A Lean Manufacturing Educational Model: Flexible Low-Cost Linking of Manufacturing Planning to Customer Requirements

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Abstract

Recent trends in Lean Manufacturing have an implied optimal target of zero inventory levels at all stages of the manufacturing system. Some volume of inventory however, may be necessary to smooth production flow inside the factory while reducing lead times, thus increasing overall profitability. One approach may be to introduce optimum levels of Work-in-Process (WIP) inventory at key stages[4] of the manufacturing system. This paper presents a Lean Manufacturing Model (LMM) which can be used in teaching Manufacturing Engineering students about computer simulation. This efficiently links flexible, low-cost manufacturing planning to customer requirements. Through computer simulation and modeling, the concepts of WIP deployment and management utilizing real production data from a worldwide manufacturer and distributor clearly demonstrates that flexible, low-cost manufacturing can be achieved through the implementation of a hybrid push-pull production and distribution system and strategically deploying work-in-process inventories at key points within the system.

Introduction

The manufacturing industry is undergoing major changes in the way products are configured. Mass customization is forcing manufacturers to respond to specific customer requirements and yet they are expected to make products efficiently, typically through larger quantities and scale of operations. Global market demands have led to three distinct forms of production planning and control systems: the conventional manufacture-to-stock or the ”Push” system, the Just-in-Time (JIT) manufacture-to-order or the “Pull” system, and a “hybrid” push-pull system based on delayed product differentiation. The hybrid system is the most difficult to optimize regarding overall system operations because it entails frequent integration of product design, process configuration, inventory requirements, and post-manufacturing delivery constraints.

Meanwhile, recent trends in lean manufacturing either directly or imply a target inventory level of zero at all stages of the supply chain. It is argued, however, that inventory is necessary in many instances to help smooth the production flow inside the factory and to reduce “order to ship times”, thus increasing the overall profitability through higher sales at minimized total cost. One approach to reaching this state is to introduce optimum levels of Work-in-Process (WIP) inventory into key stages of the production system.

The study is inspired by a current research on strategic deployment of Work-in-Process (WIP), or safety stocks, for flexible low-cost manufacturing system by the same authors[4]. The authors have discovered that the direction toward low cost, flexible, and highly customer responsive manufacturing systems is through the deployment of WIP at strategic locations instead of minimizing or controlling WIP at every station or depending on larger levels of finished goods inventories. To construct and test the hypotheses, a computer-based simulation of the roller cone bit manufacturing processes was employed.

This paper takes that research a step further by simulating the added effects of batch size on the levels of WIP required at these strategic locations and to determine economical batch sizes for low cost and lean manufacturing system. Manufacturers typically produce parts in large batches to satisfy product demands while other components are being processed. However, large batches also mean large cycle-time WIP along with its large finished goods inventory, thus increasing holding costs and obsolescence risks. Thus, computer simulation can aid lean manufacturers with the quest for business process reengineering as the various constraints of the manufacturing system make the analysis more difficult and complex. In the present paper a LMM simulation is demonstrated for training students to tackle the challenges of lean manufacturing conversions. In this model, a methodology for conducting manufacturing research studies using computer simulation is developed incorporating real world production data in a commercially available software. The ARENA software was chosen to model the actual manufacturing system in its entirety and test the random nature of some key variables without severe assumptions.

Inventory Management Trends

The concept and practice of building inventory, popular as recently as a few years ago, was based on the costs benefits of economies when buying, producing and storing in bulk. However, that policy does not hold the same validity today as product varieties increase and carrying costs gain more attention. This was particularly true for the consumer products industry such as consumer electronics, automobiles, et cetera. Manufacturers that have used the push system are now committing to the pull approach. Perhaps the most logical approach is a combination of both, known as "hybrid" system that is the most practical for responding to demand variations and lead times.

