THE CONCEPTS OF OPTIMIZED PRODUCTION TECHNOLOGY OPT - THE WAY FORWARD

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Introduction

Optimized Production Technology, or OPT, is a new concept in the control of manufacturing companies. It embodies both software and a philosophy which challenge the core of some of our current systems and control techniques. It starts from first principles by looking at the goal of the manufacturing organisation, and then shows us how by utilising the large investment already built into our current systems in a better way, we can challenge and beat competition from the East.

OPT has been proven in a large number of major U.S. Corporations and is now recognised as a major enhancement to the traditional Material Requirements Planning, or Just-in-Time systems.

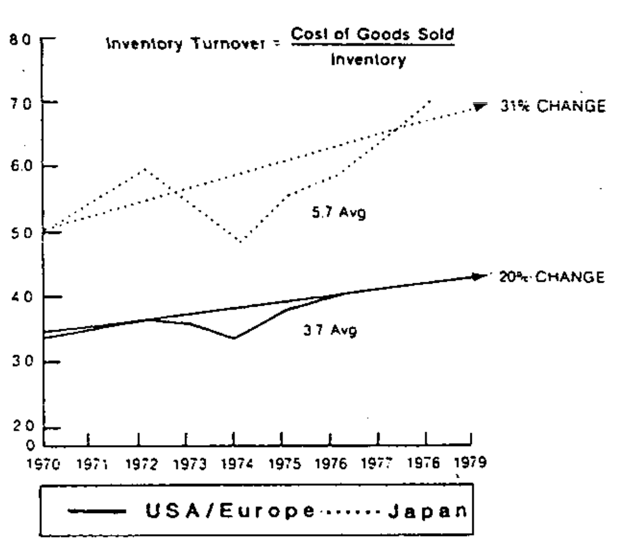
The Japanese Threat

Over the past twenty years, British, European, and American industry has invested many millions of pounds in the implementation of computer based Material Requirements Planning systems. Frankly, the results have been disappointing and largely restricted to improvements created by the mechanisation of previously long-winded manual routines.

If we look to the East, the Japanese on the other hand have performed a manufacturing feat that has left much of our industry gasping or dead,e.g., motorcycles, televisions, cameras, and now cars. We wonder how they achieved it, and reassure ourselves that it can be put down to a different culture or work ethnic, jobs for life, docile labour and attention to quality.

An analysis of Japanese and Western companies during the seventies by Booz Allen and Hamilton shows the extent of the problem. A prime measure for these purposes is Inventory Turnover. An improvement in this figure demonstrates increased throughput or reduced inventories or a combination of both, pointing to better profits, shorter production lead times and a healthier company. During the seventies (Fig. 1), Western Industry on average turned its stock 3.7 times, improving 20% during the decade. The Japanese turned their stocks on average 5.7 times, but more worringly the improvement over the decade was 31%.

Fig 1

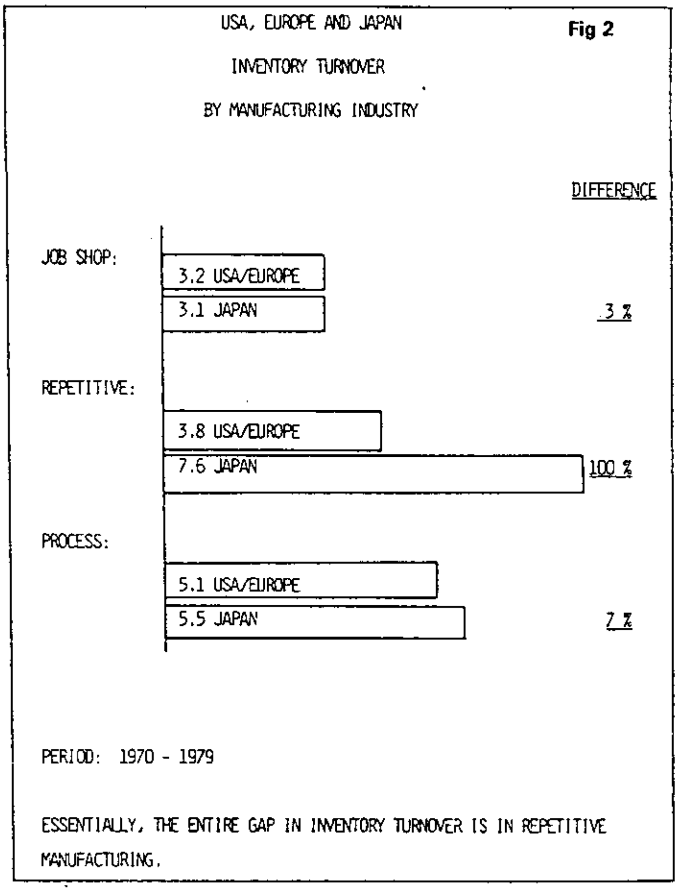


Source. Booz Allen & Hamilton Survey of 1500 Companies

Not only were the Japanese better, but moving quickly further ahead. Further information into the 1980's shows that the gap continues to widen.

