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The Empirical Determinants of Inventory Levels in High-Volume Manufacturing

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COMMENTS WELCOME

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The Empirical Determinants of Inventory Levels in High-Volume Manufacturing

Abstract

This study uses survey data on several hundred automotive suppliers in North America to evaluate the determinants of inventory levels in high-volume discrete parts manufacturing. We assess the magnitude of raw materials, work-in-process, and finished goods inventories, as well as production lot sizes and through-put times. Results are broadly consistent with the EOQ formula and related models of optimal inventory holding. Inventories are shown to be jointly determined by technological factors and managerial practices.

Several categories of managerial practices are found to be important. Low inventories are linked to employee training and problem solving activities and frequent communication with customers. More unexpected findings show the absence of inventory differences between US-owned and Japanese-owned plants operating in the United States. This suggests that Japanese transplant parts makers have not been completely successful in adapting Japanese manufacturing methods to the US environment.

Keywords: inventory, automotive, JIT manufacturing

The Empirical Determinants of Inventory Levels in High-Volume Manufacturing

1. Introduction

What factors determine the inventories held by manufacturing companies? Are inventory levels more strongly influenced by technological requirements or by managerial practices? Does closer communication with customers, and greater problem solving activity by employees, lead to lower inventories? And to what extent do Japanese manufacturers operate with less inventory than their US counterparts? This paper examines these issues, using comprehensive data on North American automotive suppliers.

The main function of manufacturing inventories–raw materials, work-in-process, and finished goods–is to serve as a buffer against variability. Some variability is stochastic, arising from demand fluctuations, machine breakdowns, quality defects, transportation delays, and other unforeseen problems. Other variability is predictable, stemming, for example, from the efficient batching of production quantities in response to equipment set-up costs. Firms hold "safety stocks" and "cycle stocks," respectively, to buffer against these two types of variability.[1]

Variability is partly determined by technological factors, but it is often amenable to managerial influence. The "just-in-time" (JIT) revolution, which swept Japan in the 1970s and has been transplanted more recently to the United States, recognizes that the true costs of inventories may vastly exceed the financial holding costs, as inventories often obscure sources of improvement on the shop floor. JIT seeks to cut the need for inventories by reducing the variability inherent in manufacturing processes. Through the efforts of managers and shop floor workers, set up times are reduced and the sources of product defects and machine breakdowns are rooted out. In Japan, and increasingly in the United States, these improvements have been facilitated by vertical communication between producers in the supply chain. Such interaction promotes problem solving and enhances scheduling coordination.

[1] In addition, "pipeline stocks" are held while the product is being processed or transported. The amount of pipeline stock is proportional to the processing and transport time.

This paper uses survey data on several hundred auto parts suppliers in the United States and Canada to examine the empirical determinants of inventory levels in high-volume discrete parts manufacturing. We assess the magnitude of raw materials, work-in-process, and finished goods inventories, as well as production through-put times and lot sizes. Using statistical tests, we evaluate the influence of various technological and managerial factors. The auto supplier survey includes a wealth of information on product and process technology, workforce characteristics, relationships with customers, and Japanese ownership. Such detailed data have never before been available for research purposes.

Inventory levels can be viewed as indicators of process capability and production efficiency. Indeed, manufacturing managers often use comparative inventory ratios for benchmarking purposes. This paper provides a set of such benchmarks and an assessment of factors that must be considered in making valid comparisons across factories. In related work we compare the historical levels of inventories held by automotive suppliers in Japan and the United States (Lieberman, Demeester and Rivas (1995); Lieberman and Asaba (1996)), and we show that inventory reductions in Japan were strongly linked to productivity gains (Lieberman and Demeester, 1995).

The remainder of this paper is organized as follows. Section 2 provides a conceptual framework for assessing various factors that might be expected to influence inventory levels. Here, we briefly describe some basic results of mathematical models of optimal inventory holding. We also consider types of managerial intervention that may affect the parameters of these models, thereby enabling a reduction in inventories. Section 3 describes the auto supplier survey and the measures used in the empirical analysis. Section 4 reports statistical tests of the connection between inventory levels and specific technological and managerial factors. These factors are then combined using multiple regression analysis, as described in Section 5. Findings are summarized in Section 6, which concludes the paper.

2. Factors Expected to Influence Inventory Levels

2.1. Models of Optimal Inventory Holding

Numerous models of optimal inventory holding are described in the operations literature (c.f., Peterson and Silver, 1979). These models aim to help managers compute optimal amounts of cycle and safety stocks, given assumptions about parameters. While our objective in this paper is not to estimate any specific model of inventory determination, the basic findings of this literature provide a framework for assessing the factors that would be likely to influence inventory levels in practice.

Optimal cycle stocks are commonly computed using the economic order quantity (EOQ) formula and its many variants. The EOQ formula is:

$$Q^* = (2\,D\,S\,/\,iC)^{1/2}$$

where Q^* is the optimal lot size (or order level), D is the demand per period, S is the setup (or ordering) cost, and iC is the holding cost per period, which we assume equals the interest rate, i, multiplied by the item cost, C. The average level of inventory is $Q^*/2$. The EOQ formula shows that the optimal lot size, and hence the optimal level of inventory, increases with the set-up cost, S, and falls with the cost per unit, C. Our empirical analysis, presented later in this paper, includes data on C, as well as technological factors that are likely to influence set-up costs, S.

