A conceptual framework for supply chain management: a structural integration

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Abstract

Purpose – The main purpose of this paper is to document the research on development of a conceptual framework for the supply chain. The aims of the research were to develop an integrated framework, and to provide a methodology for planning of many components in the supply chain such as suppliers, materials, resources, warehouses, activities and customers. The proposed framework is based on the unitary structuring technique where bills of materials, bills of warehouses, project networks and operations routings, in both manufacturing and distribution networks, are combined into a single structure.

Design/methodology/approach – The framework is described along with illustrated numerical examples in the manufacturing and distribution environments.

Findings – The numerical testing has shown that each network in the supply chain provides an integrated approach to planning and execution of many components, and is capable of providing visibility, flexibility and maintainability for further improvement in the supply chain environment.

Originality/value – The framework and planning approach developed in this research are new in the area of supply chain management and provide a foundation for planning, control and execution in supply chain in various industries.

Keywords Supply chain management, Distribution, Parts, Structural systems

Paper type Research paper

1. Introduction

The importance of logistics and supply chain management (SCM) has been increasingly recognised in the manufacturing environment. While a supply chain consists of a number of partners or components (such as suppliers, manufacturers, distributors and customers), its effective management requires integration of information and material flow through these partners from source to user. Erenguc *et al.* (1999) proposed an operational framework for addressing production and distribution problems in supply chains. Their framework is related to the three major stages of the chain (supplier, manufacturer and distributor). The interest in supply chain and related logistic issues has also led many companies to analyse their supply chains in terms of players, activities and tools/techniques involved (Simchi-Levi *et al.*, 2000). This is mainly due to the deregulated markets, globalization and a business environment that is conducive to integration, cooperation, information sharing and information technology (IT) support. SCM is becoming more crucial for the survival of a world-class enterprise. With the advances in IT, there has been a shift of research focus on SCM in terms of framework, concept and model development (Samaranayake, 2002a; Caprihan *et al.*, 2001).

Nowadays many organisations become a part of at least one supply chain. They have to perform equally well, in order to achieve better performance. This also requires elimination of interfacing between many techniques across applications and individual departments. Using an integrated system (applications integrated at the structural level and implemented on a system supporting such structures) can eliminate such interfacing and thereby unproductive time and effort required earlier. At the structural level, using an integrated approach, also benefits organisations to go into e-commerce with business-to-business (B2B) procurement and internet sales. This could provide visibility of components involved, effective and efficient schedules, as well as control over the supply chain. The SCM literature confirms the view that integration of various components involved in a supply chain, should be carried out, so that integration provides visibility, flexibility and maintainability of components involved at the structural level. The implementation and maintenance of supply chain could be made simple for small to medium size enterprises (SMEs) (Samaranayake, 2002a).

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A typical supply chain comprises SMEs (Lamming *et al.*, 2000). SMEs could benefit from a supply chain model, when implemented with minimal changes to the existing business processes. Lamming *et al.* (2000) argue that such a model requires a framework integrating all the components using component relationships at an operational level. As such, there is a need for a framework in SCM as a foundation for development of model(s) of industry applications. This paper describes the development of an integrated framework for SCM, and contributes to knowledge of potential improvements and developments in business processes. The framework becomes a foundation for model developments in many industry applications, using individual networks.

The paper is structured as follows. First, the supply chain processes and systems are introduced followed by an overview of the unitary structuring technique. Concepts and basis of the supply chain framework are considered next. These include:

- components and their relationships;
- functionality assigned to components and links;
- manufacturing and distribution networks; and
- level of integration.

Next, planning and execution of components in both manufacturing and distribution environments are illustrated using numerical examples. The paper then discusses the integration of individual networks and the level of integration, planning and execution of the supply chain components. Finally, this paper concludes with key findings and suggests directions for future research.

2. Supply chain processes and systems

The supply chain is a network of autonomous or semi-autonomous business entities involved, through upstream and downstream links, in different business processes and activities that produce physical goods or services to customers. It consists of a series of activities that an organisation uses to deliver value, either in the form of a product, service, or a combination of both, to its customers (Lin and Shaw, 1998). Furthermore, the supply chain could be considered as an integration of materials and information flow between customer, manufacturer and supplier.

Recent economic trends have de-emphasised the benefits of vertical integration (e.g. economies of scale, access to capital, and large physical infrastructure investment) and instead have focused on the benefits of being specialised (e.g. speed, agility, and rapid growth). These trends have forced even large organisations to rely on hundreds or even thousands of external firms or suppliers to deliver value to the marketplace. As this shift has taken place, the importance of managing and coordinating the activities between these disparate entities has become paramount. Such effort is often referred to as "supply chain management" (Archibald *et al.*, 1999). The supply chain process involves a number of sub-processes which include: sales and operation planning; demand management; customer order management; production planning; control and execution; materials, quality and inventory management; material procurement; distribution requirements planning; transportation and shipment management; and integrated supply and demand planning.

A careful analysis of the processes in a supply chain would reveal that there are a large number of components involved, including suppliers and customers. Managing these components would be more challenging than ever before. Therefore, SCM represents an evolutionary step beyond logistics. Chandra and Kumar (2000) argue that it is necessary to improve the planning and management of complex interrelated systems such as materials planning, inventory management, capacity planning and production management within the chain.

Successful SCM requires an integration of all the components involved into a combination of business processes within and across organisations. This requires integration of the organisational elements responsible for each activity and the external suppliers and customers who are part of the planning and execution process. The goals are to achieve speed-to-market, agility, and flexibility to respond more quickly to actual customer demand, while keeping cost at a minimum. In order to make the goals, it is necessary to integrate the processes at the operational level. All components involved in any supply chain need to be managed properly for effective and efficient operations. Integration of those components within and outside organisations would result in number of complexities. Dainty *et al.* (2001) identified significant barriers in the supplier integration within the construction sector. These barriers could result in a number of complexities such as the existence of supply networks, links between components, precedence and interdependencies between components.

However, recent studies reported in the developments on business processes and integration of components in supply chain environment have been focused mainly on integration of components at the database level and/or interfaced processes within individual departments rather than at the structural level. Integration at the database level is a set of relational database tables with links between them specified by primary and foreign keys. These tables contain simplified data elements due to the limitation of the relational database management systems. For example, a multi-level bill of materials (BOM) of a finished product is represented by a set of single level BOMs in a relational database instead of a single multi-level BOM. If the data are integrated at the structural level, multi-level BOM needs to be maintained as a single object in the system for efficient planning and scheduling of components involved. Lack of developments in SCM is attributable to the restriction on the level of integration operating on relational databases that do not provide the actual benefits of integration. Alternatively, data integration at the structural level can provide the visibility of both data elements (e.g. materials) and structures (e.g. BOM, operations routing), incorporation of more accurate data elements at the structural level (e.g. activity duration lead-time), flexibility for change and/or modification and maintainability. For example, lead-time, represented as a data field in the material master of traditional systems, can be replaced by an activity component in the network. As a result, lead-time takes more accurate timing of activity duration and allows for dependencies such as lot-size dependent and independent components. Further, structural integration provides the flexibility of incorporating resource(s) attached to the activity for accurate planning of the activity, eliminating the need for an iterative process of capacity levelling of overloaded capacities. This is possible only as a result of structural integration of many components including activities and resources. An activity is a component in the network and

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could incorporate relationships (such as activity precedence, component-component and parent-component) to simplify the planning process.

