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Abstract: In this paper we suggest a method to achieve optimum system efficiency when used on very small production lot sizes with associated high costs and dynamic changes, as are typically found in high dollar capital equipment manufactures. We analyze a specific case, and applied a hybrid planning and production approach to achieve an optimum solution.

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DESIGN OF AN OPTIMUM PLANNING/PRODUCTION SYSTEM FOR VERY SMALL PRODUCTION LOTS: JIT/MRP/ROP SYSTEMS TO OPTIMUM PERFORMANCE

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Design of an Optimum Planning/Production System for Very Small Production Lots: Applying JIT/MRP/ROP systems to Optimum Performance

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ABSTRACT

This paper suggests a method to achieve optimum system efficiency when used on very small production lot sizes with associated high costs and dynamic engineering changes, as are typically found in high dollar capital equipment manufactures. The paper describes a specific case, and uses a hybrid planning and production approach to achieve an optimum solution.

Introduction

Although many problems exist in producing a low volume, high dollar product, for the purposes of this paper, I've chosen to concentrate on what has been determined the most difficult, highest risk, and highest cost area of such a system, the production of electronic circuit assemblies (ECA's). It is also understood that JIT, and JIT/TQC, as used in the literature, comprise many more elements than are discussed in this paper. Areas such as single digit set-ups, autonomation or applying the human touch to automation, and multiple-process lines (work cells), are not addressed in this paper.

This paper, rather than trying to research a subject, concentrates on a situation, and tries to apply the best methodology(s) to achieve an optimum solution. As such, various methods are addressed, but not in the depth each methodology needs to be fully comprehended.

For purposes of simplicity, a sub-set of ECA's of a system is used as an example throughout. The subset are all ECA's used in the handler portion of our lowest price system, a system which has a list price of $225,000. The handler comprises approximately one-third of the total product cost, is approximately one-third of the system count of ECA's, and is otherwise representative in areas such as complexity, size, and layer count, of the system ECA's as a whole.

The Desire to Use JIT and JIT/TQC

The US semiconductor equipment industry is in a perilous position. Of the 300 members in SEMI in 1985, only 60 remained by 1989[1]. Of those 60 firms held publicly (55%), only two firms had consistently sustained profitability over any four consecutive quarters[2]. Initially, these firms were characteristic of stereotypical "American" excesses: very high profits, ignoring manufacturing efficiency, insensitive to customer needs because of a multi-year backlog of orders, and unresponsive to reliability needs of their customers. These companies were the "glamour" industries of 1985, before the world wide glut in semiconductor devices occurred in mid-1985. Those firms which have survived, however, have done so by correcting the majority of the problems listed above. In my own firms case, we have successfully stopped our major competitor, Nikkon of Japan, from entering either the US or European markets. We have 50 % of the domestic Japanese market, and are gaining market share in that country, based on superior reliability as well as system throughput. We cannot, however, compete profitably on price because of our low profit margins. Because of the small number of customers worldwide (30), and the continued depressed market, every potential sale comes down to price, with Nikkon and ourselves pitted against each other. This low margin cannot continue. The only area left to compete against this competitor is on manufacturing efficiency.

JIT is being investigated, both because of the volume of literature being generated on the subject as a savior of American industry, as well as being identified as the methodology used by our competitor. We have successfully implemented within the last two months the "Just-in-Time" delivery of system

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[1] SEMI's (Semiconductor Equipment Manufactures Institute) 1990 Annual Report of Statistics To Members.

[2] Hambeck and Quist, Investment News Letter, Sept, 1990, recommending one of those firms, Novellus, as an investment. The other profitable firm is Applied Materials.

frames, and work is underway to address sheet metal enclosures. The next logical step appeared to be applying JIT delivery to ECA's.

As a new Manufacturing Manager, I decided to investigate this approach, as we were having severe difficulties with ECA's from our vendor. My first investigation was to understand what JIT was. I started with Ohno Taiichi[3],[4].

In many ways, I could immediately relate to the position Ohno found himself in. Starting with Toyota Motors in 1943, he was faced with the very survival of the Japanese automotive industry after WW II. Toyoda Kiichiro instructed him on August 15,1945, the day the war ended, to "Catch up with America in three years. Otherwise, the automobile industry of Japan will not survive"[5]. Ohno did not start out to improve on the American system, as is stated by Sandras [2] and others, but rather out of desperation because he could not hope to duplicate the American methods which relied on large volumes. Toyota's production of cars in 1949, four years after the war, was 1,008[6]. Toyoda and Ohno, were both very knowledgeable about American techniques, having visited the US, and it's automotive industry, prior to WW II[7]. Ohno sites Ford's 1926 accomplishment of 41 hours from the start of offloading of iron ore to the delivery, with cash in hand, to the dealer of a finished car, as an inspiring accomplishment,

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[3] Throughout this paper, I use the direct translation approach when listing Japanese names. In this case, Ohno is the family name, and Taiichi the given name.