In addition to the optimum cycle stock defined by an EOQ type model, some level of safety stock is normally desirable. Common models of optimal safety stock imply that inventories should increase with: (1) variability in demand (i.e., unanticipated changes in volume), (2) variability in product quality (e.g., higher rates of defects), (3) the desired service level (i.e., the probability that demand will be met), (4) the lead time needed to replenish supplies; and inventories should decrease with (5) the cost of holding safety stock (equivalent to iC in the EOQ formula).

In a simple, one-stage manufacturing process where raw materials are transformed instantaneously into finished goods, there is no work-in-process. But in more complicated, multi-stage production processes, such intermediate inventories are essential. The basic concepts of the EOQ and safety stock models still apply, although their form becomes more complex.[2] In multi-stage manufacturing processes, coordination across stages becomes necessary to minimize the inventories arising from machine scheduling and set-up costs. Moreover, stochastic

[2] If production is not instantaneous, work-in-process will also include pipeline inventory, whose quantity increases with the physical processing time.

variability due to machine breakdowns and worker errors leads to bottlenecks, scrap, and rework. The amount of work-in-process increases with the number of stages and with the set-up costs and stochastic variability at each stage. While these factors primarily affect the level of work-in-process, some additional raw materials and finished goods inventories may also be required, to provide a higher level of safety stock.

2.2. Managerial Influences on Optimal Inventory Levels

The optimal inventory models take most input parameters as given. However, the JIT revolution has shown that nearly all forms of variability are subject to managerial control. The basic aim of JIT is to achieve minimal lot sizes and inventory levels by reducing process variability.

In pursuit of these objectives, the managerial literature on JIT is replete with techniques for reducing set-up times, machine breakdowns, and worker errors. For example, set-up times for stamping presses, which were once measured in hours or days, have often been reduced to minutes (Monden, 1981; Shonberger, 1982; Hall, 1983). Many types of “jidoka” or “fool-proof devices” are described in the literature on Japanese operations management practices (Monden, 1983; Suzaki, 1987).

Communication between suppliers and their customers can help to promote this improvement process. For example, the sharing of warranty data and other information on defective parts can help the supplier to improve quality and reduce costs (Helper and Sako, 1995). In the automotive industry, the frequency of face-to-face contact between suppliers and assemblers has been shown to be strongly correlated with various measures of efficiency (Dyer, 1995, 1996). Moreover, improved communication can help to coordinate upstream schedules with downstream production, thereby reducing the need for intermediate inventories. Indeed, communication and inventory often serve as substitutes for each other (Milgrom and Roberts, 1988).

3. Automotive Supplier Data

3.1. Plant and Sales Manager Surveys

The data in this study are from surveys of automotive parts manufacturers administered by Helper in 1993 under the auspices of the MIT International Motor Vehicle Program. The surveys were administered to first-tier (direct) suppliers to automaker plants in the United States and Canada. Two surveys were administered. The survey of plant managers, which dealt primarily with production issues, received 456 responses (representing a response rate of 31%).

However, only about half of these provided accounting data on their plant's inventory levels, as such information was often not readily available. A separate survey covering relationships with customers and business-unit performance was sent to marketing directors; this survey received 671 responses (55% response rate). It was possible to match half of the sales manager surveys with a plant manager survey.

For many of the questions, respondents were asked to answer with respect to their most important customer regarding a product that was typical of their plant's output. Other items pertained to characteristics of the plant as a whole, and its relations with customers and suppliers. In this study we generally combined the product-specific and the plant-specific information, since the product was typical of the plant's output. The text of the survey questions used in our inventory analysis is provided in Appendix 1. See Helper (1993) and Leete and Helper (1995) for more detail.

3.2. Inventory Measures

Our measures of inventory levels are from the plant managers survey. In that survey, respondents were asked to report the "turns ratio" (annual sales / average value of inventory) for raw materials, work-in-process, and finished goods, at the plant level. In this study we take the reciprocal of these measures, i.e., the average level of inventory as a fraction of sales. For the representative product identified in the survey, plant managers were also asked to give an estimate of "throughput time"---the number of calendar days from the time their plant began processing a part until it was placed in finished goods inventory. Assuming that this product was typical of others in the plant, we would expect that "throughput time" would be correlated with the level of work-in-process inventory.

Table 1 gives summary statistics for these inventory and throughput time measures. Raw materials, work-in-process, and finished goods inventories averaged about 6% to 7% of annual sales. The standard deviation is fairly large, roughly equal to the mean. We found wide variation in inventory levels from plant to plant, even for plants making ostensibly similar parts. [3]

For purposes of comparison, Table 2 shows inventory levels that were estimated from other data sources available in the US and Japan. The *Census of Manufactures* in both countries publishes aggregate data on inventories and sales for automotive parts suppliers. These Census data imply that inventory levels in the US have been two to four times higher than levels in Japan. The differential for work-in-process inventory falls at the low end of this range, while raw materials

[3] We eliminated outlier observations lying within the top and bottom 2% tails of the distributions, as some appeared to be cases where managers did not fully understand how to correctly report the inventory data.

inventory falls at the high end.

