How to Cut Manufacturing Throughput Time

by

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Manufacturing firms are facing an environment where success depends on quick response to customer demands. Despite important contributions by Blackburn (1991) and Stalk and Hout (1990), we lack large-scale, empirical evidence that time-based manufacturing practices can reduce throughput time. More importantly, we lack an understanding of which practices are vital in achieving throughput time reductions and what management actions are critical to achieve high levels of these practices.

This paper presents a framework for understanding time-based manufacturing practices. It reports on the results of a large-scale empirical study that determines which practices have a significant impact on throughput time reduction. The study included 244 discrete part manufacturing firms primarily from four industries: fabricated metal products, industrial and commercial machinery, electrical equipment, and transportation equipment.

Results of the study indicate that quality improvement efforts and pull production approaches are critical time-based manufacturing practices. Quality improvement efforts are facilitated by dependable suppliers and shop-floor employee involvement in problem solving. Pull production is facilitated by reengineering setups, cellular manufacturing, and preventive maintenance. These three practices are, in turn, enhanced by shop-floor employee involvement in problem solving. Based on these results, manufacturing managers seeking improved operations should begin by enhancing employee empowerment and participation.

Time-based competition focuses on reducing response time by squeezing time from every facet of the value-delivery system from research and development, to product development, to manufacturing, to marketing and delivery (Abegglen and Stalk, 1985). While time-based competition focuses on time reduction, it often also accomplishes substantial improvements in costs, quality, and productivity. Blackburn (1991) and Stalk and Hout (1990) describe case studies where manufacturing firms that redesigned their business processes to compress time achieved higher productivity, increased market share, reduced risk, and improved customer service.

Time-based manufacturing is one weapon for time-based competitors. Time-based manufacturers implement a set of practices designed to reduce throughput time. A literature review identified seven key practices including: shop-floor employee

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involvement in problem solving, reengineering setups, cellular manufacturing, quality improvement efforts, preventive maintenance, dependable suppliers, and pull production approaches (Davy, White, Merritt, and Gritzacher, 1992; Handfield and Pannesi, 1995; Monden, 1983; Sakakibara, Flynn, and Schroeder, 1993; Saraph, Benson, and Schroder, 1989). Many of these time-based practices are key elements of just-in-time (JIT) as defined by Monden (1983). In fact, Abegglen and Stalk (1985) observed that some JIT innovators became the first time-based competitors as their emphasis on speed propelled their skills in time reduction throughout the value-delivery system.

Case studies illustrate how some manufacturing firms have applied these seven time-based practices to cut response time and enhance competitiveness (Blackburn, 1991; Hamilton, 1991; Lindsley, Blackburn, and Elrod, 1991; Merrills, 1989). However, large-scale empirical studies that investigate the relationships between these manufacturing practices and throughput time are unavailable. At present, we know little about whether, or under what conditions, particular time-based manufacturing practices affect a firm’s throughput time.

This paper provides a framework that conceptualizes time-based manufacturing. It describes the results of a large-scale empirical study that measures the extent to which a firm has implemented time-based manufacturing practices. The study seeks to determine if firms that achieve high-level of these practices also attain low throughput times. Finally, the paper indicates which manufacturing practices may have a significant impact on throughput time reduction.

A Framework for Conceptualizing Time-Based Manufacturing

Time-based manufacturing is defined in terms of seven organizational-level practices (see Figure 1) that reduce throughput time (Koufteros, Vonderembse, and Doll, 1997). These practices measure the extent to which:

- Shop-floor employee involvement in problem solving (First-level employees participate in activities to define and solve problems)
- Reengineering setup (Efforts are taken to reduce setup time)
- Cellular manufacturing (Units are produced in a product oriented layout)
- Quality improvement efforts (Methods are developed and used to reduce defects and enhance quality)

Figure 1. Model of Time-Based Manufacturing and Throughput Time
Preventive maintenance (Equipment is routinely maintained on a proactive basis)

