Integrated Scheduling of a Two Stage Supply Chain Network using Simulation – A Case Study

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Summary
This paper is the result of the work carried out to study the performance analysis of two stage supply chain network using simulation. The objective of study is to model an integrated system for a two stage supply chain network of an automobile company and measuring the performance parameters and establishing the priority decision and queuing rules for improving the utilization of resources. The study is restricted to measuring operational processes in a two stage supply chain between the supplier - manufacturer - distributors. The qualitative data collected has been used to understand the various processes in the supply chain at the stage of component manufacturing and sub-assembly at suppliers, assembly in the final line at the manufacturer plant and the logistics involving the supplier and manufacturer on one hand and the manufacturer and distributor on the other. The data collected have been modeled using the simulation package PROMODEL, using manufacturing oriented modeling elements and rule based decision logic. The data obtained as output from the suppliers has been fed as input arrival data into the manufacturer model to facilitate integration. Rule based decision logics have been applied to the models developed and its behavior on the application of various PDR (Priority Decision Rule) has been documented. Performance measures have been obtained for various scheduling logics.

Key words:
Two Stage Supply Chain Network, Simulation.

1. Introduction

Production Scheduling problems and distribution and vehicle routing problems have been extensively researched over the years. Most production scheduling models only consider job processing and seek to optimize a time-related performance measure that is usually a function of job completion times. On the other hand, most vehicle routing models assume that jobs to be delivered have already been processed and are only concerned with minimizing the total distribution cost. Most existing production – inventory – distribution models study strategic or tactic levels of decisions, and few have addressed integrated decisions at the detailed job – scheduling level. Though production scheduling and distribution scheduling can

optimize the profits and resource utilization at the product and distribution stages individually, lack of synchronization between the two can lead to large losses in the supply chain. Thus, it is essential to integrate the two schedules to maximize the profits of an organization. Integrated Scheduling is the process of synchronizing the production and the distribution schedules of the supply chain in accordance with the competitive strategy of an organization. In the current scenario of cutthroat competition, cost and customer service are the major concerns of the decision maker. The total cost of the system is contributed by the production and distribution operations. The cost of a delivery shipment generally consists of a fixed charge and a variable cost proportional to the total distance of the route taken. Thus, the number of shipments used and the specific routes taken determine the total distribution cost. To achieve shorter lead times, more delivery shipments have to be used which will lead to higher distribution costs. Therefore, optimizing the tradeoff between the distribution cost and the customer service level is often a major goal of the decision maker of systems. The close linkage between production and distribution necessitates coordinating production and distribution operations at the level of detailed scheduling. This detailed schedule is an integration of the distribution schedule with the production schedule so that the right quantity is available at the right place at minimum possible cost.

2. Literature Review

Integrated supply chain - White paper by Aerospace Industries Association (2000), a white paper on the Integrated Supply Chain by AIA says that the integrated supply chain is an evolving concept focusing on merging a buyer's requirements directly into a supplier's production schedule and its objective is to ensure the timely delivery of a properly configured product, to the right place, at the

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right time. It also says that effective business processes make the integrated supply chain work. Without effective processes in place, the integrated supply chain will fail. The challenge of successfully creating an integrated supply chain system resides primarily with the buyer. The buyer is creating the demand the seller is trying to satisfy. The intent of the integrated supply chain concept is to generate benefits for both the buyer and the seller. The benefits ideally include: Eliminating non-value added activities in the buy-sell relationship and minimizing inventory investments at all levels within the supply chain .An important issue is identifying some of the major impediments to successful implementation of an integrated supply chain and then developing some approaches for overcoming them. The paper also suggests a few risk mitigation ideas like drafting new agreements that incorporate protections for both parties involved in the integrated supply chain and careful consideration of integration of the buyer's business processes with that of the supplier.

