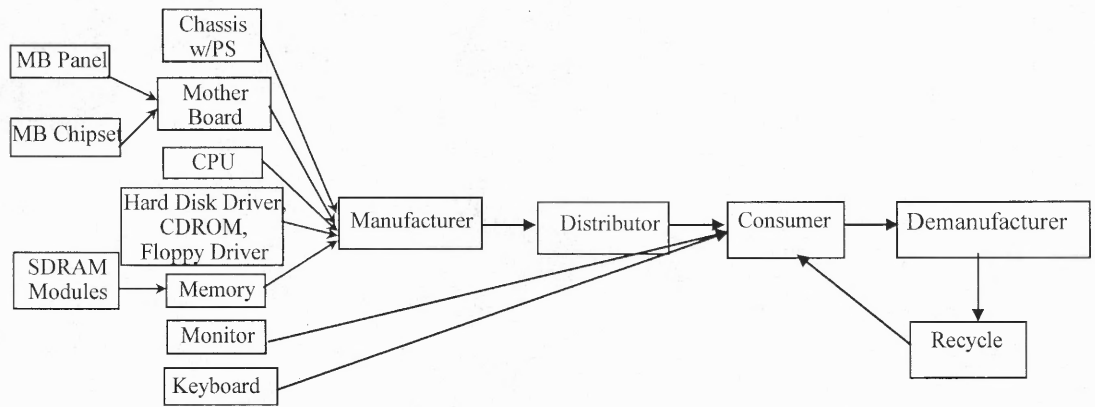
The structure of the supply chain is shown in Figure 6.2.



**Figure 6.2** Case 1 Traditional Supply Chain

- Case 2: E-supply chain

In this case, products are assumed to be build-to-order. Manufacturer sends orders from customer to upstream suppliers when orders are received. Subsequently, suppliers send parts to manufacturer in just in time (JIT) system. The model reflects the growing of e-business practice in which modularized components of the computer can be shipped directly from supplier to customer. Thus, in this case, the products are consolidated in customer location. It also includes the use of recovered materials from discarded products. Figure 6.3 illustrates the structure of this case.



**Figure 6.3** Case 2 E-Supply Chain

The manufacturing lead times for each components and processes is assumed to follow normal distribution with mean equal to the most likely value (Table 6.1) and standard deviation equal to (maximum-minimum)/6. The times, units in day, are shown in Table 6.2.

**Table 6.2** Supplier and Manufacturing Times (Normal Distribution)

Processes	Time		Processes	Time	
	Mean	Std.Dev.		Mean	Std.Dev.
MB Panel (MP)	8	0.7	Hard disk (HD)	25	1.7
MB Chipset (MC)	25	1.7	Memory (MEM)	5	0.7
SDRAM (SM)	20	0.7	Monitor (MON)	13	1.0
Chassis (CH)	25	1.7	Keyboard (KB)	5	0.3
Mother board (MB)	3	0.3	Manufacturer	1	0.2
CPU	25	1.0	Distributor	1	0

Transportation time is determined by assuming the distance and velocity. Transportation mode is assumed to be truck with velocity of 60 miles/hour or air with velocity of 500 miles/hr. Distances between each unit are in Table 6.3. Each model was run for ten independent replications with simulation time 120 time units or six months production in each replication.

**Table 6.3 Distances Between Sites**

Original	Destination	Distance	
		Case 1	Case 2
MB Panel	Mother board	100	150
MB Chipset	Mother board	200	180
SDRAM	Memory	200	300
Chassis	Manufacturer	500	650
Mother board	Manufacturer	550	600
CPU	Manufacturer	400	300
Hard disk drive	Manufacturer	520	560
Memory	Manufacturer	610	630
Monitor	Distributor	800	
Keyboard	Distributor	700	
Monitor	Customer		1000 (a)
Keyboard	Customer		1000 (a)
Manufacturer	Distributor	600	400
Distributor	Retailer	600	
Distributor	Customer		600
Retailer	Customer	20	
Customer	Demanufacturer		100
Demanufacturer	Recycle		400
Recycle	Customer		100

Remark: (a) Air Transportation

Figure 6.4 and 6.5 illustrates the supply chain model for Case 1 and Case 2 using the supply chain templates developed in Chapter 5.