A more detailed analysis by industry type (Fig. 2) shows where the area of greatest concern lies. In both Job Shop and Process industries the difference between the West and Japan is minimal. But in the Repetitive Batch manufacturing sector, by far the largest, the Japanese turn their stocks twice as fast as the West. No longer can we point to cultural and other reasons for the difference, we must look in detail at our methods of manufacturing and production control.

Fig 2



What is the Goal?

We must start by asking what is our purpose in the field of production control. It must be not just to employ people, to produce product or to improve efficiencies on the shop floor. It is to ensure that the company MAKES MONEY. But not just profit on its own. In order to survive and improve, a company must simultaneously improve NET PROFIT, RETURN ON INVESTMENT and CASH FLOW. Any system which fails to consider these facts as its purpose, is destined to drive us in the wrong direction.

But these are Financial Measures which one applies to a complete plant or business and which are difficult to monitor on a daily basis, so we need to derive Operational Measures which will help us with our daily decision making. The first can be specified as Throughput (T), **not** output of finished product to warehouse, but the production of items which will immediately generate cash through sales. The second is Inventory (I), including Raw Materials, Work-in-Progress and Finished Goods, the levels of which reflect the cash tied up and directly, the length of production lead time. The last and 'catch all' is Operating Expense (OE). Operating Expense covers all the expenditure of the

Company other than that related to the purchase of raw material and components for conversion into Throughput.

So what are the aims of the company and its production control system? We should aim to increase Throughput, whilst SIMULTANEOUSLY reducing Inventory and Operating Expense (Fig. 3). To improve one without considering the effect on the other two, may take us in the wrong direction.

We will use these criteria to judge the effectiveness of our systems.

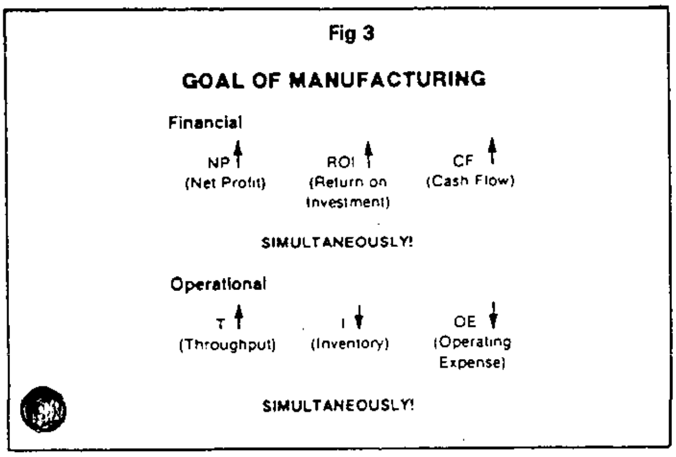


Fig 3
GOAL OF MANUFACTURING

Balance the Flow - Not the Capacity

Now that we have set the goals, what do we need to do to achieve them? The Japanese use the analogy of a river system to explain that the all important rule is to balance the flow of production. One has only to look at the process industry or the assembly line to see two examples where material flows smoothly with only limited inventory in the system. Both are considered very efficient, and yet everyone will realise that, 'in the line', there are processes working at significantly less than their capacity. So why is it that we don't recognise the same phenomena in batch production? It is impossible even in a dedicated assembly line to balance the capacity of all machines exactly. How much more difficult is it to balance capacity in a general purpose machine shop? We should recognise capacity imbalances and concentrate on achieving fast efficient flow through the resources with a minimum of inventory in the system. This leads us to the first of the rules of manufacturing developed by Dr. E. M. Goldratt, known as the Rules of OPT.

RULE 1: BALANCE FLOW
NOT CAPACITY

Understand the Role of the BottleNeck

If it is impossible to balance capacity, we have to recognise that in any plant there will be two different kinds of resource - bottlenecks that constrain production and non-bottlenecks which have spare capacity. Production control is an attempt to organise our resources and the flow of materials to produce a schedule of operations which leads us towards the goal of the manufacturing organisation. In order to do this we must first understand the inter-relationships between the two types of resources we have in all our plants:- bottlenecks and non bottlenecks. A resource can be any element needed to produce a product such as people, equipment, machines, fixtures, guages, space and the like. Let us denote a bottleneck resource as X and assume that the total of all market demands for this resource is 200 hours per month. Let us further assume that this demand exactly matches the available potential or capacity of this resource (200 hours/month). Let us also denote Y as a non-bottleneck resource with market demands of 150 hours per month and a potential of 200 hours/month. We can now examine the four different relationships between bottleneck and non-bottleneck resources which comprise the fundamental building blocks of any manufacturing operation (Fig. 4).