In this paper, the unitary structuring technique has been adopted with appropriate components and their relationships for integration of many components at the structural level. In order to utilise fully the benefits of the technique, the main technical constraint of relational databases in existing enterprise resource planning (ERP) and manufacturing resource planning (MRPII) systems needs to be removed. Further, many ERP systems are application specific where planning and scheduling of supply chain components could not be carried out using a single planning tool. Instead, a number of individual tools such as MRP, critical path method (CPM) and distribution resource planning (DRP) could be applied in different application areas.

3. Overview of the unitary structuring technique

In Woxvold's (1992) research, the activities, materials, resources and suppliers involved in manufacturing projects were combined into a "unitary" structuring technique. Thus, the basis for development of a framework of SCM was the unitary structure, which supported the integration of components at structural level, visibility, functionality of components/relationships and flexibility. Samaranayake *et al.* (2002) argue that the unitary structure could even be used to integrate manufacturing with maintenance in particular with large maintenance projects such as aircraft maintenance. Recently, the technique has been extended for planning, control and execution of distribution networks using integration of components such as materials, activities, warehouses and customers (Samaranayake, 2001). Further, redesigning of product and process delivery processes in business process reengineering (BPR) can be carried out using an integrated approach based on the unitary structuring technique (Samaranayake, 2002b).

The unitary structure allows CPM network links and three forms of precedence: parent-component relationships, operations routing and component-component relationships. This enables four types of components to be represented: materials, activities, resources and suppliers. Resources are associated with a particular activity and represent work centre, tooling and/or labour required to execute the activity (operation). Suppliers are used to model the purchasing of externally procured materials required by the process. An example of the unitary structure is shown in Figure 1. In the terminology of the unitary structuring approach, the outline of the component icons appear as "M", "A", "R" and "S" which represent material, activity, resource and supplier respectively.

Planning and execution of components involved in a unitary structure requires additional information other than the information available in individual structures. The first of this kind is the relator. The relator field determines whether the component quantity affects other components of the assembly. There are four relator field values as given in Table I.

The traditional BOM uses only the "m" relator for its component materials to indicate the component quantity that is required for each unit of the assembly. The CPM uses only the "a" relator for its activities as all duration quantities are absolute quantities (which are unaffected by an assembly material). The "m" relator does not affect the calculated assembly quantity, nor does it affect the exploded quantity of preceding adjacent component materials on the horizontal axis. The "a" relator provides an absolute (batch) value that does not affect the calculated assembly quantity nor does it affect the exploded quantity of preceding adjacent component materials on the same level. The "M" relator does affect the calculated assembly quantity and the exploded quantity of preceding adjacent component materials on the horizontal axis. The "A" relator does affect the calculated assembly quantity and the exploded quantity of preceding adjacent component materials on the horizontal axis. These four relators are shown later in the numerical testing of individual networks in manufacturing and distribution environments along with the numerical results.

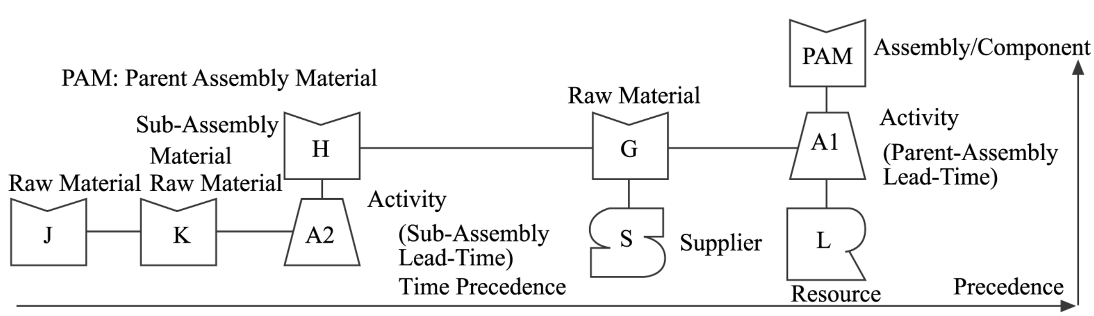
4. Concepts and basis of the supply chain framework

In general, a supply chain consists of a large number of partners including customers, distributors, manufacturers and suppliers. The supply chain involves a number of other components such as materials, resources and activities within each partner. Thus, managing a supply chain requires an approach where components are integrated at the structural level and implemented in systems capable of supporting such integration.

Table I Relator field values and effects

	Affects only lower level components	Affects same level and lower level components
Multiple	"m"	"M"
Absolute	"a"	"A"

Figure 1 An example of the unitary structure – manufacturing application



On the initial development stage of supply chain framework, the basis is considered: the components involved, relationships between components, level of integrations and integration of individual networks across business processes. Relationships are represented by links between components with appropriate precedence. Further, a number of conditions and/or requirements on which the supply chain is based are identified. These include components and relationships, functionality assigned to components and links, planning/execution of components in individual networks, integration of individual networks and the level of integration. Thus, the framework could become a foundation for developments of supply chain model(s) for industry applications and would be extended for the e-business environment such as e-procurement and e-commerce.

Components and relationships between components

Materials, activities (operations), resources and suppliers are four main components involved in a business process within the manufacturing environment. If the business process and related strategies are associated with supply of raw materials, the supplier becomes an additional component. If the business process involves a customer at any stage, the customer can be considered as one of the components for the purpose of planning and execution. For example, make-to-order strategy is initiated with a customer order. Therefore, the customer is a component in the associated structure under this strategy. Other components such as warehouses and delivery activities and resources involved in distribution networks can also become a part of the business process. Each component can be represented by an icon or a symbol in a structure with all the relationships between components using appropriate precedence. The number of components involved in a structure depends on the type of the application. For example, a CPM project could involve materials, BOM, suppliers, activities and resources as components when represented in a unitary structure.

Planning and execution of manufacturing and distribution networks require identification of the inputs, outputs, processes and components involved. These networks involve a number of relationships between components that are necessary for the planning and execution of components in the process. Relationships between components lead to component dependencies, in the form of component-component relationships and activity precedence. The most common is the parent-component relationship. The second type is component-component relationship. These relationships can be represented in the unitary structure using appropriate links between components. When represented in the structure, they could also provide a number of functionalities into the structure.

Functionality assigned to components and links

It is possible that a business process represented by a unitary structure is already simplified by eliminating non-value-added elements (e.g. wait and queue times in the lead-time) and incorporating all the components involved including the resource component attached to an activity. It would also eliminate the need for number of sub-processes required by traditional process management tools (Samaranayake, 2002b). Flexibility to the planning and execution of the process could be added assigning functionalities to both components and links. Those functionalities include: modify; change; add component/link; delete component/link; and move component. Implementation of all or part of the above functionalities could be best carried out using a software module or a simple computer program. The basis of the framework is treated as the development of individual networks in the manufacturing and distribution environments.