Strategies such as a hybrid push-pull system for a high-value, low-volume, long lead-time product such as rock-bit drilling tools may be particularly effective, perhaps more so that it would be for a consumer product line where an assembly line approach has little feasibility. Almost all of the major rock-bit components are manufactured at the factory and design changes are frequent with high customization demands. These factors combined with intense global competition require rethinking of manufacturing flexibility in relation to customer requirements, least total costs, and the integrated supply chain management. As more firms adopt the lean manufacturing concepts, the requirement for manufacturing engineering students to be trained in total cost analysis and optimization becomes more essential.

The Push and Pull Systems

The conventional form of production uses the "push" system wherein raw materials in large batches are pushed through the manufacturing processes in anticipation of a future sale[1]. This anticipation is based on sales forecasts with limited amount of accuracy. Plenty of WIP exists within the system to smooth production and alleviate substantial queuing at bottlenecks. Product varieties are typically large and finished goods stocks for each product are kept in appropriate amounts at various locations in the supply chain in order to respond quickly to daily demand. Information technology-based tools[2,3,5] such as Manufacturing Resource Planning (MRP II), Optimized Production Technique (OPT), and Enterprise Resource Planning (ERP) are used extensively by the push manufacturing systems for planning and scheduling production and related resources.

In pull production processes, finished goods stocks are absent in theory or kept at a bare minimum to be made available at the point of sale at or after the time of an order. The entire manufacturing system is flexible enough and laid out in the form of a flow shop or assembly line, to respond quickly to changes in demand. Very little WIP exists in the system and flexibility occurs due to small and standardized machine set-up times, shortened production times, standardized product components, and modular product and process design to adapt to market changes and demands.

Pull systems are information intensive manufacturing systems. Strategic alliances are forged between the raw material suppliers, manufacturers and the supply chain logistics and distribution firms, to manage inventory at each stage. Information visibility at each stage of the production enables the delivery of products at the right time, at the right place, in the right amount – which is the philosophy of Just-in-time (JIT).

The Hybrid Push-Pull System

Manufacturers of large varieties of products with unknown demand distributions and long production times will achieve a greater effect when utilizing a hybrid push-pull system. The hybrid systems provide the positive aspects of both the push system based on MRP II and the pull system based on Kanban and JIT concepts. The key to successfully implementing a hybrid system is to locate the push-pull interface where generic products in a family can be withheld from further production until a customer order is received. This strategy has come to be known as postponement, first coined by Alderson in 1950 in his *Marketing Efficiencies and the Principle of Postponement*.

Postponement, or delayed differentiation[6, 7] as it is sometimes called, divides the manufacturing system into segments of push and pull. The push segment of the manufacturing system makes generic parts that can be customized according to individual customer's requirements. These generic products are withheld from further customization as WIP at a certain point, known as the point of differentiation, or the push-pull interface, in the manufacturing sequence. When an order is received for customization and delivery, the appropriate numbers of generic products are released from the WIP into the pull segment of the manufacturing system that is ideally optimized for flexibility and throughput to accommodate variety in the product family. In short, a push system builds out generic products to the point of differentiation from where the pull system builds out final products in standard or customized SKU form.

Need for Manufacturing Strategies

In the engineering industry, not many examples are available where a manufacturer of products such as machine tools, automation tools, processing equipment, or specialized cutting tools has utilized postponement to its full advantage. In the engineering industry, although the products are of high value, the demand is usually unknown as is the number of products to be supplied. This paper investigates one such manufacturing company – ReedHycalog (a Grant Prideco company). It manufactures high value products with unknown demand distributions. It is known that most of the manufacturing activities have shifted from the United States to the overseas manufacturers. However, highly specialized items as those used in the engineering industry, are still manufactured within the US. These manufacturers must now look at manufacturing strategies to retain market share and profitability against global competition. Managing inventory is one of the ways to control costs yet ensure timely order fulfillment to stay competitive.

To increase output under constrained capacity, manufacturing firms can turn to a number of remedies such as increasing the number of hours per shift of production, increasing the number of shifts from one to two and then to three, increasing manpower, increasing capacity or automation at one or two stages of production, or finally adding more capacity in the entire manufacturing sequence by acquiring or building more manufacturing facilities. On the other hand, if the current manufacturing capacities and practices, including inventory control, are to managed and optimized without the time or costs of further capacity expansion, then another approach is warranted.