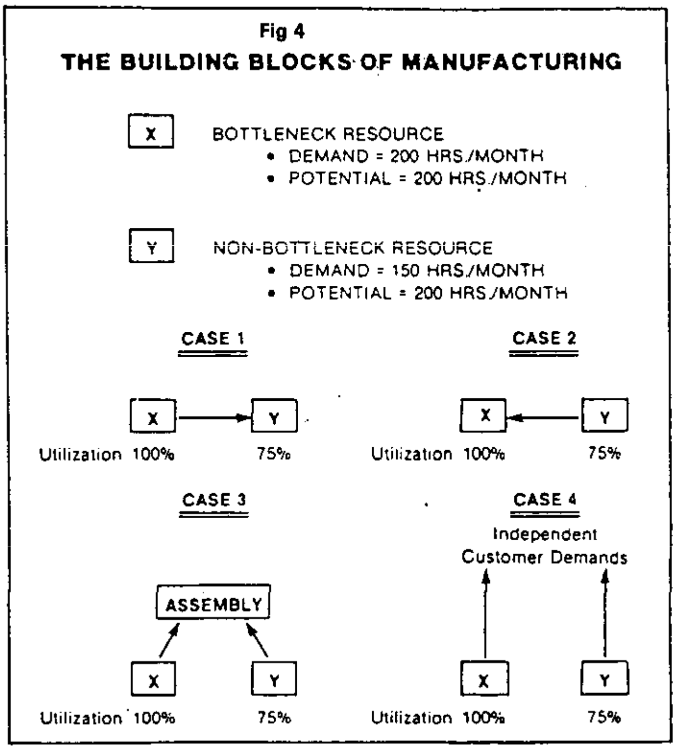


Fig 4
THE BUILDING BLOCKS OF MANUFACTURING

• **Case 1**- All product flows from X to Y. In this situation, we can fully utilise resource X 100%, but we only utilize resource Y 75% of time. X starves Y. It does not produce enough product to keep Y working all the time.

• **Case 2** - All product flows from Y to X. Again, we can utilise X 100% of the time and if there are sufficient raw materials we can activate Y 100% of the time. However, since our goal is to simultaneously increase throughput and reduce inventory and operating expenses, we must conclude that we can only utilise Y 75% of the time. To activate Y more than 75% of the time results in the build-up of work-in-process inventory ahead of X. This action increases inventory and operating expense without increasing throughput. It moves us away from the goal of manufacturing and should not be called utilisation.

• **Case 3** - X and Y, instead of feeding each other, feed a common assembly. Again, we can fully utilise resource X 100%. However, if we attempt to activate resource Y beyond 75%, we will build finished parts inventory in front of assembly. So we must conclude that we can only utilise resource Y 75% of the time.

• **Case 4** - Resource X and Y do not feed each other or a common assembly, but feed completely independent market demands. Once again, we can fully utilise resource X 100%, but we can only utilise resource Y 75% of the time. To activate it above this level results in finished goods inventory, since the market demands for Y are only 150 hours/month.

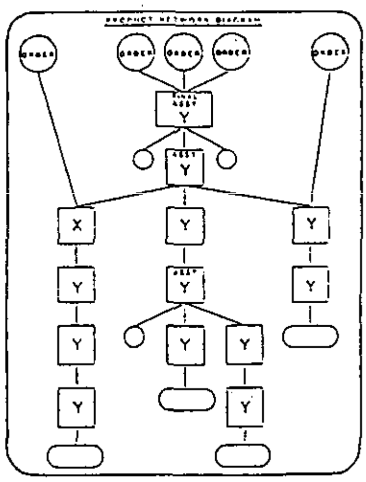
There are many other relationships between bottleneck and non-bottleneck resources which we could consider. Fortunately, we have obtained exactly the same answer in each of the above situations. Therefore, we can conclude that we will get exactly the same answer for any linear combination of these four cases. Linear combinations of these four building blocks can be used to depict every type of manufacturing and every manufacturing plant that exists. So what we have is not four relationships between bottlenecks and non-bottlenecks, but a representation of the reality of manufacturing. Consider the more normal diagram of a product manufacturing process (Fig. 5) showing both the structure and the operational routings. We can choose to put the bottleneck at any operation. But whenever we do so, we find that the relationship between the bottleneck operation and any non-bottleneck operation is governed by the four cases alone. Consequently, we can derive two further rules of OPT.

Fig 5

SINCE THE ANSWER IS THE SAME IN ALL FOUR CASES,

IT WILL ALSO BE THE SAME IN ANY LINEAR COMBINATION

OF THESE FOUR BASIC BUILDING BLOCKS.



RULE 2 - THE UTILISATION (profitable) OF A NON-BOTTLENECK RESOURCE IS NOT DETERMINED BY ITS CAPACITY BUT BY SOME OTHER CONSTRAINT IN THE SYSTEM.

RULE 3 - ACTIVATION (making it produce) OF A RESOURCE IS NOT THE SAME AS UTILISATION (profitable) OF THAT RESOURCE.

