Managing system constraints: a cost/utilization approach

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Modern management philosophies, such as just in time (JIT), the theory of constraints (TOC) and total quality management (TQM), place a strong emphasis on operations management. These approaches create techniques and procedures for effective flow of materials, but do not provide sufficient tools to consider the economic outcomes of the various alternatives. This paper applies the cost/utilization model to the analysis of production lines and materials flow. The model combines the Pareto approach with the TOC approach. The Pareto approach concentrates on the important and costly elements of the organization. TOC focuses on the organization's constraints. It is presented in a simple graphic display aimed to allow managers to locate better constraint resources, detect faults in the planning of the production line, examine improper fluctuations in the process and pinpoint their sources. The model is a top-management decision-support tool that may be applied in areas such as buffer policy, assessment of protective capacity, investment in production resources and identification and priorization of areas for improvement.

1. Introduction

Methodologies such as optimized production technology (OPT) and the theory of constraints (TOC) concentrate on the location of constraints and bottlenecks in the production process (Ronen and Starr 1990). A constraint is defined as anything that prevents the system from achieving a better performance measure *versus* its goal (Goldratt 1990). In these methodologies, the management process consists of the following steps (Goldratt 1990, Floyd and Ronen 1989):

1. Set up the system's goal.
2. Determine the performance measures.
3. Identify the system's constraint(s).
4. Decide how to exploit the system's constraint(s).
5. Subordinate everything else to the above decision.
6. Elevate the system constraint(s).
7. If, in the previous steps, a constraint has been violated, go back to step 3, but don't allow inertia to become the system's constraint.

The main feature of this process is the *ad hoc* nature of the analysis—i.e. the acceptance of the processes' present status as given. There is, moreover, a danger in these methodologies of perpetuating the given status by subordinating the entire system to constraints existing in the system at the moment and ignoring the possibility that a constraint does not necessarily have to be where it is. The decision of accepting the

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existing constraint and its present location is a strategic one that must be taken by the organization's top management, considering the economic element, the firm's position in its market, and general organizational strategy. If it is decided that the constraint is to be internal (i.e. a resource), it should preferably be the most expensive or most critical component of the system. If management decides that the constraint should be external (the market demand), a permanent or temporary situation whereby the constraint is internal will constitute a fault in the system and management must take corrective action. This means that an economic analysis must consider the cost of system components and not accept the existing structure of the process as a force of nature.

This paper presents a graphic model combining operational measures of performance for analysis and design of operational systems. The model enables in-depth analysis, and at the same time is easy to use. It allows the manager to identify problems and improve operating systems by:

(*a*) locating and classifying external, internal, and policy constraints;
(*b*) classifying the subsystems by their cost;
(*c*) identifying the right or desirable place for the constraint;
(*d*) analysing the present load structure of the system's components;
(*e*) suggesting a better load structure for the system and positioning of subsystems within the system;
(*f*) performing a sensitivity analysis concerning the effect of changes (investments in resources, change in product mix or market demand) on the system's structure and constraints;
(*g*) determining indices for comparison between alternative flows of operational systems; monitoring production trends;
(*i*) analysing statistical deviations in the system's load profile;
(*j*) assisting manager to achieve a global view of their system.

Section 2 of this paper presents the basic model. Section 3 deals with the analysis of production systems by use of the model. Section 4 discusses the analysis of production processes over a period of time through use of the model and Section 5 concludes the study.

2. Cost/utilization model

The cost/utilization model was developed by Borovits and Ein-Dor (1977) to allow analysis of utilization of resources in relation to their cost. The model was originally used as an economic tool to analyse hardware in computer systems. It breaks down the computer hardware into components such as CPU, RAM, external memory, etc., and presents the proportional cost and level of utilization for each component. In this paper we apply the model to managerial and operational systems. The original model was designed to deal with deterministic systems. In this paper we will expand its use to stochastic environments as well.

To illustrate, let us assume that the production system in question consists of six departments: A–F. We will determine the percentage of utilization and the relative *marginal* cost for each department in the production process over a period (month, year, or any other length of time). In our expansion of the model, the term costs means the price that the firm has to pay in order to add the same amount of a given resource.

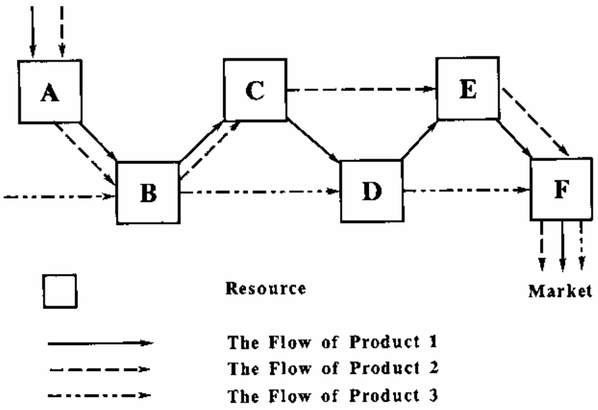


Figure 1. Flow chart of the production line.