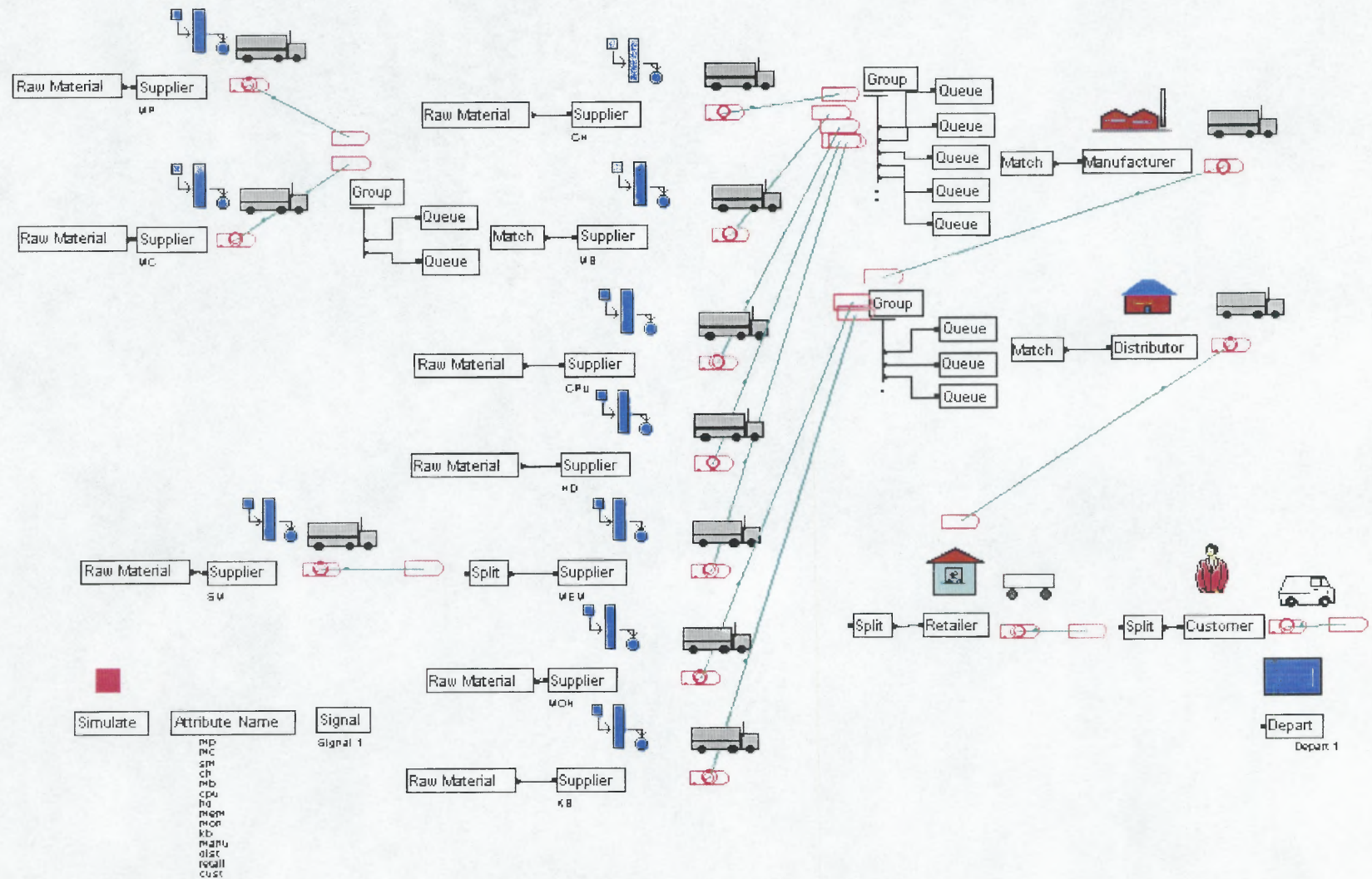


Figure 6.4 Simulation Model for Case 1



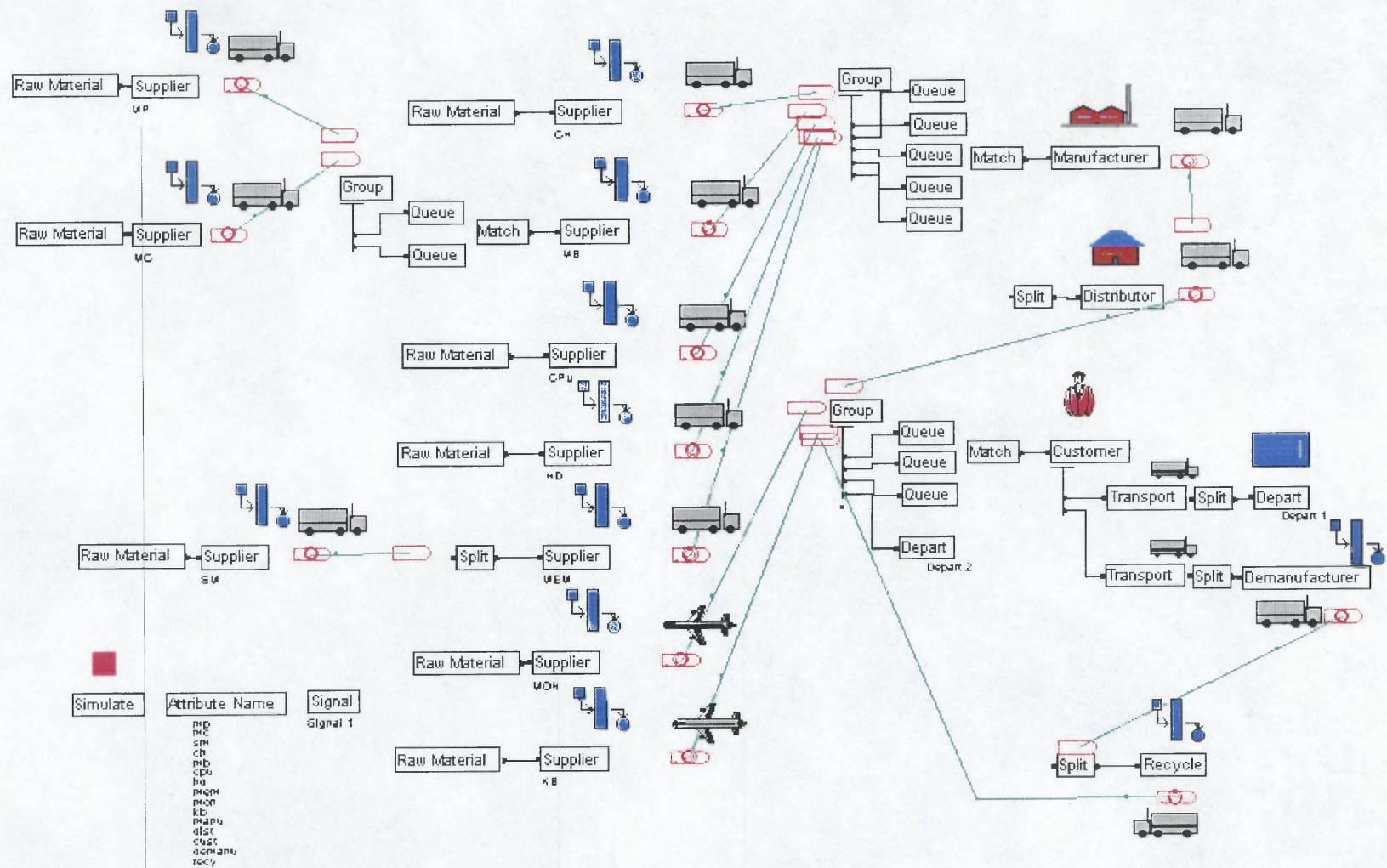


Figure 6.5 Simulation Model for Case 2

### 6.3 Results and Analysis

The simulation results for Case 1 and Case 2 are shown in Table 6.4.

