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Supply Chain Inventory Planning: System Dynamics Model

SUMMARY This chapter models a system dynamic process for inventory planning in a supply chain. The dynamical tools of casual loop and state flow are employed for analyzing the effectiveness of variables. The model is implemented in Vensim simulation environment.

4.1 Introduction

Fierce global competition over sophisticated customers demanding increasing customization and constantly faster response in addition to advancements in information and communication technology have resulted in making supply chain networks critical contributors in the production and distribution of goods in contemporary markets. The growing interest in supply chain networks has in turn pointed out the importance of relying on efficient management practices specially designed to manage the complexity, enormity and breadth of scope of the supply chain structures. Supply chain management (SCM) has evolved to one of the most prevailing 21st century manufacturing paradigms focusing on the design, organization and operation of supply chains.

In a supply chain there are three types of flow—that of materials, information and finance. The objective of this chapter is to model a manufacturing supply chain, which is assumed to have a moderate complexity of four echelons, to measure its performance under different operational conditions and finally identify and understand its dynamic behavior. A system dynamics (SD) approach is used to build the model and measure the system's performance. SD is a methodology that is capable of studying and modeling complex systems, as in our study, for supply chain networks. The operations performed within a supply chain are a function of a great number of key variables which often seem to have a strong interrelationship.

Systems dynamics aims to provide a holistic view of the system and to identify how these interrelationships affect the system as a whole. The ability of understanding the whole system as well as analyzing the interactions between various components of the integrated system and eventually supplying feedback without breaking it into its components make SD an ideal methodology for modeling supply networks. A structure is provided to transform the system from a mental model to a computer-based level and rates model. Further experimentation is then carried out on the model involving a number of designed scenarios. Conclusions are drawn on the behavior displayed.

The area of supply chain management is being increasingly investigated by both academia and industry. The successful implementation of supply chain improvement programs has pointed out the benefits of efficient SCM. All supply chains are different and a lot of companies struggle to understand the dynamics of their supply chain.

The traditional supply chain problems studied in the literature are more related to location/allocation decisions, demand planning, distribution channel planning, strategic alliances, new product development, outsourcing, supplier selection, pricing, and network structuring at the strategic level. The tactical level problems cover inventory control, production distribution coordination, order/freight consolidation, material handling, equipment selection and layout design. The problems addressed at the operational level include vehicle routing/scheduling, workforce scheduling, record keeping, and packaging.

Various alternative methods have been proposed for modeling supply chains. According to Beamon (1998), they can be grouped into four categories: deterministic models where all the parameters are known, stochastic models where at least one parameter is unknown but follows a probabilistic distribution, economic game-theoretic models and models based on simulation, which evaluate the performance of various supply chain strategies. The majority of these models are steady-state models based on average performance or steady-state conditions. However, static models are insufficient when dealing with the dynamic characteristics of the supply chain system, which are due to demand fluctuations, lead-time delays, sales forecasting, etc. In particular, they are not able to describe, analyze and find remedies for a major problem in supply chains.

System Dynamics is a powerful methodology for obtaining insights into problems of dynamic complexity and policy resistance. Forrester (1961) introduced SD in the 1960s as a modeling and simulation methodology in dynamic management problems. The system under study in this chapter is dynamic and full of feedback; therefore SD becomes an appropriate modeling and analysis tool.

The first published work in system dynamics modeling related to supply chain management is found in *Industrial Dynamics: A Major Breakthrough for Decision Makers* (Forrester, 1958). Forrester (1961) expanded on his basic model through further and more detailed analysis, and establishes a link between the use of the model and management education. Figure 4.1 shows the classic supply chain model that was used by Forrester in his simulation experiments.

There is a downstream flow of material from the factory via the factory warehouse, the distributor and the retailer to the customer. Orders (information flow) flow upstream and there is a delay associated with each echelon in the chain, representing, for instance, the production lead time or delays for administrative tasks such as order processing. Researchers since have coined the expression of the 'Forrester Supply Chain' or Forrester Model, which essentially is a simple four-level supply chain (consisting of factory, a warehouse, a distributor and a retailer).

