Proceedings of the 1988 Winter Simulation Conference
M. Abrams, P. Haigh, and J. Comfort (eds.)

Analysis of low inventory manufacturing using MIM

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ABSTRACT

The Manufacturing Integration Model (MIM) provides a method for analyzing the lost productivity due to low inventories. Many popular Just-In-Time techniques lead one to believe that inventories can be reduced without an affect upon production rates, however this has not proven the case in many applications.

Little's Law, which states that production is equal to inventory divided by flow time, establishes the positive relationship between inventory and production. Using this law, when inventories drop, production will also drop unless flow time decreases an equal percentage to the reduction in inventory. MIM provides a means to study the relationship between inventory and flow time. In this sense, MIM is the integration of Little's Law for all combinations of inventory and flow time.

MIM defines the relationship between inventory and flow time as being a function of capacity, flexibility, balance and work in-process levels. But flexibility can not be quantified mathematically so computer simulation is used to solve this integration equation.

Computer simulation is used to identify the net production rate from a combination of flexibility, balance and work in-process levels. Then, increases in flexibility can be described and their relative effects can be quantified using simulation to solve the integration equation.

MIM provides a mathematical model for analyzing manufacturing productivity. But instead of using approximate solutions, it defines a specific role for computer simulation to solve the complicated integration equation.

INTRODUCTION

There are many different views of manufacturing and each one promotes some theories which assist in explaining and understanding the problems associated with producing a product. For example, the job shop has scheduling rules, priority rules and product versus process layouts. With each of these views and algorithms which range from shortest processing time scheduling to due date priority schemes. In all of these algorithms, the objective is to obtain efficient use of all stations. However, not one of these rules deals directly with integration effects. Two typical integration effects are seen in Table 1:

Table 1

INTEGRATION EFFECTS

> Station Available with No Parts

> Station Blocked by Part with No Place to Go

In a sense, previous job shop algorithms tend to assume there are no integration effects and the solution for maintaining productivity is to constantly prioritize the work. However, when running in a low inventory environment, there is no large buffer of work to prioritize and, more importantly, the service of one station will directly affect the usage of another. In this environment, there is a need to identify and measure these integration effects. This type of study is referred to as the analysis of low inventory manufacturing.

Little's Law

Little's Law states that production rate is determined from the division of inventory by flow time.

$$P = I/F$$

This expression is true for yearly averages or other averaging approaches to identify the relationship between production, inventory and flow time. With this equation, inventory and flow time can be viewed as independent variables which predict the dependent variable production. But Little's Law provides no information as to the relationship between inventory and flow time.

Changes to inventory will have an effect upon flow time. In fact, increases in inventory will increase flow time, but the amount of change is an important factor. Using Little's Law, if a 10% increase in inventory yields a 10% change to inventory yields only a 5% increase in flow time, production will increase by 4.7%.

In the dynamic operation of a production facility, the inventory level is changing (due to material shortages or blockages) and flow time is changing due to resource (stations-tools-operators) availability. To study this dynamic production environment will require the study of production, inventory and flow time but also the study of the relationship between inventory and flow time. In a calculus sense, the dynamic study requires the integration of Little's Law. This integration is represented graphically with the WIPAC Curve.

Work In-Process Against Capacity Curve

The WIPAC Curve is the locust of points, each being represented by Little's Law calculation. This curve integrates Little's Law with respect to all levels of inventory. An example follows:

Production

$$P = I/F$$

Inventory

The WIPAC Curve solves Little's Law for all levels of inventory. Thus, the flow time can be computed for any point on the curve. The shape of the curve defines the relationship between inventory and flow time. In the upward sloping position, inventory is increasing but flow time is increasing by a smaller amount. Therefore, production rate is increasing. In the flat part of the curve, inventory is increasing and flow time is increasing at an equivalent rate. The marginal effects upon production due to inventory changes are "washed out" by counter effects of changes in flow time. Therefore, production rate remains unchanged. In the downward sloping position, flow time has become the dominant variable predicting production. Here a 10% increase in inventory results with a greater increase in flow time which causes production to decline.

It is easy to observe the curve and explain the dynamic nature between inventory, flow time and production. But before this analysis can be done, there must be a technique for generating the curves. This technique is described as part of the Manufacturing Integration Model.

Table 2

MANUFACTURING STRATEGY

System		Integration Effects
Job Shop	-	Eliminated through Increased Inventory
Transfer Line Perfect Balance	-	Eliminated through
Low Inventory MAnufacturing w/ Unbalanced Operations	-	Does Not Eliminate Integration Effects

The Manufacturing Integration Model (MIM)

The Manufacturing Integration Model starts with a general equation of manufacturing and derives a set of equation from which production can be measured. These equations involve several identifiable variables of production but can not establish a mathematical relationship between all of these variables. Computer simulation is used to measure this relationship and provide results in the form of a mathematical model which, in turn, can measure the benefits of alternative strategies to manufacturing.

The general equation of manufacturing is:

$$\text{Net Production} = \text{Gross Production} - \text{Sation Unavailability} - \text{Integration Effects}$$

Gross production is the measure of the theoretical maximum production which can be achieved from the production facility. This is determined from process definitions, operation cycle times, number of work station, amount of labor and other capacity planning terms. The gross production is measured in terms of numbers of parts for each part type cumulated for its process and resource availability.

