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A Systems Theory of Supply Chain Management

Summary

Business educators have often described their topics as systems, identifying the key elements and how they work together. Such approaches have been especially popular in marketing, where models have been developed for such subjects as consumer behavior, sales management, and marketing information systems. In this paper, the authors present several graphical models to explain how systems theory is reflected in supply chain management. An understanding and application of the systems theory enables managers to take a *systems approach* in the design and management of supply chain systems and subsystems.

Key Words: Systems approach, theory, system, systems theory, physical resource, virtual resource, supply chain management, subsystem, standard of performance, warehouse management system (WMS), Transportation Management System (TMS)

Theory

Theory can be defined as a coherent group of general propositions that are used as principles to explain some class of phenomena. A *system* is an integration of elements that function together for the purpose of achieving some objective. *Systems theory*, therefore, uses system structure as a means of explaining phenomena.

Systems Theories of Business

Systems theory was first applied to science. In 1956, economist K. E. Boulding advocated a general systems theory as the skeleton of science "on which to hang the flesh and blood of particular disciplines."[1] Systems theory was then applied to business very broadly, and then gradually refined to focus on management in general, and then on such business areas as manufacturing and marketing. In 1969, R. J. Hopeman described a business organization as a system through which resources flow.[2] His explanation was especially applicable to

manufacturing operations where it is easy to see how the inflow of raw materials are transformed into finished goods.

Marketing academicians were quick to use systems theory to explain phenomena in consumer behavior and marketing information systems. The systems model of consumer behavior by J. F. Engel, D. T. Kollat, and R. D. Blackwell received especially widespread exposure.[3] In 1968, R. H. Brien and J. E. Stafford described a marketing information system as consisting of flows of information and decisions through major modules based on the ingredients of the marketing mix (product, price, place, and promotion).[4]

These systems theories of business took the form of graphical models supported by narrative explanations. Typically, they were first published in scholarly journals and then in textbooks as a means of identifying the main elements of an activity and describing how the elements must work together in order to achieve the desired results.

Application of Systems Theory to Supply Chain Management

An area of marketing that is currently attracting much attention is supply chain management. Books are being written, scholarly research findings are being published, and business school majors are being offered.[5]

Even with all of this attention, the underlying principles of systems theory are often not recognized. The theory offers the potential of providing a framework for organizing the various supply chain functions and providing a mechanism for a systematic approach to solving supply chain problems.

Systems Theory

Systems can be classified in various ways. In their most elemental form, they can be open or closed. An *open system* communicates with its environment, and a *closed system* does not. Most systems are open. A closed system exists only in such artificial environments as settings for scientific experiments where outside interference is prohibited. Systems can also be open-loop or closed-loop. An *open-loop system* does not have a feedback loop and control mechanism, and, for this reason, it has no way of adjusting its operation to perform as intended. A *closed-*

loop system has a feedback loop and control mechanism, and can adjust its operation. Figure 1 illustrates a closed-loop system. As shown in the figure, the control mechanism can adjust the input to achieve an intended output. A thermostatically controlled heating unit is an example.

An organization of any type—profit or nonprofit, government or non-government—is an open, closed-loop system. Also, subdivisions of an organization are open/closed-loop systems. Therefore, a firm's supply chain operation can be regarded as an open/closed-loop system.

The General Systems Model of the Firm

In 1979, R. McLeod applied Hopeman's description of an open system to a business organization and named it the *general systems model of the firm*, recognizing that the model provides a structure for any type of organization.[6] As shown in Figure 2, physical resources flow through the firm at the bottom—through the input, transformation, and output areas. This is the *physical system of the firm*. The *physical resources*, as defined by Hopeman, consist of materials, machines, personnel, and money.

The physical resource flow is managed by the control mechanism in the upper part of the model, consisting of the standards of performance that the system is to achieve, management, and an information processor. The information processor consists of all of the firm's capability of gathering data, transforming that data into information, and providing information to appropriate users. In today's firm, a major element of the information processor is the electronic computer system and its communications network.

The feedback loop can be seen in the upper portion of the model. Data describing the physical resource flow is gathered from the input, transformation, and output areas, and entered into the information processor. The term *virtual resources* is used to describe the data and information that represent the physical resources. Virtual resources are also gathered from the environment and entered into the information processor. The information processor converts data into information and makes it available to management. This information describes what <u>is</u> happening in the firm. Management compares this information to that provided from the performance standards (describing what <u>should be</u> happening) to identify areas where problems are to be solved or opportunities are to be seized. When changes are to be affected in the

physical system of the firm, management makes decisions that are transmitted to the appropriate areas—input, transformation, and output.

The feedback loop of the firm therefore consists of data (entered into the information processor), information (generated by the information processor), and decisions (issued by management to the physical system).

The Eight-Element Environmental Model

In addition to describing the flow of resources through the firm, Hopeman also defined the environment of the firm as consisting of eight elements. These elements are pictured in Figure 3. The elements are connected to the firm by physical and virtual resource flows.

Some physical flows between the firm and certain elements are more prevalent than others. For example, there are prevalent flows of materials, machines, and money from suppliers to the firm, and of materials from the firm to customers. These are physical flows that represent the supply chain. Flows of virtual resources representing the physical resources are also vital to supply chain management.

Scope of Supply Chain Management

Handfield and Nichols identify three challenges facing supply chain managers.[7] These are (1) implementing an integrated supply chain, (2) inventory management, and (3) establishing trust between parties. They view the integrated supply chain as the integration of information requirements and inventory flows across multiple tiers of suppliers and customers. These flows originate with suppliers and then go through assembly/manufacturing, and then proceed to the distribution centers, retailers, and finally to customers. Bowersox, Closs, and Cooper describe a similar flow, which includes a supply network, an integrated enterprise (procurement, logistics, manufacturing, and customer accommodation), and a market distribution network.[8]

This view of the flows, originating with suppliers and ending with customers, is the one taken by the Council of Supply Chain Management Professionals in defining *supply chain management* as "encompassing the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities."[9] The Council

adds "Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers."

The Marketing Nature of Supply Chain Management

It can be argued that supply chain management affects all four of the ingredients of the marketing mix. Consumers' perception of a product can be influenced by the ability to acquire it when and where it is desired or needed. For example, the image of Coca Cola was influenced by the ability to make a purchase anywhere—in any country, and in any size of community. By the same token, a firm can cite in its promotion an ability to make its products available when needed. Federal Express has promoted its ability to make deliveries "Absolutely, Positively Overnight." The competitive ads of Master Card advised their card holders not to try to use their American Express cards at such events as the Olympics since they would not be accepted. In this case, Master Card was using a weakness in the American Express supply chain as a promotional theme. An even stronger case can be made for linking supply chain management with the price ingredient. Cost savings from an efficient supply chain can be reflected in lower prices that the consumer must pay. Whereas none of these relationships are unimportant, the strongest case, by far, links supply chain management to the place ingredient. The firm uses supply chain management to optimize the manner in which its products flow through the channels of distribution, consisting of distribution centers, distributors, wholesalers and retailers, on their way to the customers.

Since supply chain management is a critical component in a firm's marketing program, it plays a key role in the firm's marketing plan and strategy. This relationship is shown in Figure 4. The marketing plan includes supply chain objectives and strategy. The supply chain strategy coordinates the seven major *supply chain functions* (purchasing, receiving, order processing, storage, shipping, transportation, and billing) so that the supply chain objectives can be achieved.

It is important to recognize that each of the functions can be regarded as a system. The seven functions therefore can be treated as subsystems of the supply chain management system. A system within a system is called a *subsystem*, and it has all of the same components as a system.

Figure 4 shows the intricate relationships that exist among the supply chain subsystems. The subsystems are linked together and to the firm's suppliers and customers by flows of virtual and

physical resources. The figure also positions the supply chain objectives and strategy, and supply chain management in relationship to the marketing plan.