5. Manufacturing and distribution networks in SCM

SCM involves planning and execution of manufacturing and distribution across many partners of a supply chain. For the manufacturing network, it employs MRPII tools, while for distribution planning and execution, it is on distribution resource planning (DRPII) tools. A combination of MRPII and DRPII tools along with other integration aspects/features becomes the basis of a SCM framework. Such a combination, leading to a framework, is based on unitary structures of individual networks. The unitary structure in manufacturing involves both BOMs and operations routing (a structured set of activities). Traditionally, these activities take place in lead-times and are not a part of the BOM. In order to illustrate the development of unitary structure for the planning and execution of the manufacturing assembly, the following approach is adopted.

In the first step, a simple BOM with traditional lead-times is considered. Manufacturing lead-times involved in the complete assembly are defined by lead-times of individual components and sub-assemblies. In the next step, the lead-times are converted into operations or activities with appropriate relationships. In the case of the simple BOM shown in Figure 2, lead-times are average operations times, which are independent of lot size. Relationships between components include activity precedence, commonly known as network links in project networks. The resulting operations routing is shown in Figure 3. Finally, it is necessary to integrate the both BOM and operations routing. A resulting unitary structure representing the integration is shown in Figure 4. This is a representation of a manufacturing network with the materials and activities. In order to complete the structure, resource components (labour, machines, etc.) involved can be attached to respective activities while supplier(s) can be attached to respective raw materials.

Once the unitary structure is developed with components and links, it is necessary to whether an activity contributes to the schedule of its parent product only or whether it also contributes to the schedule of preceding components in the same branch. This can be handled by assigning the

Figure 2 An example of BOM

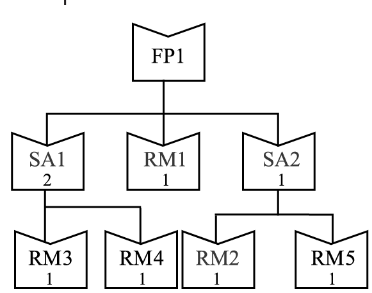


Figure 3 An example of operations routing

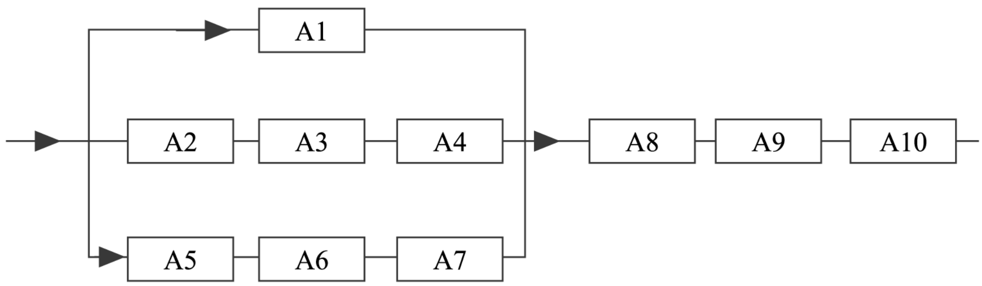
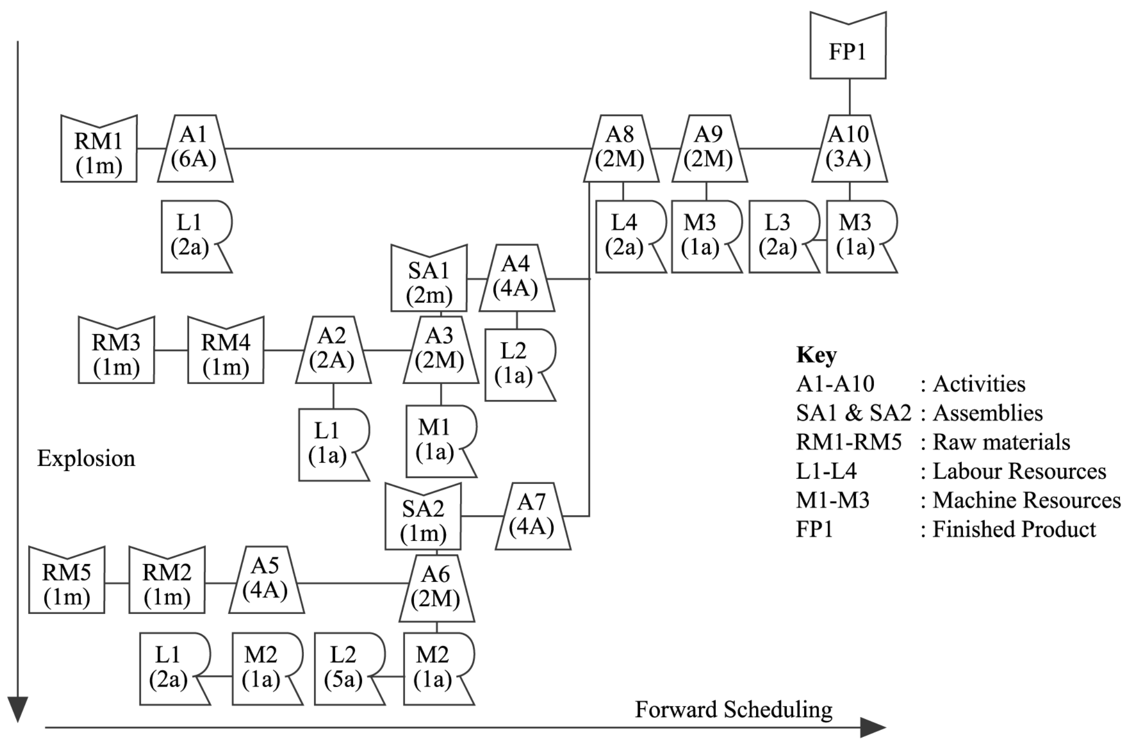


Figure 4 BOM/operations routing – a unitary structure



appropriate relator. The time phasing of a branch of the structure enables an operation routing to be formed. Links attached to components represent the relationships between components as discussed. Using an existing relational database management system, planning of components in this unitary structure could be possible only by separate planning runs for materials and operations (see Figure 4). Thus, materials can be planned using traditional MRP and activities can be scheduled using forward or backward scheduling techniques of traditional shop-floor control systems.

Planning of the unitary structure components using the traditional MRP technique would result in many records (e.g. planned orders, purchase requisitions and stock reservations) for each material component of the BOM. Planned orders and purchase requisitions are characterised with quantity and basic dates (start and finish dates). This information is directly transferred into the operations routing and is used in the scheduling of all activities with start and finish times, taking precedence between components and the availability of the materials into consideration. Alternatively, if the unitary structure were implemented in an objected-oriented database system, it would be possible to plan both materials and operations simultaneously. It would also eliminate the need for any synchronisation of material and activity schedules. Numerical testing could be carried out using manual explosion and operations scheduling of components (see Figure 4).