Using the Forrester Model as an example, Forrester (1961) describes the modeling process used in modelling continuous processes, while clearly emphasizing the importance of information feedback to the SD method (Towill, 1996). Pointing out that the first step in an SD study is the problem identification and the formulation of questions to be answered, he illustrates the stages of model conceptualization, model parameterization, and model testing through various experiments. Forrester (1958) disapproves of the approach taken by operations research (OR) in the 1950s, where OR methods are applied to isolated company problems. He suggests that the success of industrial companies depends on the interaction between the flows of information, materials, orders, money, manpower, and capital equipment, and states that the understanding and control of these flows is the main task of management.

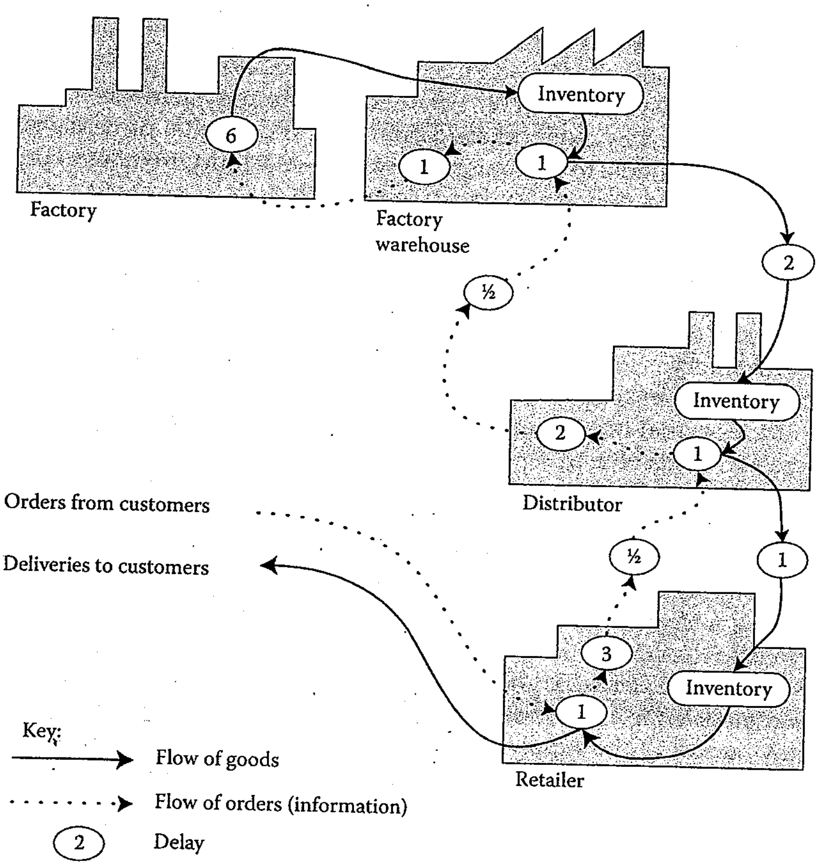


FIGURE 4.1
The Forrester supply chain.

The Forrester Model received much criticism over the years, which served as a basis for applying and extending Forrester's research further. Despite its simplicity, the Forrester Model yielded important insights into supply chain dynamics. Demand amplification, a fundamental problem in supply chains, has only recently been recognized to the full extent of the problem (Towill, 1996). Forrester accidentally established the ground rules for effective supply chain design when he showed that medium period demand amplification was an SD phenomenon which could be tackled by reducing and eliminating delays and the proper design of feedback loops (Towill, 1996).

4.2 Problem Definition

SD is a method to cope with complex system problems, with the combination of quantitative and qualitative methods, based on feedback control theory, using computer simulation technology as its measures (Özbayrak, 2007). According to an SD viewpoint, a system dynamic model analyzes a system's objects changing trends by simulating them dynamically in order to study and future action plan and to study the future action plan and assist the corresponding decision-making. The model is characterized by the object studied as a dynamic system (Towill, 1996). The dynamic system has a certain internal structure and is affected by external conditions. Its fundamental principle is: use system modeling, ending the model to computer and verify the validity, in order to provide a basis to work out strategy and decision-making (Feng, 2012).