Supply Chain Management as a System

Supply chain management can be viewed as a system using the format of the general systems model, and is illustrated with the Figure 5 diagram. This diagram provides the basis for describing how supply chain management is practiced at Houston Wire & Cable (HWC) in Houston, Texas, USA. HWC is the largest value-added supplier of electrical wire and cable in the United States. HWC has an $80 million inventory of over 12,000 products from the industry's leading manufacturers of electrical wire and cable. Eleven strategically located distribution centers provide for same-day shipping and next-day deliveries to 95 percent of the continental U.S. HWC is committed to providing superior customer service and top quality products—shipped correctly, accurately, and on time.

As in the general systems model, the upper portion of Figure 5 contains the control mechanism. The system *standards* of performance are represented at HWC by *key performance indicators (KPIs)* that are used by management to ensure that supply chain objectives are achieved. There are four categories of such indicators: productivity, cost control, accuracy, and customer service. Combinations of these indicators are used to provide direction to the supply chain management system and each of its subsystems.

Management consists of the vice president of logistics and mid-level and lower-level managers in the logistics unit. The *information processor* includes three major software systems. The Enterprise Resource Planning (ERP) System performs the standard back office and accounting processes such as purchasing, inventory, order entry, and billing. The Warehouse Management System (WMS) performs most of the processes related to storage, and the Transportation Management System (TMS) is concerned with the inbound transportation processes from suppliers and the outbound transportation processes to customers.

On the system level where physical processes are performed, material resources are provided by suppliers. These resources are delivered to HWC by the *transportation subsystem*, and are then made available by the *receiving subsystem*. Receiving enables the materials to be placed in storage by the *storage subsystem*, where they remain until shipment. Shipment is accomplished

by the *shipping subsystem*, and delivery to customers is achieved by the *transportation subsystem*. All of the flows at the bottom of the diagram are physical flows. Data describing these physical flows is gathered from each supply chain management subsystem, and also suppliers and customers. The information processor transforms the data into information, which is used by management (along with information provided by the key performance indicators) in making decisions that keep the physical flows proceeding as intended.

Purchasing Subsystem

Figure 6 presents the purchasing subsystem in the general systems model format. Here, the key performance indicators include rebates and discounts, OS&D (Over, Short, and Damaged) and other quality measures, timeliness of deliveries, manufacturing defects, and lead time for replenishments.

The information processor performs four major tasks:

1. Maintain supplier ratings based on historical performance
2. Select suppliers, based on supplier ratings, to replenish inventories
3. Determine order quantities to satisfy needs
4. Prepare purchase orders

For the supplier ratings, HWC tracks each supplier based upon a supplier "scorecard." The scorecard measures the supplier-based quality (errors of quantity, errors of substitution, and errors of quality), product availability (out-of-stocks and product lead times), and value (discounts, billing accuracy, and cost).

The flow at the bottom of the diagram is the flow of data, originated by the ERP system, that recognizes the need to purchase replenishment stock. The ERP system provides the inventory and supplier data that is needed to prepare the purchase orders (POs), which are then submitted to suppliers. PO submission is typically accomplished by electronic data interchange (EDI), transmitting the data directly to the suppliers' computer systems. There are no physical flows through the purchasing subsystem. The data flows produce the POs, which ultimately will produce physical flows from the suppliers.

In the purchasing subsystem, as in all of the other supply chain management subsystems, feedback is obtained from the system output and entered into the information processor. Here,

feedback from the purchase order preparation and from the suppliers enables the system to monitor its performance, comparing the output to the key performance indicators and other measures.

Receiving Subsystem

The key performance indicators of the receiving subsystem pictured in Figure 7 focus on all four areas—productivity, cost control, accuracy, and customer service. Receiving performance is tracked by looking at both what is being received and who is receiving it. Metrics for the receiving process include delivery timeliness, product OS&D, and units received per labor hour. The information processor software updates the supplier ratings based on the receipts.

Inputs to the receiving subsystem are provided by the transportation subsystem, through ASNs (advance shipping notifications). ASNs usually take the form of an EDI transmittal that communicates information from the supplier to their customer. Information contained in the ASN includes such product information as part number and quantity, and also such carrier information as transportation mode, ship and expected delivery dates, overall weight, and count information. The ASN is not always communicated in an EDI format. Many suppliers communicate ASNs via email or provide information on their websites.

At this point, the transportation subsystem handles the inbound material flows from suppliers; later, the subsystem will handle outbound flows to customers. The figure illustrates the input resources being processed by materials handling. The materials handling consists of removing the materials from inbound trucks. The transformation processes of the receiving subsystem:

1. Confirm the accuracy of the receipt
2. Confirm the quality of the receipt
3. Acknowledge the receipt to the ERP System for inventory availability
4. Report exceptions such as overages, shortages, and damage

Once these processes have been performed, materials handling moves the inventory to the proper storage location, where it is managed by the storage subsystem.

Order Processing Subsystem

The order processing subsystem, diagrammed in Figure 8, performs the tasks that are necessitated by receipt of a customer order.

Many key performance indicators apply to this system. Productivity can be measured by the number of orders, lines, and cuts processed per direct labor hour. (Cable is cut to length to add customer value.) Cost measures can focus on the number of orders, and lines and pounds processed per controllable expense dollar. Customer service measures include the average cycle time, degree of same-day shipping achieved, customer reported damage, and shipping accuracy.

The information processor provides the billing capability that will prepare invoices once shipments are made.

Here, input is provided by customers in the form of customer sales orders. The processing consists of evaluating the credit worthiness of the customers, and triggering the processes that will select, sort, and add value to the materials by the storage subsystem. Outputs of the order processing subsystem take the form of picking tickets that will be used by the storage subsystem to perform their value-added functions and process the order.

Storage Subsystem

The storage subsystem, shown in Figure 9, is the heart of the supply chain system. This is where the materials are held until shipment to customers. A full set of key performance criteria is applicable**.** Reviewing product volume assists in determining where the material is best stored to lower labor and to increase availability. Unexpected stock-outs are tracked as a measure of general warehouse inventory accuracy. The storage processes are concerned with utilizing the storage facilities and managing the inventory. The information processor consists of the Warehouse Management System (WMS).

This is the first system that we have encountered with two environmental inputs. One is provided by the order processing subsystem, which notifies the storage subsystem that an order has been received and must be filled. The other is provided by the receiving subsystem that notifies the storage subsystem that materials have been received from suppliers.

Materials handling makes materials provided by the receiving subsystem available for storage by providing a put-away function that accomplishes ABC slotting. This slotting strategy stores inventory based upon how often it is ordered. Higher volume material is best stored close to where it will be processed for shipment so as to decrease labor dedicated to putting and pulling from stock. Taking into account environmental factors can also affect where the stock might be placed. Weight will determine which storage systems are used, and water and sunlight resistance of the product will determine if material can be stored inside or outside. The processing performed by the storage subsystem takes the form of utilizing the space to its maximum, providing the salespersons with information concerning the available inventory, and directing inbound material to be put away where it best suits the efficiency of the operation and storage requirements of the material. To HWC, being able to know the availability of inventory, in real time, is critical. When a customer places an order with HWC they expect that HWC will be able to deliver what is promised.

On the output side of the storage subsystem, materials handling provides the processed orders to the shipping subsystem.

Shipping Subsystem

The shipping subsystem is concerned with moving the materials from storage to the transportation subsystem and notifying the billing subsystem that the customers can be invoiced. Therefore, there are two output environmental elements at the bottom of Figure 10.

A full set of key performance indicators apply to shipping, including on-time measurements for shipping and delivery, routing and billing accuracy, and freight claims. The information processor performs two major tasks: preparation of the required shipping documents such as bills of lading, and notification to the billing subsystem that shipment has been completed.

Materials handling moves the materials to the cutting area for cut-to-length services, then to the shipping staging area to await loading. The shipping subsystem prepares the items for shipment by making cuts, palletizing the items, and tendering the load to the carrier to arrange a pickup. Shipments are tendered to a carrier in two ways—electronically and by phone. Once an order is processed by the TMS and made ready for shipment, an electronic communication occurs

between the TMS and the carrier's system. The carrier is provided with such information as shipment origin, destination, quality, weight, freight classification, and service level.

After these processes are accomplished, materials handling moves the materials to the shipping staging lines and then into trucks.