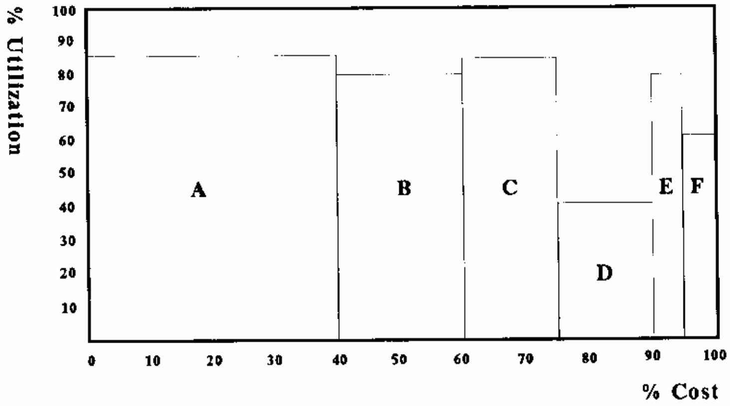


Figure 2. Cost/utilization diagram.

Flow of materials through the system is as described in Fig. 1. For the production system under discussion we will assume the following cost percentages out of total costs and the respective utilization rates:

Department	Costs (%)	Utilization (%)
A	41	85
B	23	80
C	13	84
D	12	40
E	6	80
F	5	60

The cost/utilization graph will appear as in Fig. 2.

In addition to the graphic presentation, there are two parameters in the model which allow quantification and measurement of the system's balance and the average utilization of the system's components. These indices are (see also Borovits and Ein-Dor 1977):

$$B=2\left[\sum(F-U_i)^2P_i\right]^{1/2}$$

$$F=\sum(P_iU_i)$$

F is average utilization normalized to cost, for the production system, and B is the normalized index for the system's balance. In the system's balance equation the expression in square brackets is an indication of the variance of utilization of the entire system. The remainder of the expression normalizes the index to a range between 1 for a completely unbalanced system and 0 for a completely balanced system. In this example $F=0\cdot76$ and $B=0\cdot32$.

3. Graphical analysis of systems with the cost/utilization model

In this section we will show how various situations can be identified and diagnosed by means of the model.

3.1. *Faulty (dummy) internal constraint*

The first case is shown in Fig. 3. This is a case of an internal constraint in the system which is a faulty (dummy) internal constraint. It is a mistake to consider this a true constraint in the sense that a relatively inexpensive component (subsystem, machine, department, employee, etc.) in the system is causing the bottleneck. In the terminology of the theory of constraints (TOC) (see Schragenheim and Ronen 1990) this is a policy constraint.

As can be seen on the graph, component E is the constraint in the system. Utilization of this component is total (100%), while its relative cost is $<10\%$ of total system cost. It can also be seen that the other system components are only partially utilized. This means that 90% of the investment (capital, labour, etc.) is underutilized. According to existing production management methodology, the entire system must adjust itself, in this case, to the constraint—i.e. the entire system is being constrained by a relatively inexpensive subsystem.

For example, a large hospital found, on performing constraints analysis, that the constraint in the operating rooms was not the surgeons, nor the expensive equipment,

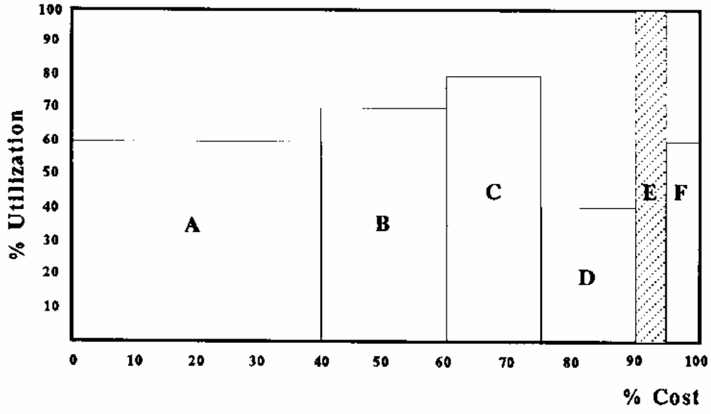


Figure 3. A 'dummy' constraint.

but a member of the auxiliary staff, namely, a cleaner. In a Research and Development department where this methodology was applied it was found that the constraint was not the expensive programmers but secretarial staff. In both these cases, the graphic and methodological analysis brought about an immediate solution to the problem. The indices of the model (B and F) in the above case are

$$F = 0{\cdot}64$$

$$B = 0{\cdot}285$$

The F index shows that the production system is only partially utilized, on average 65% utilization of the organization's capital. The B index shows that the system is balanced, although not completely. The combination of indices shows that the system is balanced in a state of underutilization. Obviously, this is not a desirable situation and indicates a waste of resources.

Conclusions the management should draw are as below:

(*a*) The system has a dummy bottleneck which is a faulty constraint resulting from system policy. The source should be examined and the constraint broken by added capacity in that area. In such cases one should identify the constraint (step 3 of the TOC), then bypass the next two steps (exploitation and subordination) and elevate the constraint immediately;

(*b*) If the system still has excess capacity which can be sold on the market, marginal pricing strategy may be considered.

Experience shows that managers in most cases fail to locate the constraint because of the complex nature of the systems. In most cases, by drawing the cost/utilization graph and calculating the indices, the problem is immediately solved.