[4] Ohno, is accepted as the creator of JIT principles, having implemented them at Toyota over a 35+ year span. He is often mentioned with Henry Ford as one of two people who have defined automotive production. He is well known and respected world wide, however, his writings have just recently been translated outside the Japanese language. The reason for this late credit may be his writings are not necessarily complimentary towards American/European cultures.

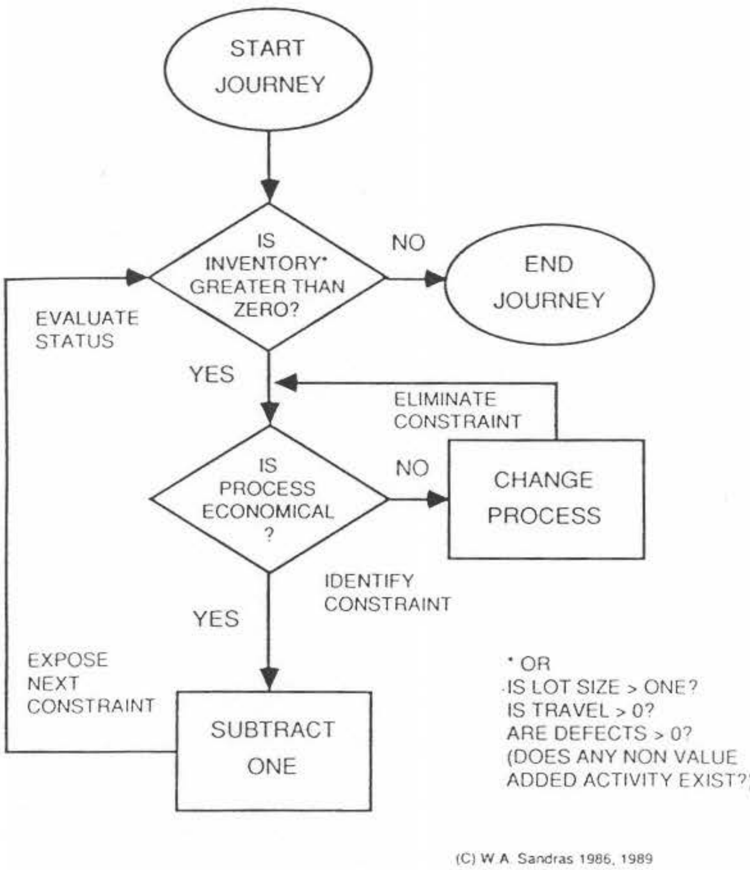
[5] Ohno [6], pg 3

[6] Ohno [6], pg 9

[7] Onho holds a considerable amount of respect for earlier American automotive production techniques, especially those implemented by Henry Ford. Ohno quotes Ford frequently, and devotes a chapter of his book to Ford. In his book, Ohno feels that in 1926, Ford was on the verge of implimenting JIT, when Alfred Sloan at GM introduced the "full line policy", which posed the first serious major threat to Ford Motor Company, and forced Ford into a market driven approach and away from pure manaufacturing efficency.

one which caused Ohno to set new bench marks for Toyota[8]. After studying Ohno, I became convinced that this was a valid method, and one which would supply needed efficiencies.

The next step in looking at the process, was how to implement it. Sandras [7] suggest a method where by each process is looked at , one part at a time. His example uses a quantity of 500, and asks what happens when we produce 499 parts rather than 500? If nothing happens, then we proceed on to 498 parts, etc, and continue the process until something forces us to evaluate our process. Sandras refers to this as his "one less at a time" methodology[9]. Sandras expresses this in a flow chart, listed below.



When using Sandra's flow chart on a very small lot size of ECA's, the first pass through will result in a "change process" branch. This is because at quantities of less than approximately 20 to 40

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[8] Ohno [6], Pg 97

[9] Sandras [7], Pg 17

ECA's, the cost increases linearly until a lot size of under 10 is achieved, where the cost increase begins to act geometrically.