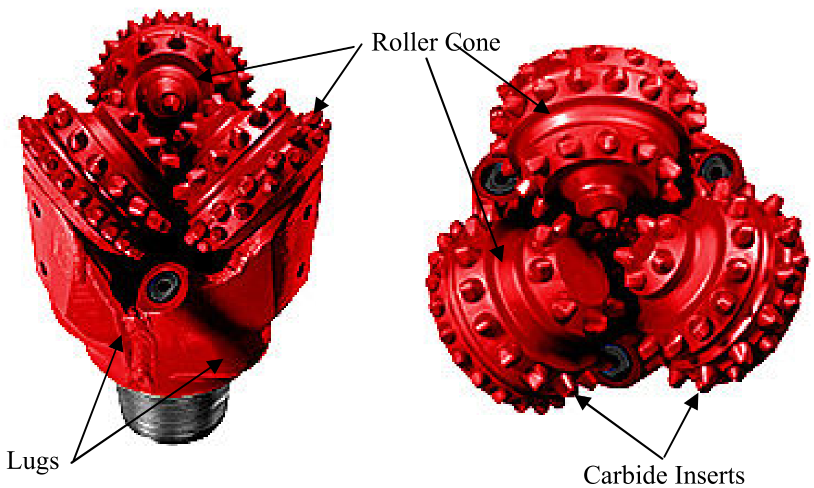

Figure 1: A typical rock bit. Obtained from the official website of the Reed Hycalog company. (ReedHycalog.com/rollercone/products/ems.htm)

The present study investigates the concepts of WIP deployment and management using commercially available computer simulation software. Real production data from ReedHycalog was used to model an actual manufacturing process instead of resorting to assumptions and speculations, and test the effects of the theory on a real and complex process. ReedHycalog is an oilfield service company and worldwide manufacturer and distributor of rock bit drilling tools. An illustration of a roller cone bit and its basic components are shown in Figure 1.

Oilfield manufacturers and service companies, such as ReedHycalog, market their products on the basis of instantaneous availability, product performance, quality, and reliability, technical support and services, and most importantly, price. Due to the nature of the oil industry, the oilfield service companies perform under extremely fluctuating, seasonal, and geographical demand patterns[9, 10]. They typically carry a range of sophisticated product lines to support different levels of the exploration and production activities.

Costs of oil rigs sitting idle due to equipment or tool failures can run into thousands of dollars a day, so manufacturers must respond quickly to fill orders. A driller's demand for tools can command a premium on drilling supplies based on availability of inventory. For this reason, companies like ReedHycalog maintain plant and field inventories of finished goods during peak Exploration & Production (E&P) activities so that orders can be filled in a very short time. However, these companies must also maintain adequate cash flows and huge inventories to get through the times of low oilfield activities.