3.2. *Plausible internal constraint*

A plausible internal constraint is one that is located in one of the system's more expensive components (Fig. 4). As can be seen, component A is the system's constraint—an internal bottleneck. This component is 100% utilized, and its relative cost is 40% of total system cost. It can also be seen that the other components of the system are partially utilized.

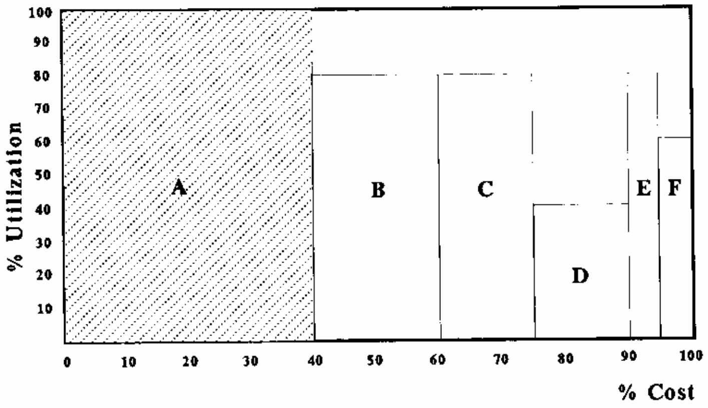


Figure 4. A 'plausible' internal constraint.

The model's indices (B and F) in this case are

$$F = 0{\cdot}814$$

$$B = 0{\cdot}41$$

The F index shows that the production system's utilization has increased and is about 80%. Experience shows that this level of utilization is acceptable and indicates that the system is sufficiently utilized. Clearly, the system is still only being partially utilized, but it can be seen that the 'average' utilization has improved relative to the case shown in section 3.1 above, and 81% of invested capital is being used in the production process. Index B has risen, indicating changes in the balance of the system. Obviously, this is not yet an optimal condition, and there is still waste of resources in the production system. We must remember, however, that we are not aspiring to 100% utilization, bur rather wish to achieve better profits via more throughput. Moreover, we do not expect zero variance, since resources are located in different areas, the routeing of the system is not common, and neither the capacity nor the cost of the various resources is equally spread. This example certainly indicates a reasonable level of capital utilization.

Our experience shows that such cases occur when the expensive bottleneck is the only resource which is completely utilized. We can see this phenomenon in an operating room where the surgeon is the bottleneck and paramedics are partially utilized, an airline where the aircraft are completely utilized and crew members are partially utilized, a mechanical plant where expensive CNC machines are fully utilized (the bottleneck) and other departments are partially utilized.

Management must then confer on the following issues:

(*a*) It must be determined whether the constraint is to be internal and, if so, management must examine the marginal return on an investment in the bottleneck.

(*b*) It must be determined if the system has excess capacity on non-bottleneck which can be sold on the market, and whether marginal pricing can be considered. In the hospital example noted above, where the surgeons are the bottleneck, it was recommended that the operating room, along with auxiliary services, be rented to outside surgeons, or, as an alternative, that the constraint be elevated by hiring more surgeons.

(*c*) Market prices should be determined according to considerations of bottleneck utilization (see for example Eden and Ronen 1990).

3.3. *Market constraint*

We will refer to the situation of demand for the product being less than the system's production capacity as an external constraint, namely a market constraint.

As can be seen in Fig. 5, none of the production system's components are utilized to capacity. In this case, sales stand at 80% of the production capacity of the organization's most utilized productive resource. Obviously, other components of the system are only partially utilized. This can be attributed to two causes:

(*a*) Organization policy maintains that excess capacity must be preserved to take advantage of opportunities and to prevent competitors from entering the market; this policy enables short response time to the market.

(*b*) Planned over-capacity or an unforeseen drop in demand.

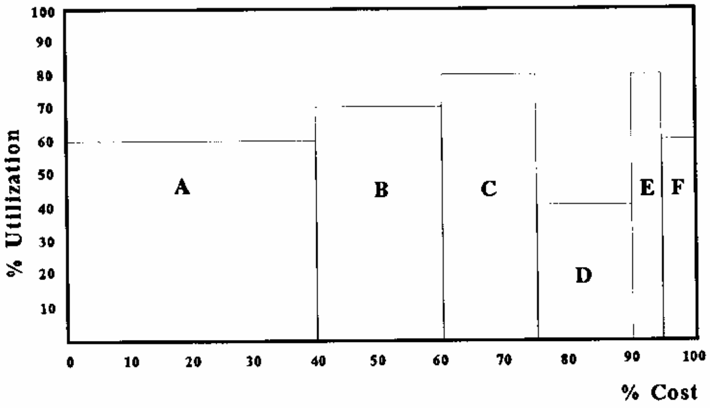


Figure 5. A market constraint.

The model's indices in this case are

$$F = 0{\cdot}63$$

$$B = 0{\cdot}245$$

These indices show that the system utilizes only 63% of its capital, and that it is balanced in underutilization.

The conclusions to be drawn in this case are as follows:

(*a*) Management must determine whether the constraint should be external, taking into consideration the cost of the excess capacity.

(*b*) Management must examine whether the market constraint is temporary or permanent and determine its causes (internal factors such as quality, price, response time, or external factors such as competition, legal or demographic changes, preferences, etc.).

(*c*) Market pricing must be according to management considerations on a case by case basis. In many cases, traditional costing and pricing policies lead to faulty decisions which prevent increased sales (see Kaplan 1984 and 1986).