Scheduling of materials and activities in manufacturing environment

The requirements for scheduling of both activities and materials are satisfied with the operations routing using a number of sequences, BOMs, component allocations and appropriate relators. Planning of both materials and activities starts with some independent demand for the finished product. Thus, for a given external demand (units over a number of periods, which could be derived from sales forecast, actual orders or planned independent requirements), MRP explosion process would provide the material plans for the whole product structure. In order to complete the scheduling of materials and activities, MRP time-phasing process is replaced by the scheduling of operations routing. Thus, the complete MRP run for the unitary structure could result in planned orders and/or purchased requisitions depending on the type of components and component relators. The scheduling of operations routing for the same structure would result in operation start and finish times for all the operations, based on actual operation times rather than traditional lead-times.

The unitary structure can be implemented as a combination of BOM and operations routing for an assembly of a finished product, FP1. Traditional MRP process for the assembly of FP1 and its components could result in number of planned orders and/or purchase requisitions with start and finish dates for material components of the BOM, based on basic lead-times and parent-component precedence. Next, scheduling of operations routing for the finished product could result in start and finish times of all operations in the routing.

Table II shows the results of scheduling of operations routing carried out for the assembly of five units of the finished product, FP1. For instance, the scheduling was based on the backward scheduling of all operations, with a due date and time of 17 June 2002 at 16.00 hours. Operations scheduling was based on a working calendar of eight hours, Monday to Friday between 08:00 hours and 16:00 hours. For testing purposes, it is assumed that there is no break during the eight-hour shift.

Supposing that all activities have been backward scheduled in terms of late start and finish times, the materials and activities involved in one unitary structure can not be planned simultaneously using a single planning run in an existing system. Therefore, separate MRP and operations scheduling runs are required. Further, even when MRP is combined with operations routing, components attached to activities and materials (resources and suppliers) cannot be planned. In order to improve simultaneous planning the components and to make use of the functionalities of unitary structuring technique, an alternative solution approach is suggested.

The planning of components in a unitary structure is carried out with a pre-defined sequence that depends on the type of planning. In the case of backward scheduling, the planning will start from the finished product, while forward scheduling of components starts from the last component in the lowest level of the BOM. Based on this approach, both BOM explosion and operations scheduling are carried out simultaneously. The components are then planned in terms of start and finish dates and the results as shown in Table III.

Many types of components involved in a unitary structure in manufacturing environment can be planned using two approaches as discussed above. The next stage of the development is to consider the integration of many components in distribution networks using unitary structuring technique and to numerically test the planning of the components. Figure 5 shows a distribution network of field warehouses, intermediate warehouses and a central warehouse based on the concept of bills of warehouses (BOW) (Samaranayake, 2001). A set of distribution activities will form an operations routing (see Figure 6). For the simultaneous planning of components, two structures need to be integrated at the network level. Thus, Figure 7 illustrated an integrated structure of warehouses (CW, IW1-IW2 and FW1-FW3) and activity components with appropriate precedence relationships between components.

In addition to warehouse components, a number of customers (C1, C2, C3 and C4) are incorporated along with appropriate delivery activities for the completion of the distribution network. Each warehouse could represent at least one material. The choice of material for any field warehouse depends on the critical material required or availability at that particular transition point. In this situation, it is assumed that each warehouse corresponds to one material and the same material for the whole network. Figure 7 also activities involved in material distribution and network links associated with delivery activities (lead-times). Letters "A", followed by a numeric number, identify each activity. For example, common activity between central warehouse (CW) and intermediate warehouse (IW1) is defined as A1. Further, each activity is identified as either independent or dependent on quantity delivered. If the activity duration depends on the quantity delivered, it could be labelled with the relator "M" and could be treated as a delivery operation. Similarly, if the activity duration does not depend on the quantity delivered, it could be labelled with the relator "A" and could be treated as a setup time. Irrespective of the type, all the activities correspond to delivery lead-times (a combination of setup time and delivery operations times). Thus, the structure

Table II Scheduling of operations routing for the assembly of five units of FP1

			Latest start		Latest finish	
Type	**No.**	**Duration (hrs)**	**Date**	**Time**	**Date**	**Time**
Sequence 0: standard main sequence with six activities (A2, A3, A4, A8, A9, and A10)						
Oper./act.	A2	2	11 June 2002	15.00	12 June 2002	09.00
Oper./act.	A3	$2 * 10 = 20$	12 June 2002	09.00	14 June 2002	13.00
Oper./act.	A4	4	14 June 2002	13.00	15 June 2002	09.00
Oper./act.	A8	$2 * 5 = 10$	15 June 2002	09.00	16 June 2002	11.00
Oper./act.	A9	$2 * 5 = 10$	16 June 2002	11.00	17 June 2002	13.00
Oper./act.	A10	3	17 June 2002	13.00	17 June 2002	16.00
Sequence 1: parallel. includes activity A1						
Oper./act.	A1	6	14 June 2002	11.00	15 June 2002	09.00
Sequence 2: parallel. includes activities A5-A7						
Oper./act.	A5	4	12 June 2002	15.00	13 June 2002	11.00
Oper./act.	A6	$2*5 = 10$	13 June 2002	11.00	14 June 2002	13.00
Oper./act.	A7	4	14 June 2002	13.00	15 June 2002	09.00

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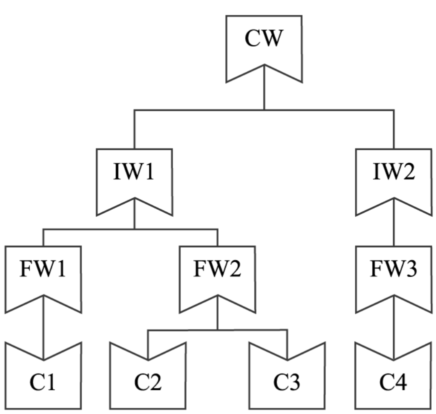
Table III Exploded quantity and time schedule for each component (backward schedule)