Transportation Subsystem

The transportation subsystem manages the inbound material flow from suppliers and the outbound flow to customers as pictured in Figure 11. These two flows can be seen at the bottom of the figure.

Although all four key performance categories apply, the one receiving the most attention is customer service. Measures are taken of errors of substitution and quantity, damages, missed shipments, and late shipments.

Here the information processor consists of the Transportation Management System (TMS), which engages in transportation mode selection, channel selection, determination of freight charges, shipment tracking, and shipment communications.

Billing Subsystem

The final subsystem has the task of invoicing the customers upon shipment. It is illustrated in Figure 12. Since this is a subsystem concerned with only virtual flows, no safety measures of performance are of concern. The key performance indicators focus on productivity, cost, and, primarily, customer service. The information processor has a single task: to invoice customers. This capability is provided by the ERP System.

The shipping subsystem provides the customer, carrier, and product data to be used in preparing the invoices. Once prepared, the invoices are transmitted to customers, by mail or electronic data interchange.

Using Systems Theory to Design and Manage the Supply Chain

Management benefits by viewing the supply chain as a system. By taking a systems view of the supply chain, attention is focused on the elements that are key to good system performance. The following benefits are achieved:

- The key performance indicators are seen as key to the system achieving its objectives.
- The physical resource flows are identified and understood.
- The supply chain functions that facilitate the physical resource flow are identified and understood.
- The interaction of the supply chain functions is made clear.
- Supply chain management is recognized as the control mechanism that adjusts system performance in order to achieve the desired system performance.
- The importance is made clear of an information processor to gather data from the physical flow and from elements in the environment of the system, transform that data into information, and provide that information to management.
- The key role is recognized of management decisions in adjusting the performance of the physical system in order to achieve the system objectives.

In summary, by viewing the supply chain as a system, management understands its task in designing and managing the system. Management clearly sees the importance of assembling a management team with the proper knowledge and skills, providing each of the supply chain functions with the resources that are required for them to function as subsystems, and assembling and maintaining the necessary virtual flows of data, information, and decisions that enable the supply chain to function as an open, closed-loop system.

Using Systems Theory to Design and Manage Supply Chain Subsystems

We have recognized that each of the supply chain functions (purchasing, receiving, order processing, storage, shipping, transportation, and billing) are subsystems. Therefore all of the benefits of viewing the supply chain as a system can be achieved when viewing each function as a subsystem.

Take, for example, the transportation subsystem. When it is viewed as a subsystem, management clearly sees the importance of having:

- Key performance indicators that address all dimensions of performance—productivity, cost control, accuracy, and , especially, customer service
- A management staff that recognizes the importance of good supplier relations, knows how to select and rate carriers, knows the importance of working well with the shipping and receiving subsystems, and has a definite customer orientation
- An information processor that can gather data to track the transportation flow from suppliers, through the firm, and to customers
- An ability to communicate management decisions that make necessary changes in the transportation process

By viewing transportation as a system, it forces management to make certain that the components are in place, which enable that supply chain function to be performed in an effective and efficient manner.

Summary Observations

The systems theory of supply chain management provides the manager with a number of real advantages. The theory:

- Prevents the manager from getting lost in the complexity of the organizational structure and details of the job
- Recognizes the necessity of having good objectives
- Emphasizes the importance of all of the parts of the organization working together
- Acknowledges the interconnections of the organization with its environment (here the environment consists of other internal organizations as well as such external organizations as suppliers and customers)
- Places a high value on feedback information that can only be achieved by means of a closed-loop system

By taking a systems view of supply chain management, the objectives for each component are spelled out, and the mechanism for achieving the objectives is made clear.

Not to be overlooked is the value of the systems view to training new managers and orienting employees. All employees benefit from taking a systems view. All customers benefit from taking a systems view as well. Costs can be driven out of the supply chain by reducing errors, as reworking orders can increase the cost of goods sold. Further savings can be realized through a systems view by using feedback to fine-tune the system and reduce the time it takes for material to travel through the supply chain.