(*d*) Management should consider accepting extra jobs, but should ensure that this action will not inadvertently lead to a bottleneck. As explained later, some excess capacity ('protective capacity') should always remain unloaded in the planning stage, to protect the system's throughput against fluctuations.

4. Using the model for decision making

4.1. *Investment decisions*

We will now see how this model can serve as a tool to assist the manager in investment decisions concerning one or more of the system's components. The case is shown in Fig. 3 and is characterized by a dummy constraint (machine E is the bottleneck and is relatively low priced). Management believes that the additional production that will be achieved by opening the bottleneck justifies the investment required. The investment is relatively low and can increase production. In order to examine the effect on the total system, we will compute the expected load for all components after the investment is carried out. The model will assist management in deciding whether to

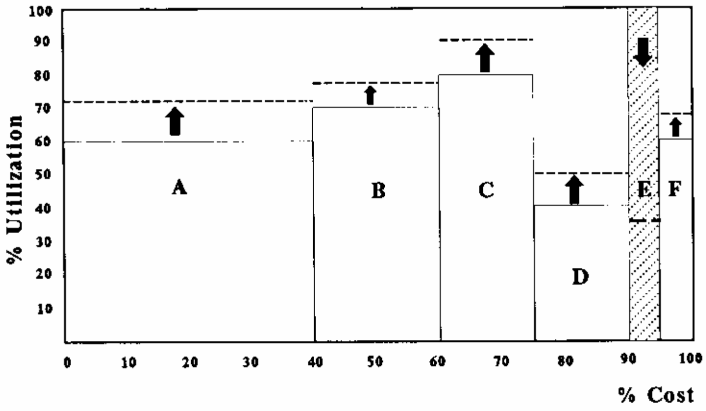


Figure 6. Effects of investment in resource E.

invest in machine C, too, which as will be seen becomes a new and relatively inexpensive bottleneck (Fig. 6). Arrows in Fig. 6 refer to the increase in the resources loading after the bottleneck (resource E) breaking.

4.2. *Make-or-buy decisions*

The same technique can be used to examine the effect of producing a new product on the system's total load. The new load will form the basis for a make-or-buy decision. The model also assists in choosing the product mix to be given to the subcontractor.

The tool can also be used to assist in decisions concerning the acceptance of a new product into the organization's product line, decisions as to discontinuing production of certain products, and strategic decisions on pricing policies and their effect on production loads.

5. Fluctuation considerations in capacity planning

Statistical fluctuations are a well-known phenomenon in any process or operations management. There are two sources for the fluctuations at a given station:

(1) Internal fluctuations, caused at the station itself.
(2) Cumulative fluctuations, arriving from previous stations.

The sources of internal fluctuations are many: machines break down, raw materials arrive late, workers are absent, the quality of an intermediate product deteriorates, sudden changes occur in market requirements. Stochastic setup times and time per part are also sources of system fluctuations. This issue has attracted much attention from quality improvement experts, particularly from Deming, who continued the work of his teacher Shewhart in developing statistical methods to stabilize and reduce fluctuations (Deming 1986).

Cumulative fluctuations arise from different causes (Schonberg 1981 and Goldratt and Fox 1986 described the phenomena of statistical fluctuations and dependent events). In a given process, the greater the number of previous stations on which a station or a resource is dependent, the more it is exposed to fluctuations that are transferred to it by the components that provide its inputs. This phenomenon is often ignored in the planning of processes and in scheduling policy, and causes lost throughput, high work in process (WIP), and increased lead time. Thus, in the modern production environment, which aims to reduce WIP, the more a resource is exposed to fluctuations the greater the desire for more excess capacity. In many cases, WIP (referred to also as the 'buffer') is used as a 'fluctuation absorber' in the system.

In the modern world of production there are two accepted methods for dealing with the problem of fluctuations:

(1) Preventing the fluctuations, for example by the TQM approach, usually affects internal ones.
(2) Protecting against the fluctuations, for example by the TOC approach, usually affects cumulative ones.

The cost/utilization graph is an effective tool in both the above approaches.

Good, reliable, and economical production line planning must consider the cost of the resource, its location in the production chain and its internal fluctuations. In the planning phase, the utilization of a resource should be in inverse ratio to its place in the process and proportional to its cost. This means that in so far as a resource is more costly its utilization should be greater, and it should be positioned closer to the gating operation (if technologically feasible).

Resources should be protected against fluctuation by buffers. The buffer size is dependent on the cost of the WIP in the buffer, the level of fluctuation to which the component is exposed, and its level of utilization—i.e. its ability to 'combat' the fluctuations.

These normative conclusions are actually action items in a general philosophy of production management. In many cases there is a tradeoff between the level of WIP and the capacity of the resource. The general trend nowadays, in many cases, is to prefer excess capacity to excess inventory (Schragenheim and Ronen 1991). In addition to the issue of buffer location, upon which previous research has generally focused (Schragenheim and Ronen 1991 and Goldratt and Fox 1986), we will deal with the economic aspects of these operative proposals, that may lead to different conclusions.