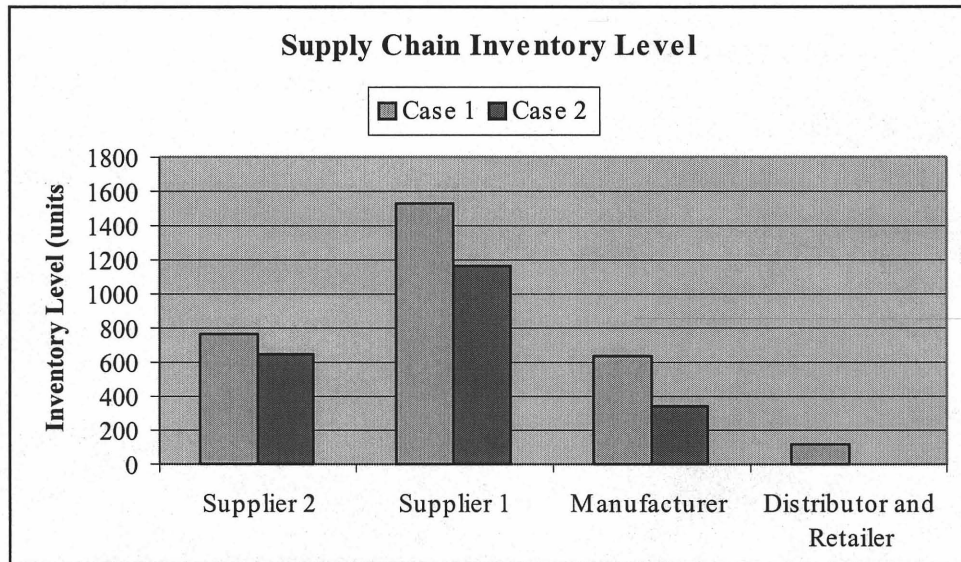
**Table 6.4** Simulation Results

Performances	Case 1	Case 2
Time in system (days)	30.4	12.3
Supplier inventory (units)	2280	1830
Manufacturer inventory (units)	637	339

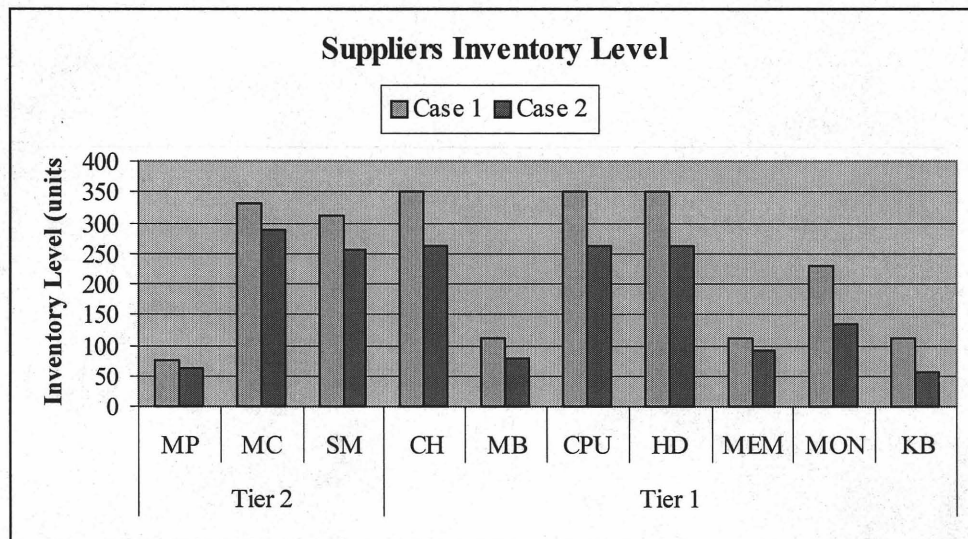
The simulation results show that the average time in system reduced from 30 days in case 1 to 12 days in Case 2 indicating improvement in system performance. Supplier and manufacturer inventory reduced approximately 20% and 47% respectively in Case 2 compared to Case 1. Manufacturing inventory reduction results from final product consolidated at customer location. Inventory level in distribution and retailer reduces 100% resulting from built to order concept in the Case 2. The supply chain partners inventory level comparison is shown in Figure 6.6. For more detailed inventory distribution, Figure 6.7 shows the inventory level for each individual supplier in both tier I and tier II. It can be seen that for each supplier, inventory level could be reduced if e-business structure is applied.

By running the simulation for 10 replications, the 95% confidence interval for the average time in system was  $30 \pm 0.239$  and  $12.3 \pm 0.151$  for Case 1 and Case 2 respectively. The half-width of the intervals are small comparing to the mean value. Therefore, the 10 replications are appropriate number of replications that could represent the output from the study.