Dependable suppliers (Suppliers facilitate customer needs for service quality)

Pull production (Production is driven by demand at the next workstation and ultimately from the customer)

Time-based manufacturing involves organizational level practices that require shop-floor employee involvement in problem solving (Doll and Vonderembse, 1991; Hall, 1987, 1993; Showalter and Mulholland, 1992). This is corroborated by the employee involvement and participation literature, which indicates that employee involvement drives improvement efforts (Johnson and Rice, 1987; Markus, 1983). Shop-floor employees have a unique understanding of the problems present in their environment and have insights that enable them to develop effective solutions (Badore, 1992).

Enhanced employee problem solving skills facilitate the reengineering of setups (Monden, 1983, Shingo, 1985), the implementation of manufacturing cells (Wemmerlov and Hyer, 1989), the establishment of quality improvement efforts (Deming, 1986; Garvin, 1983; Juran, 1981a, 1981b), and the initiation of effective preventative maintenance programs (Bockerstette and Shell, 1993; Schonberger, 1986). The abilities to develop a base of dependable suppliers (Ansari and Modaress, 1990; Handfield and Pannesi, 1992; Schmenner, 1991) and to achieve pull production (Monden, 1983; Schonberger, 1986) are also enhanced by shop-floor involvement.

Proposition 1: High levels of shop-floor employee involvement in problem solving enable firms to attain high levels of time-based manufacturing practices.

Figure 1 also illustrates a link between these practices and throughput time. Firms that have attained high levels of these practices should achieve low throughput times. This link has not been tested with a large-scale study. In a study of forty make-to-order manufacturing firms from nine industries, Handfield and Pannesi (1995) have results that “lend support to the claim that improved supplier performance, combined with efforts to establish JIT purchasing activities with suppliers of critical inputs, can assist in reducing lead-time.” Their study is an important part of the foundation on which this study is built.

Proposition 2: High levels of time-based manufacturing practices enable firms to reduce throughput time.

Methods Used in Data Collection and Analysis

To measure the time-based manufacturing practices, survey instruments developed by Koufteros, Vonderembse, and Doll (1997) were used to measure the six time-based manufacturing practices and shop-floor employee involvement in problem solving. A copy of the survey can be found in Appendix A. Throughput time was measured by aggregating the days of raw material inventory, value added time, days of work-in-process inventory, and days in finished goods inventory.

The Society of Manufacturing Engineers (SME) cosponsored a large-scale survey. From its membership, SME selected 2,500 organizations with more than 100 employees that are engaged in discrete part manufacturing. SME mailed a survey and cover letter to the senior manufacturing executive at these firms. A notification card was sent two weeks prior to mailing the questionnaire. Out of the 253 responses received, 244 were usable.

The usable responses are from fabricated metal products (35%), industrial and commercial machinery (30%), electrical equipment and components (12%), transportation equipment (15%), and miscellaneous (8%). The respondents’ positions are: presidents (12%), vice-president (31%), directors (11%), managers (19%), and
miscellaneous (27%). Seventy percent of the responses are from firms with less than 500 employees, and firms with more than 1,000 employees account for only 15% of the sample. These sample statistics are not significantly different from the corresponding population parameters, which implies no difference in characteristics between respondents and non-respondents.

The relationships described in the propositions were evaluated by examining the correlation between shop-floor employee involvement in problem solving and time-based manufacturing practices and between these practices and throughput time. In addition, the responses were divided into two parts, firms with long throughput times and those with short throughput times. For each of the practices, a t-test was completed to determine if firms with low throughput times have higher levels of each of the practices than firms with long throughput times. Finally, a regression model was executed to learn which practices might have a significant impact on throughput time reduction.

**Results: Impact of the Time-Based Practices on Throughput Time**

Proposition 1 implies that firms with high levels of shop-floor employee involvement in problem solving will have high levels of the six manufacturing practices listed in Figure 1. The positive correlation listed in Table 1 (presented in Appendix B) between shop-floor employee involvement and the six practices provide support for proposition 1.