Our experience shows that there are very few bottlenecks in a plant (usually less than 3%). We must therefore recognise that chasing the goal of high machine usage (ACTIVATION!) will not improve production or throughput but will generate excess inventories instead. Our systems must therefore reflect the need to understand the effects of finite capacity constraints on other parts of the plant. We must schedule non-bottlenecks around the capacity constraints, and not ignore them. Before we move on, consider the impact of what we have just said on the traditional cost accounting measurements we use to monitor our plants. They tend to look for high machine usage and high output of standard hours (irrespective of actual capacity requirements), and often drive us in the wrong direction. But that is the subject of another paper!

The Value of Bottleneck Management

Traditionally, we regard all our resources with equal or near-equal value. We must learn from the above the difference in value of the two types of resource and how great is the payback from extremely tight control on a very limited number of resources -the bottlenecks. Let us first consider the time available on each type of resource, and how it is divided between different kinds of activity.

The available time at a bottleneck resource is split between processing time and set-up time (Fig. 6). If we save an hour of set-up, we gain an hour of processing time. Furthermore, an hour saved at a bottleneck operation is vastly more important than just the increased hour of production at the bottleneck. It is equivalent to an extra hour of throughput for the TOTAL system.

On non-bottleneck operations we have three elements of time-processing, set-up, and idle time (Fig. 6). Here, if we save an hour of set-up, we gain an additional hour of idle time. Consequently, an hour saved at a non-bottleneck is worth nothing.

Fig 6

SET-UP - DEPENDS ON THE TYPE OF RESOURCE

X	BOTTLENECK RESOURCE	PROCESSING TIME	SET-UP TIME	

- A SET-UP HOUR SAVED RESULTS IN AN ADDITIONAL HOUR OF PROCESSING TIME.
- AN ADDITIONAL HOUR OF PROCESSING TIME RESULTS IN AN ADDITIONAL HOUR OF THROUGHPUT FOR THE TOTAL MANUFACTURING SYSTEM.

Y	NON-BOTTLENECK RESOURCE	PROCESSING TIME	SET-UP TIME	IDLE TIME

- A SET-UP HOUR SAVED RESULTS IN AN ADDITIONAL HOUR OF IDLE TIME.
- AN ADDITIONAL HOUR OF IDLE TIME IS WORTH NOTHING — IT IS A MIRAGE.

This leads us to two more OPT rules:

RULE 4: AN HOUR LOST AT A BOTTLENECK IS AN HOUR LOST FOR THE TOTAL SYSTEM.

RULE 5: AN HOUR SAVED AT A NONBOTTLE-NECK IS A MIRAGE.

Our schedules should recognise that at bottleneck operations it is very important to save set-ups. However, at non-bottlenecks, there is no benefit from saving set-ups. In fact, we would benefit from running more set-ups because our lot sizes would be smaller. While these smaller lot sizes would not increase throughput, they would decrease inventory and operating expenses.

But further than that consider the way we control machines now. Much downtime is due to lack of tooling, operator absence, wrong or absent materials or drawings. In most medium sized companies, the value of an hour on the primary bottleneck is between £10,000 and £20,000 in Throughput. Have you checked that on your bottlenecks there is a relief operator standing by, that all materials are available to the machine before they are needed, that your machine spares policy reflects a downtime of £10,000 per hour?! Does your bottleneck stop for lunch?!

By simply expending effort to ensure that a very few machines, the bottle-necks, are correctly looked after, we effectively improve the productivity of the whole plant!

Priority and Capacity

We now understand the importance of capacity constraints in the production process. But how should we plan production accordingly? Let us first consider how current Western systems work.

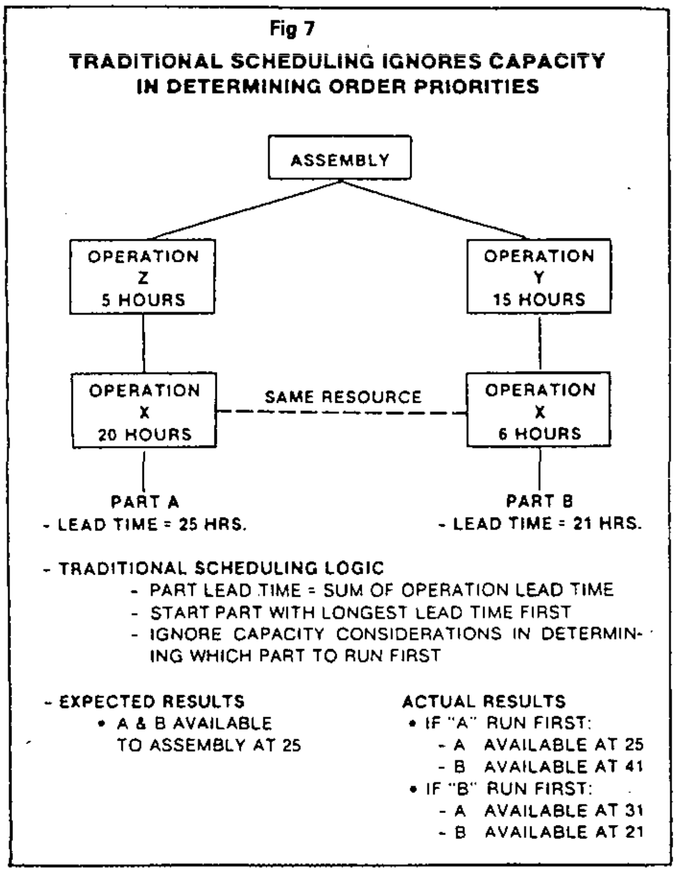
Our current scheduling logic says that the item with the longest leadtime should be released or run first. Priority and capacity are essentially considered sequentially, not simultaneously. Our typical MRP scheduling logic generates priorities through leadtime offsets. Once the priorities are established, we check to see if there is roughly enough capacity in each time bucket to meet these schedules. However, we do not check the interaction of priority and capacity within or across the boundaries of these time buckets.