The most important problem discussed in this chapter is the cost associated with fluctuations in warehouse inventory planning in the supply chain. Costs due to inventory stocking in warehouse, costs due to discount on sales to reduce inventory and even costs of perished products, shortage costs of product, lost customers costs and decreased market share when inventory is lower than market need, make forecasting of these fluctuations a very significant issue in supply chain. Undesired behavior and fluctuation in warehouse inventories have several reasons and different variables from the supply chain are influenced. Therefore, to resolve this problem, identification of important effective variables on the supply chain, defining variables' behavior, and formulating the way they influence inventory fluctuation and simulating inventory behavior in distribution centers' warehouses are necessary.

The overall supply chain model considers only four echelons—suppliers, manufacturers, distributors and retailers—and its dynamics are studied from the operational perspective. None of the companies that form the network has a partnership with any of the companies within the network; in addition, the companies forming the echelons of the supply chain modeled in this work are assumed to have no interactions whatsoever with any company outside of the supply chain considered, and hence no dedicated supply system is available for any of them. The central company cooperates with warehouses and distribution centers.

4.3 System Dynamic Model

The demand at the retailers' follows a random uniform distribution that represents customer demand. Consumers' demands are considered during a year which is altered by any seasonal or other statistically defined patterns of consumer behavior. The production capacity of the manufacturer is known per week. Production time follows a normal distribution and there are no assembly operations. The suppliers order and receive raw materials from an external source. The model only includes information and material flows. Cash flow is not considered in this work due to the added complexity. The system will be simulated for specified period of time. The process is modelled using Vensim software.

In this section, we will identify the important variables in the system. To identify effective variables, experts' opinions and study of related literature were used. Table 4.1 shows influencing variables on the proposed supply chain.

4.3.1 Dynamic Hypothesis

The original source of variables' behavior is influenced more than anything by sales behavior in distribution centers; this behavior depends on several factors, such as seasonal changes, discounts and promotions, price changes, etc. The effect of these variables is bidirectional and as we discuss later in this chapter, cause and effect variables are interchanged alternatively.

TABLE 4.1

Effective Variables on Supply Chain of Kaleh Company

The Important Variables in the System
Sale rate
Product inventory in distribution center
Product inventory in central warehouse
Safety stock in distribution center
Safety stock in central warehouse
Distribution center warehouses empty space
Central warehouses empty space
Product transfer
Production volume
Production rate
Transportation time from central warehouse to distribution center's warehouse
Order volume for production
Production time
Order volume for purchasing raw material

4.3.2 Casual-Loop Diagram (CLD)

In order to design casual-loop diagram, defined variables in dynamic theory and influencing factors on their behavior are evaluated and variables relations type and their feedback loops are designed step by step to reach the final casual-loop diagram. In continue, a general configuration of supply chain's cause and effect model is depicted and we discuss the most important loops within the model.

4.3.3 Goal Seeking Loop of Sale–Inventory

In this loop, the effect of sales on inventory and inventory on sales can be observed. Here, the effect of demand is shown as an incremental factor (+) on sales. Of course, this behavior is possible if there are enough inventories in distribution centers, otherwise the effect of demand on sales is not incremental and some adjustments are needed. To specify the time and amount of this adjustment, inventories of distribution centers' warehouses and demand are assessed and the amount of shortage is determined. In cases where there is a shortage, available inventories are sold and the remaining demands become lost sales and cannot be recovered. As shown in Figure 4.2, the relation of sales and inventory is decreasing and an increase in sale decreases inventory in distribution center. An inventory decrease in distribution center will cause an increase in shortage due to decreasing relation of inventory and shortage and consequently decreases sales. Hence, this loop behave to balance the variables and is goal seeking loop of sale–inventory.

4.3.4 Goal Seeking Loop of Transmission

In this loop, the effects of various factors on transfer as the only incremental factor on inventory of distribution center can be seen. As shown, the following factors are influencing on determining the amount of a transfer.

Warehouse fullness at distribution center indicates the amount of space needed for stock is sufficient or not.

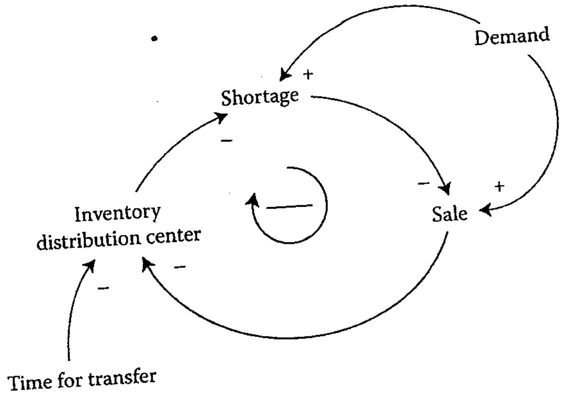


FIGURE 4.2
Goal seeking loop of sale-inventory.