In particular, the correlation between shop-floor employee involvement and reengineering setups and between shop-floor employee involvement and quality improvement efforts is very high, 0.72 and 0.55, respectively. Reengineering setups and quality improvement efforts are labor intensive activities that require shop-floor employees to be involved in planning and executing activities on a continuing basis which may help to explain the very high correlation. The correlation between shop-floor employee involvement and preventive maintenance is also high. Shop-floor employees are important participants in successfully implementing and executing preventive maintenance programs. Planning and executing cellular manufacturing and pull production systems also require participation of shop-floor employees but probably not at the same level as the other practices which may explain their somewhat lower correlation. The correlation between shop-floor employee involvement in problem solving and dependable suppliers is very low which indicates that shop-floor employee involvement may not be essential to develop a network of dependable suppliers.

Proposition 2 states that firms with high levels of the six time-based manufacturing practices will have lower throughput time. The negative correlation between the six time-based practices and throughput time support this proposition in only some of the cases. Quality improvement efforts have a high negative correlation with throughput time, which indicates that an increasing focus on quality can lead to a reduction in throughput time. Pull production has the next highest correlation with throughput time at -0.23. A manufacturing system using pull production should be responsive to changing customer requirements. Preventive maintenance programs and efforts to reengineer setups may have some impact on reducing throughput time. The correlation between cellular manufacturing and throughput time and between dependable suppliers and throughput times is not significant at the 0.05 level.

To further examine the relationship between time-based manufacturing practices and throughput time, the sample of 244 firms was divided into two groups. The average throughput time was calculated for all firms in the sample. Firms with less than the average throughput time were placed in the Low Throughput Time Group (n=114), and firms with greater than the average throughput time were placed in the High Throughput Time Group (n=130). Means and standard deviations for the six manufacturing practices were calculated for each group and are displayed in Table 2, in Appendix B.
T-tests were done to determine if firms with low throughput time have significantly different levels of each manufacturing practice than firms with high throughput time. When the mean values of the two groups are compared, the Low Throughput Time Group has higher scores for all of the time-based manufacturing practices than the High Throughput Time Group. However, only three of these differences are statistically significant at the 0.01 level. They are quality improvement efforts, preventive maintenance, and pull production. These are the same practices that are significantly correlated with throughput time.

Correlation analysis and t-test evaluate the relationships between each of the time-based manufacturing practices and throughput time independently. In other words, it is impossible to assign how much of the variation in the throughput time may be explained by variation in each of the manufacturing practices. Multiple regression analysis allows us to examine all of the practices simultaneously and to determine mathematically which practices have significant impact on throughput time and the relative magnitude of that impact. To accomplish this a stepwise, backward, multiple regression was performed on all 244 observations using SPSSX. Throughput time was the dependent variable, and the six manufacturing practices were independent variables. Backward means that all of the practices are put into the regression equation initially. Stepwise means that practices that are not statistically significant are dropped and multiple regression analysis is performed again. Steps are taken until only the variables with statistically significant coefficients remain. At the end of this analysis, the manufacturing practices with statistically significant coefficients at the 0.05 level are pull production and quality improvement effort. Final results of the model are included in Table 3, in Appendix B.

Table 3 shows that the model with pull production and quality improvement effort explains 38.4 percent of the change in throughput time (Multiple R or Multiple Correlation = 0.384). The analysis of variance clearly shows that the amount of variation explained by the model is significant (F-statistic = 20.8 and F is significant at the 0.0000 level which indicates less than 1 chance of error in 10,000).