Data obtained from company annual financial reports suggests similar differentials between the two countries. These financial data, collected for about 30 large automotive parts suppliers in the US and about 40 in Japan, suggest that the US inventory levels have been 1.5 to 4.5 times higher than the levels in Japan. Again, the differential is smallest for work-in-process inventory and largest for raw materials inventory. Because the differential is smallest for WIP, we can conclude that this pattern results not only from more thorough adoption of JIT practices in Japan , but also from the longer transport distances in the US, which induce more variability in the timing of parts deliveries.

Comparison of Tables 1 and 2 suggests that the inventory levels in our sample are somewhat higher than the US averages. One reason for this discrepancy is that some of the suppliers chose to report their inventories relative to cost of goods sold, rather than annual revenue. This would raise the average inventory ratio somewhat, and add to the sample variance. The variance in the plant level measures used in this study is greater than for the firm-level measures shown in Table 2, as would be expected given the likely effects of aggregation.

3.3. Explanatory Factors

In our analysis we linked the inventory measures shown in Table 1 with various other information provided in the automotive supplier surveys. Most of the survey questions have dichotomous, 0/1 responses, although some are on a Likert scale, (e.g., agreement with the statement: "workers in the plant are expected to make process improvements," answered on a 5 point scale). A few of the questions on the survey have a quantitative response, (e.g., the age of the plant in years). Appendix 2 gives the mean values of the explanatory measures used in the study.

Several measures from the survey deal with general characteristics of the product. These include: (1) the number of component parts; (2) an assessment of product complexity (on a scale from 1-5); and (3) the average price per piece (assessed on a 5 point scale ranging from $1.00 or less to more than $100.00).

With the assistance of an industry expert and process information provided by the respondents, we developed three sets of dummy variables relating to technological characteristics. The first set reflects the function of the product in the assembled vehicle (mechanical, electrical, trim, body, engine). The second set pertains to the raw material(s) used (steel, aluminum, plastic, glass, rubber). The third set reflects the manufacturing processes employed (stamping, heat treating, etc.). We would expect that manufacturing set-up and processing times (on which we have no direct information) would vary systematically with many of these technology variables.

Other measures in the surveys relate to general features of the plant and its work force. The survey provides information on the age of the plant and the total number of products produced. We also observe whether the plant is under Japanese ownership, and whether the work force is unionized. Several of the questions relate to the role of the work force in problem solving. These include: (1) whether workers in the plant participate in quality circles; (2) whether at least one group of workers in the plant completed a full cycle of a formalized improvement process (such as the Seven Step Improvement Process or the Plan Do Check Act Cycle); (3) the degree (on a five point scale) to which managers agree with the statement that "each year we expect our shop workers to make substantial improvements in their own method of operations." Other things equal we would expect Japanese owned plants, and plants where workers play a greater role in problem solving, to have lower inventories.

The surveys provide rich and detailed information on the relationship between the plant and its customers. General measures of this relationship include the plant manager's agreement with statements such as: “We are engaged in an ongoing discussion with our customer about ways to improve both their operations and ours;” and “Just in time" (JIT) only transfers responsibility for inventory from customers to suppliers.” For the representative automotive part selected by the respondent, there is information on the length of the supply contract as well as the length of the more general relationship with the customer. The survey also provides more specific measures of information transfer, including whether the supplier and assembler exchange: (a) process information, (b) scheduling information, and (c) warranty data. The sales managers indicated the frequency of direct, face-to-face meetings between representatives of their company and the assembler, as well as the frequency of other contacts by phone, fax and electronic mail. The sales managers also indicated whether the assembler “provided personnel who visited (the supplier) to aid in implementing improved procedures.”

We would expect that, other things equal, closer communication between the supplier and the assembler would lead to lower inventory requirements. Such communication should help to reduce variability in the suppliers production process and the demand rate of the assembler, and enhance the coordination of production schedules. However, greater contact might be elicited by quality or delivery problems or other coordination difficulties. Such problems would lead to both more frequent communication and higher inventory levels.

Finally, we observed the degree to which the plant ships to Japanese assemblers operating in the United States. For the representative product identified in the survey, the production manager indicated whether it was sold to a Japanese assembler. At the level of a plant as a whole, the sales manager survey gives the total number of Japanese assemblers, if any, that are customers of the plant. If Japanese assemblers imposed greater discipline on their suppliers with respect to the implementation of JIT methods, lower inventory levels should be observed for plants that sell extensively to the Japanese transplants. Alternatively, if Japanese transplants made greater quality demands, required higher service levels, or held less raw materials inventory, it is possible that supplier inventory levels might be higher, particularly for finished goods. Since suppliers to Japanese assemblers make more use of components shipped from Japan (which have at least a 90-day lead time), we might expect that these suppliers would have higher raw-materials inventories.