Transfer time which is the time required to transfer inventory from central warehouse to distribution center. Here we only consider the average transfer time of different distribution centers. The existence of this factor causes a lag in relation of transfer and inventory variables in distribution center. In this loop, warehouse fullness is higher when the inventory levels are higher in distribution center or warehouse capacity is smaller. Also, with higher fullness percentage, the transfer amount decreases even if higher inventory needed, and it indicates a decreasing relation between fullness percentage and transfer variables (see Figure 4.3).

4.3.5 Goal Seeking Loop of Transmission Material

Within this loop, the transfer order of materials to supplier is determined as a key variable based on demand not responded, inventories in supplier's warehouse and the production

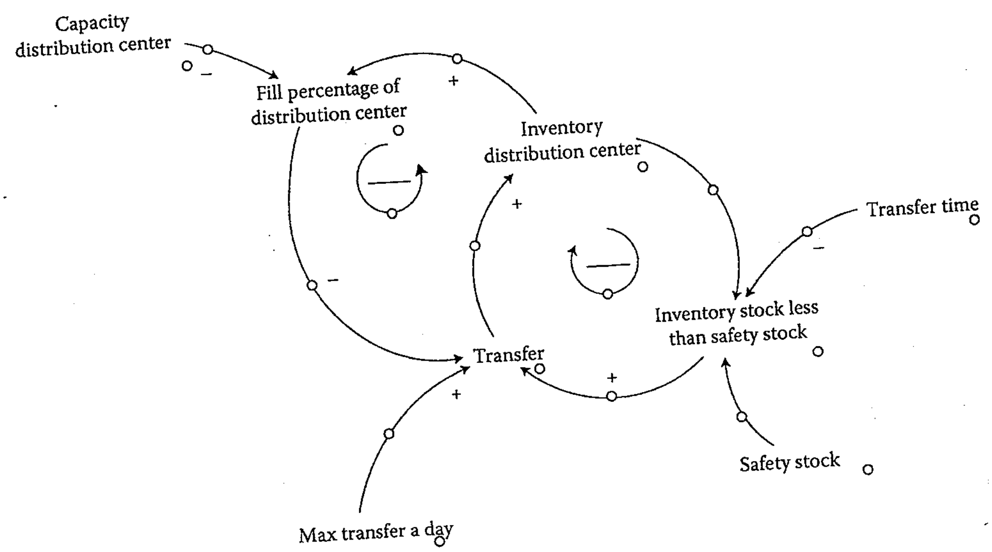


FIGURE 4.3
Goal seeking loop of transmission.

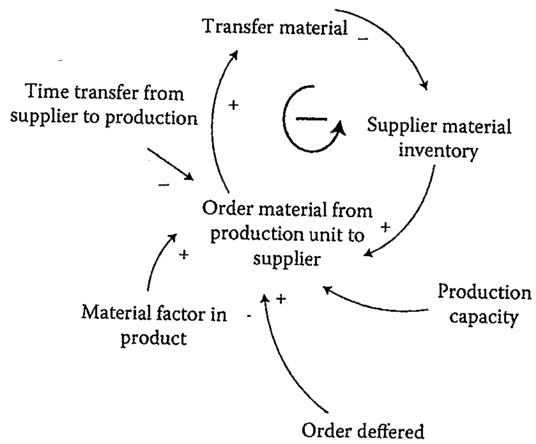


FIGURE 4.4
Goal seeking loop of transmission material.

capacity. After ordering materials to supplier, they are transferred to the production units and it causes a decrease in inventory of supplier's warehouse. Moreover, if there is no order for transferring materials, they are transferred to the production units with amount up to production capacity until the inventory at supplier warehouse becomes zero. This issue exists to sustain production and leads inventory to increase and prevent production shut down (see Figure 4.4).