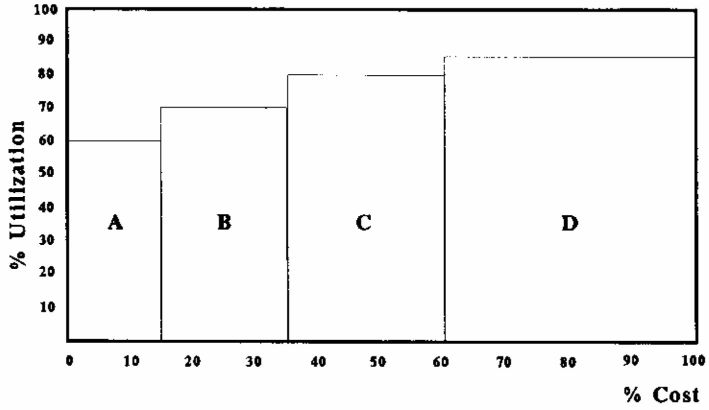
The following examples will clarify the use of the cost/utilization model in better designing of new arrays and better use of existing ones. At this stage, we will assume that there is no WIP (either planned buffers or unplanned WIP) in the production process. At a later stage, we will release the model from this assumption.

5.1. *Internal constraint positioning*

The first case dealing with process analysis focusing on fluctuations in the process is presented in Fig. 7.

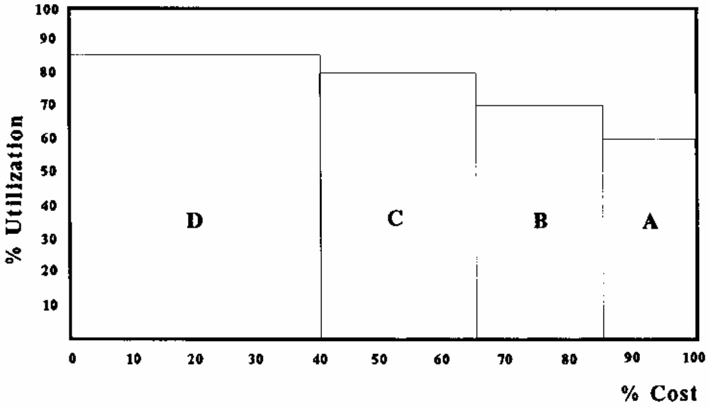
This example shows a process consisting of four components. Apparently, the process fulfills the standard requirements of the process planning methodology: it has no bottleneck and is relatively balanced. The process also fulfills some of the requirements presented in the first part of this paper—i.e. the more expensive components are more intensively utilized.

However, the internal constraint is incorrectly located in this example. Process components should be arranged in decreasing order of their utilization. This means that component D should be positioned first in the process so as not to expose it to the fluctuations of other components, since its high level of use does not allow it to cope with fluctuations. The other components are to be located after D in decreasing order of utilization. (In cases where the technological order of the process may not be changed, component D may be protected from fluctuations of previous components by a buffer.



Note: The most expensive resource is also the most loaded, and is positioned at the end of the line.

Figure 7. A given line.



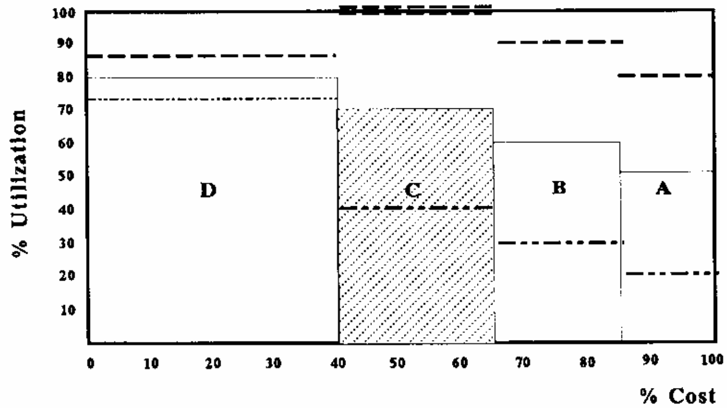
Note: If technologically possible, the most expensive resource should be placed at the beginning of the line and be most loaded.

Figure 8. Ideal design line.

Further on in this paper, we will provide an example of fluctuation protection by buffers.) Figure 8 depicts the desired way of allocating the constraint. Another alternative for designing such a line is to change the proportion of the resources' capacity, i.e. increase resource A etc.

5.2. *Reduction of internal fluctuations and buffer planning*

Referring to Fig. 8, we will see how the above production process can be planned in the spirit of the previous section's recommendations. (In certain cases, where the yield is relatively low, it is recommended to locate the constraint at the end of the line, and thus to fully utilize it to maximize throughput.) We must, of course, qualify these recommendations by stating that it is not always possible to organize a production line in the prescribed order.



Note: Because of fluctuations, resource C becomes an intermittent constraint.

Figure 9. Effect of internal and cumulative fluctuations.

For a more realistic picture of the line, we have to add the components' fluctuations to the graph. We will add these fluctuations to the diagram as shown in Fig. 9.

The standard deviation to be measured is the actual standard deviation of component utilization. This standard deviation is caused by the two major groups of factors noted previously: internal fluctuations, arising from setup times, maintenance problems, personnel problems at the workstation, and product quality, and cumulative fluctuations, accumulated from previous workstations.