Further, when you attempt to change the process, you initially run into quality degradation because of changing the process from a programmed automatic insertion machine, to a hand built model, where each board is loaded with components manually, subject to the variability of a human being stuffing as many as four hundred components into an area twelve inch square. As you drop this process below a quantity of ten, you also start to see geometric rises in component costs, ultimately resulting in costs increase as much as twenty five times higher per ECA for a single unit purchase then if ECA's are purchased in multiples of twenty or more.

The initial impression is that JIT techniques cannot be used on ECA's, unless extreme cost penalties can be incurred, which is clearly contradictory to the intended objectives. Readings from Vollmann [9] confirms that other firms, such as Hewlett Packard's (HP) Waltham, MA, medical instrument plant, do not use JIT techniques on components or the basic element of all ECA's, the printed circuit board[10].

Expanding the Definition of JIT

Using the information gained from HP in the previous example led to the first exploration of using a mixed mode planning model. HP uses JIT to create a pull system, while at the same time using MRP to plan for component buying. Other literature (Sepehri [8], Hall [5], and MRP II and JIT...[1]) supported this mixed mode operation. Sandras' articles on overall objectives stated that above all the following three things must be accomplished:

- o Increase the quality and reliability of our products, processes, and services.
- o Improve our delivery, dependability, and responsiveness.

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[10] Vollmann [9], pg 106

o Lower our costs for value delivered[11].

Ohno had said there were seven great waste that must be avoided:

o Waste of overproduction

o Waste of time on hand (waiting)

o Waste in transportation

o Waste of processing itself

o Waste of stock on hand (inventory)

o Waste of movement

o Waste of making defective parts[12,13]

With the opening of the mixed mode planning system, these concepts which I had come to value and wanted to apply, once again became valid. I now expanded the JIT concept away from the supplier, and to the point of use. I was also determined to use whatever method best fit the situation to achieve the above two authors principles.

This decision also freed my though process to address another area of concern with ECA's, that of spare parts supply. Unlike components such as the system frame and sheet metal kits , which had been, or appear to be, successfully implemented in JIT delivery, all ECA's fail at some point in time. The effects of thermal stress, voltage and current shock, and fatigue take there toll on ECA's to various degrees. We have a policy of a replacement ECA sent to the customer within 24 hours. This requires a

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[11] Sandras [7], pg 15

[12] Ohno [6], pg 19-20

[13] In US literature, these Famous Seven Wastes are attributed to Shigego Shingo. Both Sandras [7] and Hall [4] credit this source. However, Shigego's article appeared in 1981, and had the advantage of being translated into english. Ohno published these items verbatim in 1978 in the Japanese language, and relates using them as early as 1951. Shigego credits Toyota for the concept. However, Shigego has been labeled as the author, and has to some degree been institutianalized in the US with these thoughts. They are cleraly not Shigego's. Ohno does not claim they are his, he does not attribute them to any source, as is the style of most of his writting.

certain inventory be maintained to insure we can meet this demand. It is not possible to use JIT for this, and to insure success, a certain amount of safety stock is required. It is also desirable to maintain this inventory at it's lowest possible level. Under initial JIT concepts as I perceived them, we would have had to plan for this inventory in a separate plan, a very costly process.

Webber [10] further expanded the horizon of planning methods by re-introducing the Re-order Point system (ROP), a method which was very much out of favor with MRP advocates in the early-to-mid 1980's, who saw it as safety stock, and not allowing full system efficiency.

A forth method of procurement also was suggested in discussions with a vendor. That concept was to purchase shop capacity in hour blocks, versus submitting specific purchase requests.

Costs

Before proceeding further with a planning/production model, a detailed look at costs is required to determine the sensitivity of any factor to these models. Presently, a modified version of the A, B, C classification is used, with an A+ designation being added for the top one hundred dollar items in a rolling twelve month period. Eighty percent of all ECA's are A parts, Fifteen of all ECA's are B parts, and five percent are A+ parts. The ordering rules for these parts is apparently designed to produce a low inventory value by allowing A+ parts to be ordered for one weeks demand, A items ordered for two weeks demand, B items for 8 weeks demand, and C items for up to one years demand. The average production quantity of any given system, however is 5 per quarter, making these rules prohibitively expensive if a vendor has high or even moderate set-up costs, and is not willing to hold material for you. ECA vendors will not hold inventory because of the risk level associated with engineering change orders (ECO's). Using the above ordering rules would equate to order quantities of one or two boards, which is prohibitively expensive. Investigation into what was actually be done showed that all purchasing agents were violating the rules, although they were not consistent in their ordering rules, and an average lot size of 5 ECA's was being procured at any one time. This resulted in the following cost formula:

$C = K^* 5(L+M)$

where K is the set-up cost, L is labor required to produce one board, and M is the material to produce one ECA.