Item name	U/M	Component Relator	Qty	Exploded Qty	Duration (hrs)	Ass. qty	Start/due Date	Time
FP1	PC					5	14 June 2002	16.00
A10	HRS	A	3		3	5	14 June 2002	16.00
M3	HRS	a	1	1	3		14 June 2002	16.00
L3	HRS	a	2	2	3		14 June 2002	16.00
A9	HRS	M	2		10	5	14 June 2002	13.00
M3	HRS	a	1	1	10		14 June 2002	13.00
A8	HRS	M	2		10	5	13 June 2002	11.00
L4	HRS	a	2	2	10		13 June 2002	11.00
A7	HRS	A	4		4	5	12 June 2002	09.00
SA2	PC	m	1	5		5	12 June 2002	09.00
A6	HRS	M	2		10	5	10 June 2002	15.00
M2	HRS	a	1	1	10		10 June 2002	15.00
L2	HRS	a	5	5	10		10 June 2002	15.00
A5	HRS	A	4		4	10	10 June 2002	11.00
M2	HRS	a	1	1	4		10 June 2002	11.00
L1	HRS	a	2	2	4		10 June 2002	11.00
RM2	PC	m	1	5		5	10 June 2002	11.00
RM5	PC	m	1	5		5	10 June 2002	11.00
A4	HRS	A	4		4	5	12 June 2002	09.00
L2	HRS	a	1	1	4		12 June 2002	09.00
SA1	PC	m	2	10		5	11 June 2002	13.00
A3	HRS	M	2		20	10	11 June 2002	13.00
M1	HRS	a	1	1	20		11 June 2002	13.00
A2	HRS	A	2		2	10	07 June 2002	09.00
L1	HRS	a	1	1	2		07 June 2002	13.00
RM4	PC	m	1	10		10	06 June 2002	15.00
RM3	PC	m	1	10		10	06 June 2002	15.00
A1	HRS	A	6		6	5	12 June 2002	09.00
L1	HRS	a	2	2	6	5	12 June 2002	09.00
RM1	PC	m	1	5		5	11 June 2002	11.00

Figure 5 An example of BOW



shown in Figure 7 is a combination of BOW and operations routing involved in distribution environment. Although resource components are not shown in Figure 7, each activity could be attached to one or more resource component(s) such as forklifts, drivers, trucks, etc. Quantity and relator values corresponding to each component are shown in the latter section on scheduling of materials and activities in distribution networks.

For coordination of distribution activities, appropriate network links need to be introduced between components. For example, if all customers need to be satisfied at the same time in each planning cycle, the completion times of delivery operations at the customer location are required to be the same time. Incorporating links between operations A7, A9, A13 and A19 could satisfy the above condition. This could result in additional sequences in the operations routing. Thus, operations involved in the entire distribution network including their precedence (e.g. parent-component and network links) have been identified and included in an operations routing as a number of sequences (see Figure 6). These two networks become the backbone of the basis of a framework of SCM.

Planning of materials distribution can be carried out using traditional DRP implosion process. Similarly, activities in the distribution network can be scheduled using forward or backward scheduling techniques of shop-floor control systems. This approach of planning does not plan all the components simultaneously. As a result, material and activity plans could not guarantee compatibility in terms of timing and quantity. Fortunately, this problem could have eliminated partially at the time of planning using operations routing with the material allocation functionality available in many existing systems.

Figure 6 Operation routing for distribution activities

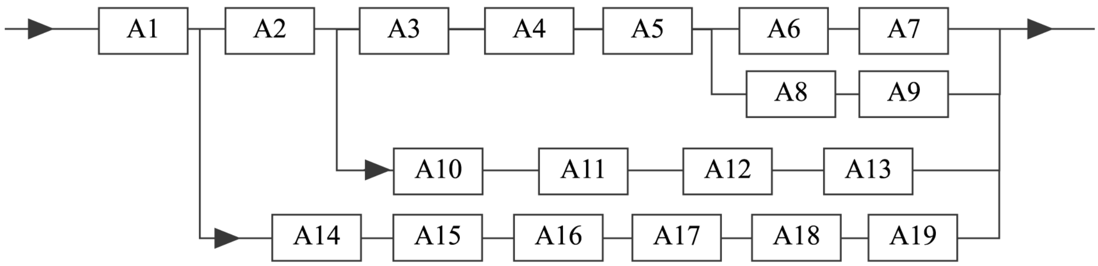
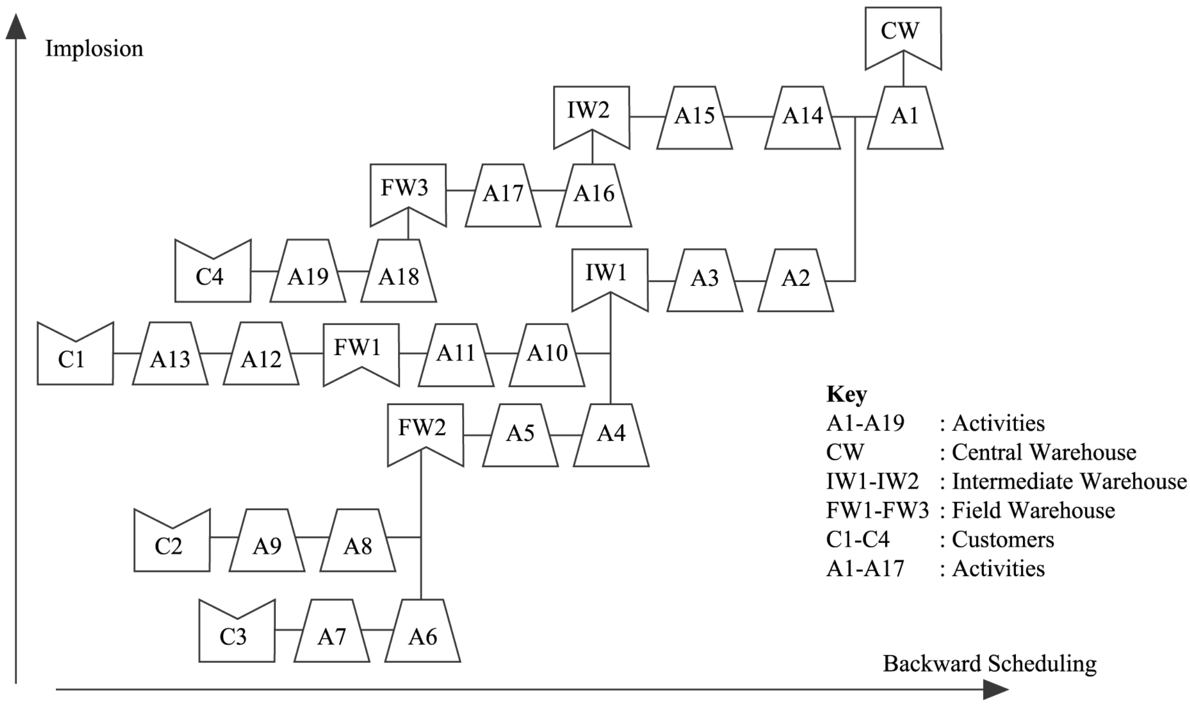


Figure 7 BOW/operations routing – a unitary structure



Scheduling of materials and activities in distribution environment

Planning and scheduling of the components in the distribution network are carried out using the traditional approach of two separate planning runs (materials planning and operations scheduling) and the approach based on the unitary structure for simultaneous planning of components, adopted earlier for manufacturing network. Based on the traditional approach, components can be scheduled using separate planning runs for materials and delivery operations. In this case, materials can be planned using the traditional DRP implosion process while operations can be scheduled using either traditional DRP time-phasing functionality or backward/forward scheduling of operations routing. Alternatively, the components on the unitary structure can be planned simultaneously using combined implosion and scheduling processes. Besides, other components attached to operations and materials would be planned if the unitary structure is implemented in an existing ERP system, capable of supporting such structure and developed as a separate software module.