The problems generated by this approach can be illustrated in a simple example. Fig. 7 shows Parts A and B going through two manufacturing operations prior to being assembled together. Our traditional scheduling logic suggests that we release Part A 25 hours before it is due to be assembled and then release Part B 21 hours in advance of the assembly's schedule. If everything goes well, both parts will arrive on schedule. Unfortunately, the actual results differ widely from our expectations.

We must consider the capacity constraint of having only one machine X which provides the first operations on both pieces. If we release A first, it will take 25 hours. But B will have to wait for A to complete its operation on X and then proceed, so it will take 20 + 6 + 15 = 41 hours to reach Assembly. If, on the other hand, we release B first, it will take 21 hours, but similarly A will now take 6 + 20 + 5 = 31 hours. In both cases our lead time calculation was dramatically wrong, but we also suggested releasing the wrong piece first! How many of us rely on MRP systems which provide a release date and expected completion date, and leave us to sort out the muddle inbetween?!

What we have just seen is a case of priority and capacity being considered sequentially - not simultaneously. Our system must in future use another rule of OPT:

CAPACITY AND PRIORITY SHOULD BE CONSIDERED SIMULTANEOUSLY, NOT SEQUENTIALLY. LEAD TIMES ARE A DERIVATIVE OF A SCHEDULE AND CANNOT BE PRE-DETERMINED.



OPT - The Way Forward

So far, we have recognised some truths about how we should manage our plants and have drawn some rules from them. Tremendous improvements in Throughput and reductions in Inventory and Operating Expense can be achieved by putting them into practice - but we need help!

OPT provides a set of nine commonsense rules, 6 of which we have seen so far, to govern the way we should run our plants, but it also provides a powerful tool to help us implement the rules. We need the use of the computer to help unravel the complexity of manufacturing, to tell us which are the true bottlenecks, to prioritise and schedule the work to be done on them and to create schedules for the non-bottlenecks which will serve the bottleneck master schedule.

So OPT also provides a set of computer software to act as the management tool to accomplish the task. OPT is an evolution from MRP. It can utilise all the investment that has gone into creating our MRP databases. It can utilise the major sub-systems such as stock control, purchase order control and sales order processing. But it provides a 'brain-transplant' for the Material Requirements Planning suite itself. Let me explain how it works.

Firstly, let it be clear that OPT carries out all of the traditional functions of MRP, co-ordinating requirements, netting, exploding and netting again. But it does it in a very different way.

OPT builds a model of the plant. The model contains all of the Bill of Material structures and the Routing layouts. It contains the sales demand and the current inventories of finished goods, work-in-progress and raw materials. It also contains a great deal of information about the resources of the plant, the machines, the manpower and, where necessary, jigs, tools and fixtures. The model is made to reflect the reality of the plant. It sounds a big task but really it isn't. We only need to model in detail, with a high degree of accuracy, those parts of the plant that are bottlenecks - that have no idle time; based on Pareto (ABC) analysis, that is a very small proportion of the total data. Some inaccuracy is tolerable in the majority of routing and operation data because of the idle time inherent on most resources. So OPT avoids the trap of insistance on 100% data accuracy.

OPT then explodes the demand through the model and loads the resources to infinite capacity. The bottlenecks are identified and then verified through limited checks on the accuracy of the relevant data. Remember that the true bottle necks, and therefore the relevant data elements, are very few in number.