A framework of supply chain management literature by Keah Choo Tan (2000), in this paper reviews the literature base and the development of supply chain management from two separate paths. He talks about the evolution of supply chain management from the purchasing and supply activities, and the transportation and logistics perspective of supply chain management with a focus on integration, visibility, cycle time reduction, and streamlined channels. He describes supply chain management as a handy synonym to describe purchasing and supply activities of manufacturers or to describe the transportation and logistics functions of retailers and merchants. The paper also says that genuinely integrated supply chain management requires a massive commitment by all members of the value chain. Poor supplier performance is one of the pitfalls, the other risks being passing of company secrets by the supplier to competitors, conflicting objectives and missions, inadequate definition of customer service and separation of supply chain from operational decisions.

Effect of supply chain integration on the relationship between diversification and performance: evidence from Japanese and Korean firms – Narasimhan and Kim (2002) addresses that supply chain strategies and practices depend on not only the nature of the business, the competitive environment, and technological intensity of the product, but also on product and market characteristics. Consequently, supply chain integration (SCI) strategies should be evaluated in the light of a company's market and product strategies. This paper examines the effect of SCI on the relationship between diversification and a firm's competitive performance. The results of the study can be useful in integrating supply chain strategy into market and product diversification (PD) strategy. By comparing the main and interaction effects of SCI and diversification on performance, the paper shows that SCI strategy modifies the relationship between diversification and performance. Additionally, it is argued that coordinated use of SCI and diversification strategies has a significant effect on firm performance. Through extensive research the authors have found that the need to react to market ranges and the critical role of supply chain in meeting this need, and the potential benefits of integrating the supply chain can no longer be ignored. This potential however will be realized only if the inter-relationships among different parts of the supply chain are recognized, and proper alignment is ensured between the design and execution of the company's competitive strategy. This paper is an attempt to show how this potential can be realized through linking SCI strategy to the corporate diversification strategy. The result of regression on three different models for testing the hypotheses of this study indicate that internal integration across the supply chain and external integration with suppliers and customers positively moderate the curvilinear relationship between product diversification (PD) and performance, and between international marketing diversification (IMD) and performance, respectively. Also, the results of regression analysis for subgroups classified by the type of SCI, show that as the level of SCI increases, the interaction effect of PD and IMD on performance is significant, thus reflecting that SCI may substitute for the role of interaction between PD and IMD as a moderator of the positive relationship between diversification and performance. Results of this study make several theoretical contributions. First, strategy literature has not consistently shown that there is a linkage between diversification and performance. The effect of SCI, which this paper has justified, has significance for successful diversification beyond simply a substitute for the interaction between PD and IMD.

Integrated scheduling of production and distribution operations by Chen and Variaktarakis (2005) addresses the problem to find a joint schedule of production and distribution such that an objective function that takes into account both customer service level and total distribution cost is optimized. Customer service level is measured by a function of the times when the jobs are delivered to the customers. The distribution cost of a delivery shipment consists of a fixed charge and a variable cost proportional to the distance of the route taken by the shipment. Two classes of problems under this integrated scheduling model have been addressed. In the first class of problems, customer service is measured by the average time when the jobs are delivered to the customers; in the second class, customer service is measured by the maximum time when the jobs are delivered to the customers. Two machine configurations in the processing facility – single machine and parallel machine – are considered. For each of the problems studied, they have provided an efficient exact algorithm, or a proof of intractability accompanied by a heuristic algorithm with worst-case and asymptotic performance analysis. Computational experiments demonstrate that the heuristics developed are capable of generating near-optimal solutions. Also investigated the possible benefit of using the proposed integrated model relative to a sequential model where production and distribution operations are scheduled sequentially and separately. Computational tests show that in many cases a significant benefit can be achieved by integration.

3. Objectives

The objectives set to overcome the drawbacks of lack of communication and integration are: to study processes at the supplier, manufacturing and logistics stages of a supply chain at the advance planning level and to model the processes using the simulation package PROMODEL and to develop models for a two stage supply chain of an automobile company and to compare the performance of the models under the priority decision rules such as random and oldest with queuing rules First In First Out and Last In First Out.