The t-statistic and the significance of t indicate that the coefficients for quality improvement effort and pull production are both statistically significant. This means that changing these variables may affect throughput time. The impact of a change in quality improvement efforts is more than twice the value of a comparable change in pull production. The scales for pull production and quality improvement effort are the five point Likert scales described earlier. The constant in the list represents the maximum throughput time (i.e., the throughput time when a firm is rated a 0 in both quality improvement effort and pull production). Changing pull production and quality improvement efforts will cause this time to be reduced. For example, if a firm scores a 4.0 in both pull production and quality improvement effort, then throughput time should be reduced to 3.584 [Throughput Time = 5.26 - (0.127)(4.0) - (0.292)(4.0)]. This would be a 31.9 percent reduction in throughput time. The usefulness of this calculation is not the absolute value of throughput time but the relative value that can be achieved by improved performance.

**Discussion of the Time-Based Manufacturing Framework**

Based on the results in this study, it may be appropriate to reconfigure the model presented in Figure 1. The study indicates that the primary determinants of manufacturing throughput time are pull production and quality improvement efforts. This result seems to be consistent with our conceptual understanding of time-based competition. Manufacturing systems that are driven by customer demand (pull production) and that get product quality right the first time (quality improvement effort) should be more responsive than “push” systems that produce to schedule in anticipation of possible customer demand or systems that consume extra time to rework parts due to quality problems.
How do managers create systems that have high-levels of quality improvement effort and pull production? Are the other items of time-based manufacturing irrelevant? Further evaluation of the time-based practices listed in Figure 1 and examination of the data seem to indicate that successful pull production is likely caused by the firm’s ability to reengineer setups, create product-focused manufacturing cells, and implement preventive maintenance. Figure 2 indicates that pull production may be caused by specific process design activities. Short setup times allow manufacturers to respond quickly to changing customer orders. Cellular manufacturing reduces throughput time by streamlining material handling time, reducing waiting time, and cutting changeover time. Preventive maintenance systems improve system reliability so unplanned downtime is greatly reduced or eliminated. To support these claims, there are statistically significant correlations between pull production and these three factors: 0.34 with reengineering setups, 0.29 with cellular manufacturing, and 0.33 with preventive maintenance. All are significant at the 0.01 level.

The development of successful quality systems and process engineering capabilities require substantial and continuing involvement and support from employees. As shown in Figure 2, shop-floor employee involvement in problem solving is an antecedent to these time-based manufacturing practices. In today’s factories, work is increasingly intellectual and shop-floor employees are recognized as the actors who plan and do work. Integrating “work planning” and “work doing” in employee teams is essential to learning through changes in setup, layout, preventive maintenance, and quality practices. These changes allow organizations to eliminate waste in the system, improve competitive capabilities, and achieve pull production (Hall, 1987 and 1993; Zuboff, 1984). This is supported by the data presented in Table 1 which indicate that shop-floor employee involvement in problem solving is significantly correlated with reengineering setups, cellular manufacturing, preventive maintenance, and quality improvement efforts.

In addition, creating manufacturing systems that can deliver high quality parts depends upon suppliers that can do the same. Dependable suppliers and quality improvement efforts have a correlation coefficient of 0.57, which is significant at the 0.01 level. Improved supplier performance can help to reduce downtime and the shortages associated with delivery delays (Ansari and Modaress, 1990; Blackburn, 1991; Clark, 1989). If a supplier’s parts are defective, time-consuming rework is required or production is delayed until replacement parts arrive (Handfield and Pannesi, 1992). Developing quality systems that achieve high-quality outputs requires both internal and external quality to be high. From a customer service perspective, it makes little difference whether a quality problem occurs.

**Figure 2. Revised Model of Time-Based Manufacturing and Throughput Time**
in-house or at a supplier’s facility.

**Implications for Managers**

There are three major lessons that can be learned from this study. The foundation of throughput time reduction seems to be creating an organizational climate that encourages employee empowerment and participation. Second, building a base of dependable suppliers is critical for manufacturing competitiveness. Third, keep your eye on the “right” ball. Managers need to focus their actions on reengineering setups, cellular manufacturing, preventive maintenance, and quality improvement efforts rather than on outcomes such as reducing inventory and cutting costs.