4. Tests of Individual Factors

Table 3 presents the results of statistical tests linking specific survey questions to each of the four inventory measures. Significant correlations are denoted by entries in the last four columns of the table. The coefficients in these columns represent the percentage change in the mean level of inventory (or throughput time) associated with a unit change in the survey measure.[4]

4.1. Technological Factors

Product price. The tests revealed a strong negative correlation between the price of the product and the levels of the three types of inventory, as predicted by the EOQ model. Inventories fell by roughly 30% for each unit increase along the five point scale on which prices were classified. Other general characteristics of the product, such as the number of component parts and management's assessment of product complexity, had no discernible impact on inventories or throughput time.

Type of part. Many of the technology variables listed in Table 3 were significantly linked to inventory levels in ways that are consistent with expected differences in the amount of time required for set-up and processing. For example inventories and throughput times were uniformly low for trim parts, which are relatively simple to manufacture. Engine components, on the other hand, had work-in-process levels about 50% above average. Engine parts often require more process steps, including heat treating and forging, which are directly associated with greater work-in-process. There was no significant difference in inventory levels between electrical and mechanical parts.

[4] In order to compute these effects as percentage changes, the inventory measures were converted to logarithms. The same logarithmic conversion was used for the regressions reported in Section 5.

Compared with other component materials, steel parts had higher inventory levels and processing times---on average, work-in-process was about one-third higher, and throughput times were nearly 50% longer. Similar differentials were found for specific steel fabrication processes such as stamping, heat treating[5] and forging. In all these cases, inventories and processing times appeared to have been 30% to 60% above the sample average. These findings are consistent with the long set-up and processing times that often accompany these operations.

4.2. Managerial Factors

Production and delivery lot sizes. As would be expected, the production lot size was positively related to the amount of work-in-process and the production throughput time. In addition, raw materials and finished goods inventories were significantly correlated with the production lot size. But interestingly, there was no such correlation between the delivery lot size and the level of finished goods inventory. This suggests that suppliers who delivered to their customers in small, JIT lots typically did not make corresponding reductions in their overall stocks of finished goods inventory.

Worker problem solving. Several measures in the survey relate to workforce characteristics. Table 3 reveals a significant connection between inventories and the improvement efforts made by shop floor workers. Most plants had fully-trained at least one group of workers in a formalized improvement process (such as the "Seven Step Improvement Process"). But roughly 15% of plants had not; these plants displayed levels of work-in-process and finished goods nearly double the sample average. The data also show a strong link between inventory levels and management's expectation that workers make improvements within the plant. Quality circles, however, appear to have had little impact, except in the area of raw materials inventory. No connection was found between inventory levels and unionization.

Supplier-assembler communication. The surveys provide strong evidence that more extensive communication between supplier and assembler was associated with lower inventory. The supplier's general perception of the degree of communication was associated with lower work-in-process and finished goods. Surprisingly, no inventory benefits were detected for the exchange of scheduling information, but suppliers appear to have benefited greatly from receipt of warranty data. Suppliers that obtained such data from the assembler had work-in-process levels 74% lower than average, and throughput times 31% below the mean. Receipt of warranty data may help weed out problems in the production process, or it may simply be correlated with the presence of other activities that have this effect.

[5] Parts are often sent to outside subcontractors for heat treating, which adds to the processing time.

Visits by the assembler to improve procedures at the supplier's plant were associated with higher levels of supplier work-in-process and raw materials. This suggests that such visits were typically elicited by production and quality problems, rather than by an ongoing commitment to process improvement. In rare cases where the assembler's personnel spent two weeks or more in the supplier’s plant, the supplier’s throughput time was significantly below average. Such long term personnel exchanges are consistent with significant improvement in the production process (Dyer, 1995). Taken together, these results imply that long-term interventions were so helpful that the treatment effect outweighed the selection effect.

Frequent face-to-face contact, and to a lesser extent telephone contact, was associated with lower finished goods inventory. This finding can be viewed as strong evidence that communications and inventories serve as substitutes within the supply chain. The length of the formal contract, and the length of the more general relationship with the customer, had no connection with inventory levels.

Not surprisingly, suppliers held less raw materials inventories when their upstream vendors provided JIT delivery. More frequent delivery presumably allowed firms to operate with less cycle and safety stock. Interestingly, suppliers who took a cynical view of JIT (“JIT only transfers responsibility for inventory from customers to suppliers”) did not hold above-average amounts of finished goods inventory.

Japanese management. The data in Table 3 provide a mixed assessment of the impact of Japanese management. Japanese-owned suppliers had significantly shorter throughput times, but their inventory levels were not significantly below the sample average. This suggests that the comparatively lean operations of Japanese suppliers in their domestic environment, as documented in Table 2, have not been effectively transferred to their plants in the United States.