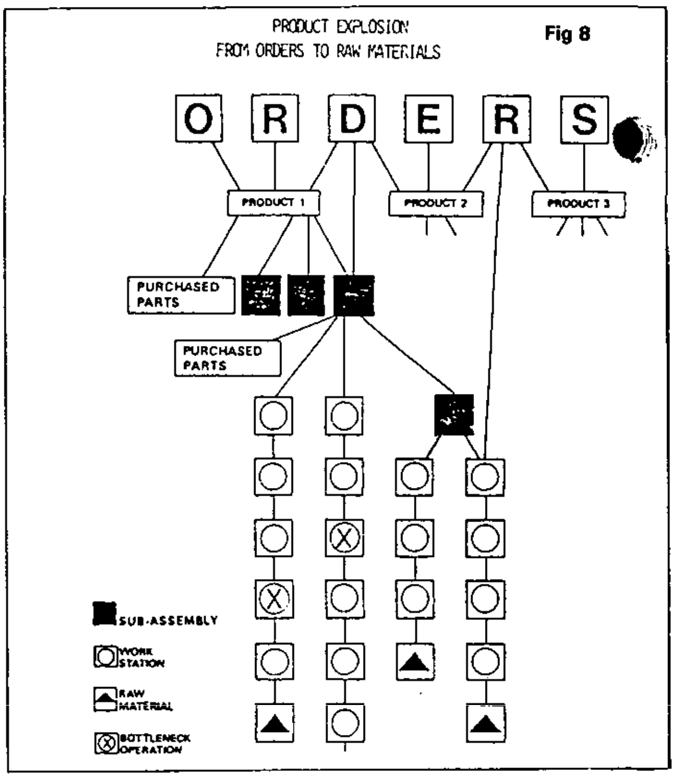
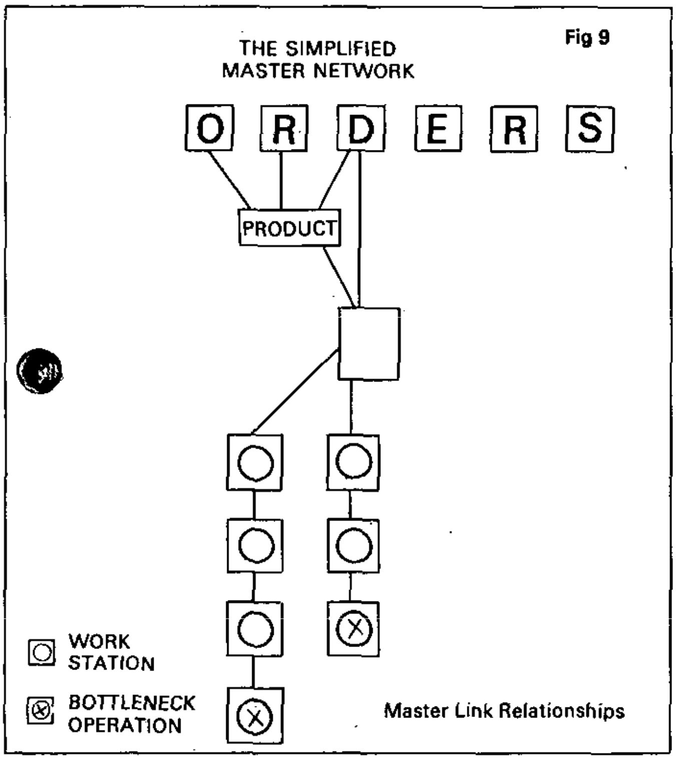


Fig. 8 shows a typical simple product explosion. Two operations have been identified as occurring on bottlenecks. The model will include the maximum amount of time we can run the bottle necks. If we schedule the work on these bottlenecks to take up their maximum capacity of 100%, we can get no greater production out of the plant. All the other resources will only need to be scheduled at less than 100% to achieve the objectives set by the bottlenecks.

In order that the schedule on the bottlenecks is optimised, OPT splits the model into two networks, the MASTER NETWORK and the SERVE·NETWORK. The Master network contains the orders and the bottle neck operations and a simplified picture of their inter-relationships (Fig. 9).



Remember that the bottlenecks could be machines, men, jigs, tools, fixtures or the supply of material or components. OPT then uses a proprietory algorithm in its software to produce the best possible co-ordinated schedule on the bottle necks, to meet the market demand as nearly as possible. Priority and capacity are considered simultaneously, and the use of the bottlenecks is maximised by **forward** scheduling from today, resulting in both a *realistic schedule for the bottlenecks* **AND,** *after allowing* for the lead time between bottleneck and order, a feasible Master Manufacturing Schedule for the orders based on achievable dates (Fig. 10). And Throughput has been maximised.