Traditional delivery lead-times (independent of quantity) could be replaced by appropriate operations routing where activity times are dependent on the delivery quantity. Delivery operations would be represented by a CPM network in which an accurate forward and backward scheduling could be carried out.

In both approaches, planning of components in the distribution network starts with some independent demand for the finished product(s) at individual field warehouses. Thus, for a given external demand (units over a number of periods, which could be derived from sales forecast, actual orders or planned independent requirements), the DRP implosion process would provide the distribution requirements plans of the whole distribution network including the central warehouse. In order to complete the scheduling of all activities, DRP time-phasing process is replaced by the scheduling of operations routing. Thus, DRP implosion process could result in a number of planned shipments at intermediate and central warehouse locations. Besides, backward or forward scheduling of operations routing for the same distribution network could determine the start and finish times for the operations in the distribution network. Thus, representation of hierarchical BOW and operations routing could provide the basis for scheduling of both activities and materials in a unitary structure of distribution network.

The unitary structure can be implemented as a combination of BOW and operations routing for delivery activities CW to customers (i.e. C1, C2, C3 and C4). Traditional DRP implosion process could result in number of planned shipments with start and finish dates for each material involved in the distribution network. This would come up with a simple list of planned shipments with basic dates (i.e. opening period, delivery start and finish dates).

The next planning step is the scheduling of delivery operations involved in the distribution network. It can be carried out using the scheduling of operations routing. Assuming that all customer requirements are satisfied by a certain date and time (14 June 2002 at 16.00 hours). The scheduling is based on backward scheduling of operations, starting from last delivery operation for each customer to the central warehouse. A working calendar of eight hours, Monday to Friday between 08:00 hours and 16:00 hours is used. Table IV shows the results of the scheduling of operations routing.

The activities have been backward scheduled in terms of late start and finish times. These scheduling results for operations are comparable to those obtained from the activity scheduling functionality of CPM. Therefore, scheduling of activities can be achieved through operations routing with a number of parallel sequences in the distribution network. Appropriate component allocations within the operations routing could resolve the incompatibility of timing and quantity plans at the time of plans execution. In order to allow for multiple materials at individual warehouse, hierarchical structure of BOW can be extended with additional material components. It has been shown earlier (Samaranayake, 2001) that scheduling of multiple materials can be carried out using CPM scheduling of activities in unitary structure. Thus, CPM scheduling of delivery operations can be extended for the multiple materials at individual warehouses.

The second approach to the planning and scheduling of components starts with some external demands from customers to field warehouses. Based on unitary structure, the components in the distribution network can be planned simultaneously, when the DRP implosion process is combined with operations scheduling. Although the results could be same as the results obtained from separate planning of materials and activities, this approach could remove any time and quantity incompatibility.

Some results from the manual implosion and operations scheduling are shown in Table V. These components are planned in terms of appropriate quantities and due date and times. Due date and time of a material at a field or intermediate warehouse is determined by the minimum of latest start date(s) and time(s) of activity/activities originating at the warehouse. Considering the field warehouse FW2 as an example, in order to meet demands of customers C2 and C3 by the due date (14 June 2002, 16.00 hours), activity A8 has a latest start time of 10.00 hours 14 June 2002. Similarly, activity A6 has a latest start time of 11.00 hours 14 June 2002. Then, FW2 must have all the materials by minimum of latest start times of activities A8 and A6 since they are two activities starting from FW2. Thus, latest finished time of activity A5 at FW2 is 10.00 hours 14 June 2002.

Table IV Scheduling of operations routing for the distribution network

		Duration	Latest start		Latest finish	
Type	**No.**	**(hrs)**	**Date**	**Time**	**Date**	**Time**
Sequence 0: standard main sequence with seven activities (A1-A7)						
Oper./act.	A1	2	11 June 2002	09.00	11 June 2002	11.00
Oper./act.	A2	3	11 June 2002	11.00	11 June 2002	14.00
Oper./act.	A3	8	11 June 2002	14.00	12 June 2002	14.00
Oper./act.	A4	3	12 June 2002	14.00	13 June 2002	09.00
Oper./act.	A5	10	13 June 2002	09.00	14 June 2002	11.00
Oper./act.	A6	1	14 June 2002	11.00	14 June 2002	12.00
Oper./act.	A7	4	14 June 2002	12.00	14 June 2002	16.00
Sequence 2: parallel. includes activities A8 and A9						
Oper./act.	A8	2	14 June 2002	10.00	14 June 2002	12.00
Oper./act.	A9	4	14 June 2002	12.00	14 June 2002	16.00
Sequence 3: parallel. includes activities A10-A13						
Oper./act.	A10	2	14 June 2002	09.00	13 June 2002	11.00
Oper./act.	A11	5	14 June 2002	11.00	13 June 2002	16.00
Oper./act.	A12	2	14 June 2002	08.00	14 June 2002	10.00
Oper./act.	A13	6	14 June 2002	10.00	14 June 2002	16.00
Sequence 4: parallel. includes activities A14-A19						
Oper./act.	A14	2	12 June 2002	09.00	12 June 2002	11.00
Oper./act.	A15	5	12 June 2002	11.00	12 June 2002	16.00
Oper./act.	A16	3	13 June 2002	08.00	13 June 2002	11.00
Oper./act.	A17	8	13 June 2002	11.00	14 June 2002	11.00
Oper./act.	A18	1	14 June 2002	11.00	14 June 2002	12.00
Oper./act.	A19	4	14 June 2002	12.00	14 June 2002	16.00

6. Development of supply chain framework

The next step in the development of supply chain framework is the integration of individual networks. Supply chain is a combination of individual networks in manufacturing and distribution environments. Managing a supply chain requires a number of planning and execution steps to be carried out. Individual processes and elements need to be considered with a view to extending individual networks into the development of supply chain. Further, it is also required to identify the benefits of individual networks and implement those benefits when integrated to make a single supply chain framework.

Integration of individual networks and level of integration

Many ERP and MRPII systems have attempted to integrate many business processes in a number of application areas using data and components at the database level. Any change to an existing process could be visualised only when a report is generated. However, integration of individual networks, which are already integrated at the structural level, could provide overall integration of supply chain components. Such integration could provide visibility and extra functionality such as a view of any changes online.