The assumptions and restrictions made during building the model are: the overall supply chain profits are shared between the stakeholders, only processes at the Tier-1 supplier are modeled and it has been assumed that the other tier suppliers can meet the arrival rates required by the Tier-1 supplier, once the defective pieces have been sent for rework, if any defectives are found in the reworked parts after subsequent inspection, the rejects are sent directly to scrap, the data collected is restricted only to 4-wheelers in the small segment, the resource capacity has been fixed after many trials and only product flow has been considered, funds flow and information flow are not accounted for.

4. Data Collection

Qualitative data are related to the nature of the processes taking place at various stages of the supply chain. The data collected was related only to the more significant processes at the advanced planning level, not going in-depth into all steps of the processes. The data collected was for the supplier, assembly and the logistic processes including inbound and outbound logistics.

The supplier processes are:

- Assembly of engine - This involves the assembly of several components into the engine system and the transmission system followed by the assembly of these to give the engine sub-assembly.
- Manufacturing of front suspension - This is achieved through the assembly of components like torsion spring, shock absorber etc.
- Fabrication of the frame - The frame is fabricated through several forging and welding processes.
- Assembly of the rear axle - This involves the assembly of components like gasket, axle, etc.
- Manufacturing of car body - This is done by joining different parts of the car body like door, bonnet, hood etc.
- Manufacturing of tyres - Tyres are manufactured by vulcanizing and molding of raw rubber.
- Production of sheet metal parts - Sheet metal parts are taken through several processes to get definite shapes from blanks.

Assembly line processes are:

- Assembly of components and sub-assemblies - This is carried out in various work stations where the parts manufactured by the suppliers above enter the system.
- Painting of the assembled Car - this is performed in the painting booth.
- Inspection of WIP and Finished products - In process inspection takes place at the end of each assembly station to send back defectives for rework followed by the final inspection at the end of the assembly line.

  Logistics process: These are processes involved in transportation of raw materials and sub-assemblies into the assembly line (inbound logistics) and those involving transportation of the finished goods from the assembly line (outbound logistics).

Quantitative Data are related to:

- Annual Demand Data: The annual demand for small segment 4 wheeler in India was found to be around 130000.
- Quality: The average percentage defective in the WIP of an assembly line was found to be around 5%. Through in depth surveys, it was found that after the defectives had been sent back for rework, the percentage of defectives in reworked parts was around 15%.
- Average Processing Times: The average processing times of all the processes in the supplier's facility and in the assembly line were collected from various sources and are listed. It was found that processing times generally follow the normal distribution. A sample data of processing times of final assembly processes are shown in Table 1:

5. Methodology

The methodology adopted for study after collecting the required data is as follows:

Step1: Component, Assembly and logistic processes - The selected car model consists of six workstations.

Table 1 - Processing Times of Processes in Final Assembly

Processes	**Processing Times N (mean, standard Deviation)**	
	Car 1	**Car 2**
Assy. of front suspension with frame	(4,0)	(9.5,1.5)
Inspection 1	(5,0.5)	(5,1.5)
Assy. of engine	(4,0)	(6,2)
Inspection 2	(5,0.5)	(6,2)
Fixing rear axle	(8,0.8)	(6,1)
Inspection 3	(5,1)	(5,1)
Attach tyres	(8,1)	(6,2)
Inspection 4	(5,0.5)	(8,2)
Fit car body	(8,1)	(12,2)
Inspection 5	(5,0.5)	(6,2)
Fix sheet metal parts	(8,1)	(10,2)
Inspection 6	(5,0.5)	(6,2)
Painting	(15,1.5)	(20,1)
Final inspection	(8,1)	(10,1)