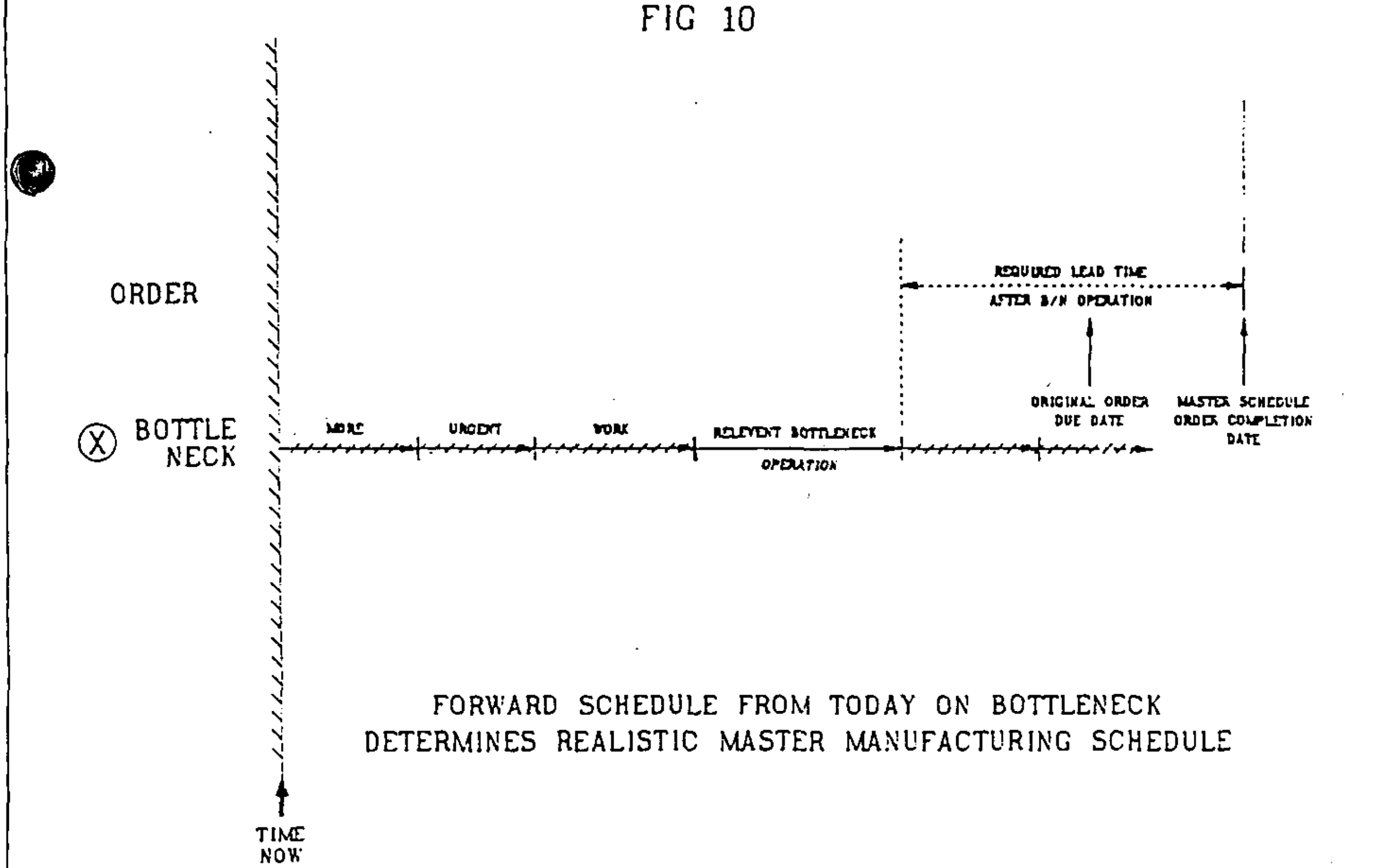
Now that we have rearranged the Master Manufacturing Schedule dates based on the optimised schedule for the bottlenecks, OPT passes the information to the SERVE network. We know from our previous work that the required capacity on all the other resources is less than 100%. We can now take the revised 'due dates', not only for orders but also for supply of components to the bottleneck machines, and backward schedule the operations to make the unconstrained items from the required due dates, to 'serve' the Master schedule (Fig. 11).

Throughout both the forward scheduling with the Master network, and the backward scheduling with the Serve network, OPT utilises Transfer Batch technology, similar to the Japanese Just-in-Time system, allowing the work to flow in small consignments. When forward scheduling on the bottleneck, it brings together like batches to save set-up and maximise throughput (an hour of a bottleneck is worth £10,000!), while during the backward scheduling in the non-bottleneck areas, it utilises the idle time to make in small batches, so saving on Inventory and Operating Expense. A more detailed explanation of the batching techniques is the subject of another paper.

