Global relations between inventory, manufacturing lead time and delivery date promises

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Abstract

This paper reports a study of the inventory, lead time and delivery promise data from the Global Manufacturing Research Group. It finds that manufacturing lead time increases as work-in-process inventory increases, as theory suggests. Also, many companies promise delivery in less time than it takes to produce the product, and the difference is not explained by finished goods inventory. The research also shows that the chief benefit of JIT, for those few firms that are achieving benefits, seems to be reduced raw materials.

1. Introduction

This paper describes an analysis of some of the data collected by the Global Manufacturing Research Group (GMRG) on manufacturing practices in two industries: non-fashion textiles and small machine tools. The data gathering was begun in 1986 in South Korea and the People's Republic of China, and has been extended to Australia, Bulgaria, Chile, Finland, Hungary, Japan, Mexico, North America, Russia and Western Europe. A common questionnaire was used in order to be able to compare findings between the regions. Information obtained from the surveys is contained in a data base housed in the Kenan Institute at the University of North Carolina.

The data cover areas of practice from forecasting to materials management, principally from the materials planning and control functions. The industries were chosen because they are found virtually everywhere in the world. In addition, the machine tool companies mainly use batch processing, while the textile companies are closer to a process form of production. A comprehensive description of the project, questionnaire and data formats is provided in Ref. [1].

A variety of studies have been performed on the data base. Regional differences have been studied in bilateral (e.g., Korea and Western Europe [2]), to multilateral comparisons [3]. Specific issues like the linking of the market to manufacturing [4] have also been investigated. The analysis described in this paper is also concerned with a specific issue, that of the relationship between inventories, manufacturing lead times, and promised delivery dates.

The discussion of the analysis starts with a description of the data used in this study. The next Section describes the relationship between manufacturing lead time and inventory. Following that, promised delivery times are compared to the manufacturing lead time and the effect of variables that might mitigate the manufacturing lead time, customer promise date relationship is explored. Finally, the
impact of JIT is evaluated and some conclusions are drawn.

2. The data used for this study

This study uses a subset of the Global Manufacturing Research Group database. Specifically, data on typical manufacturing lead times, delivery times promised to the customer, and levels of inventory, as well as values for variables that relate to the management of inventories were investigated. To provide insights on developed and less developed economies, data from the People’s Republic of China, Hungary, Japan, North America, and Western Europe were used. Both the machine tool and textile industry data were included.

Table 1 shows the distribution of companies sampled by type of economy, region, and industry. Even though the minimum number of companies for any subgroup is 17, the sample size for any single experiment could be less, due to non-responses.

3. Manufacturing lead time as a function of relative inventories

The first set of experiments on the data had to do with manufacturing lead time and inventory relationships. Is there a general relationship (i.e., one that can be seen for the data as a whole) between lead time and any of the three inventory types: raw materials, work-in-process, or finished goods? The lead time was reported as the typical manufacturing time for batch or product. The inventory data consisted of total inventory (in monetary terms) and the percentage distribution between raw materials, work-in-process, and finished goods.

Some theory exists to help frame the hypotheses. Shop floor control theory indicates that as work-in-process (WIP) increases, the manufacturing lead times should increase. While there is no direct theory concerning raw material inventories, their existence might reduce manufacturing lead times. The argument is that there would be no need to wait for raw materials to be delivered before starting manufacturing. Finally, finished goods inventory levels should not affect manufacturing lead times.

The first step was to normalize the inventory data for company size. The database provides annual sales (in SUS) and total inventory was also expressed in SUS. Using sales as a measure of company size, inventory values were normalized by computing the number of days of supply of each type of inventory. The manufacturing lead times were compared to the number of days of supply.

The analysis was started by preparing scatter plots of the manufacturing lead time as a function of the days of supply of the different types of inventory. These are reproduced in Figs. 1–3. To help determine any general
Fig. 1. Manufacturing lead time versus raw material inventory.

Fig. 2. Manufacturing lead time versus work-in-process (WIP) inventory.

Fig. 3. Manufacturing lead time versus finished goods inventory.

To help detect any underlying relationships that might be more complex than linear, the LOWESS regression technique of Cleveland was applied [5]. This robust method does not impose any specific model on the data but weights the dependant variable points (the manufacturing lead time) in successive narrow regions around the independent variable (the inventory) to develop a smooth curve through the data. The data are allowed "to speak for themselves". The LOWESS regressions are the curved dotted lines also shown in Figs. 1–3.

Despite the conjecture about the relationship between raw material and lead time, there is a significant positive slope to the linear regression line in Fig. 1. The slope indicates that, roughly, for every day of added raw material inventory, there is slightly less than a half day added to the manufacturing lead time. The relationship is a weak one, however, explaining only about 4% of the overall variance.

For the work-in-process data, Fig. 2, the slope is positive and significant. Approximately 25% of the overall variance is explained by the WIP inventory and, on the average, for every additional day of WIP there will be approximately one more day of manufacturing lead time. That suggests that the additional day of WIP means one more day a batch must spend in queue on the factory floor.