**Figure 6.6 Supply Chain Inventory Level**



**Figure 6.7 Suppliers Inventory Level**

Assuming energy consumption for warehouse floor space is 2 MJ/PC [40], reduction in inventory results in reduction in associated energy consumption. Transportation energy is assumed to be 3 MJ/ton-mile for truck and 21 MJ/Ton-mile for air [4]. Total energy including material and production energy, inventory energy, and transportation energy was calculated as shown in Table 6.5.

**Table 6.5** Supply Chain Energy Consumption

Supply Chain	Energy (MJ)	
	Case 1	Case 2
Supplier	6078	5447
Manufacturer	203	159
Distributor& Retailer	102	51
Demanufacturer	0	-8.5

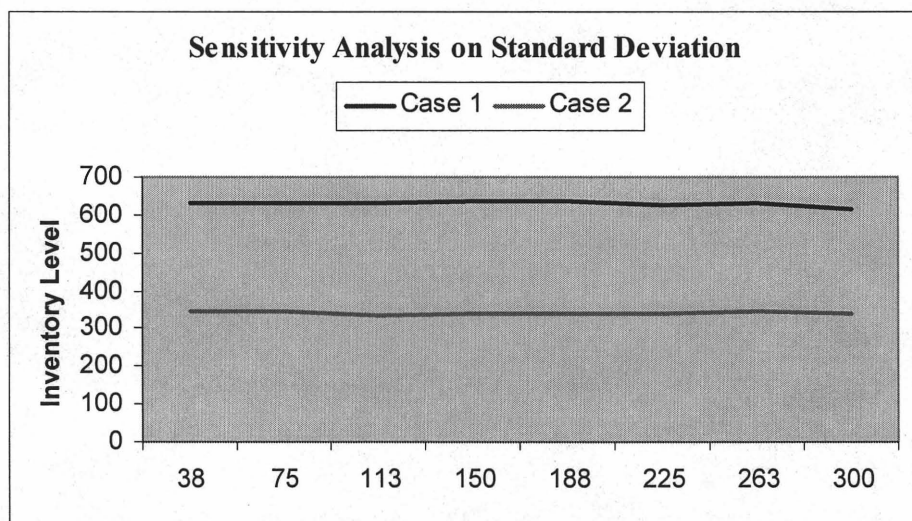
Energy saved in the supplier, manufacturer, and distributor is approximately 10%, 21%, and 50% respectively. In the demanufacturer stage, energy savings can be achieved due to components and material recovering. It can be concluded that the E-supply chain has the potential to yield significantly better performance in terms of business goals and environmental goals than traditional supply chain based on the structure in this case study.

## 6.4 Sensitivity Analysis

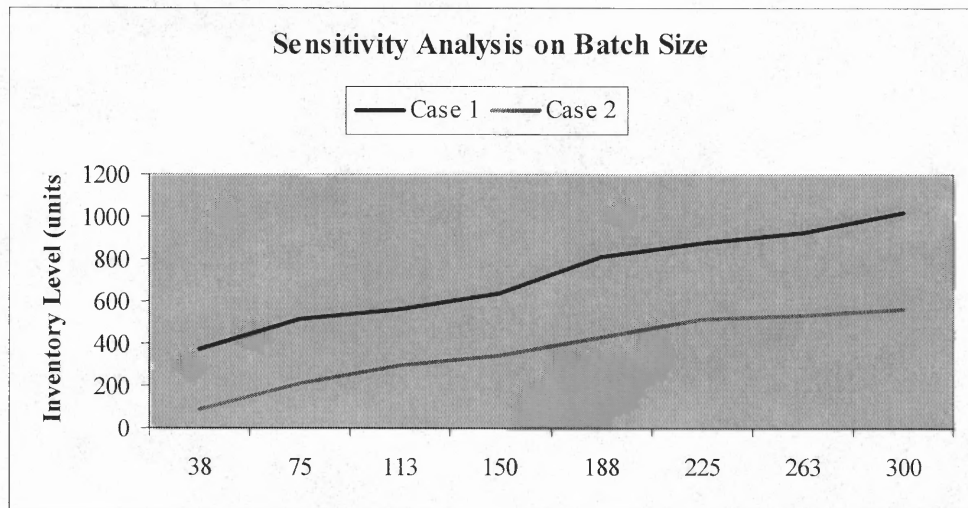
Sensitivity analysis is used to access the impact of changes on data on the model results. Since the data such as processing time for each activity in the supply chain are based on assumptions, the sensitivity analysis was used to see if the system's performance changes significantly. In this case study, changes in standard deviation for processing time and batch size were used for the sensitivity analysis.