This resulted in an average cost of $531 per ECA for the subject assembly.

Using the traditional Economic Order Quantity formula of:

$Q = (2CpA/Ch)^{.5}$

where Cp = $75, A=15 , and Ch values were varied from twelve percent to fourty-eight percent, in multiples of twelve, resulted in a suggested Q of three units. There is, however, a significant pricebreak on quantity at ten units. Applying the same formula to the upper one third of A, demand, resulted in ten being the optimum Q in that range. Evaluating price at quanties of three and ten resulted in average prices of $567[14] for three and $332 for ten units. Clearly, quantity discounts far outweight any other factor, as was expected.

An additional analysis was done taking into consideration the risk of obsolescence. ECA's are frequently updated and changed for other reasons, and account for two thirds of all ECO's requiring rework or scrap in this firm. On an average basis, there is a seventeen percent chance of any given ECA being obsoleted or requiring rework in any given year. this is considerably higher than the traditional less-than one-percent figure used in inventory holding calculations[15]. Masters [5] suggests that where the risk of sudden obsolesence is high, it should be accounted for in the Q equation. Masters modified Q formula is:

$Q = [2CoA/Ch(H+1/L)]^{.5}$

where L is a factor derived by dividing average inventory value by annual obsolenscence costs, in this case, using only ECA's in both the numerator and denominator. Co is order replensihment cost.

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[14] At first glance it may appear to be contradiction that a quantity of 3 is the optimum figure when the last paragraph showed a Q of 5 to cost less. The first method was strictly a price calculator, and did not account for such items as purchasing and shipping costs.

[15] Masters [5], pg 1180

Using Master's formula at various ranges from five percent to twenty percent significantly altered the cost of holding the material until the quantity of ten was reached, from a previous cost of $332 to $368. However in comparison to the quantity price break, it still was not significant enough to alter taking advantage of the price break.

Therefore, ordering rules should be changed to take advantage of the quantity price break as long as the Q falls within the demand for a given period.

Optimum Solution

The solution suggested by the previous discussions was to look at each level of material requirement and determine the best method of production/planning. The criteria for a successful solution is to maximize all of the following:

o The lowest possible cost

o The lowest possible processing time

o The shortest possible cumulative lead time

o The highest possible flexibility

o The highest possible reliability of process

o Allow the vendor to maximize all of the above criteria with their vendors

Based on findings offered previously, a hybrid solution was already decided upon as the optimum solution, but at what level and what type still needed to be defined. I decided to break the process into independent steps, make a decision on the best method for that step, then re-assemble the process steps back into a continuous process and re-evaluate the methods to make sure they still made sense in a larger model.

The initial steps were:

Process	Planning method	Control method
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System Assembly	JIT delivery	Kanban
ECA vendor	MRP	Order Release reports
Component supplier		Purchase Order

This initial method, however, did not allow for the decided Q of ten units from the vendor, allow for spare parts, or allow flexibility for the vendor's suppliers.

To adjust for these concrens, the following modifications were made: the stockbank would have to take delivery of lots of ten at a time, and issue them to assembly on a Kanban basis. By stocking the kits, this would also allow us to minimize risk by having a stock-out situation when emergency spares demand occurred, thus still reducing the overall inventory carried. A second modification was to allow the ECA vendor the ability to order all materials as part of this newly conceived kit of ECA's versus ordering one specific part number at a time. This step cannot be over emphasized - by not only increasing the minimum order quantity to ten of each type, but ordering all ECA's within the same product at the same time, the vendor, and ultimately our price, benefits by allowing combinations of similar components [16]. An estimate of cost savings on this step alone is an additional fifteen percent reduction in the cost of ECA's of this product. This method also included looking at ECA's vendors differently. A typical cost of a printed circuit board, the base unit of all ECA's, is $650. This cost is a minimum batch run, and whether you order one or ten, the cost is the same. This is due to raw panel sizes and the size of processing machinery in this industry. Rather than purchase each printed circuit board separately, capacity of X hours is purchased, allowing all printed circuit boards in a kit to be manufactured in this block of time. Savings of ten to thirty percent can be achieved by this method, as well as an overall reduction of paperwork and leadtime associated with paperwork.

[16] Approximately 30% of components are common within this product groups ECA's.