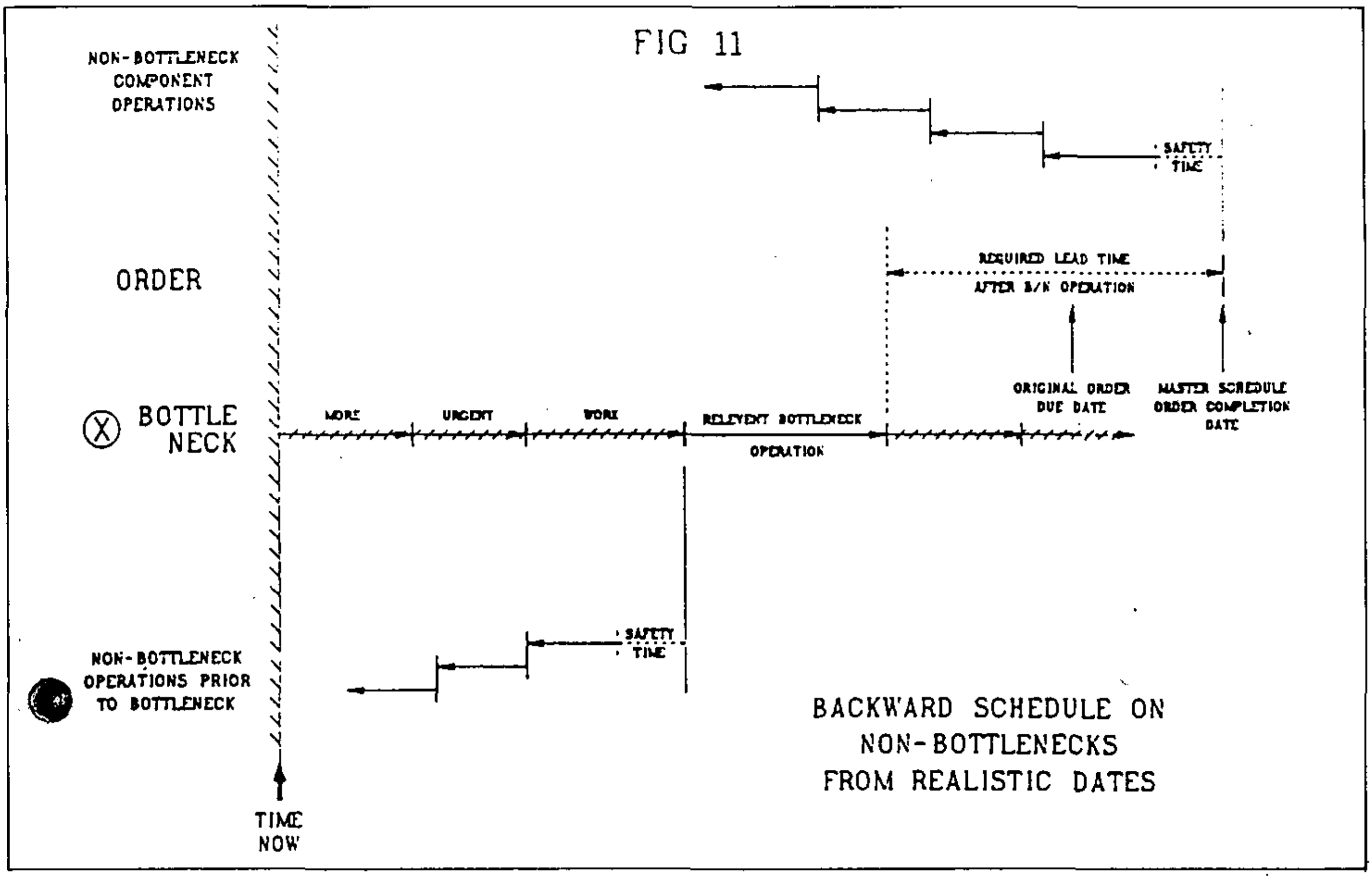
Conclusion

So what have we achieved? By re evaluating the nature of

FIG 10



FORWARD SCHEDULE FROM TODAY ON BOTTLENECK DETERMINES REALISTIC MASTER MANUFACTURING SCHEDULE



production and applying some simple commonsense rules, the rules of OPT, we have been able to develop a technique which will allow management to concentrate their effort so that:

1. THROUGHPUT IS MAXIMISED by producing an optimized forward schedule to 100% capacity on the bottlenecks, and concentrating management effort to ensure that **nothing** stops these few resources from running.

2. INVENTORY IS REDUCED by:

   (a) Co-ordinating activities and only making items in time to meet the realistic assembly dates for finished product set by the Master Schedule, so that large quantities of mismatched items are no longer in stores for long periods.

   (b) Using the idle time on non-bottlenecks to produce in smaller batches, even though it means extra set-ups, so that the flow is maintained in all areas and total work-in-progress inventory is reduced.

OPERATING EXPENSE IS REDUCED:

   (a) The reduction in Inventory means that the cost of holding inventory is significantly reduced. But so is the cost of obsolescence and engineering changes because the associated lead time to manufacture is also reduced, and items are produced later and only when they are required.

   (b) The balanced flow of work means a significant reduction in the levels of excess overtime worked in most plants. How often do we have to lay on overtime to clear urgent work, when at other times during the week the same men are standing idle? Our experience shows overtime, and even labour requirements, are reduced by the balancing of the flow, not the capacity!

   (c) Sub-contract is also often reduced. We sub-contract to off-load peaks in our work-load. The balancing of the material flow means that the need for sub-contract is significantly reduced.

OPT is not just another prospective computer solution. It is a combination of a commonsense re-evaluation of the rules governing manufacturing with a software tool which helps to implement the rules.

OPT works, as has been shown by an impressive list of users in the USA, and is almost certainly the West's answer to the threat of the Japanese. It gives us not just a way of catching up, but of going forward and beyond, and regaining our manufacturing supremacy.

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