Suppliers that sold to Japanese assemblers had more streamlined manufacturing processes, but they also held large amounts of finished goods inventory. Table 3 gives evidence of superior throughput times for part suppliers having at least one Japanese customer. Japanese assemblers may have selected suppliers with more streamlined production processes, and over time, Japanese assemblers may have contributed to the improvement of supplier plants. However, such plants held above-average amounts of finished goods inventory, and the inventory level increased with the number of Japanese customers supplied by the plant. One interpretation is that part suppliers serving Japanese assemblers in the US chose to hold large amounts of finished goods as safety stock, perhaps to counterbalance the limited amount of raw materials inventory held by Japanese assemblers.

5. Regression Results

Table 3, discussed in detail in the previous section, is based on simple correlations between the inventory levels and the survey measures. In this section we report the results of multiple regression analysis which allows a number of explanatory factors to be considered jointly. It is conceivable that the pattern and magnitude of influences might change when controls are included to account for other factors. For example, Table 3 shows no connection between Japanese ownership and inventory levels, but a relationship might be found after controlling for product characteristics.

We estimated a series of regressions to assess the determinants of work-in-process and finished goods inventories and the production throughput times reported in the survey. In addition, we estimated regressions for production and delivery lot sizes. Our objective in the latter analysis was to determine whether Japanese companies might be distinctive in their choice of smaller lot sizes, even if other findings suggest the absence of inventory differentials between US and Japanese component suppliers operating in the United States.

5.1. Work-in-Process Inventory Regressions

Table 4 reports the regressions for work-in-process inventory. The dependent variable is the plant's average level of work-in-process inventory, divided by annual sales, expressed in logarithms. The sample size varies across regressions, depending upon the availability of data. In particular, the inclusion of measures from the sales manager survey, which can be linked to only about half the production manager survey observations, reduces the sample size substantially. Moreover, most variables have some proportion of missing responses.

The regressions include most of the technology measures that were found to be statistically significant in Table 3. These measures (trim, engine, steel, and stamping) appear in table 4 with the expected signs and are at least weakly significant in Regression 4.1. There is some colinearity among these measures, which may account for the low t-statistics obtained when the measures are included jointly.

The regressions show that WIP inventories were significantly lower when products had a higher price per piece, a finding consistent with the EOQ model. The two measures of worker problem solving ("formal improvement process," and "workers expected to make improvements") also have the expected negative coefficients in Table 4, and they are both statistically significant in Regression 4.1, which has the largest sample size. Moreover, the receipt of warranty information was associated with lower inventory. In general, the magnitudes of these coefficients are similar to those for the single-factor regressions reported in Table 3. This finding indicates that worker problem-solving and receipt of warranty information are effective inventory reduction techniques across a wide variety of processes.

The regression results in Table 4 suggest that Japanese ownership had mixed effects. As in Table 3, there is no evidence that Japanese-owned suppliers held lower work-in-process inventories than their American-owned counterparts. If anything Japanese ownership had a small positive effect on the level of WIP inventory. There is some indication of below-average work-in-process inventory for US-owned suppliers selling to Japanese assemblers (regression 4.1). However, the level of work-in-process tended to increase with the number of Japanese customers, as shown in Regression 4.3.

In general, the signs and magnitudes of the coefficients in Table 4 are consistent with the single factor correlations shown in Table 3. The variables included account for roughly one-fourth of the substantial variation in WIP inventory levels observed from plant to plant.

5.2. Throughput Time Regressions

We would expect throughput time and WIP inventory to be directly related. In our sample, however, the correlation coefficient between these measures is only 0.26. This falls well below the pairwise correlations linking the three inventory measures (raw materials, work-in-process, and finished goods, as a fraction of sales), which range from 0.55 to 0.62. In general the throughput time data appear noisy, perhaps because plant managers had difficulty assessing this non-standard measure.

Table 5 reports the throughput time regressions. These are less successful than the corresponding WIP regressions analysis in explaining interplant variation. Nevertheless, most of the technological and managerial variables in Table 5 have signs that are consistent with the work-in-process regressions, and some measures are statistically significant.

The major difference between the WIP and throughput time regressions is in the effects of Japanese ownership. The throughput times of Japanese-owned plants appear to have been significantly shorter than those of American-owned plants in the sample, by a factor of about one-third. The presence of Japanese customers, however, appears to have had no effect on throughput time, adjusting for plant ownership.

5.3. Finished Goods Inventory Regressions

Table 6 reports the results of the finished goods inventory regressions.[6] The measures of price per piece, workforce problem solving, and supplier assembler-communication are all highly significant with the expected signs. These results imply that suppliers held less finished goods inventory when their product was comparatively costly, when workers in the plant were trained and expected to make improvements, and when there was substantial face-to-face contact between supplier and assembler personnel. These measures account for much of the plant-to-plant variation in finished goods inventories.

The findings for Japanese-owned suppliers and customers fail to support the conventional wisdom on the "leanness" of plants owned by or shipping to the Japanese. Contrary to expectations (but consistent with Table 3) there is no evidence that Japanese-owned parts plants held below-average levels of finished goods. Moreover, finished goods inventories increased significantly with the number of Japanese customers being serviced. These higher than average stocks of finished goods may have been intended to provide a higher service level to Japanese customers or to offset the relatively low raw materials inventory presumably held by the Japanese transplant assemblers.