The following modifications were made:

Process	Qty	Planning method	Control method
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System Assembly	1 Sys kit	JIT delivery	Kanban
Stock Bank	10 Sys Kits	ROP	Electronic Kanban[17]
ECA vendor	10 Sys Kits	MRP	Order Release reports
Component supplier	All components in a kit of 10	MRP	Purchase Order
PCB supplier	X hours capacity	ROP	Purchase Order

This method also has an immediate effect on planning overhead and it's related cost, both in complexity and actual dollars. Instead of planning and purchasing each ECA individually in lots of five, as is done today, ECA's would be built to forecast in lots of tens and backflused from the system as used. An initial evaluating of expenses alone in this operation, if this method is applied to all ECA's used on systems, indicates a savings of one persons time per year, and $15,000 dollars in excess shipping charges alone.

Another consideration is the high level of ECO's against these parts. Presently ECO implementation is a very difficult operation to manage because of what is called revision skew. This occurs because different ECA's (and other components) are ordered at different times and in different lot sizes. There is always the problem of incompatibility within a system because of the merging of these various ECA at some unknown and virtually impossible to calculate point. Additionally, there is always the problem of old stock. This problem occurs because inventory was "somewhere" in the production system, but was overlooked when reworks were done. System kits would be controlled as a single kit by

[17] Electonic Kanban is a method discussed in Webber's [9] article, and describes using an electronic means of communicating with a vendor once a ROP is reached. It has the advantages of a kanban system by decreasing paperwork and backflushing requirements, but can be used at a distance and when a visual reorder point is reached in kits.

creating a traveler for those kits. As in any kanban system, an ECO can be implemented by blocking the "pigeon hole" as Sandras suggests, or otherwise pegging a specific kit for change.

In the event extraordinary spares demands occurs, as in the case of a product "recall" [18], individual orders for ECA's can still be launched. Also, if problems occur due to engineering delays, HP's silver bullet method can be used[19].

An additional consideration is the effect on product leadtime. A major solution to large inventories is to insure flexibility in product mixes as well as a quick reaction to market changes, both positive and negative. Eventually, when this method is applied to all three system in production, we can go away from the brand name kanban suggested here, and to the generic kanban where the next product is pulled for assembly based on selling a unit of that product line[20]. Another lead time savings is achieved by building from forecasts versus waiting for a purchase order to be launched. The cumulative savings from reducing que time for paperwork alone on this assembly is three weeks of a ten week cycle.

Summary

This paper has shown that by re-evaluating decisions rules in place within a firm, and then using a hybrid approach to the planning and production of various assemblies, significant gains can be made in achieving higher quality, significantly lower costs, and reduce leadtime on products which have very low volumes of end products.

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[18] We do not actually recall our product. On occasion, however, we have had to rework our product because of an unforseen problem. When this occurs, we have to send field service technicians to each system to upgrade the system.

[19] HP's silver bullet method is described in Sandras [7], pg 64. This method allows a certain amount of extra kanban cards to be used in the system for such emergencies. HP allows 6 such extra kanbans before deciding the process is out of control. The limit of six places a very high value on each one (hence the "silver" connotation), as well as the tie to six bullets in a revolver, thus "silver bullets". In looking at my process, I'm considering using an updated weapon annalogy, the 9mm, which has a magazine of 25...

[20] The brand name and generic kanban discussion is from Sandras [7], pg 64.

These changes would result in a lowering of costs of an average of forty eight percent on this systems ECA's and reduce this portion of the system lead time by thirty percent. System quality will increase because we have minimized revision skew and eliminated "other" inventory locations which were not typically identified.

An additional consideration in this method is the simplicity. Although it may appear to be complex, there is actually very little required once the system is set up. As it turns out, this is very fortunate, since a major problem in materials management today is the availability of hybrid planning systems. Benson [2] and Vollman [3] discuss some hybrid systems in use at a few companies, but limit there discussion to combining two systems. The method described in this paper requires a three system hybrid. The expense, if a firm were to try and purchase, maintain, and operate three systems ,would make the decision to use a hybrid system a certain failure. This does not have to be, however. In this case the ROP system as well as JIT are both operated on a visual basis, and only require backflushing of the existing MRP system already in use. Additionally, the separation of ECA manufacturing from an in-house process to a vendor supplied process, does not even require that we maintain a MRP system in the future, certainly not one which is as elaborate as the existing system needs to be to handle the management of all these various components. The area of hybrid planning systems, however, is in need of much further development as more of these solutions are proposed, and is an area of opportunity.

Further, although not germane to this paper, the extreme cost of failing to design an ECA right the first time is empathized, and must be explored, and well as investigations into other means of defining machine control logic (ie pneumatic controls vs electronic). These issues will become even more pronounced as continue emphasis is placed on international competition and we isolate product costs as the largest single remaining issue to be resolved to remain competitive.

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