4.3.6 Growth Loop of Sale-Transfer

In this loop sales feedback to transfer is created via forecasting sales and determining safety stock. By increasing forecasted sales, safety stock also increases. By increasing safety stock, the amount of shortage decreases which in turn causes a higher transfer in following periods. Therefore the relations of mentioned variables are of incremental type and this issue leads to creation of a growth loop from sales to transfer and from transfer to sales. This growth loop in cases where there is enough inventory is central warehouse, adequate warehouse space, and existence of enough demand, leads to incrementally higher transfer and sales up to completely responding to market needs. It should be noted that this increasing growth could transform to incremental decline as well (see Figure 4.5).

4.3.7 Growth Loop of Sales-Production

In this loop, in addition to variables related to sales, intermediary variables between sales and production and production variables are entered as well which leads to creation of a growth loop with some internal loops that finally all of them create a growth sales loop causing increased forecasted sales and safety stock. The relations of these variables, as shown in Figure 4.6, is incremental and by increasing lagged orders, the amount of transferred materials to product ion units and in turn production rate and product inventory in warehouse increase.

4.3.8 State-Flow Diagram

State-flow diagrams are about physical structure of feedback loops and involve casual diagrams that draw entering data for a decision policy. In these diagrams, the focus is on data

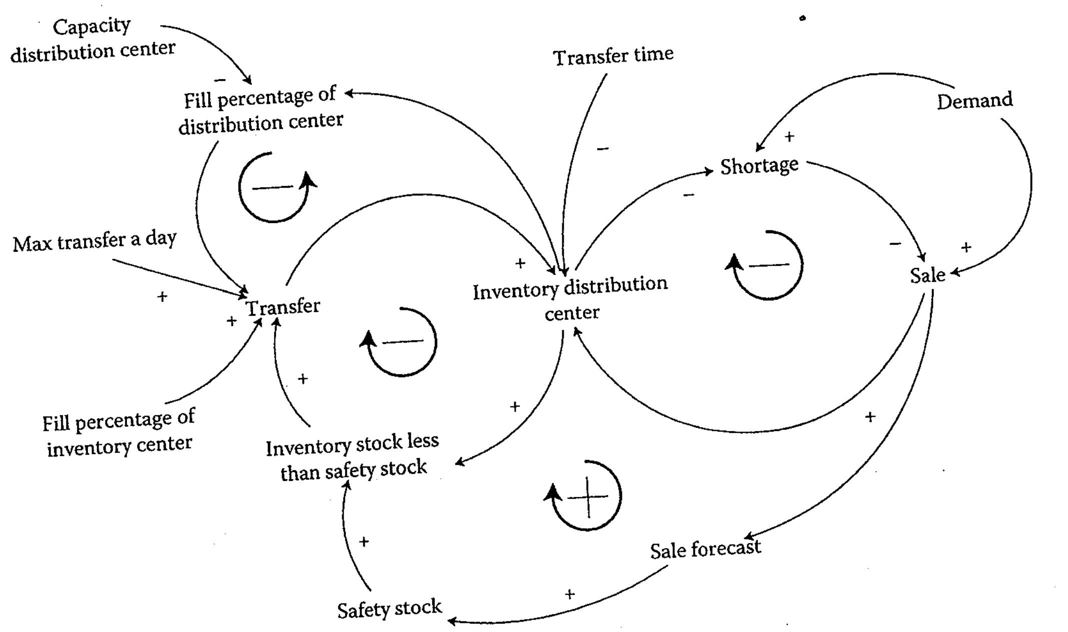


FIGURE 4.5
Growth loop of sale-transfer.