The framework described in Figure 2 implies that a key to success in time-based manufacturing is the ability to create an organizational climate and culture that facilitates employee empowerment and participation. The creation of cross-functional teams of shop-floor employees, managers, and representatives from other key areas to tackle key operating problems and develop successful solutions is an important prerequisite for success. These groups should be charged with developing and implementing systems to reduce setup time, creating manufacturing cells, increasing systems reliability through preventive maintenance, and improving quality. The shop-floor employees must be committed to these activities and be involved in continuous improvement initiatives. They must believe that their inputs make a difference.

It is also important to build a dependable supplier network. Suppliers are merely an extension of a firm’s manufacturing system. Suppliers and customers are linked into a supply chain, and that is the critical entity in defining competition. When customers buy cars from General Motors, they are paying for all the activities in the entire supply chain from basic raw materials such as iron ore (steel), sand (glass), and crude oil (plastics) to the finished product. For General Motors, competition for the car-buying public’s business is really competition between its supply chain and the supply chains of its competitors, i.e., Ford, Chrysler, Toyota, etc.

It is important to focus on achieving the time-based practices listed in Figure 2. Reengineering setup, cellular manufacturing, preventive maintenance, and quality improvement efforts can deliver pull production and throughput time reductions. Focusing on cost reductions often leads to decisions that hinder quality and/or increase response time. For example, excess inventory is a common problem for many firms. An organization that focuses on costs may attempt to strip inventory from its manufacturing system without changing key factors in the system. As inventory declined, the company’s slow and inflexible production systems are unable to respond. The results are often missed shipments, late deliveries, and dissatisfied customers. Firms that focus on time reduction often achieve substantial benefits in quality and costs, while creating a manufacturing system that is more responsive to the needs of its customers.

**References**


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Mark Vonderembse, Ph.D., is a Professor of Operations Management at The University of Toledo. He earned his doctorate from The University of Michigan in 1979. His research interests are time-based competition, quality management, and manufacturing strategy.

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APPENDIX A

Time-Based Manufacturing Practices Survey

Employee Involvement in Problem Solving:
- Shop-floor employees are involved in problem solving efforts.
- Shop-floor employees are involved in suggestion programs.
- Shop-floor employees are involved in designing processes and tools that focus on improvement.
- Shop-floor employees are involved in improvement efforts.
- Shop-floor employees are involved in problem solving teams.

Reengineering Setup:
- Employees work on setup improvement.
- Employees redesign or reconfigure equipment to shorten setup time.
- Employees redesign jigs or fixtures to shorten setup time.
- We use special tools to shorten setup.
- Our employees are trained to reduce setup time.

Cellular Manufacturing:
- Products that share similar design or processing requirements are grouped into families of products.
- Products are classified into groups with similar processing requirements.
- Products are classified into groups with similar routing requirements.
- Equipment is grouped to produce families of products.
- Families of products determine our factory layout.

Quality Improvement Efforts:
- We use fishbone type diagrams to identify causes of quality problems.
- We use design of experiments (i.e., Taguchi methods).
- Our employees use quality control charts (e.g., SPC charts).
- We conduct process capability studies.

Preventive Maintenance:
- We emphasize good preventive maintenance.
- Records of routine maintenance are kept.
- We do preventive maintenance.
- We do preventive maintenance during nonproductive time.
- We maintain our equipment regularly.

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2 The survey uses a five-point Likert scale where 1 = not at all, 2 = a little, 3 = moderately, 4 = much, and 5 = a great deal. The instruments are valid and reliable with all factor loadings above 0.60, no cross-loadings above 0.30, and reliabilities, Cronbach’s alpha, (Cronbach, 1951) of 0.85 and higher.
Dependable Suppliers:
- We receive parts from suppliers on time.
- We receive the correct number of parts from suppliers.
- We receive the correct type of parts from suppliers.
- We receive parts from suppliers that meet our specifications.
- Our suppliers accommodate our needs.
- We receive high quality parts from suppliers.