Roller Cone Bit Manufacturing Process

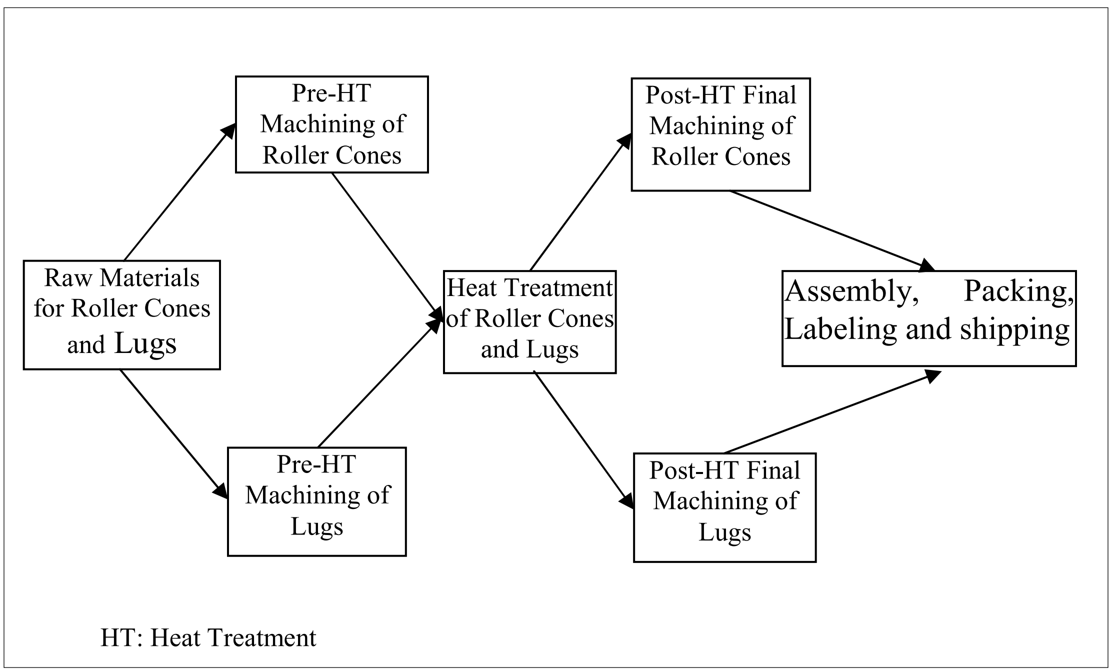

Figure 2: A schematic diagram of roller cone bit manufacturing sequence

The theory of strategic WIP deployment and management was tested on the manufacturing process of ReedHycalog, manufacturers of roller cone drill bits. Roller cone drilling bits[12, 13,14] are oilfield industry related tools, used to drill through hard rocks and similar geological surfaces for oil exploration and production. The entire bit is subjected to intense pressures and hard materials during drilling. A schematic diagram of the manufacturing sequence of a roller cone bit is shown in Figure 2 above.

Depending upon the drilling application, ReedHycalog offers unique combinations of inserts on the roller cones to address virtually any drilling situation. Cost of drilling per foot is of the greatest concern for oil exploration companies[8]. For maximum penetration rates and durability, the company offers bits with unique combinations of inserts according to shape, size, spacing, protrusion and material[12]. The holes for these inserts are drilled on the roller cones after the heat treatment stage, which means that till the heat treatment stage, most of the roller cones are very generic in form, and can be used for any type of bit configuration in a particular size. In short, a product differentiation occurs immediately after the heat treatment stage, giving rise to variety in the product line of the company.

LMM Simulation of Manufacturing Processes

The LMM simulation was built to test the effects of batch sizes on the WIP levels, using one of the optimized models in the authors' concurrent research[4] on strategic WIP deployment. In the concurrent research, multiple scenarios ranging from pure push to pure pull were simulated to test the theory of strategic WIP deployment. A pure push model utilized only finished goods inventory to respond to customer orders. While this scenario ensured high levels of customer satisfaction in terms of order to ship cycles, the associated inventory carrying costs were high too. In order to implement a low-cost lean manufacturing system, the finished goods inventory has to be minimized to expose the weakness of such manufacturing planning system.

On the other hand, a pure pull model resulted in a very low WIP levels in the system, as expected. However, due to these low levels of WIP in the system, customer satisfaction in terms of order to ship cycles was also low. Clearly, a balance is required between the levels of WIP in the system corresponding to reasonable levels of customer satisfaction. To achieve this balance, strategic WIP at the point of differentiation and point of assembly were tested. A low cost, flexible system was obtained by maintaining WIP at the point of differentiation. Within the LMM simulation, several batch sizes were tested at random for different components to observe the effects on the WIP levels and the order to ship cycles. Three different finished bit sizes representing the major size ranges (SKUs) were tested in the LMM simulation.

The data and information of roller cone bit manufacturing processes for the model was collected from the manufacturer through archival operating reports[11] along with a series of discussions with key operations and planning personnel. Manufacturing planning data sheets were used to record manufacturing and material related information such as (1) manufacturing sequence, (2) manufacturing capacity – number and size of the manufacturing/assembling stations, (3) manufacturing time including setup time on each of the processing/assembling stations, (4) manufacturing costs at each stages including labor costs and setup costs wherever applicable, (5) initial raw material cost, and (6) costs of any other custom items that went into the product at the time of the final assembly.