Regression 6.3 adds the production lot size as an explanatory variable. An increase in production lot size should lead to an increase in the cycle and safety stocks of finished goods, for reasons discussed in Section 2. This positive connection between production lot size and finished goods inventory is confirmed by the regression results.[7]

5.4. Lot Size Regressions

The multiple regressions in Tables 4 through 6, and the simple correlations in Table 3, give an unexpected picture of the impact of Japanese management on inventory levels. We therefore explored the possibility that US plants under Japanese ownership might have adopted smaller lot sizes for production and delivery, but without achieving correspondingly lower levels of inventory. In plants that have only partially implemented JIT, as might be expected for many Japanese plants in the United States, there may be little connection between lot sizes and the average level of inventory. Indeed, with long set-up times or bottlenecks in the plant, smaller production lot sizes could lead to larger amounts of work-in-process. And delivery lot sizes can easily be cut without any effect on finished goods inventory.

[6] The technology measures are omitted from these regressions, as they would not be expected to influence finished good inventory levels; and in fact they proved insignificant when included.
[7] For similar reasons the production throughput time might be included in the regression, in lieu of the production lot size. The throughput time was not, however, statistically significant when included in this way.

Table 7 reports these lot size regressions. A higher price per piece was associated with smaller lot size, consistent with the logic of the EOQ model. Lot sizes were only weakly influenced by the degree of worker problem solving. (The worker measures were insignificant for the delivery lot size and are omitted in Regression 7.1). These results seem to indicate that while bottlenecks can be reduced through worker participation, lot sizes continue to be determined using more traditional criteria.

The lot size regressions show Japanese ownership effects that are consistent with the conventional wisdom and highly significant statistically. Delivery lot sizes were about 50% smaller when the supplier was Japanese-owned. The regression implies an additional reduction of about 50% when the customer was Japanese-owned, regardless of the supplier's nationality. The production lot size regressions suggest effects of similar magnitude.

Thus, the survey data provides strong evidence that Japanese-owned suppliers chose substantially smaller lot sizes for production and delivery. Moreover, US-owned suppliers to Japanese transplant assemblers delivered in substantially smaller lots. These lot size choices do not, however, seem to have translated into lower average inventory levels for Japanese plants in the United States.

6. Conclusions

The results of this study give a broad picture of the factors that influence inventory levels in high-volume discrete parts manufacturing as found in the automotive industry. We have focused primarily on work-in-process and finished goods inventories, but we have also examined determinants of raw materials inventory, production and delivery lot sizes, and manufacturing throughput time. Our findings point to the importance of both technological and managerial factors in determining inventory levels.

Our results on the role of technology factors are consistent with predictions derived from the EOQ formula and related models of optimal inventory holding. Inventories were higher when the underlying technologies required longer setup and processing times. The largest inventories tended to be for parts made of steel, particularly engine components and stampings that require long setup or processing. Moreover, our results show that inventory levels fall sharply with the average price per piece, as predicted by the EOQ formula.

We also find evidence that management and workforce practices have substantial influence on inventory levels. Greater employee training and problem solving activity had a strong effect in reducing inventories. Presumably, these general workforce characteristics facilitate a reduction in manufacturing process variability, thereby reducing the need for large inventory buffers. Unionization and specific practices such as quality circles had little or no effect on inventories.

We find a strong connection between the frequency and extent of supplier-assembler communication and the supplier's level of inventory. These findings are consistent with models (e.g., Milgrom and Roberts, 1988) that view inventory and communication as substitutes. They are also consistent with the idea that specialized "human capital," acquired through frequent face-to-face contact, leads to greater efficiency in problem-solving and coordination (Dyer, 1995).

Perhaps the most surprising findings relate to the lack of strong differences between American-owned and Japanese-owned plants operating in the United States. Corporate financial data for parts producers in the US and Japan show dramatic inventory differences between the two countries. Compared with their counterparts in Japan, US parts makers held about twice as much work-in-process inventory, three times as much finished goods inventory, and four times as much raw materials inventory. Nevertheless, our survey data shows that Japanese transplant parts makers operating in the US maintained inventory levels that were virtually indistinguishable on average from those of American-owned companies. (There is, however, evidence that Japanese-owned plants in the US used smaller lot sizes for production and delivery, and may have had shorter production throughput times than their American-owned counterparts.) These results suggest that the Japanese transplant parts makers have not been completely successful in adapting Japanese manufacturing methods to the US environment.

Further, our data show that parts makers in the US (both American- and Japanese-owned) typically delivered to the Japanese vehicle assemblers in small lots, consistent with JIT practices. But these small delivery lot sizes were not coupled with low finished goods inventories. Indeed, we find evidence that finished goods inventories increased with the number of Japanese assemblers being supplied by the plant. Moreover, for the sample overall, we find no correlation between delivery lot size and the supplier's inventories of WIP and raw materials. These results imply that for many plants, particularly those supplying the Japanese assemblers, JIT has been implemented for deliveries only, and not on a broader basis within the plant.