The graph shows the upper and lower limits of the fluctuations, expressed by twice the standard deviation from the average. This range shows, therefore, the range of utilization of the specific tool or machine, with 95% probability. These limits may change according to the line's environment (Ronen and Spector 1991).

As in previous models, Fig. 9 shows average utilization and relative cost for each component in the system. We can also see the limits of fluctuations in a range of twice the standard deviation. We see that component C, which was not problematic in the previous graph, will be an *intermittent* bottleneck. Though its average utilization is far less than 100%, in contrast to the bottlenecks shown previously, it can nevertheless become a constraint that requires corrective action. The corrective action is, however, different from that taken in the 'classical' managing constraints methods (exploitation of the constraint, subordination of the system to the constraint, elevation of the constraint, etc.). With an intermittent bottleneck, corrective action must concentrate on the fluctuations, and this will require a primary investigation of the source of the fluctuations, and then implementation of the following actions:

(1) If the source of the fluctuations is internal, the following steps should be taken:
  (*a*) analysing the process, variation reduction and monitoring by control charts and other SPC methods (see, for example, Deming 1986). Experimental design may be used (for further details, see Suzaki 1987);
  (*b*) reducing setup times;
  (*c*) training personnel;
  (*d*) improving machine maintenance;
  (*e*) improving raw material quality, etc.

(2) If the source is external, the following steps should be taken:
  - (*a*) building a constraint buffer before the bottleneck to damp the fluctuations;
  - (*b*) introducing buffer management to discover the source of fluctuation and reduce fluctuations of previous components (see Schragenheim and Ronen 1991);
  - (*c*) increasing the component's capacity;
  - (*d*) reducing production and 'transfer batch' sizes to smooth the system's flow and prevent wandering bottlenecks due to oversized batches;
  - (*e*) scheduling the system using the DBR methodology;
  - (*f*) building a space buffer (if necessary) after the constraint.

Figure 10 shows the reduction of the fluctuations using appropriate buffers in the system. In Fig. 10 the width of the buffer (WIP) represents its handling costs. For simplicity and consistency with the TOC philosophy, the value of WIP will be equal in each phase to the cost of the raw material invested (see Ronen and Starr 1990). The vertical axis of the buffer is the number of inventory days (or percentage of them) for working the material at the next station. The horizontal axis refers to the relative cost of the WIP.

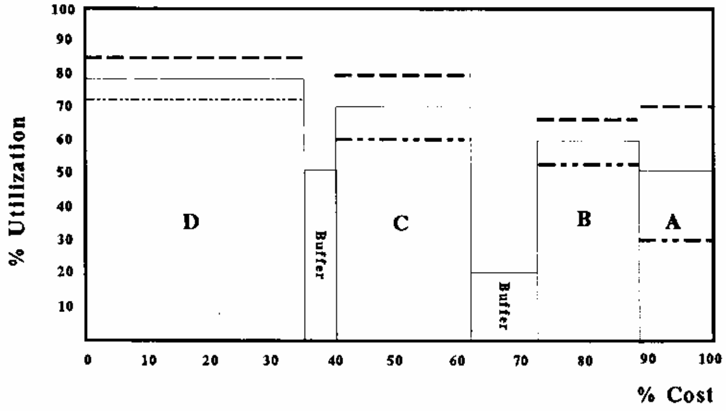
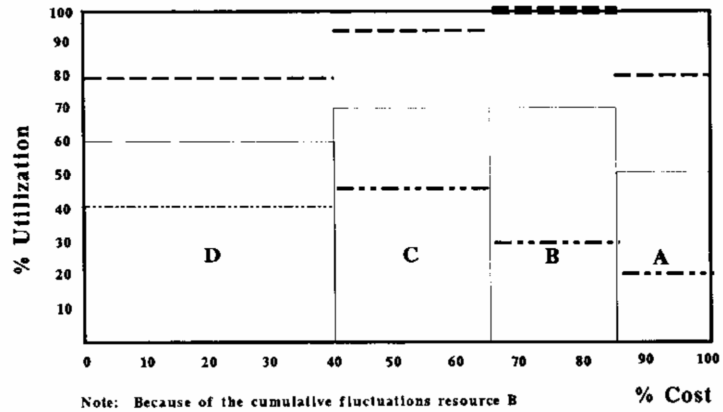


Figure 10. Protecting the system by buffers.



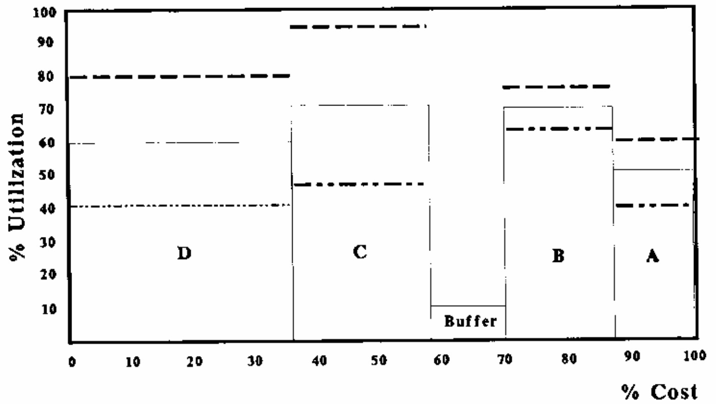
Note: Because of the cumulative fluctuations resource B becomes an intermittent constraint.