Figure 1
A Closed-Loop System

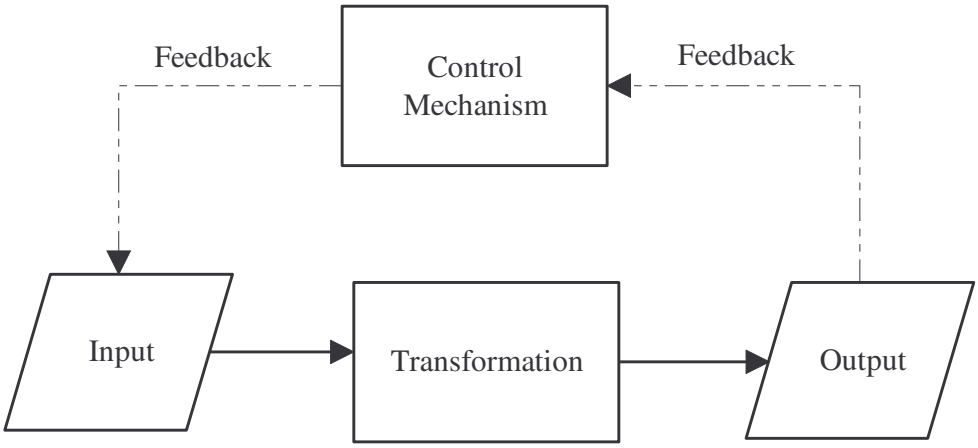


Figure 2
The General Systems Model of the Firm

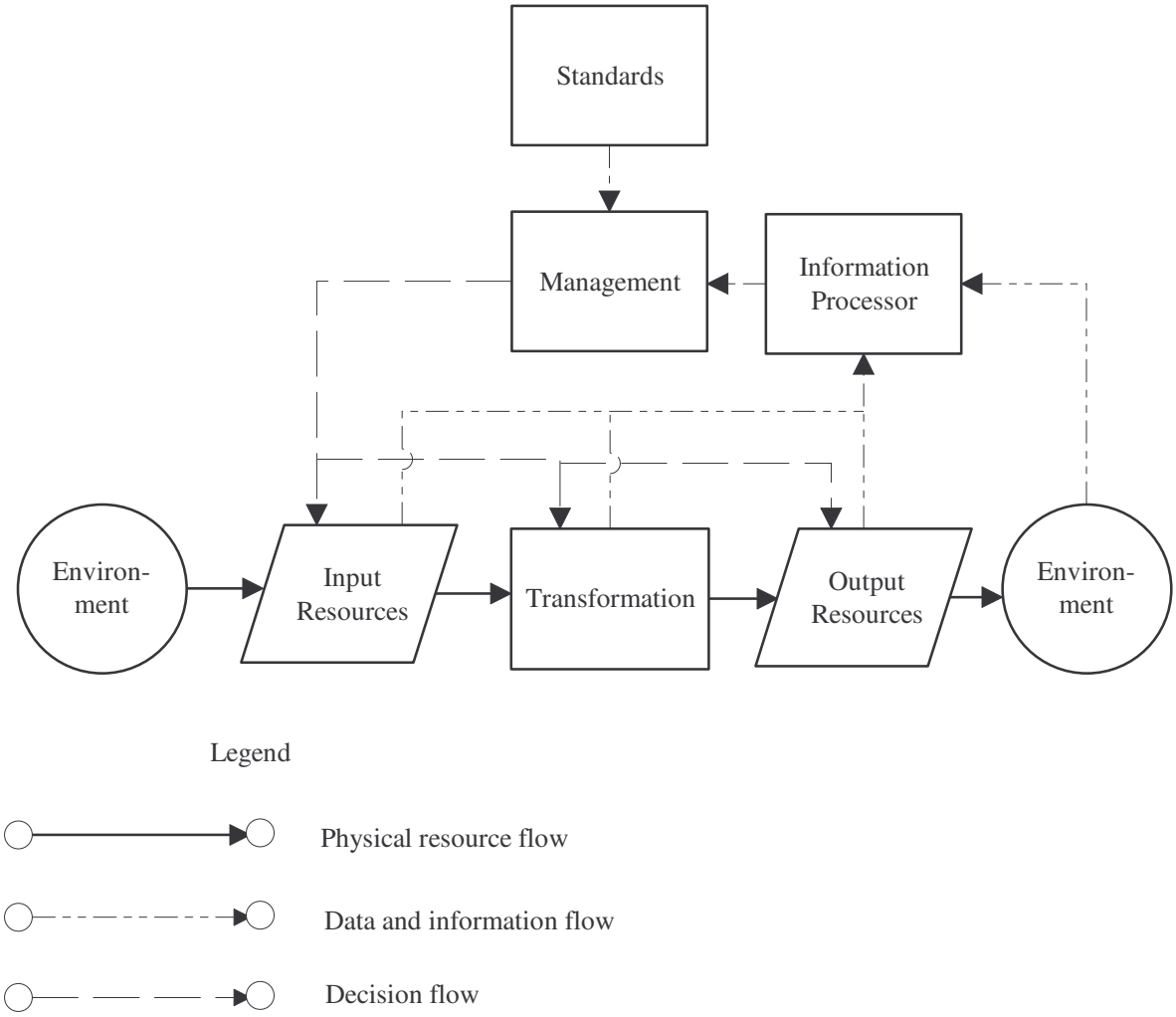


Figure 3
The Eight-Element Environmental Model

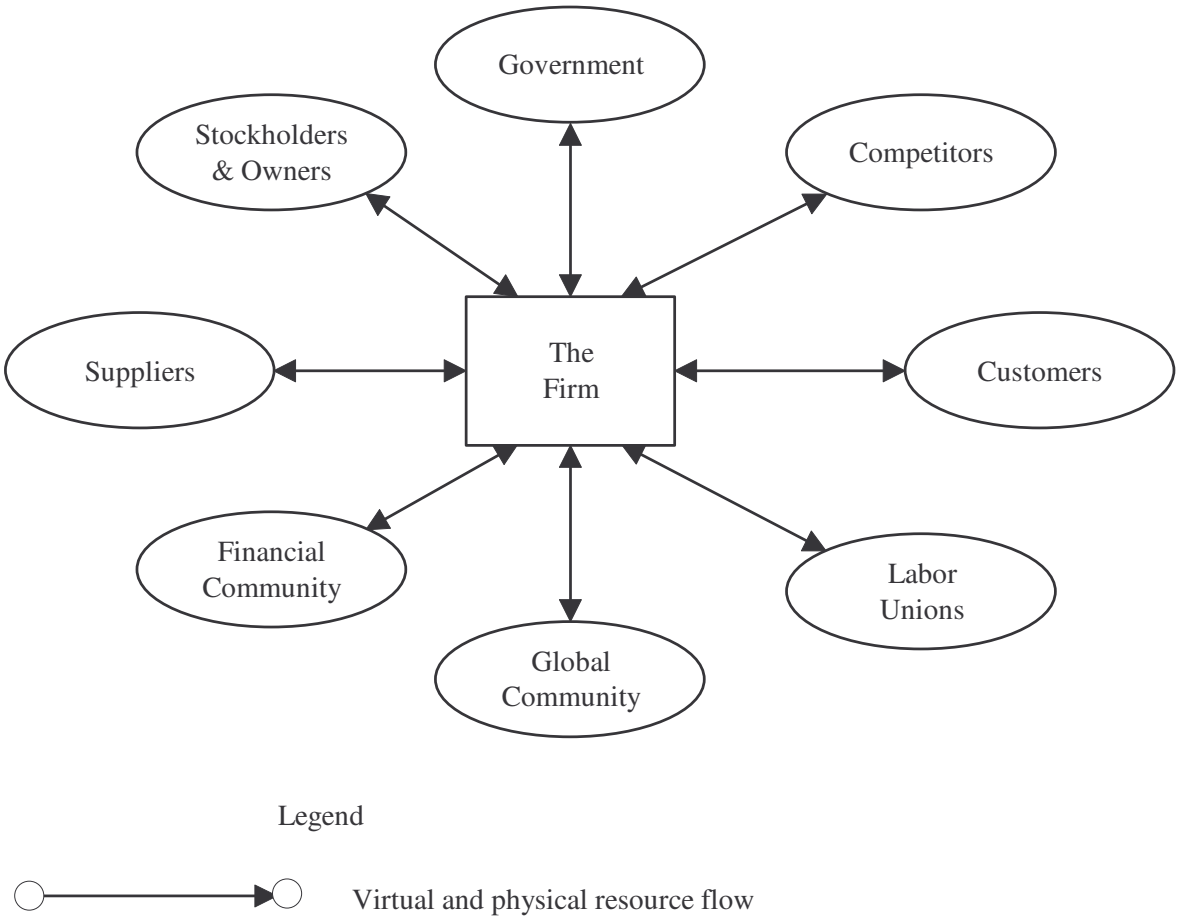


Figure 4
Supply Chain Management
As a Component of the Marketing Plan

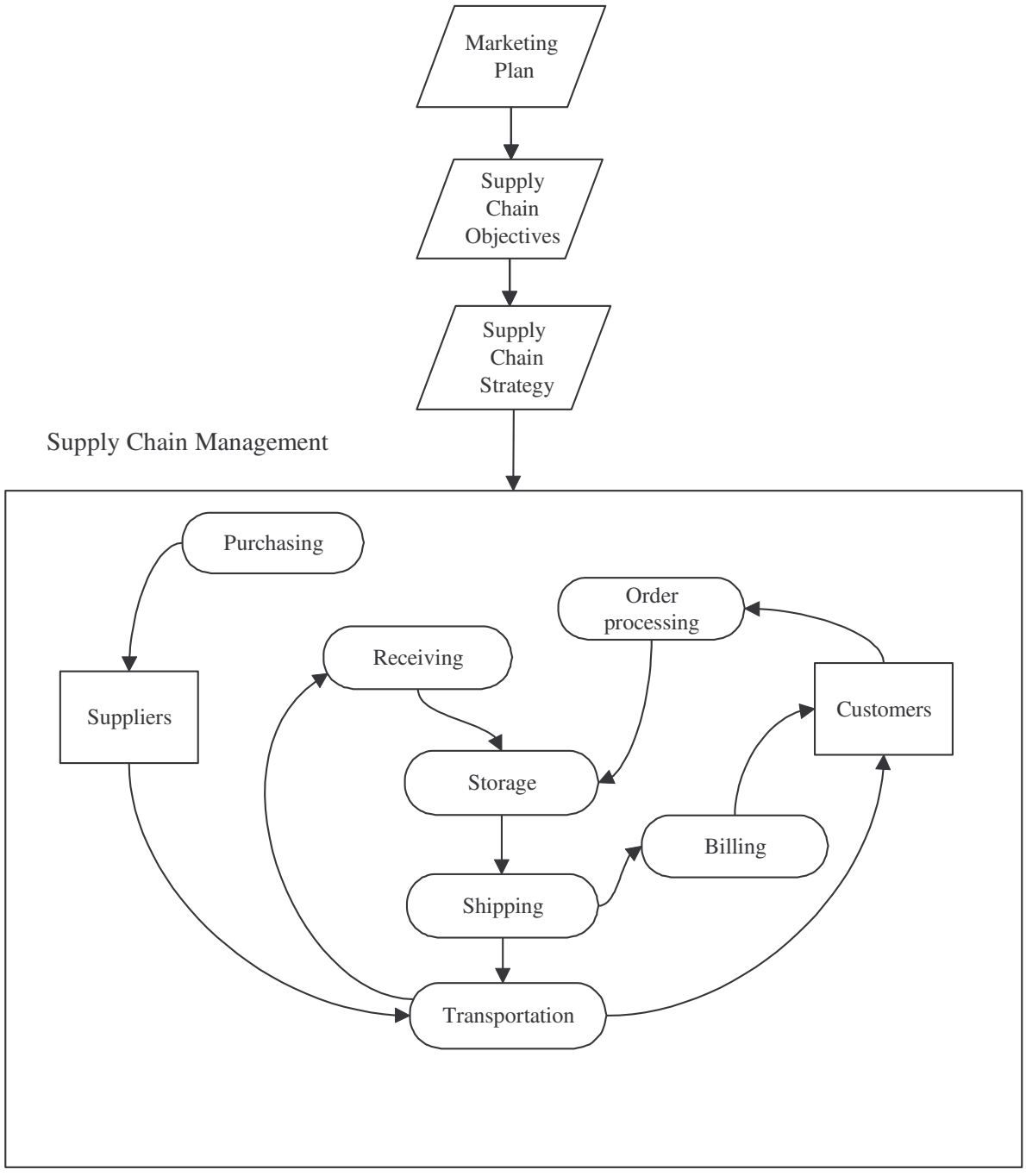


Figure 5

Supply Chain Management as a System

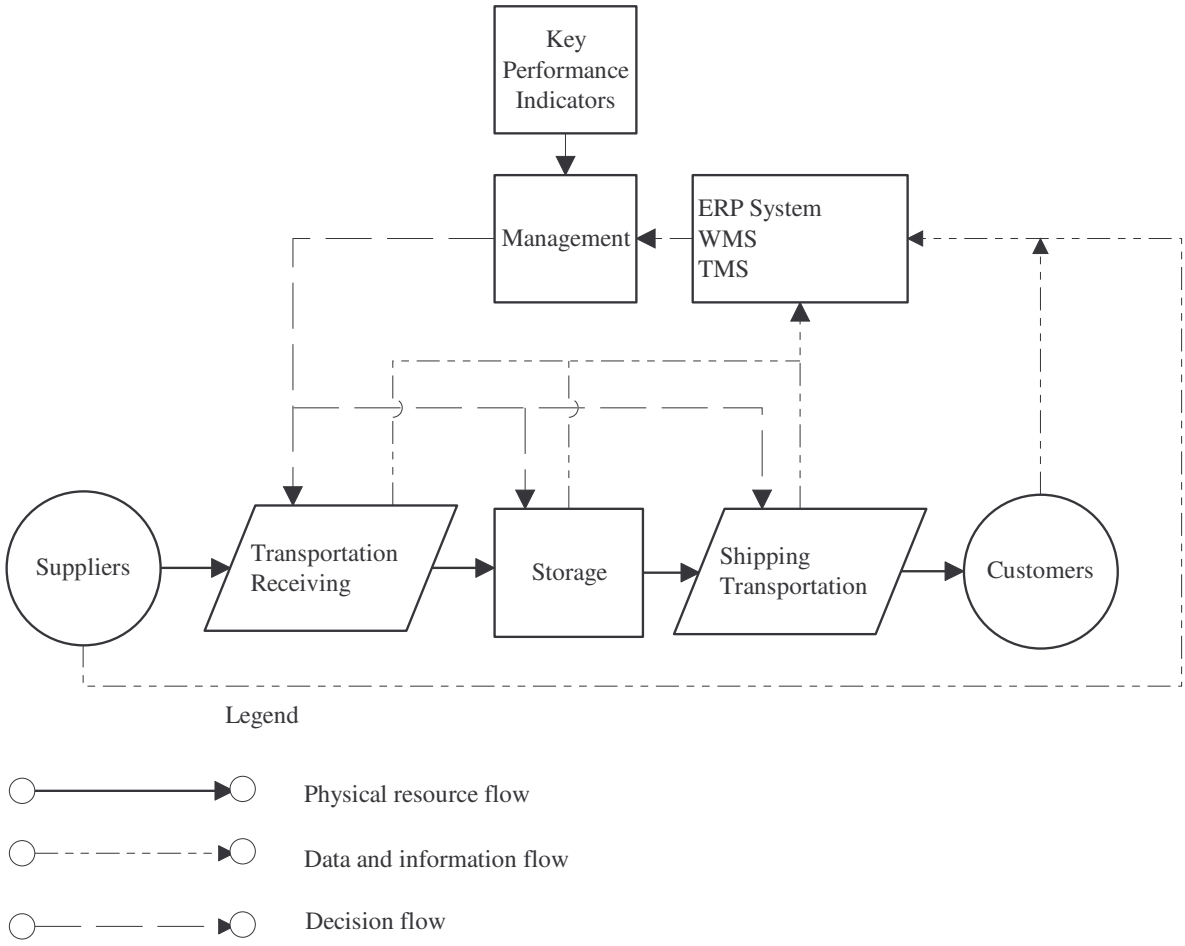