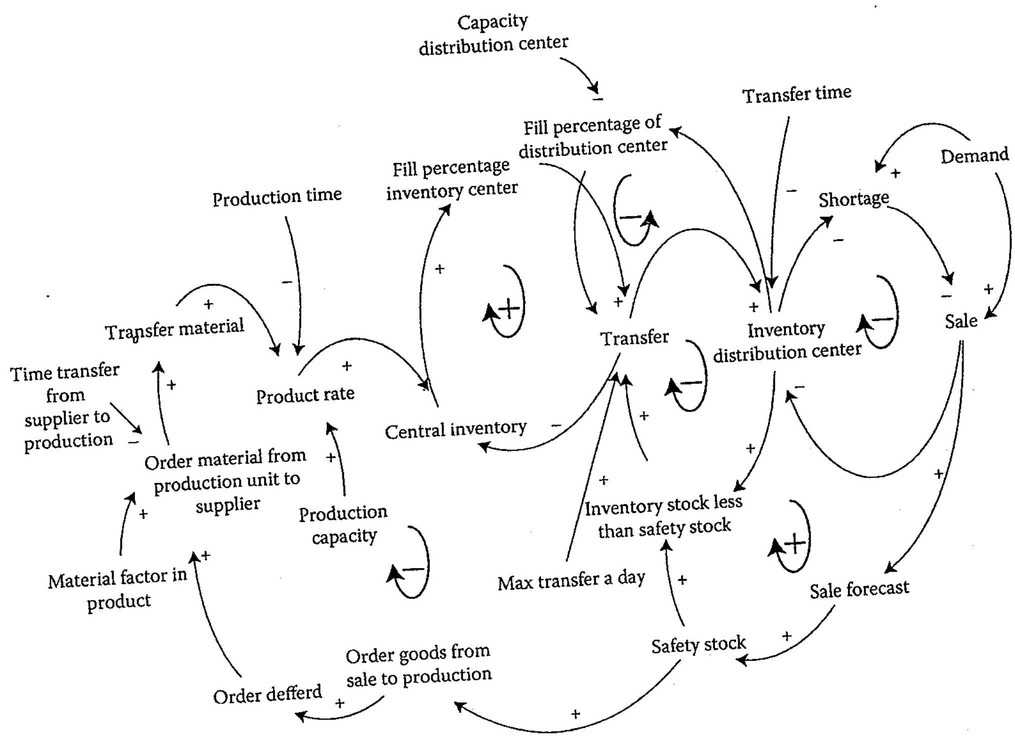
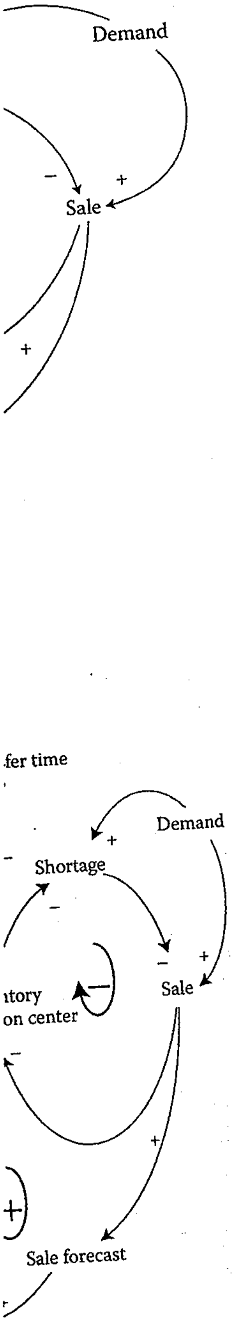


FIGURE 4.6
Growth loop of sales-production.