The regression line for finished goods, shown in Fig. 3, is not significant which
supports the contention that there is no relationship between lead time and finished goods. This result could be due, in part, to the use of the linear model when it is not appropriate. Indeed, even though the LOWESS regression lines lie close to the linear regressions in all three figures, they still suggest that the relationships may be curvilinear. The clearest conclusion, however, is that there is still a lot of scatter in each of the figures.

To address some of the possible reasons for the scatter, the relationships for the sub-groups of Table 1 were explored, still using linear regression and scatter plots for general understanding. For raw materials there was a significant relationship only for the textile industry in the two less developed economies and for both industries combined in the LDEs. The slope was still positive (e.g., the more raw material, the longer the lead time), but the maximum amount of variance explained was still only about 25%. At the country level, the slopes turned negative (in line with the original conjecture) but there were no significant relationships. The conclusion from these experiments is that there is not a clear, strong relationship between raw material levels and manufacturing lead time, even at the country level.

The results of the detailed studies for the relationship between finished goods inventories and manufacturing lead times were again not consistent, but were even less supportive of relationship than in the raw material case. There were significant relationships for the textile industry in all regions and for both industries combined for the LDEs, but the maximum variance explained was less than 15%. At the country level there were no significant relationships, and the slopes were both positive and negative, indicating no consistent relationship.

The WIP relationship was significant and positive for all sub-groups except the machine tool industry in the LDEs. In all cases the slopes were positive, but substantial scatter still remains (the maximum variance explained was for the textile industry at 35% in the developed economies and over 50% in the LDEs). The differences in lead times and WIP levels was not significant between the two economies, but was between the two industries. Figure 4 shows the average lead times and WIP inventory levels for the textile and machine tool industries. In both cases, the greater values are in the machine tool industry, which may help explain why the greatest amount of scatter is in that industry. The overall conclusion remains, however, that there is a strong positive relationship between WIP and manufacturing lead time in the data.

4. Promised delivery time versus lead time

Data are available in the data base on delivery promises made to customers by the companies in the sample. It comes in two forms. One form of the data is for firms that make fixed delivery time promises that remain constant for quite some time. This can occur when there is a standard delivery time set by the industry. The fixed time is reflected in a comment like “we always tell our customers we will deliver in three weeks”. For those firms, the data consists of the fixed promised delivery times.
The other form of promised delivery times is for companies that vary the time as conditions change. The minimum and maximum times used in promising delivery to their customers is available for these firms. The times can vary because of local conditions, like the amount of business, or external factors, like delivery of raw material. In this study, the causes are not analyzed, but the times are related to the manufacturing lead time and other factors.

Theory indicates that the manufacturing lead time should be a lower bound on the delivery lead time. That is, the sales force should not promise delivery before manufacturing can build the product. In circumstances where the promise times are less, the explanation should be found in finished goods inventory, or poor delivery service. The relationship between the fixed delivery time promises and the manufacturing lead time is plotted in Fig. 5. The 45° (dashed) line divides the companies into those with "feasible" promise times and those whose promises are "infeasible". Companies which lie above the line promise to deliver the product in more time than it takes to produce it. Companies below the line promise delivery times that are less than the manufacturing lead time. The companies which lie on the line are those which promise a delivery time equal to the time it takes to produce the product.

Forty-five (30%) of the companies are in the infeasible region (below the line), nearly the same number of companies that are above it (65). Thirty-eight companies lie on the line. To help visualize any tendencies that might exist, both a LOWESS (the dotted curved line) and a linear regression line (solid) are plotted on the chart. Both lines indicate that it is more likely that a company with a long manufacturing lead time will promise delivery in less than the manufacturing lead time.

To search for an explanation for the companies that promise deliveries in less time than it takes to make the product, the finished goods inventory, safety stock, and order lateness data were studied. The mean values and significance levels, using the Kruskal-Wallis test, of those data are provided in Table 2. Only the finished goods inventories are significantly different. They are higher, as might be expected, for those companies that have promise dates less than the manufacturing lead times (those in the infeasible region).

Surprisingly, the companies with shorter promise times than manufacturing times do not have any greater lateness than those who promise after the manufacturing lead time. Likewise, safety stock, which could have been used like regular finished goods inventory to improve delivery times, is also similar for each group. Only finished goods inventory is left to account for the differences between the time to manufacture and the promise time.