These findings have numerous implications for managers and researchers. From a research perspective, we have confirmed some basic predictions from the operations research models and have shown how technological and managerial influences interact to determine inventory levels in practice. From a managerial perspective, our data on the typical range of inventory levels, and the influence of explanatory measures, provide guidance for benchmarking purposes. For companies striving to cut inventories, our findings highlight the importance of workforce training and close communication with customers. And contrary to expectations, we show that low inventories are not characteristic of the Japanese transplant parts makers in our North American sample; indeed, these transplants appear to lag substantially behind their counterparts in Japan. Such findings, while specific to the automotive sector, may be applicable to other high-volume discrete parts manufacturing industries.

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Table 1.
Average Inventory Levels in the Supplier Survey Sample*

	RM / Sales	WIP / Sales	FG / Sales	Throughput Time (days)
Average	.071	.057	.059	6.5
Std. dev.	(.062)	(.058)	(.058)	(8.1)
Number of obs.	229	211	221	395

*Extreme observations (top and bottom 2%) deleted.

Table 2.
Average Inventory Levels of US and Japanese Auto Parts Suppliers
Data from Government Censuses and Annual Financial Reports

		RM / Sales	WIP / Sales	FG / Sales
<u>*Census Data*</u>				
US (1991):	Average	.045	.034	.031
Japan (1990):	Average	.011	.017	.012
US/Japan:	*Ratio*	*4.1*	*2.0*	*2.5*
<u>*Company Financial Data*</u>				
US (1992):	Average	.049	.031	.065
	Std. dev.	(.028)	(.016)	(.046)
	Number of companies	32	25	27
Japan (1991):	Average	.011	.020	.018
	Std. dev.	(.007)	(.015)	(.013)
	Number of companies	41	41	41
US/Japan:	*Ratio*	*4.5*	*1.5*	*3.5*

Table 3.

Tests of Potential Determinants of Inventory Levels

	Category	Measures	Units	Survey	RM/Sales	WIP/Sales	FG/Sales
Technological Factors	**General Product Characteristics**	Number of component parts	1-N	PM			
		Product complexity	1-5	PM			
		Product price/piece	1-5	SM	-28% **	-36% ***	-32% ***
	Technology: Functional	electrical	0/1	PM			
		mechanical	0/1	PM			
		trim	0/1	PM	-49% *	-80% *	-67% *
		body	0/1	PM	-98% **		
		engine	0/1	PM		48% *	
	Material	aluminum	0/1	PM			
		steel	0/1	PM		31% **	22% *
		plastic	0/1	PM			
		ceramics +glass	0/1	PM			
		rubber	0/1	PM			
	Mfg. Process	assembly	0/1	PM			
	Mfg. Process	stamping	0/1	PM		36% *	
		heat treat	0/1	PM		35% *	32% *
		weld	0/1	PM			
		mold, extrude, draw	0/1	PM			
		cast	0/1	PM			
		forge	0/1	PM		49% *	50% *
		paint	0/1	PM			
		machine	0/1	PM			
Managerial Factors	**Batch Size**	Production lot size	days	SM	2% **	3% ***	2% **
		Delivery lot size	days	SM			
	Plant characteristics	Number of products in plant	1-N	PM			
		Plant age	years	PM		0.5% *	0.5% *
	Workforce	Formal improvement process	0/1	PM		-87% **	-96% ***
		Union	0/1	PM			
		Quality circles	0/1	PM	-32% *		
		Workers expected to make improvements	1-5	PM	-11% *	-14% *	-22% ***
	Vertical Communication	Communicate with assembler	1-5	PM		-11% *	-12% *
		Process info exchange	0/1	SM			
		Exchange scheduling info	0/1	SM			
		Exchange warranty data	0/1	SM		-74% **	
		Assembler visited to improve procedures	0/1	SM	42% ***	29% *	
		Visting personnel stayed >2 weeks	0/1	SM			
		Frequency of face to face contact	1-5	SM			-24% **
		Frequency of phone contact	1-5	SM	-12% *		-14% *
		Fax	1-5	SM			
		E-mail	1-5	SM			
		C. solicits sugg.	0/1	SM			
		C.captures some savings	0/1	SM			
		C. not welcome suggestions	0/1	SM			
		Length of contract	years	SM			
		Length of customer relationship	1-9	SM			
		Est. length of future C. relationship	years	SM			
		Cynical view of JIT	1-5	SM	10% *		
		JIT facility	0/1	SM			
		JIT delivery by upstream suppliers	%	PM	-12% **		
	Japanese Management	Supplier is Japanese-owned	0/1	PM			
		Sell this product to Japanese Assembler	0/1	PM			
		Plant has at least one Japanese customer	0/1	SM			28% *
		Number of Japanese customers	0-N	SM	8% *		12% **
		Number of US customers	0-N	SM			

Percentages give average change in inventory level for each unit change in factor listed.
(Figures are shown only when factors were statistically significant at the 5% level or greater.)

* significant at 5% level
** significant at 1% level
*** significant at 0.1% level

Table 4.