Given the number of complexities in individual networks (number of components in a network, relationships between components, flow of information and planning of all components across networks), managing a complex supply chain using a number of individual networks without proper integration at the structural level is too complex to be worked out manually, without the help of an integrated approach at the structural level. Integration of individual networks at the

Table V Imploded quantity and time schedule for each component (backward schedule)

Item name	U/M	Component Relator	Qty	Imploded Qty	Duration	Distribution quantity	Due Date	Time
C3		m	1	100			14 June 2002	16.00
A7	HRS	A	1		4		14 June 2002	16.00
A6	HRS	A	1		1		14 June 2002	12.00
C2		m	1	100			14 June 2002	16.00
A9	HRS	A	1		4		14 June 2002	16.00
A8	HRS	A	1		2		14 June 2002	12.00
FW2		m	1	200		200	14 June 2002	10.00
A5	HRS	m	1		10		14 June 2002	11.00
A4	HRS	A	1		3		13 June 2002	09.00
C1		m	1	75			14 June 2002	16.00
A13	HRS	A	1		6		14 June 2002	16.00
A12	HRS	A	1		2		14 June 2002	10.00
FW1		m	1	75		75	14 June 2002	08.00
A11	HRS	A	1		5		13 June 2002	16.00
A10	HRS	A	1		2		13 June 2002	11.00
IW1		m	1	275		275	12 June 2002	13.00
A3	HRS	A	1		8		12 June 2002	13.00
A2	HRS	A	1		3		11 June 2002	13.00
C4		m	1	150			14 June 2002	16.00
A19	HRS	A	1		4		14 June 2002	16.00
A18	HRS	A	1		1		14 June 2002	12.00
FW3		m	1	150		150	14 June 2002	11.00
A17	HRS	A	1		8		14 June 2002	11.00
A16	HRS	A	1		3		13 June 2002	11.00
IW2		m	1	150			13 June 2002	08.00
A15	HRS	A	1		5		12 June 2002	16.00
A14	HRS	A	1		2		12 June 2002	11.00
A1	HRS	A	1		2		11 June 2002	10.00
CW		m	1	425		425	11 June 2002	08.00

structural level could then form a basis for a supply chain framework. This is the initial stage of reporting the progress of ongoing research on development of the framework and a reference model for SCM. This could also become a foundation for development of model(s) in many industry applications.

Once individual networks are integrated, information could flow through the complete supply chain. Further, planning and execution of both manufacturing and distribution make simple when output of one network becomes input to the other network, and vice versa. This could assist in simultaneous planning of all the components in terms of planned orders, purchase requisitions for raw materials, and delivery orders for distribution of materials, etc. Final integration at the structural level can be carried out using the links between MRP and DRP records.

Planning and execution of supply chain components

Planning of all components of a supply chain could be more demanding than that of those of individual networks discussed before. Individual networks could have been planned using two approaches. The first approach used a combination of two separate planning methods. It could be very difficult, if not impossible, to arrive at feasible material and activity plans if a supply chain with a large number of components needs to be planned without any incompatibility. Planning of such a network is required to be carried out only through the simultaneous planning of all components. Therefore, the approach adopted earlier for simultaneous planning of components in manufacturing and distribution networks will be demonstrated here with a numerical example.

A numerical example of supply chain

A numerical example with a number of components covering both manufacturing and distribution is chosen to demonstrate the integration process in two individual networks. Figure 8 shows the distribution network with three field warehouses (FW1, FW2 and FW3), three materials (A, B and C), a number of packing, loading, delivery and unloading activities (PO1-PO10, LDU1-LDU6), and labour and equipment resources (TK1-TK7, LB1-LB9). Figure 8 shows three individual unitary structures for assembly of three finished products (A, B and C). It shows a number of assembly activities (A1-A6), resources (R1-R4), raw materials (RM1 and RM2) and suppliers (S1 and S2) who provide raw materials.

Based on the concepts, component integration and relationships in individual networks, individual networks can be integrated to form a SCM framework. The distribution network shown in Figure 9 can be planned using traditional DRP implosion for materials and forward and/or backward

Figure 8 MRP networks with raw materials, activities and suppliers

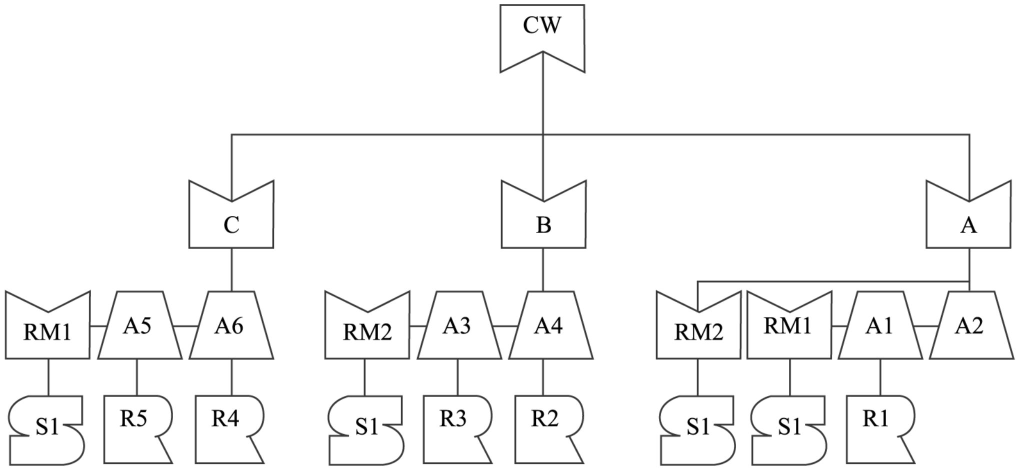
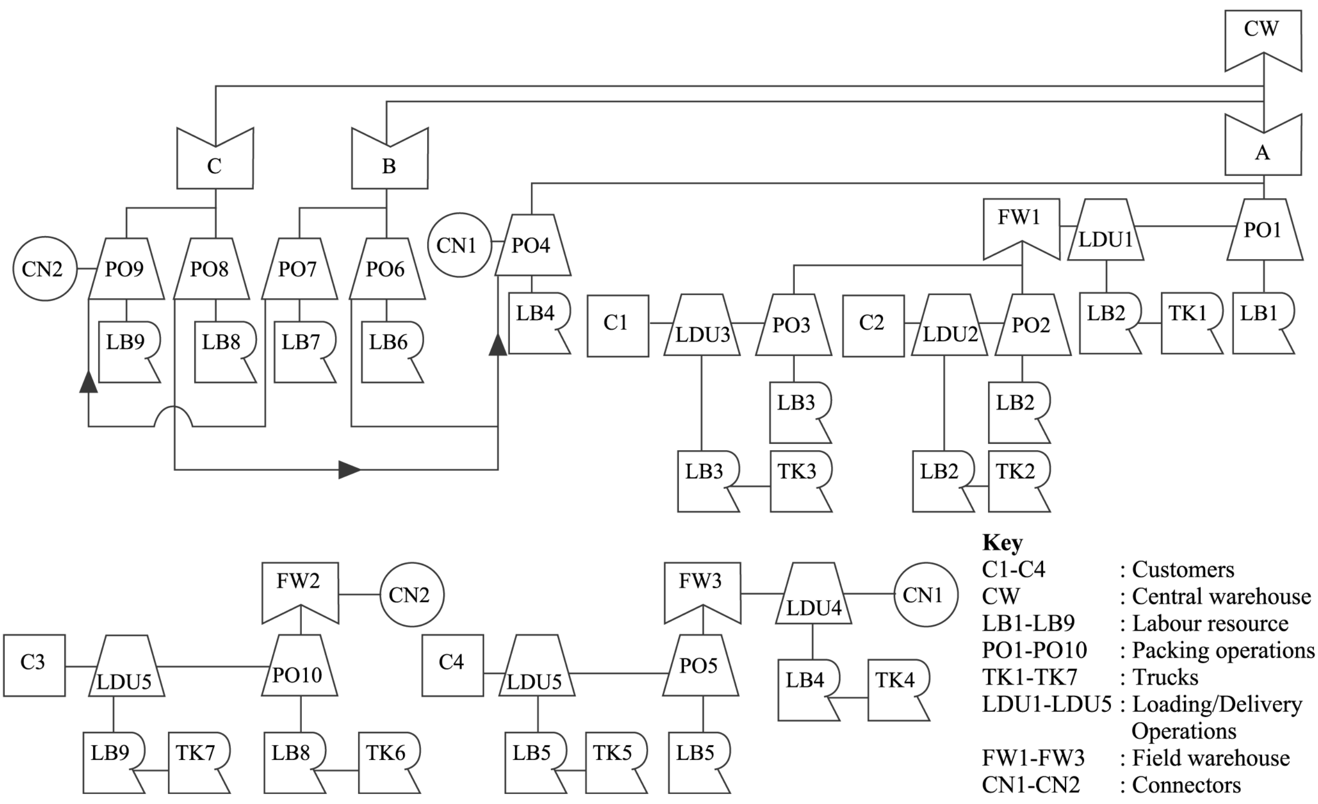