For simplicity and practicality, material handling, maintenance, machine failures and production rejections were not considered in the present model. In addition, components and raw material availabilities entering the factory were not constrained, and entities arriving at any station were entered for processing in a First-Come-First-Serve (FCFS) queue. Demand distribution was varied among each bit size to simulate constraints on the manufacturing capacity, which included the size of the order and the frequency of the orders for each size.

Company personnel from ReedHycalog participated in the LMM development. Meetings were conducted as the model development progressed and whenever clarifications were required. These meetings gave the opportunity to verify the work done to that point, increase the confidence level of the company representative in the LMM simulation, and gather more information on the process for further developing the model. Values of the simulation output parameters such as machine utilization, manufacturing cycle time, etc., were compared with the actual values of the performance measures in the company. Similarities in the two values helped to confirm the validity of the model. An aerial-view, screen-shot, of a section of the LMM computer model which was developed in the ARENA simulation environment, is shown in Figure 3 below, just for illustration purposes. The reader is referred to the complete Master Thesis of Mr. J. Rathod[15] for a detailed description of the research methodology and the simulation model.

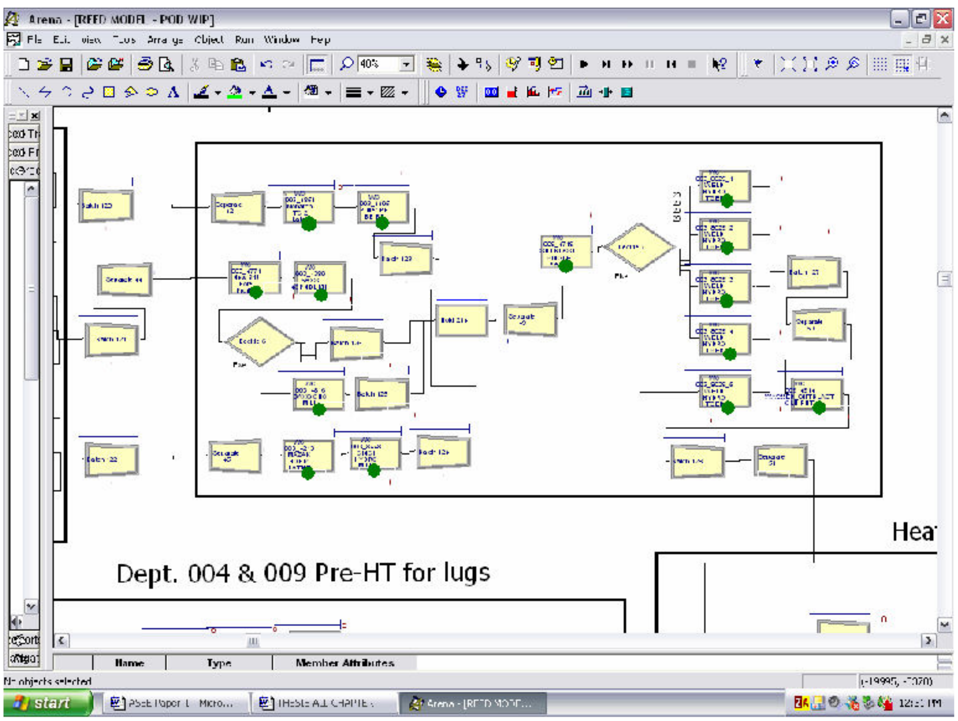

Figure 3: An Aerial-view screen shot of the LMM simulation of manufacturing processes

LMM Simulation Results

The LMM experimentations resulted in the determination of WIP levels of assembled bits in the system for cost effective, yet minimum time to delivery[15]. Although ReedHycalog follows the manufacturing of products to stock, implementing WIP levels at strategic locations, such as the points of differentiation, helps in a better system utilization. Only those components, for which an order exists, are released for further processing. This ensures availability of manufacturing capacity for the most needed items, while the components for which orders do not exist, can be held at much lower costs as WIP.