Station unavailability is the amount of lost capacity due to station breakdown and repair, operator availability, tool availability, set-up frequency and scrap parts. The lost capacity is estimated by use of an efficiency factor which is based upon experience gained from the actual operation of the facility. Typically these efficiency factors are as high as 85% for stand alone work stations, to 70% for transfer lines. The higher the degree in integrated operation, the lower its efficiency will be.

In facilities that contain high inventory, integration effects are filtered out and have a value of zero. As a result, the net production is simply a function of station availability and experience is adequate to plan for this effect. However, when the inventory is removed, integration effects will become non-zero.

This characteristic was first noticed in traditional flexible manufacturing systems (FMS). The FMS was installed and, instead of reaching the planned new production level of 80%, it produced a net rate of 65%. Work station efficiency is the same as other stations so there was some reason why the FMS was losing an additional 15% of production capacity. This loss is attributed to integration effects. The occurrence of a station standing idle without a part is common in the FMS, and this situation is costing net production.

This phenomenon is not restricted to the FMS and can be attributed to characteristics of the production environment therein. Specifically, an FMS is a low inventory unbalanced production situation. The degree of computerization and automation are only a means to implement flexibility and their respective impact upon net production is included in work station availability. The amount of lost production due to integration effects is determined from a function of three variables.

Integration Effects =

F Work in Process, Balance, Flexibility
Inventory Level Load

This equation states that the amount of integration effects which will occur in a production facility is determined, in part, from the amount of inventory. Inventory is measured as the number of parts which accumulate between operations and are either waiting for a station to become available or for transportation. Integration effects are also due to the degree of balance between work station or work departments. This utilizes the characteristic of a bottleneck station and as long as the bottleneck station and as long as the bottleneck does not move, it will maintain a higher balance than all other stations. The occurrence of such a bottleneck will impact upon the amount of lost production when this bottleneck experiences integration effects. Integration effects are also determined from the mount of flexibility which is available in the facility. This can be observed as the number of potential paths that a part can take through a facility. These do not have to be all set-up and on-line such as the case in FMS and can range from alternative operations to moving a fixture to another work station.

Given the equation for integration effects it is only useful if it can be used to provide quantified results. The following section presents the method for measuring integration effects in a production facility. Although this methodology is still under development, it has been successfully applied to real-world problems.

Triangle of Integration

In order to quantify the integration effects, first the input variables (inventory-balance-flexibility) must be given specific units of measure. Inventory is measured as the number of parts in-process. Balance is measured with the flow time of parts through the production process. In the case of the transfer line, a single value was used. In the general case, however, the flow time of each part must be used. Thus balance is not measured by a single value but rather through a vector where each part types flow time represents one position in this vector.

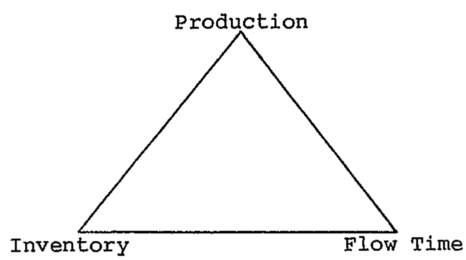
Flexibility is the most abstract of the three variables because it can appear in many forms from machinery to operators, can be on-line or require set-up. Despite this wide range of forms, flexibility's measurable impact upon the production facility will be related to the deviation of flow time. The higher the number of paths for a part the smaller its deviation in flow time because the process with only one path will have flow time deviations equal to repair times of machinery. As more paths are available, the flow time deviations will become less sensitive to station repair times and congestion with other parts. The input variables to integration effects can then be measured with the number of in-process parts and the vector of flow time for each part, and the vector of flow deviations for each part. Little's Law provides a mathematical relationship between work in-process, flow time, and production and is shown below.

FLOW-TIME x INVENTORY = PRODUCTION

This law allows that with any two variables, the third can be mathematically derived. However, it assumes that flow time and inventory are independent variables which is not the case for integrated manufacturing. As inventory increases, congestion in the system will increase as well and part flow time will increase. How much a given increase in inventory will increase actual flow time(s) is impossible to determine mathematically, but may be obtained via simulation.

The Triangle of Integration is used to illustrate the fact that flow time and inventory are not independent of one another. Their relative impact upon production must be considered but their relative impact upon each other must be included as well. This characteristic is more easily observed through the use of the Work In-Process Against Capacity (WIPAC) Curve.

TRIANGLE OF INTEGRATION



Work In-Process Against Capacity Curve

The WIPAC Curve is a graphical representation of the inventory, flow time and production. Each point of this curve is a single instance of Little's Law and shows the dynamic relationship between inventory level and flow time. production is graphed as the vertical axis and inventory is plotted along the horizontal axis. The curve moves upward as inventory increases. However, the curve starts to bend due to increases in flow time because of the increased inventory level. This increase in flow time is giving a negative effect upon production just as it would in any closed production system. How fast this curve bends, its height and whether it bends downward after reaching an optimal depends upon the balance and degree of flexibility in the production facility.

When the complete WIPAC Curve is found, the actual quantities for gross production, station unavailability and integration effects can be entered into the MIM equation to determine net production. Then alternative strategies for different balance through a different process or changes to the degree of flexibility can be proposed and studied for their respective integration effects.

WIPAC Curve

Production

Gross Production Level

Station Availability Level

Net Production Level

Inventory

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