Figure 9 Distribution network with warehouses, materials, resources and activities



scheduling for operations scheduling based on a set of parallel and standard sequences representing all activities in the network. DRP implosion would result in a number of DRP records for each material over a planning horizon. These records are similar to MRP records with planned shipments at individual warehouses including central warehouse for each material. The DRP records at the central warehouse for each material becomes the link to manufacturing networks where all the planned shipments at central warehouse become gross requirements for materials at manufacturing plants. Depending on the inventory status (stocks, scheduled receipts, open orders), net requirements for each material can be determined using MRP explosion process. At the same time, activities involved in each network (see Figures 8 and 9) can be planned using backward and/or forward scheduling and the operations routing derived from respective unitary structures. Thus, the link between distribution and manufacturing networks are DRP records where planned shipments at DRP networks become gross requirements to manufacturing networks.

DRP records (i.e. planned shipments), MRP records (i.e. planned orders and purchase requisitions) and operations routing schedules (backward and/or forward activity schedules) for both distribution and manufacturing networks provide plans and schedules of materials and activities. Besides, raw material requirements arising from MRP records can be used to plan purchase requirements. Resources can also be allocated to each activity at the time of activity scheduling if resources are attached to them. This is the overall planning process of the supply chain components. This process can be further enhanced if the structure is implemented in an existing system, as a single object in an object-oriented database with required planning tools. Alternatively, existing ERP systems based on relational databases, across supply chain partners, can be used for planning of supply chain components in each network of manufacturing and distribution using separate planning runs for materials, operations and subsequent planning of capacities. This suggests that when all the networks are integrated and provided with appropriate relationships between components (i.e. activity precedence, parent-component and component-component), it would become the integrated framework for SCM. Further, unitary structure comprising of the components in a supply chain environment could provide the functionalities required for later changes and modification of components and links.

Manufacturing and distribution networks as a part of this framework are already integrated at the structural level since they represent not only traditional data (materials, suppliers), but also dynamic data such as activities (operations routing), resources (labour, machine, etc.) and relationship between components. These dynamic data and relationships were not possible in a single structure if not integrated at the structural level. Further, lead-time traditionally confined to material records as a lot-size independent quantity has been replaced by a more accurate activity component and incorporated into the structure with resource component(s) attached to it. Furthermore, data integration at the structural level is different from the data integration at the database level due to a number of reasons: representation of real-time data; interaction with many components; and basis for simultaneous planning and scheduling of many components. Further, integration of components at the structural level provides the visibility of more data, flexibility for change and/or modification and maintainability. Integration of activity component at the structural level provides more accurate timing of activity duration and dependencies such as lot-size dependent and independent components separately. Further, it provides the flexibility of incorporating resource(s) attached to the activity for accurate planning of the activity, eliminating capacity levelling of traditional capacity planning process.

The proposed framework is a conceptual model that could be used as a guide for many industry applications. Development of supply chain model(s) of a selected industry requires mapping the business processes into the proposed framework. Once the framework is translated into such a mapping (a model with all the supply chain components and links), next stage is to implement those structures within and across ERP systems depending on the boundaries of such processes. If existing ERP system(s) is/are based on relational database, the mode of planning and scheduling would be separate runs for manufacturing and distribution networks. Further, resources involved in each activity need to be identified. In the case of integration across organisations, technology such as electronic data interchange (EDI), automated guided vehicles (AGV), electronic *kanban*s and barcode technology could be involved.

Once the model is developed based on the industry application situation, the whole structure needs to be implemented as a single object in an object-oriented database ERP system for simultaneous planning and scheduling of components. Alternatively, separate networks (manufacturing and distribution) can be implemented in relational database ERP systems for separate planning and scheduling of components. Once the planning and scheduling of components are carried out using appropriate tools/techniques (MRP, DRP, CPM), material and capacity plans can be executed at operational level (shop-floor and distribution-floor) using appropriate techniques depending on the area of operations.

Future work would be to develop supply chain model(s) for a selected industry and/or a set of industries and to evaluate the application of the model(s). The evaluation results could include a number of MRP records for planning materials in terms of planned orders, DRP records for individual materials at respective warehouses including one at the central warehouse and operations scheduling in terms of start and finish times including slack and float times for both manufacturing and distribution activities. It is expected that, a separate software module, based on this unitary structure and the solution approach, be developed. Besides, a mathematical model based on the framework could be developed and thereby algorithms and solutions could be tailored for any selected industries.

7. Conclusions

This paper identified the need for an integrated approach for SCM. Recent developments in the area show that many industries have undertaken the implementation of new strategies in order to stay touch with ongoing developments. Integration of various components has been the main focus of many of the projects undertaken. Recent research has overlooked the structural level integration aspect of the SCM. Having identified the need and the current level of development, this paper presented a basis in terms of factors and concepts for the integrated approach. The approach is based on the unitary structuring technique, which has been successfully implemented in many applications such as maintenance, manufacturing and distribution. The proposed framework integrates various components (materials, resources, activities) involved in a business process across a number of partners in the supply chain. Main features include the integration of individual components, elimination of various interfacing steps between partners, representation of relationships (component precedence, parent-component, component-component) and functionality for planning and execution of components at the structural level. The numerical testing results also show that the structure could eliminate a number of interfacing steps between supply chain partners and provide a basis for an integrated approach to model supply chain environment. In addition, it is capable of providing visibility, flexibility and maintainability for further improvement in a supply chain. It is expected that the framework could be developed as a generic supply chain model and a software module and/or implemented in existing

ERP and other systems where these systems support object-oriented database structure.

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Further reading

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