Components and subassemblies are assembled in each of these workstations. The front suspension is fitted onto the frame in assembly station 1 after which the engine is fixed in position near the front suspension in assembly station 2. The engine and the suspension are the most important components of the car assembly. Hence, it is necessary to ensure that these are mounted perfectly on the frame. On the next assembly station, the rear axle is attached. After this the tyres with the wheels are fitted. Various sheet metal parts are then attached wherever required in assembly station 5. In the final assembly station, the car body is fitted on top of the frame to complete the car assembly. The assembled car is then sent to the painting booth where the car is painted according to a definite colour scheme. Research has shown that it is more efficient to paint all cars of the same colour in sequence rather than changing colours at regular intervals. To simplify the model, all cars of the same colour are assumed to be manufactured. The arrival rates of the components into the system are the outputs of the production rates from the supplier models. This is followed by final inspection from where products are sent to the finished goods warehouse.

In process inspection has been incorporated after each stage of assembly. At each inspection station, the defective parts are sent back to the same assembly station for rework. The percent defectives are on an average 5% and after rework, percentage defectives in the reworked pieces are 15%. In process inspection has been used because research has shown that if defectives are not corrected after each stage the effect of the defects just multiplies at the end leading to a cascading effect and very poor quality. The data considered are all for the small and medium range segment cars. Thus, 2 sets of data have been entered, one for CAR 1 (a small segment car) and the other for CAR 2 (a medium segment car).

The seven suppliers are located in different parts of the country at various distances from the manufacturer. The distributors are also located in different areas catering to the needs of four regions. Time taken for logistics is calculated on the basis of distances and the average speed of the transportation resources used i.e. the trucks.

Step 2: Data modeling using promodel simulation package - Entities, Attributes, Activities with times and random events were identified for suppliers, manufacturing and logistics processes. PROMODEL simulation package has been used to build models. The stages included are supplier's process cycle, car body assembly model, sheet metal parts manufacturing, frame manufacturing, front suspension assembly, tyre manufacturing, rear axle manufacturing, engine assembly, final assembly and the logistics processes at supplier and distributor stages.

Step 3: Priority decision and Queuing rules - The supplier models are executed under 2 priority decision rules. These are:

(i) Oldest: Parts which have stayed for the longest time in the system are given a higher priority over all other parts. The priority ranges from the oldest being given highest priority to the newest part being given the least priority and
(ii) Random: According to this rule no specific sequence is used for prioritizing the processing of the parts. Any part is chosen at random and processed.

The simulation is executed for 2 types of queuing rules for each of the priority decision rules are:

(i) First In First Out (FIFO): In this rule, the product entering a resource for processing first is sent out of the resource first and
(ii) Last In First Out (LIFO): In This rule, the part which enters the system at the end leaves it first and the part entering first continues to be processed for the longest time.

Step 4: Integrating the Models - The models were integrated by entering the output data obtained at the end of the supplier stage, as inputs to the assembly stage in the form of entry arrival rate and same in other stages too. The table 2 below shows sample timing data from supplier being input into assembly line process:

Step 5: Model Verification and Validation – The simulation is run for the 2 cars, using the four sets of rules. The average of the outputs for 1,5,10 replications of the

Table 2 – output data from suppliers as input to assembly line

Components	Batch Size	Type Of Vehicle	Average Minutes per Batch	
			Oldest FIFO	Random FIFO
Engine Assembly	20	Car 1	181.80	181.71
		Car2	181.98	180.19
Frame	20	Car 1	161.46	161.46
		Car2	161.46	161.46
Tyre	180	Car 1	1743.94	1743.94
		Car2	1744.14	1744.14
Rear Axle	180	Car 1	1818.36	1818.00
		Car2	1820.70	1819.98
Car Body	180	Car 1	1742.54	1742.08
		Car2	2179.80	2179.80
Sheet Metal Parts	180	Car 1	1741.24	1740.96
		Car2	1743.98	1743.69
Front Suspension	20	Car 1	183.61	179.93
		Car2	182.11	182.52

simulation run of the model for each of these priority rules is recorded. The value of the output for each of 4 individual replications is recorded and shown in Table 3 below. The performance of the model is measured in terms of number of minutes per car. This is recorded for car 1, car 2 and the total of the two cars.