Scenarios	WIP Levels			Customer Orders
	Point of Differentiation			
	#1 Cone	#2 Cone	#3 Cone	Order to ship cycle (in days)
1	14	14	15	49.886
2	15	15	15	18.296
3	15	16	16	9.161
4	21	21	21	12.583
5	26	27	27	10.585
6	27	27	27	2.935

Table 1: Summary of WIP levels of bit components at point of differentiation

Table 1 summarizes the typical WIP levels of bit components at the point of differentiation obtained as a result of simulating of different batch sizes. The batch sizes corresponding to these WIP levels are also shown in Table 2. The point of differentiation is the interface between the push and the pull sections of the system. Different batch sizes were tried before and after the point of differentiation to test their effect on the order to ship cycles.

Scenarios	Before point of differentiation						After point of differentiation							
	12 1/4 in		16 in		26 in		12 1/4 in		16 in B1		16 in B2		26 in	
	Cones	Lugs	Cones	Lugs	Cones	Lugs	Cones	Lugs	Cones	Lugs	Cones	Lugs	Cones	Lugs
1	5	15	5	15	1	3	5	15	1	3	1	3	1	3
2	10	10	5	5	1	1	10	10	5	5	5	5	1	1
3	10	30	5	15	1	3	10	30	5	15	5	15	1	3
4	10	10	5	5	1	3	10	10	5	5	5	5	1	3
5	10	10	5	15	1	1	10	10	5	5	5	5	1	1
6	10	10	5	15	1	1	10	10	1	3	1	3	1	1

Table 2: Typical batch sizes of different components of bit sizes

The 12 ¼ in bits and the 26 in bits did not differentiate and were modeled to have very high and very low demand distributions respectively. It is the contention of the authors that if a product is not differentiating any further and is already in the system, the most economical solution to reduce WIP is to manufacture that product all the way through to finished goods where it can be consumed by a customer order. Hence, no WIP of the 12-¼ in. and the 26 in. was needed. However, maintaining POD WIP of 16 in. bits – the products that differentiate – have positive effects on the capacity utilization by the bits that do not differentiate. These effects are further discussed in a related paper by the same authors[4].