WIP Inventory Regressions

Dependent Variable: log (WIP / Sales)

	Regression 4.1 coeff.	Regression 4.1 t-stat.	Regression 4.2 coeff.	Regression 4.2 t-stat.	Regression 4.3 coeff.	Regression 4.3 t-stat.
constant	-3.19	-12.0 ***	-2.66	-6.9 ***	-2.87	-7.4 ***
Trim	-0.36	-1.3 *	-0.04	-0.1	-0.35	-0.8
Engine	0.49	1.5 *	0.28	0.8	0.35	0.9
Steel	0.23	1.6 *	0.11	0.6	0.18	1.0
Stamping	0.30	1.4 *	0.23	0.9	0.25	1.0
Formal improvement process	-0.53	-2.7 ***	-0.33	-1.4 *	-0.27	-1.2
Workers make improvements	-0.12	-1.6 *	-0.10	-1.1	-0.10	-1.0
Exchange warranty info			-0.29	-1.6 *	-0.30	-1.6 *
Product price / piece			-0.24	-2.7 ***	-0.25	-2.7 ***
Japanese-owned plant	0.34	1.4 *	0.28	1.0	0.07	0.3
Japanese customer	-0.54	-2.3 ***	-0.15	-0.6		
No. of Japanese customers					0.10	1.9 **
R-squared	.135		.216		.246	
Number of observations	207		110		106	

* significant at the .10 level, one-tailed test
** significant at the .05 level, one-tailed test
*** significant at the .01 level, one-tailed test

Table 5.

Throughput Time Regressions

Dependent Variable: log (Throughput Time)

	Regression 5.1		Regression 5.2		Regression 5.3	
	coeff.	t-stat.	coeff.	t-stat.	coeff.	t-stat.
constant	1.49	6.4 ***	1.65	4.9 ***	1.80	5.0 ***
Trim	-0.33	-1.4 *	-0.30	-1.0	-0.20	-0.6
Engine	0.28	0.9	0.20	0.5	0.17	0.4
Steel	0.28	2.2 **	0.15	0.9	0.13	0.8
Stamping	0.25	1.3 *	0.41	1.8 **	0.37	1.5 **
Formal improvement process	-0.21	-1.3 *	-0.18	-0.9	-0.29	-1.4 *
Workers make improvements	0.06	0.9	0.04	0.5	0.05	0.6
Exchange warranty info			-0.22	-1.4 *	-0.23	-1.4 *
Product price / piece			0.00	0.0	-0.01	-0.1
Japanese-owned plant	-0.45	-2.3 **	-0.34	-1.4 *	-0.30	-1.3 *
Japanese customer	0.16	0.8	-0.04	-0.1		
No. of Japanese customers					0.00	0.1
R-squared	.059		.077		.075	
Number of observations	384		214		199	

* significant at the .10 level, one-tailed test
** significant at the .05 level, one-tailed test
*** significant at the .01 level, one-tailed test

Table 6.

Finished Goods Inventory Regressions

Dependent Variable: log (FGI / Sales)

	Regression 6.1		Regression 6.2		Regression 6.3	
	coeff.	t-stat.	coeff.	t-stat.	coeff.	t-stat.
constant	-3.57	-7.48 ***	-3.69	-7.9 ***	-4.15	-8.2 ***
Product price / piece	-0.18	-2.2 **	-0.20	-2.5 ***	-0.11	-1.3
Formal improvement process	-0.37	-1.78 **	-0.37	-1.7 **	-0.30	-1.4 *
Workers make improvements	-0.23	-2.35 ***	-0.21	-2.2 **	-0.18	-1.9 **
Face-to-Face contact	-0.19	-2.35 ***	-0.20	-2.4 ***	-0.17	-2.0 **
Japanese-owned plant			0.22	0.8	0.36	1.3 *
No. of Japanese customers			0.12	2.6 ***	0.13	2.7 ***
Production lot size (log)					0.23	3.0 ***
R-squared	.222		.279		.336	
Number of observations	115		113		103	

* significant at the .10 level, one-tailed test
** significant at the .05 level, one-tailed test
*** significant at the .01 level, one-tailed test

Table 7.

Lot Size Regressions

	Regression 7.1		Regression 7.2		Regression 7.3	
Dependent Variable (log):	Delivery Lot Size		Production Lot Size		Production Lot Size	
	coeff.	t-stat.	coeff.	t-stat.	coeff.	t-stat.
constant	2.17	13.2 ***	3.00	9.6 ***	3.04	9.7 ***
Product price / piece	-0.37	-5.55 ***	-0.39	-5.4 ***	-0.39	-5.4 ***
Formal improvement process			-0.30	-1.6 *	-0.32	-1.6 *
Workers make improvements			-0.03	-0.4	-0.03	-0.3
Japanese-owned plant	-0.59	-2.69 ***	-0.55	-2.7 ***	-0.29	-1.2
Japanese customer	-0.53	-2.46 ***			-0.42	-1.8 ***
R-squared	.227		.198		.210	
Number of observations	253		222		222	

* significant at the .10 level, one-tailed test
** significant at the .05 level, one-tailed test
*** significant at the .01 level, one-tailed test