Figure 6
Purchasing Subsystem

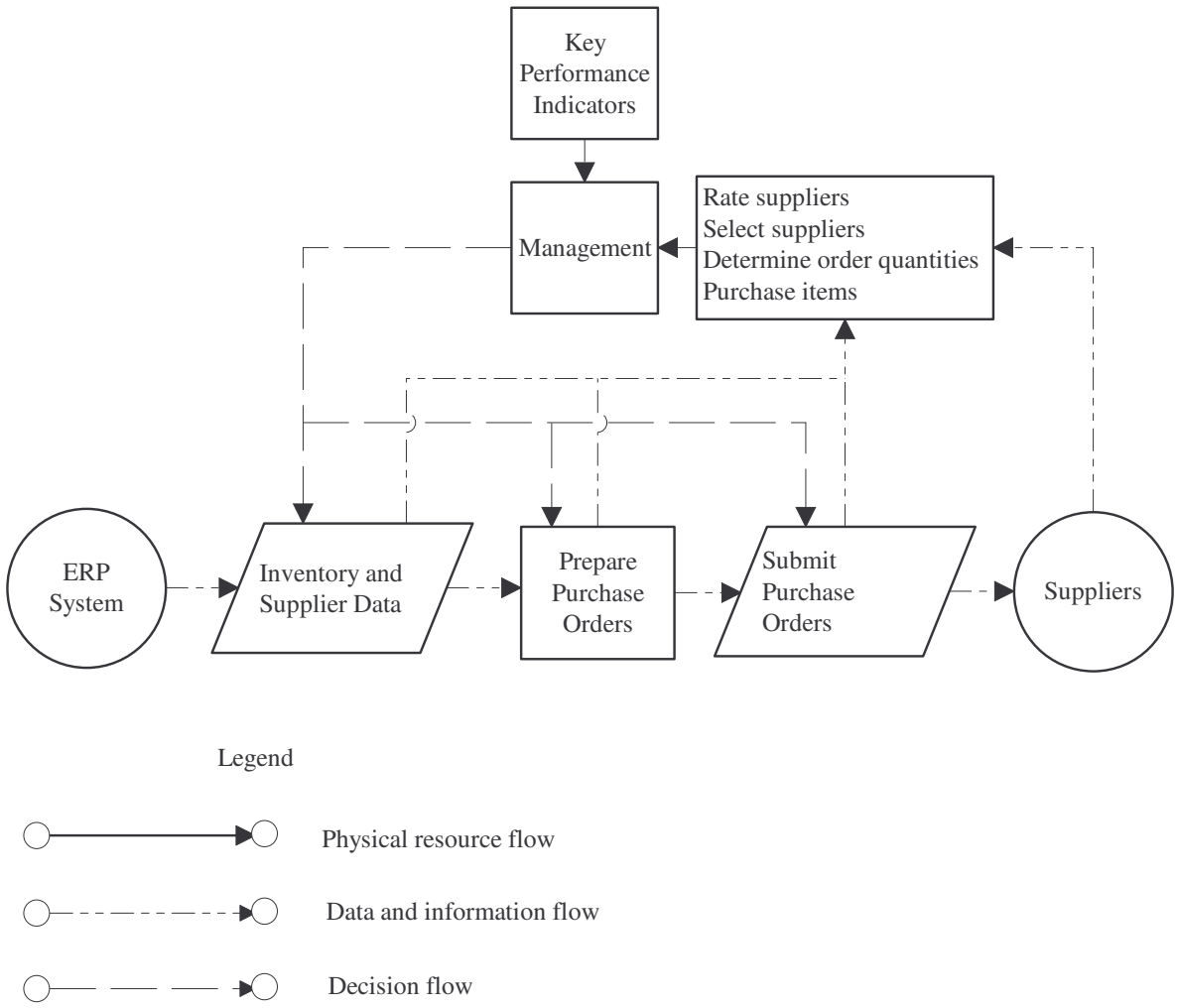


Figure 7
Receiving Subsystem

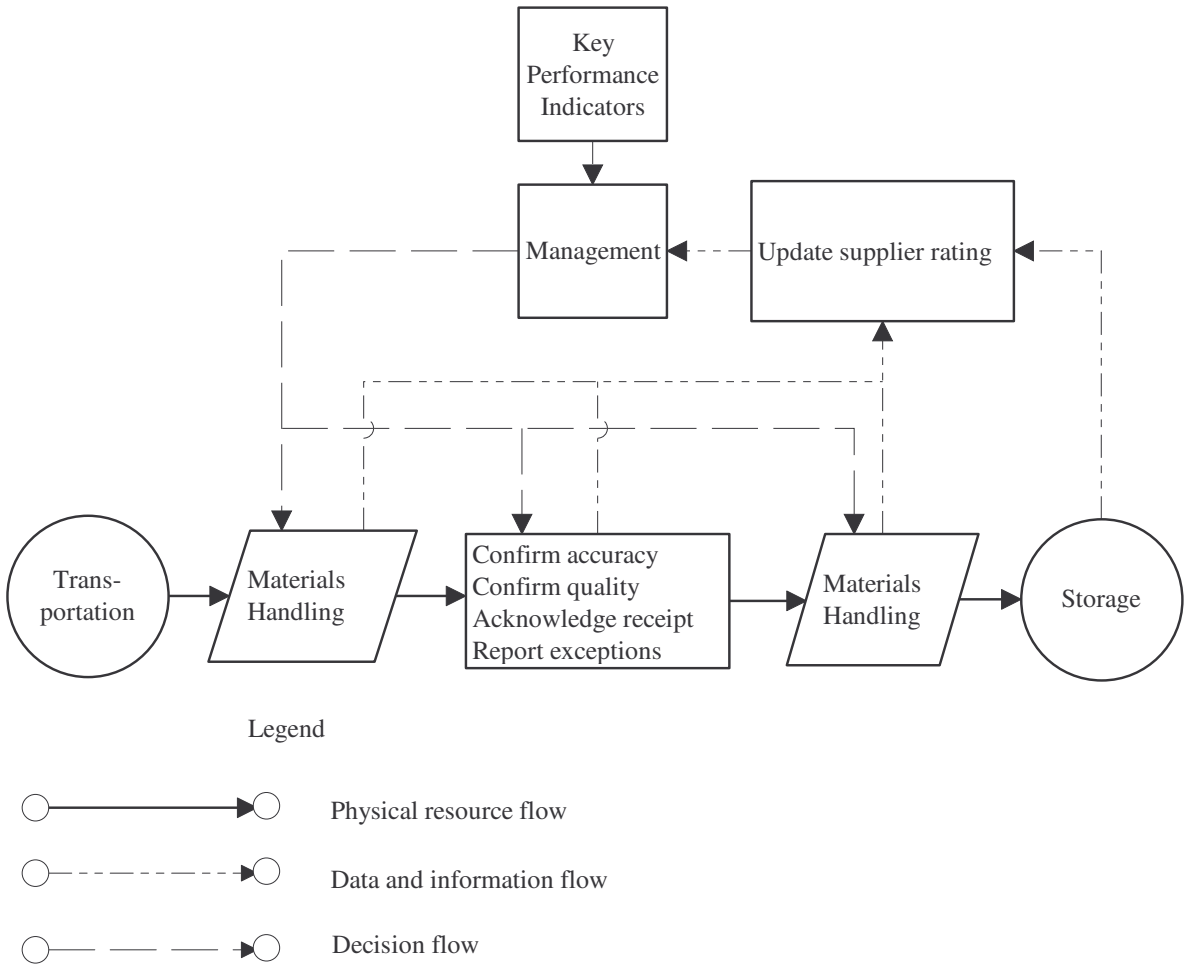


Figure 8

Order Processing Subsystem

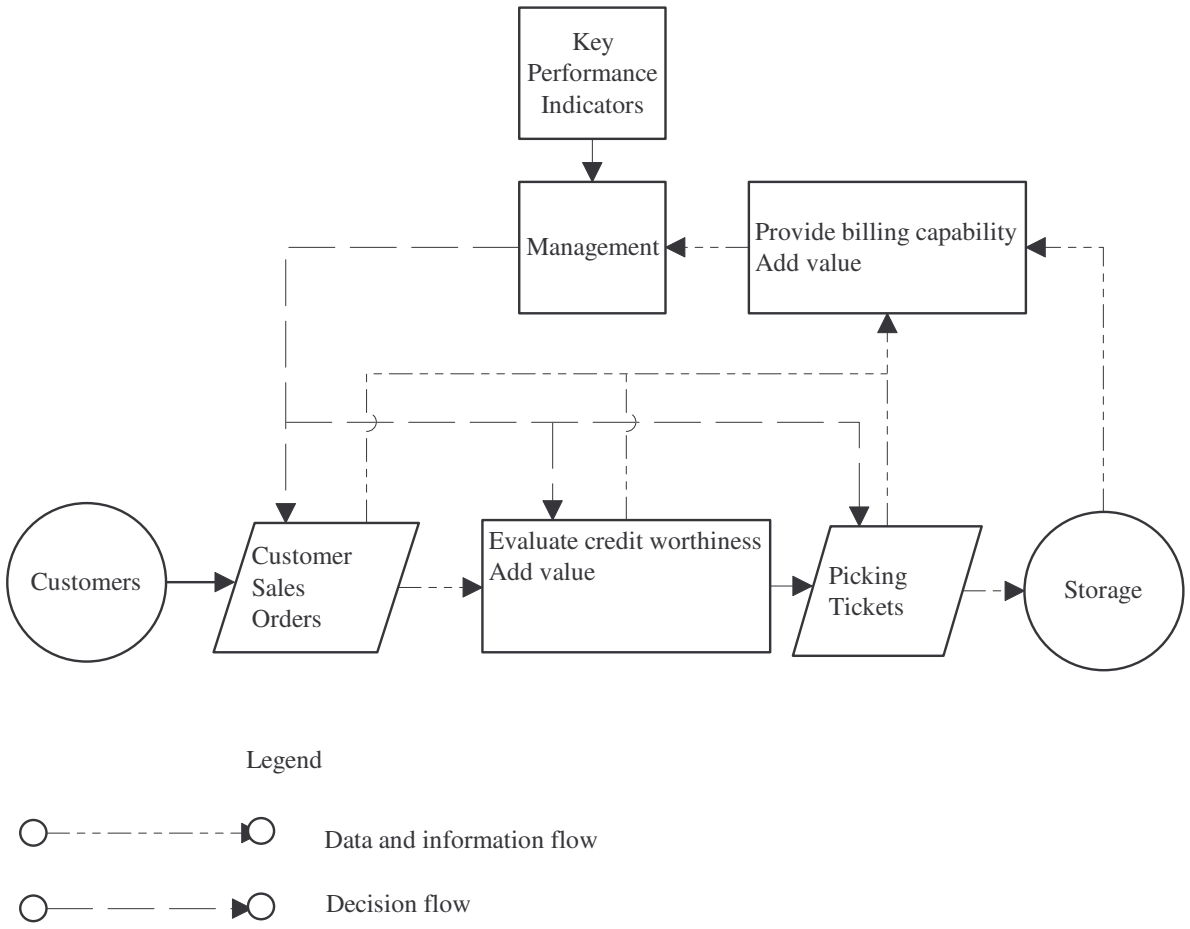


Figure 9
Storage Subsystem

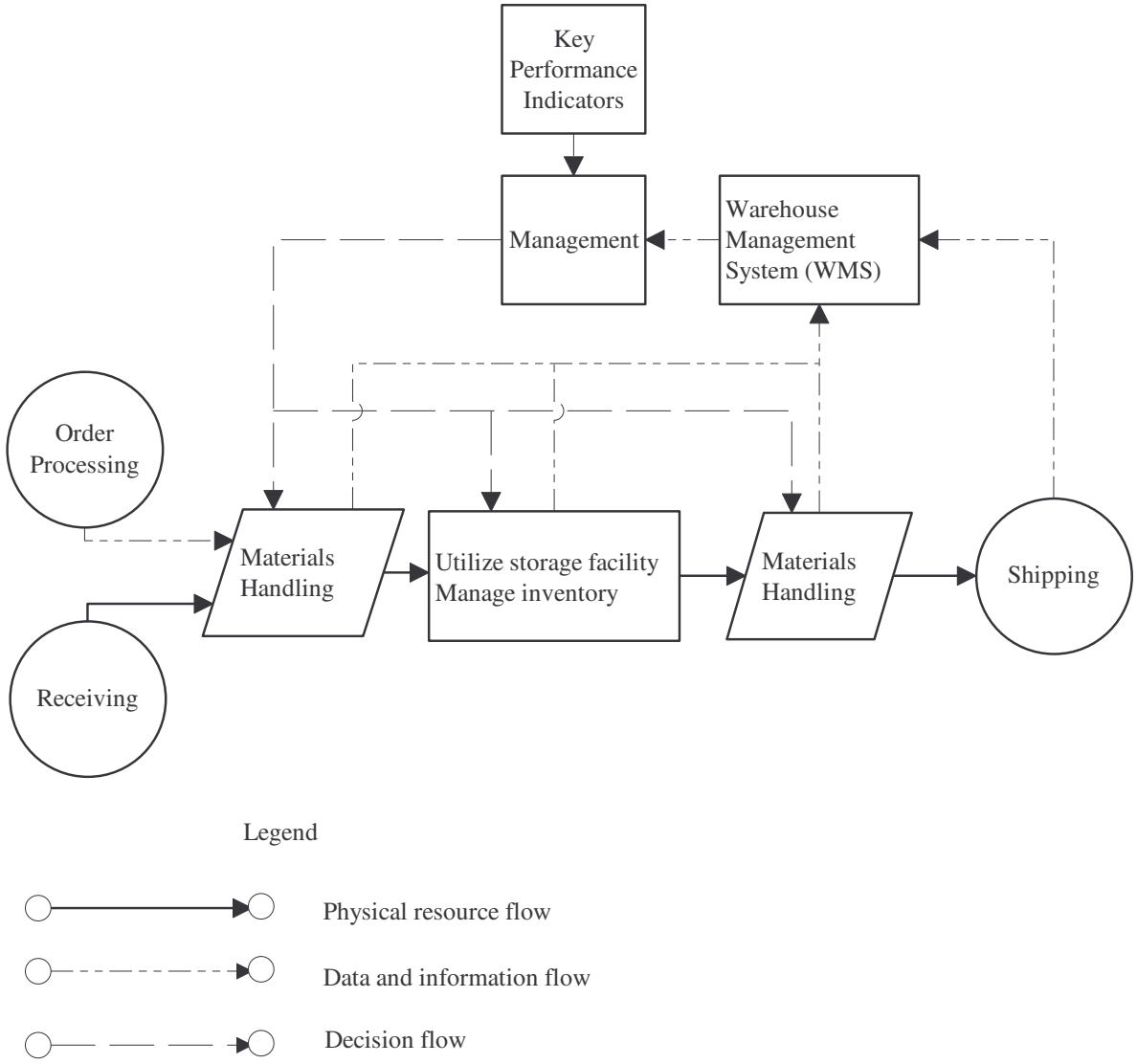


Figure 10
Shipping Subsystem

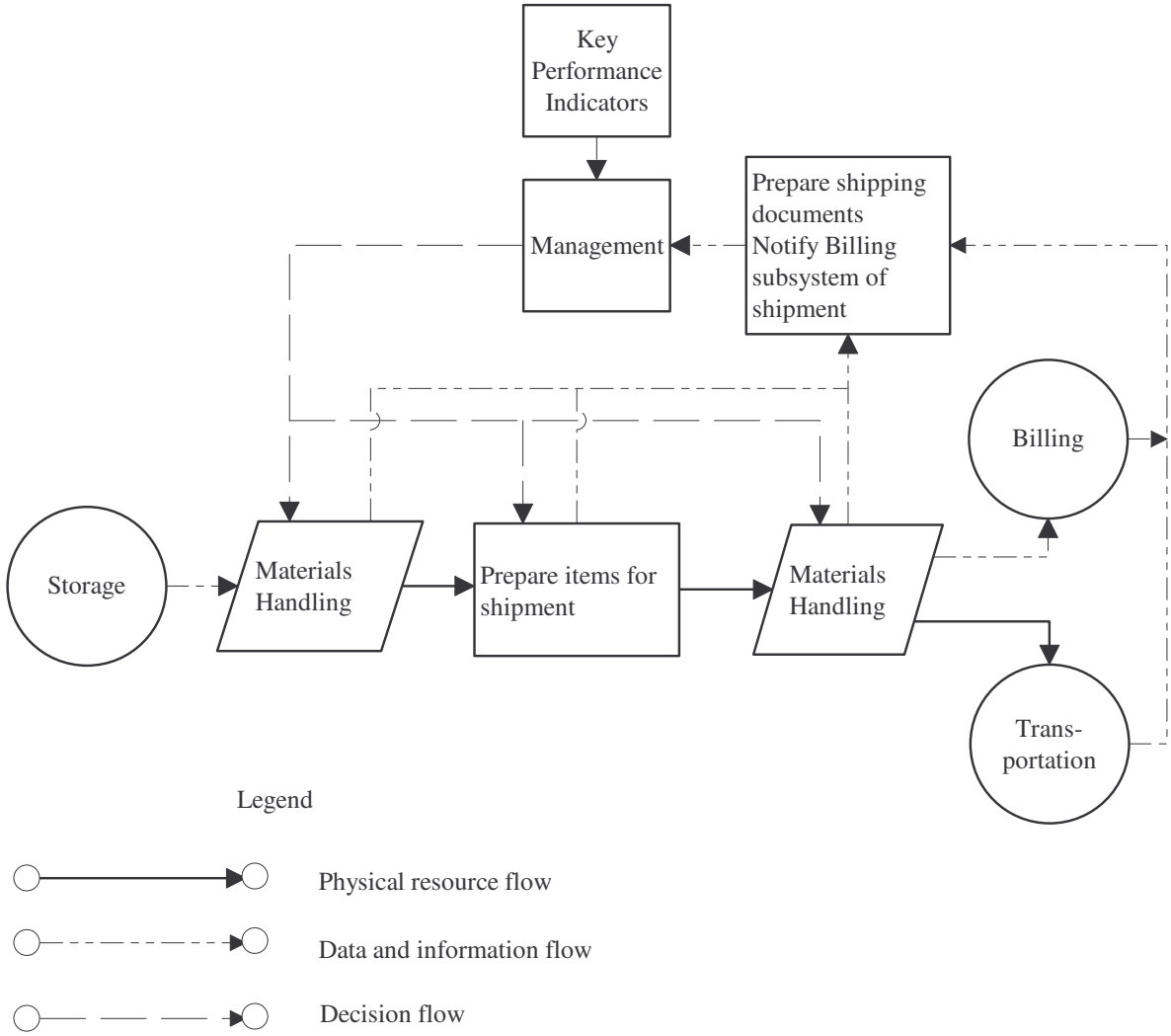


Figure 11
Transportation Subsystem

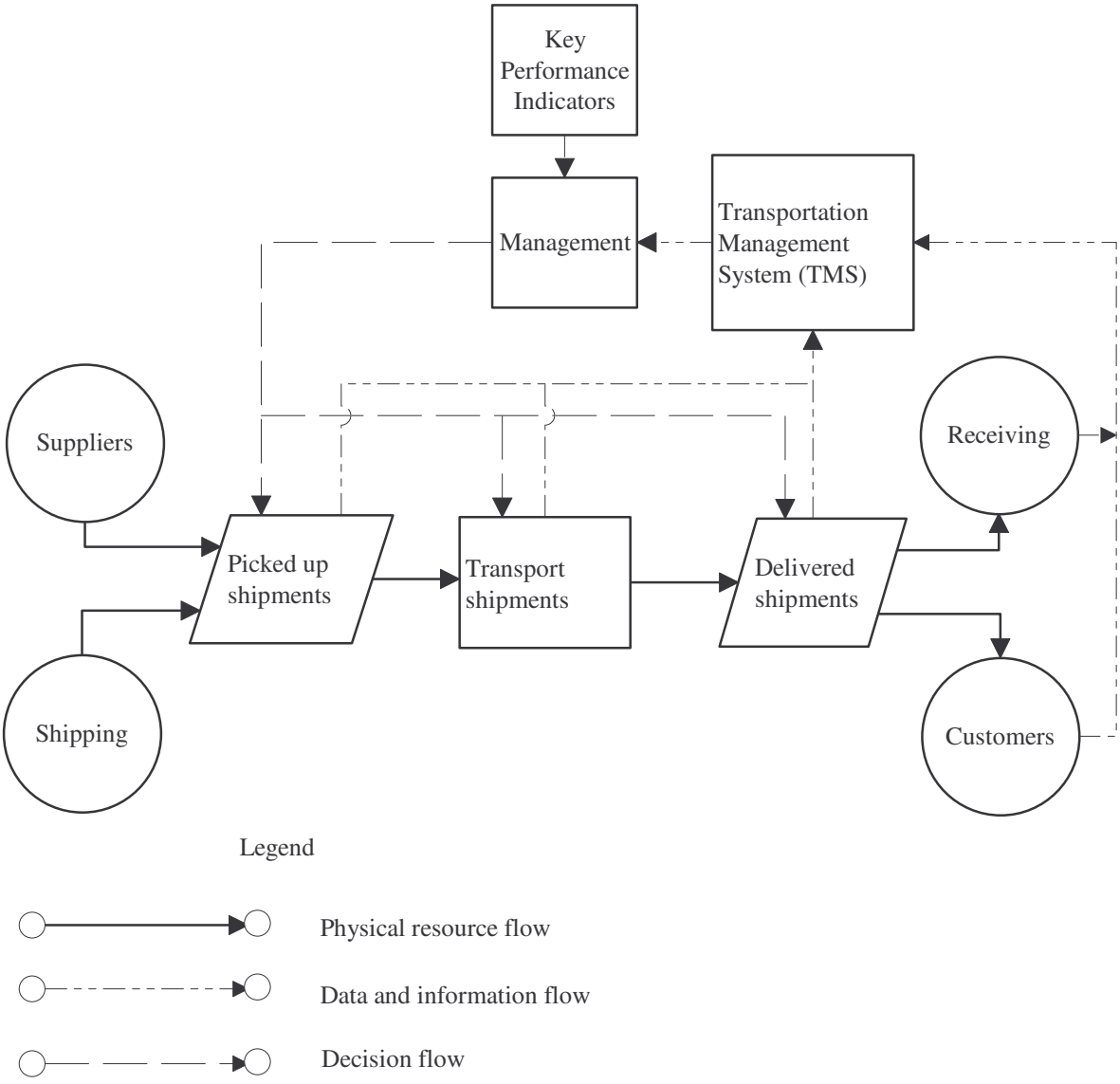