Pull Production:
- Production is “pulled” by the shipment of finished goods.
- Production at stations is “pulled” by the current demand of the next stations.
- We use a “pull” production system.
APPENDIX B

Table 1
Detailed Results

<table>
<thead>
<tr>
<th>Time-Based Manufacturing Practices</th>
<th>Shop-Floor Employee Involvement in Problem Solving</th>
<th>Manufacturing Throughput Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reengineering Setups</td>
<td>0.72**</td>
<td>-0.13*</td>
</tr>
<tr>
<td>Cellular Manufacturing</td>
<td>0.32**</td>
<td>-0.02</td>
</tr>
<tr>
<td>Quality Improvement Efforts</td>
<td>0.55**</td>
<td>-0.36**</td>
</tr>
<tr>
<td>Preventive Maintenance</td>
<td>0.38**</td>
<td>-0.18**</td>
</tr>
<tr>
<td>Dependable Suppliers</td>
<td>0.15*</td>
<td>-0.06</td>
</tr>
<tr>
<td>Pull Production</td>
<td>0.33**</td>
<td>-0.23**</td>
</tr>
</tbody>
</table>

* Correlation significant at 0.05 level.
** Correlation significant at 0.01 level.

Table 2
Comparison of Means for Time-Based Manufacturing Practices for Low and High Throughput Time Groups***

<table>
<thead>
<tr>
<th>Time-Based Manufacturing Practices</th>
<th>Low Throughput Time Group</th>
<th>High Throughput Time Group</th>
<th>Significant Difference Between Means of Two Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (n=114) Std. Dev.</td>
<td>Mean (n=130) Std. Dev.</td>
<td></td>
</tr>
<tr>
<td>Reengineering Setups</td>
<td>3.14 .86</td>
<td>3.08 .73</td>
<td>No</td>
</tr>
<tr>
<td>Cellular Manufacturing</td>
<td>3.65 .84</td>
<td>3.55 .85</td>
<td>No</td>
</tr>
<tr>
<td>Quality Improvement Effort</td>
<td>2.98 1.12</td>
<td>2.31 .99</td>
<td>Yes @ p=0.01</td>
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<tr>
<td>Prevention Maintenance</td>
<td>3.65 .89</td>
<td>3.36 .88</td>
<td>Yes @ p=0.01</td>
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<tr>
<td>Dependable Suppliers</td>
<td>3.86 .54</td>
<td>3.77 .58</td>
<td>No</td>
</tr>
<tr>
<td>Pull Production</td>
<td>3.37 1.13</td>
<td>3.07 1.11</td>
<td>Yes @ p=0.01</td>
</tr>
</tbody>
</table>

***Scales are: 1 = not at all, 2 = a little, 3 = moderately, 4 = much, 5 = a great deal
Table 3
Results of Multiple Regression Analysis for Manufacturing Practices and Throughput Time

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>T-Statistic</th>
<th>Significance of T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pull Production (PP)</td>
<td>-.126808</td>
<td>-2.327</td>
<td>.0208</td>
</tr>
<tr>
<td>Quality Improvement Effort (QI)</td>
<td>-.291539</td>
<td>-5.219</td>
<td>.0000</td>
</tr>
<tr>
<td>Constant</td>
<td>5.255692</td>
<td>25.506</td>
<td>.0000</td>
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</table>

Multiple R: .38392
R Square: .14740
Adjusted R Square: .14032
Standard Error: .92656

Analysis of Variance

<table>
<thead>
<tr>
<th></th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>2</td>
<td>35.76914</td>
<td>17.88457</td>
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<tr>
<td>Residual</td>
<td>241</td>
<td>206.90098</td>
<td>.85851</td>
</tr>
</tbody>
</table>

F = 20.83210
Significance of F = .0000
How to Cut Manufacturing Throughput Time