The standard deviation for processing time was increased from 25% to 100% and decreased from 25% to 75%. The inventory level remains relatively stable for different standard deviation which indicates that changes in standard deviation do not have significant impact on the inventory level. Figure 6.8 shows the inventory level for different standard deviation value.

The change of batch size has impact on the results for each case as shown in Figure 6.9. Thus, the accuracy of data for batch size is important when enter to the model. However, in terms of ratios of results, such as ratios of inventory levels of Case 2 over Case 1, changes in batch size remain in the same range.



**Figure 6.8** Sensitivity Analysis on Standard Deviation



**Figure 6.9** Sensitivity Analysis on Batch Size

## **CHAPTER 7**

### **CONCLUSIONS**

In order to study the integrated e-supply chain network performance, an understanding of the impact of decisions on operations and partnerships are essential. Simulation has been found to be one of the popular and suitable methods for understanding supply chain dynamics.

In this thesis, a supply chain simulation tool has been developed in order to analyze and study different structures of supply chain issues. The modules captured general supply chain process and concepts. Therefore, it could be used in wide range of applications. The simulation tool provides the capability to evaluate resource utilization, evaluate supply chain structure, identify bottleneck in system, evaluate alternative linkage changes, and analyze operational strategies. Utilization of this simulation tool to the study of other supply chain issues would be of great interest.

The integrated e-supply chain network (IESC) model was presented to explore the environmental impacts of emerging e-business on electronic product supply chains. The study indicates that the changing relationship in the e-supply chain has significant impact on supply chain performance in terms of business characteristics such as cycle time and inventory level, as well as environmental performance of each supplier and overall supply chain. The case study shown that the e-supply chain for a desktop computer has the potential to yield significantly better performance in terms of business goals and environmental goals than traditional practices.

In the design for the simulation tool, the model captures the complex dynamics of a supply chain and thus far not focusing too much attention on each supply chain activity. Further research could be performed by extending the concepts for each supply chain activity and incorporating theoretical details such as inventory management or queuing theory in designing the simulation tool.

## APPENDIX

### MATERIAL AND ENERGY INVENTORY DATA

This appendix shows the data of material inventory and energy consumption for each part and component of a typical desktop computer in the case study.

Part Name	Material	Weight (kg)	Material Energy Intensity (MJ/kg)	Production Energy Intensity (MJ/kg)	Energy (MJ)
Monitor	Plastic	4.10	120		
	Leaded Glass	6.38	15		
	Copper	0.18	150		
	Steel	1.98	23		
	PCB	0.01	120		
	Total	12.65		52.8	1329
Keyboard	Plastic	0.83	120		
	Steel	0.34	23		
	PCB	0.01	120		
	Total	1.179		129	260
Chassis with power supply	Aluminum	5.80	300		
	Plastic	2.74	120		
	Other Metals (Steel)	2.72	23		
	Total	11.27		82.8	3066
Floppy Drive	Plastic	0.01	120		
	PCB	0.05	120		
	Steel	0.31	23		
	Total	0.37		116.1	58
CD ROM	Plastic	0.02	120		
	PCB	0.05	120		
	Steel	0.96	23		
	Total	1.03		116.1	149
Hard Disk Drive	Steel	0.42	23		
	PCB	0.04	120		
	Total	0.46		116.1 (MJ/mm2)	68
Mother Board	PCB (24 x 30.5 cm <sup>2</sup> )	0.23	120	0.0018	159.0
LAN card	PCB	0.14	120	0.0018	21.7
Soundcard	PCB	0.14	120	0.0018	21.7
CPU (processor)	PCB (5 x 5 cm <sup>2</sup> )	0.02	120	0.0018	6.9
Memory	PCB (3.2 x 13.3 cm <sup>2</sup> )	0.02	120	0.0018	9.5
<b>TOTAL</b>		27.48			5148

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