The promised delivery time was adjusted to account for the days of supply of finished goods inventory, and was plotted against manufacturing lead time in Fig. 6. There was a reduction in sample size from Fig. 5, since some of the firms did not report finished goods inventory. Nevertheless, 13% of the firms are still in the infeasible region after the adjustment. The difference in finished goods inventories is not great enough to account for the difference between the promise times and manufacturing lead times. For the companies in the infeasible region, the average promise...
Table 2
Mean values of finished goods inventory, lateness and safety stock, and significance levels of the differences in the different feasibility regions

<table>
<thead>
<tr>
<th>Feasible region</th>
<th>Infeasible region</th>
<th>On the line</th>
<th>Kruskal-Wallis test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finished goods inventory (days)</td>
<td>Average lateness per order (days)</td>
<td>Finished goods safety stock (weeks)</td>
<td></td>
</tr>
<tr>
<td>11.4</td>
<td>5.3</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>40.2</td>
<td>5.6</td>
<td>7.3</td>
<td></td>
</tr>
<tr>
<td>25.4</td>
<td>4.7</td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td>0.026</td>
<td>0.133</td>
<td>0.866</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 6. Adjusted fixed delivery time promise versus manufacturing lead time.

The relationship between manufacturing lead time and customer promise time was checked for the companies that have variable promise times. If the maximum promise times are still shorter than the manufacturing lead times, that could be even more severe than in the case of fixed lead times. The maximum promise times were adjusted for finished goods inventory, and checked against the manufacturing lead times. Even under these conditions, 7% of the firms were in the infeasible area. For those firms, the finished goods inventory levels (an average of only 12 days supply) could not make up the differences between promise times of 103 days and manufacturing lead times of 201 days. The gap is very nearly the same as in the fixed delivery promise time case.

5. The impact of JIT

Another set of inquiries in this study looked at the impact of JIT on the relationships between inventories and delivery promise times to customers. JIT is one of the contemporary approaches to inventory and production management being implemented in many companies. Among the benefits claimed for JIT are reduced manufacturing lead times and reduced inventories. These claims are investigated as was the suggestion that the use of JIT would enable firms to be better at promising delivery.

The firms were divided into one group that had never heard of JIT or felt no need to introduce it, and another that is using and benefiting from JIT. Despite the global publicity for JIT, less than 10% of the respondents fall into the latter group. The performance for the firms in each of the groups is summarized in Table 3 along with the Kruskal–Wallis significance levels for the differences.

Of the inventory reductions expected from JIT only the raw material inventories are significantly lower. The other inventory categories were not significantly different, nor was the manufacturing lead time reduced. In fact, the customer promise times were less for those firms with JIT, even though the manufacturing lead times were not significantly different (indeed the average lead time is higher). This
## Table 3
Mean performance measures for firms using JIT and those not

<table>
<thead>
<tr>
<th>Variable</th>
<th>No JIT</th>
<th>JIT</th>
<th>Kruskal-Wallis test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material inventory (days)</td>
<td>59.0</td>
<td>27.4</td>
<td>0.009</td>
</tr>
<tr>
<td>Work-in-process inventory (days)</td>
<td>38.9</td>
<td>36.2</td>
<td>0.585</td>
</tr>
<tr>
<td>Finished goods inventory (days)</td>
<td>18.7</td>
<td>23.9</td>
<td>0.589</td>
</tr>
<tr>
<td>Manufacturing lead time (days)</td>
<td>82.2</td>
<td>88.7</td>
<td>0.486</td>
</tr>
<tr>
<td>Fixed promise time (days)</td>
<td>78.7</td>
<td>49.0</td>
<td>0.029</td>
</tr>
<tr>
<td>Firms in infeasible region (%)</td>
<td>12.9</td>
<td>16.1</td>
<td>1</td>
</tr>
<tr>
<td>Firms in adjusted infeasible region (%)</td>
<td>5.0</td>
<td>6.3</td>
<td>1</td>
</tr>
</tbody>
</table>

1 Not significant using the binomial test.

The difference may be reflected in the higher percentage of infeasible delivery promises given by the JIT firms, even though the binomial test did not show the differences to be significant.

It seems that JIT may engender a false feeling of confidence that leads to promising much shorter delivery times than without JIT. Moreover, the raw material reductions give credence to the complaints of suppliers who claim that JIT simply means moving the inventory back further in the supply chain.

### 6. Conclusions

This study strongly supports the theory that relates work-in-process inventories to manufacturing lead time. The theory suggests that manufacturing lead time will increase with work-in-process inventory. The raw material inventory has very little effect on manufacturing lead times, surprisingly, and finished goods inventory seems to have no effect at all. A high proportion of firms promise delivery within the manufacturing lead time, more so than can be explained by finished goods inventory. This is especially true for those firms with long manufacturing lead times.

For those firms that are using and benefiting from JIT, only the raw material inventories are reduced (perhaps by being pushed back on to the supplier). Also, reductions in the promised delivery time to customers is not matched by reductions in the manufacturing lead times for the JIT firms.

There are few differences between the lesser developed countries and the developed countries. In some cases the relationships seem stronger in the LDEs, especially for the textile industry, but no other difference stands out. The two LDE countries chosen, China and Hungary, are both reforming centrally planned economies. The data suggest that central planning has not left a differential legacy on the tested aspects of material management.

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### References