From the graphs, it has been found that the rate of production for CAR 1 is very low if the rule Oldest LIFO is used. Thus, we can conclude that the other rules should be used in preference to this rule. For CAR 2, no such specific preference could be concluded as is apparent from the graphs. We can also conclude that the emergence of one rule in preference to all others is not a necessity and is completely dependent on the input data. From the figure 1 showing the total production rate, we can see that since the variance in the rate is extremely small, we can assume the models to be in the steady state.

Figure 2 indicates the percentage occupancy of various workstations, which is helpful in determining the utilization of workstations.

As in the case of the supplier models, different capacities were used for the assembly line model as well. It was found that with a capacity of 1500, work station 1 is empty for about only 2% of the time.

Logistics model is run for a single replication and the output is studied thoroughly. The performance is measured in terms of number of cars issued by the assembly line and in terms of the number of cars received at each distributor.

6. Conclusion

The models suggested by us in this study are limited to only 2 stages of the supply chain. These can be extended further down the supply chain to include all stages till the customer stage making it more responsive and dynamic.

Table 3 – Rate of production of cars

Priority Decision Rule	Type of car	Queuing Rule	Rate Of Production (Number of Minutes/Car)			
			Replication(s)			
			1	2	3	4
Oldest	Car 1	FIFO	10.19	10.44	10.18	10.08
		LIFO	11.38	11.24	11.29	11.01
Random	Car 1	FIFO	10.16	10.20	10.38	10.10
		LIFO	10.26	10.24	10.26	10.40
Oldest	Car 2	FIFO	11.38	11.24	11.29	11.01
		LIFO	11.38	11.32	11.21	10.96
Random	Car 2	FIFO	11.06	10.95	10.83	11.08
		LIFO	11.15	11.02	10.84	11.14
Oldest	Total	FIFO	5.39	5.42	5.36	5.27
		LIFO	5.39	5.43	5.38	5.30
Random	Total	FIFO	5.35	5.33	5.34	5.33
		LIFO	5.36	5.33	5.29	5.40

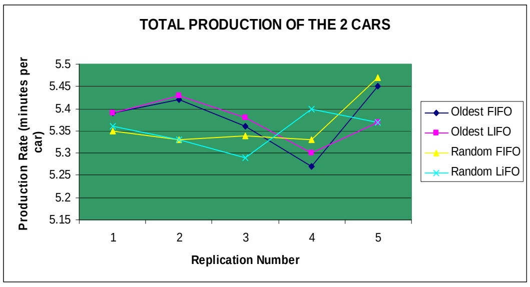

Fig. 1: Number of minutes per car and set of rules

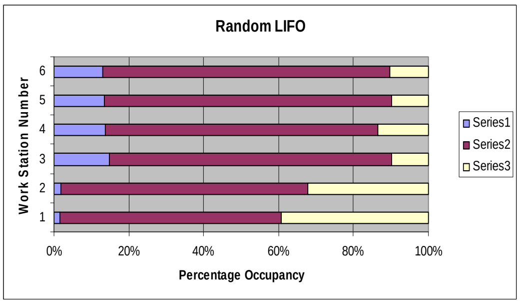

Fig. 2: Percentage occupancy of work centers

Moreover, though in-depth analysis has been carried out to understand the product flow methodology, the flow of information is not considered. The models can be expanded to consider the flow of information in the supply chain taking into consideration the information lead times and several intangibles involved. The models are limited to just one part of the entire automobile industry; it can easily be extended to other product groups and also to multi product lines with more than 2 products being rolled out simultaneously. The model built is in the conceptual stage and is very nascent. It can be made more practical by incorporating the cost data also into the model, so as to calculate the cost savings with the use of this model.

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