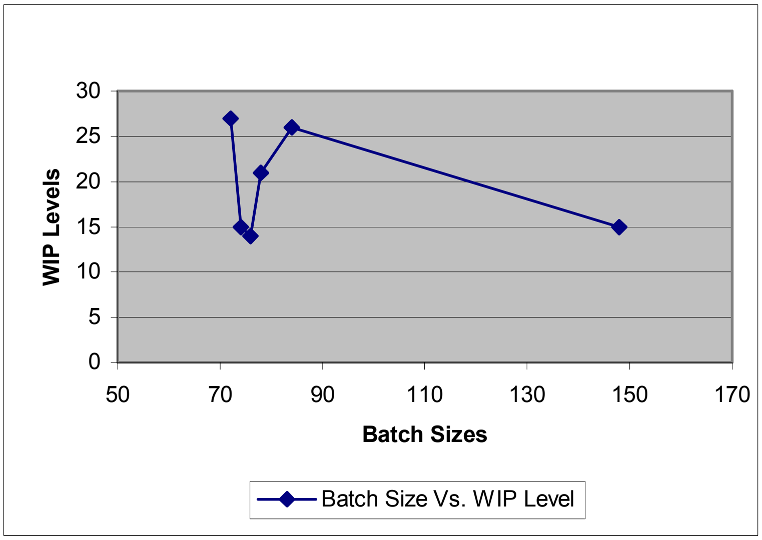

Figure 4: Effect of batch sizes on WIP levels

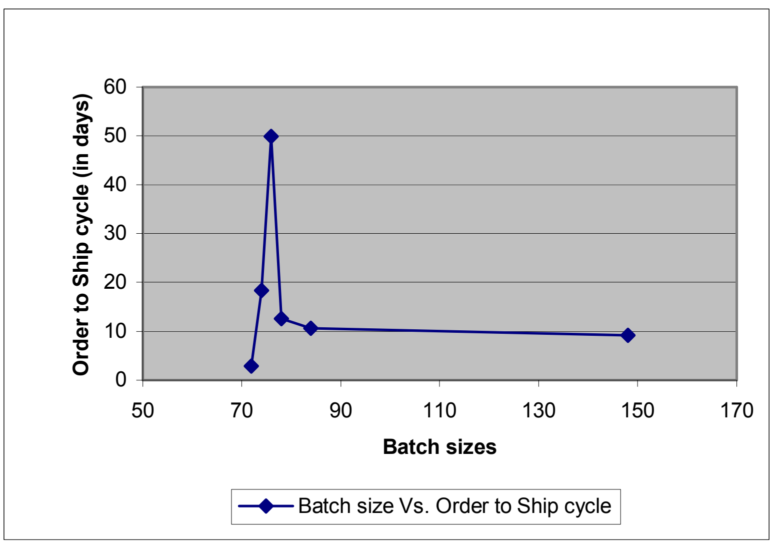

Figure 5: Effect of batch sizes on the order to ship cycle

Figures 4 and 5 above depict the effect of batch sizes on the WIP levels and the consequent order to ship cycles. Optimum batch sizes can be derived from these graphs for the least total cost of manufacturing and low WIP levels in the system while at the same time maintaining high rates of customer responsiveness in terms of the order to ship cycle. It is important to mention here that these graphs relate to the roller cone drill bit manufacturing process of three SKUs. Similar studies can be conducted for other manufacturing processes and systems, using hybrid push-pull concepts for product differentiation, and utilizing the LMM example through system design and optimization of similar computer-based simulation tools.

Conclusions

Computer based simulation environments, such as ARENA, can provide the opportunity to model manufacturing systems, and test the complex random natures of multiple variables without resorting to severely simplification assumptions. The activities that are modeled and simulated typically reside within manufacturing, supply chain, logistics and distribution, warehousing and other service systems[16]. The present study presents a methodology for conducting such research studies on manufacturing systems utilizing real world production data. The methodology of the LMM simulation, wherein students can collect the manufacturing data, develop a computer model, and then study their simulation under various testing of manufacturing parameters, in order to observe the total effects on the system.

A major advantage of the LMM simulation is the graphical representation of the system and the interaction of various entities within the system. Since the entire system is under analysis, a visual tool such as the ARENA simulation environment can help in determining anomalies throughout the system, whether they are in cost, in service, or in capacity planning. For example, it was found that during the LMM simulation, implementing a safety stock of lugs at the point of differentiation was not cost effective, because it took more time in processing and handling. Therefore, while generic components were held at the point of differentiation for flexibility, the lugs were continued for further processing until they reached the point of assembly.

Because of the complexity of such scenarios, the computer-based simulation study of the rock bit manufacturing processes has yielded a valid and reliable strategy, which is tied to the deployment and management of WIP at strategic locations. In addition, because rock bits are high-value, unknown-demand products, implementing such a strategy could help provide a cost effective responsiveness. This can reduce the total costs of materials, processing, storage and carrying costs as such risks associated with high-value finished goods stocking were spread among lower-values WIP kept at other strategic locations.

However, manufacturing processes are unique and may require computer simulation in different levels of accurate analysis. Computer modeling and simulation requires some training with regards to its functionalities, user interface, and the modeling and simulation parameters. Also, general concepts and variables in Mechanical Engineering such as product design, process design, manufacturing planning, along with their economic underpinnings, and modern concepts of Lean Manufacturing and supply chain management must be well understood to model and simulate the processes. Model development, validation, verification and simulation can take several months depending on the level of accuracy desired and the complexity of the process and its variables.

In addition, because of the multiple outcomes generated from various scenarios, the simulation results have to be assimilated and presented in an easy to understand formats; such as graphs, tables and charts. While the development of a comprehensive LMM simulation package can be very costly in terms of time and other resources, the resulting important decisions which can be reached will be very valuable in terms of all the long-term gains associated with global competitiveness, profitability, and the entire future of the manufacturing company.

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