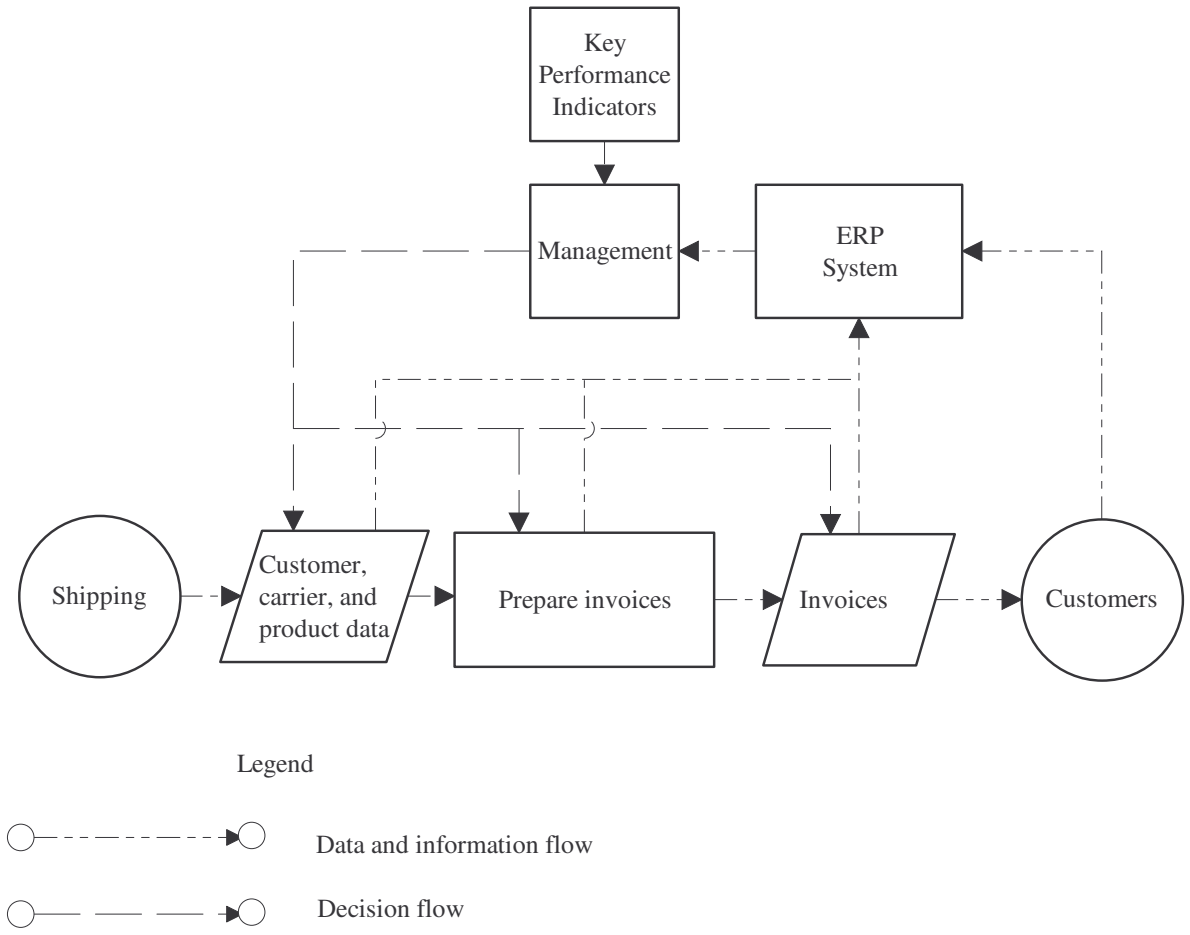


Figure 12
Billing Subsystem



Bibliography

1 Boulding, K. E. (1956). "General Systems Theory—the Skeleton of Science." *Management Science* 2, (April): 197-208.

2 Hopeman, R. J. (1969). *Systems Analysis and Operations Management*. Columbus, Ohio: Charles E. Merrill Publishing Company. 1-10, 125-141.

3 Engel, J. F., D. T. Kollat, and R. D. Blackwell. (1973) *Consumer Behavior*. 2nd ed. New York: Holt, Rinehart and Winston. 34-62.

4 Brien, R. H., and J. E. Stafford. (1968). "Marketing Information Systems: A New Dimension for Marketing Research." *Journal of Marketing* 32 (July): 19-23.

5 The University of Texas at Austin offers a Bachelor of Business Administration degree in supply chain management, and offers a Master of Business Administration degree with a concentration in supply chain and operations management.

6 McLeod, Jr., R. (1979). *Management Information Systems*. Chicago: Science Research Associates. 54-75.

7 Handfield, R. B., and E. L. Nichols, Jr. (1999) *Introduction to Supply Chain Management*. Upper Saddle River, NJ: Prentice-Hall. 12.

8 Bowersox, D. J., D. J. Closs, and M. B. Cooper. (2002) *Supply Chain Logistics Management.* 2nd ed. Boston: McGraw-Hill. 6.

9 "CSCMP Supply Chain Management Definitions." Council of Supply Chain Management Professionals. http://cscmp.org/aboutcscmp/definitions.asp