Figure 11. Fluctuation effect.

Figure 11 presents a case where high fluctuations cause a non-bottleneck resource, resource B, to become an intermittent bottleneck and to be the system's constraint.

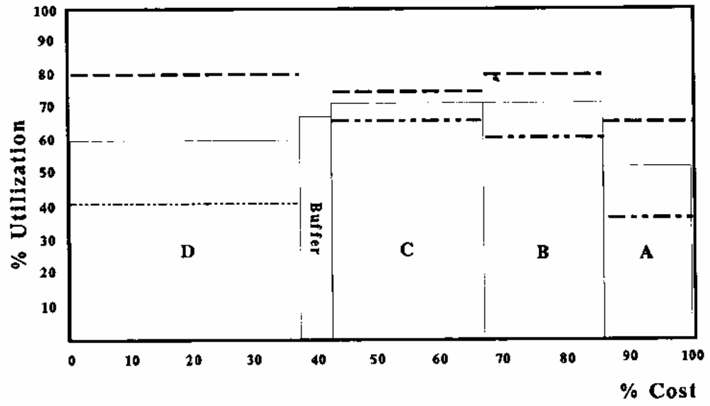
Figure 12 shows a correction of this situation. The addition of a buffer in front of B (consistent with the DBR methodology) improved the system's utilization and throughput significantly. At a relatively low cost (inventory cost) this component has ceased to be a bottleneck. Clearly, this has increased production capability. In contrast, the buffer before component B has not improved B's standard deviation, which is probably caused by the component's own internal fluctuations.

Figure 13 shows a different, and perhaps better solution to the problem. In this case we used the buffer to restrain external fluctuations for a component which is not a bottleneck (component C), instead of putting it in front of B, as in conformance with the traditional practice and theory (Goldratt and Fox 1986). Sometimes the correct action (in systems such as represented in Fig. 13) is to position a buffer after a noisy component, such as component D, in order to dampen the system's fluctuations. This



Note: The buffer before the intermittent constraint absorbs the cumulative fluctuations.

Figure 12. Buffer location before an intermittent constraint.



Note: A relatively inexpensive buffer after component D has more telling effect on the fluctuations of both resources C and B.

Figure 13. A buffer after the fluctuation's origin.

action is cheaper and more effective than the traditional practice. Clearly, it has increased production capability, at lower cost compared with the solution implemented in Fig. 12. It has also reduced the external fluctuations for component C.

Comparing the solutions presented in Figs 12 and 13, we see that the first solution, according to the TOC philosophy in the DBR approach, is less effective than the new one we have proposed. The new solution creates smoother flow with less fluctuations in the process at less holding costs. The new alternative solution deals with the roots of the problem, by damping fluctuations after component D.

6. Repercussions of JIT, MRP, TOC, GT and TQM on the model

The model assists in examining the effect of modern management philosophies on shop floor planning and control. Graphically and by means of indices, it can also be used to examine the effect of each method on increasing throughput and reducing fluctuations. In general the model can assist in examining the weak and strong points of any method for a given case.

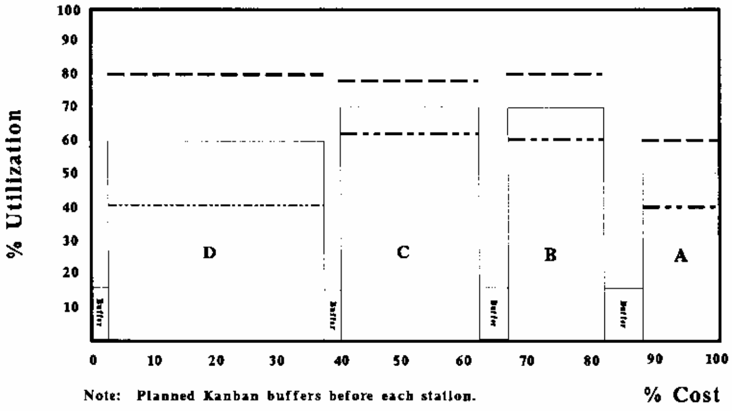
6.1. *JIT: kanban method*

The philosophy of managing the shop floor using the kanban pull systems (see Schonberger 1982) is based on the balancing of resource loads. In this method, fixed-size buffers are placed between every two stations in the production process. A system working according to the kanban method will appear as in Fig. 14.

This method achieves uniform utilization of resources through the use of small buffers at every station in the system. This philosophy ignores the existence of bottlenecks and does not consider the cost of resources. There is no doubt that the model presented in this paper can be used to prove that it is possible to achieve better utilization of capital with no impairment to throughput, lead time, and quality. It can also be shown that kanban works best in environments with low internal fluctuations.