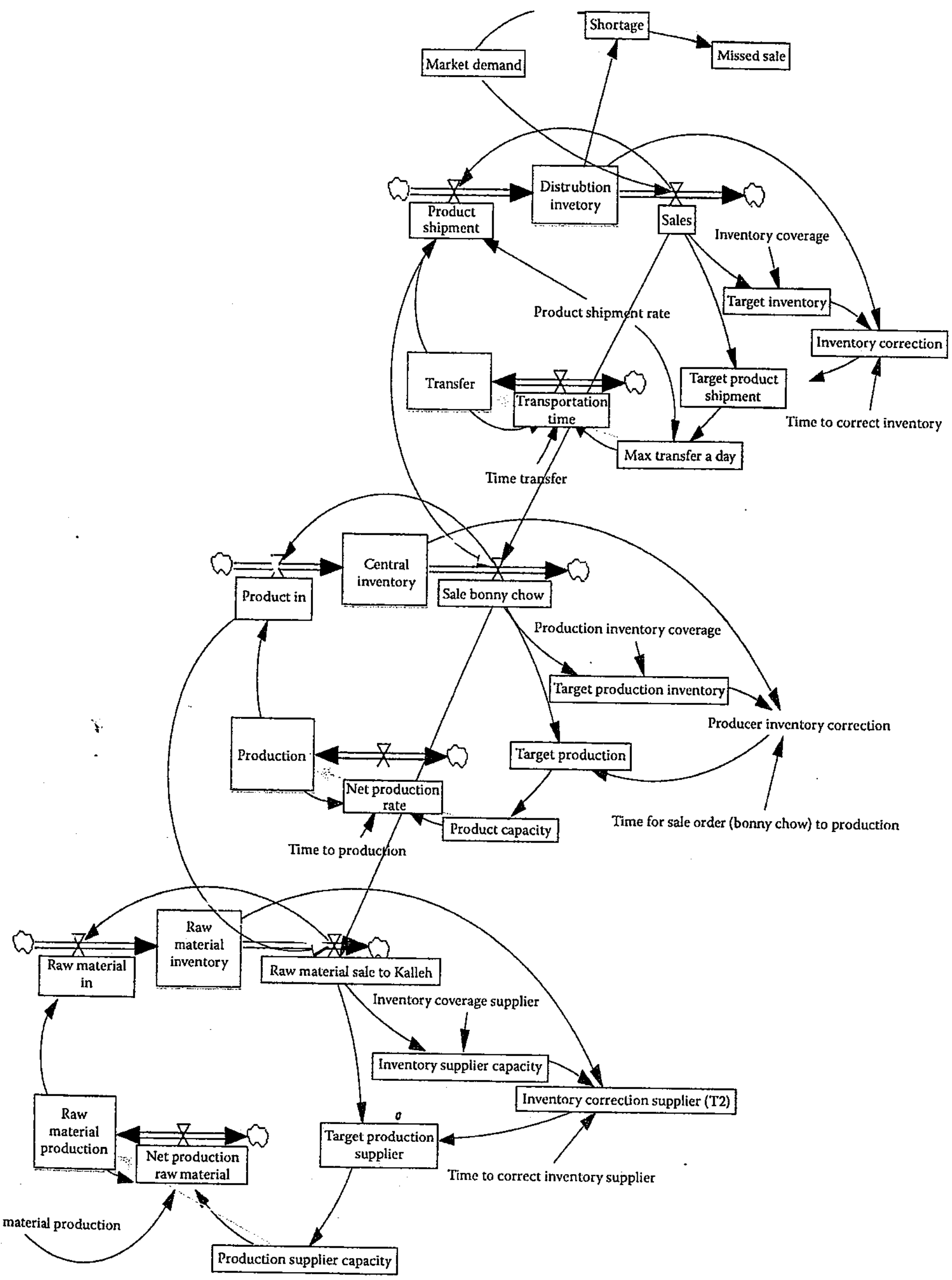


FIGURE 4.7
State-flow diagram.

that the modeler uses for the decision-making process. In state-flow diagrams, the system state variables are the number of customers, material inventory, debts, etc. System flow variables are such as production rate, material transfer rate, sales rate, etc. In these systems, decisions are determined based on state variables and executed based on flow variables (see Figure 4.7).

4.4 Discussions

In this chapter, the aim was to identify influencing variables on supply chain and their relations and effectiveness on the whole supply chain. The model was designed based on an SD method using Vensim software. The most important characteristic of this study is the possibility of implementation of the model in the reality which could prevent wrong decision in complex systems. In the designed model of this study, only one supplier was considered, which can be extended to several horizontal and vertical suppliers to the chain so that the accessibility time to the raw material for production can be reduced. Moreover, in distribution centers we only considered one distributor, which can be modeled as multi-distributor system so that to cluster products to distributors to prevent shortage.

References

Beamon BM. Supply chain design and analysis: Models and methods. *International Journal of Production Economics* 1998;55:281–94.

Feng Y. System dynamics modeling for supply chain information sharing. *Physics Procedia* 2012;25(1):1463–1469.

Forrester JW. Industrial dynamics: A major breakthrough for decision makers. *Harvard Business Review* 1958;36(4):37–66.

Forrester JW. *Industrial Dynamics*. Cambridge, MA: MIT Press, 1961.

Özbayrak M. Systems dynamics modelling of a manufacturing supplychain system. *Simulation Modelling Practice and Theory* 2007;15:1338–1355.

Towill DR. Industrial dynamics modelling of supply chains. *Logistics Information Management* 1996;9(4): 43–56.