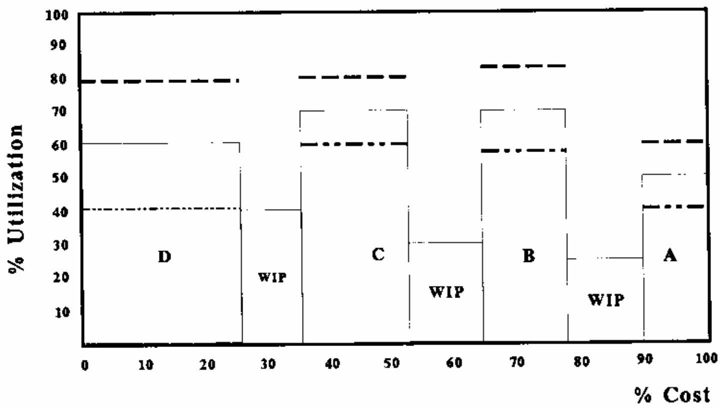
6.2. *MRP model*

According to the MRP approach, the market (i.e. the orders) is the system's external constraint. The MRP backward scheduling technique, adding the standard lead times between each station, gives rise to large buffers between the workstations. This brings about large WIP and perpetuates long lead time. Figure 15 represents this method.



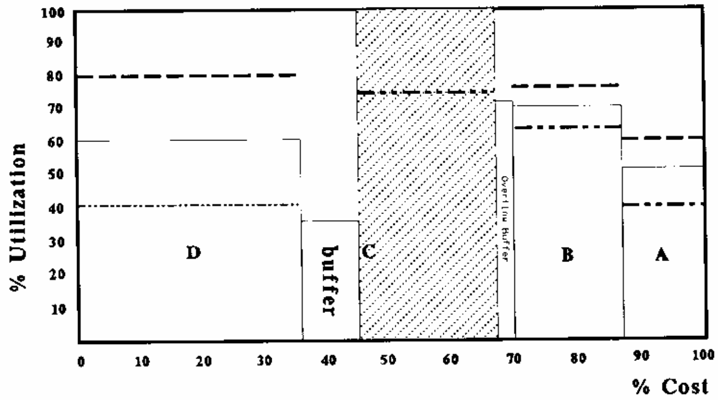
Note: Planned Kanban buffers before each station.

Figure 14. Kanban concept.



Note: The high lead time designated in the backward scheduling causes high WIP in the system.

Figure 15. MRP concept.

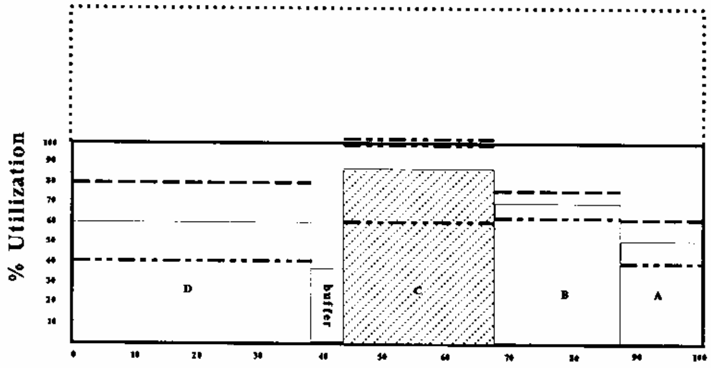


Note: A constraint buffer before a bottleneck and, if necessary, a space buffer after the bottleneck.

Figure 16. DBR concept.

6 3. *DBR model*

This model is one of the TOC techniques for shop floor control (see Schragenheim and Ronen 1990). The technique, together with the buffer management diagnostic tool (Schragenheim and Ronen 1991) protects constraints by the use of buffers. The most common type of buffer is the constraint buffer, located before an internal constraint and enabling the constraint to operate without disruption. According to the model, another buffer should be placed after a bottleneck. This buffer is called a space buffer, and its purpose is to allow the bottleneck to operate even if there is a failure in a subsequent component of the production line. It is mainly storage space which is generally empty and only fills up in case of a failure further down the line. Another buffer, the shipping buffer, is located before the market to protect customers from fluctuations. The model also suggest assembly buffers in other places. In diametric opposition to this approach, we suggest putting in the buffers as needed, according to the requirements of the system. Thus, we may put in a buffer that does not fit any of the above descriptions, but will protect the system.



Note: Group technology reduces WIP and fluctuations.

Figure 17. The group technology concept.

Figure 16 shows a production line organized according to the DBR technique. The internal constraint is component C, and there is therefore a constraint buffer before C, to dampen earlier line fluctuations, and a space buffer after C to receive material if subsequent components have failed.

6.4. *Group technology*

Group technology (GT) requires the creation of task-oriented work groups which are responsible for a specific final product (see Burbridge 1988). The division of production into groups, with each responsible for a different family of products, results in reduction of WIP, short lead times and reduced variance in the process.

6.5. *TQM model*

TQM reduces variance in all system components (Deming 1986). This is in reality a philosophical approach which is applicable in all areas of operations and management, and does not deal with production process scheduling. Our analysis shows that the application of this philosophy must be assisted by one of the scheduling methods described above. TQM is not always the most effective and economic way to increase throughput and profits, if not supported by TOC, JIT, or GT.

7. Summary

This paper adapted the cost/utilization model both as a decision-support tool and a control mechanism for use by top and middle management. The model assists in investment decision making, production line planning, capacity planning, constraint positioning, and locating of buffers. The model, in its stochastic form, assists in managing the system's fluctuations. This in turn provides management with a tool which not only locates standard internal constraints (bottlenecks) but also finds intermittent bottlenecks. The model is simple and convenient to use, and it can be expanded for application to various and differing environments, such as hospitals, administration, or research and development.

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