DECISION SUPPORT TOOLS FOR MANAGING UNPREDICTABILITY IN THE SUPPLY CHAIN

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ABSTRACT

Effectively managing unpredictability requires decision support tools that can predict the financial and business outcomes of various supply chain strategies. This paper will discuss the role of these decision support tools and their characteristics as well as review a case study. In the case study, decision support tools facilitated development of strategies that increased after tax profit by $140 Million. These strategies included

- **Reliability improvement strategy**: Identifying the reliability improvements that offered the biggest profitability impact.
- **Supply chain strategy**: Defining inventory management and production scheduling rules that ensured order shipment within two days.
- **Capital investment strategy**: Defining when new capacity should come on line as well as the minimum capital investment.

INTRODUCTION

Agile Manufacturing can be thought of as a philosophy for effectively dealing with unpredictability through mass customization. Highly profitable implementations of Agile Manufacturing require the ability to develop customized supply chain strategies. The ability to develop customized supply chain strategies requires appropriate decision tools. These tools allow development of supply chain strategies that take into account the impact of customer and manufacturing unpredictability on

- Capital cost for incremental capacity,
- Cost for inventory,
- Manufacturing cost structure, and
- Ability to meet market expectations for service.

NOMENCLATURE

Manufacturing Efficiency (ME) is a manufacturing metric that indicates the ability of manufacturing to run reliably. As shown in Figure 1 and Equation (i), manufacturing unreliability reduces Manufacturing Efficiency.

$$\text{ME} = \frac{\text{On-spec production}}{\text{On-spec production} + \text{Manufacturing losses}} \times 100\% \qquad \text{(i)}$$

Market Utilization (MU) is a supply chain metric that indicates the percentage of available production that was sold as shown in Figure 1 and Equation (ii).

$$\text{MU} = \frac{\text{On-spec production}}{\text{Available production}} \times 100\% \qquad \text{(ii)}$$

Profitability is profit relative to investment. There are many profitability metrics including Return on Net Assets (RONA), Return on Equity (ROE), and Economic Value Add (EVA). For this paper, the profitability metric will be RONA, as defined in the following equations.

$$\text{RONA} = \frac{\text{Net Income}}{\text{Total Assets}} \qquad \text{(iii)}$$

$$\text{Net Income} = \text{Sales Revenue}^{1} - \text{COGS}^{2} - \text{Expenses}^{3} + \text{Non-recurring Items}^{4} - \text{Taxes} \qquad \text{(iv)}$$

$$\text{Total Assets} = \text{Net Fixed Assets}^{5} + \text{Inventories}^{6} + \text{Receivables}^{7} + \text{Cash} + \text{Other Assets}^{8} \qquad \text{(v)}$$

Response Time is the time lapse between an input change and system response. One type of response time is Order-to-Ship time. Order-to-Ship time is the time lapse between a customer placing an order and a manufacturing site shipping an order. Another type of response time is Time-to-Market which is the time lapse between product conception and its first delivery to the market.

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[1] Sales Revenue is the sales volume multiplied by average selling price.

[2] COGS, or Cost of Goods Sold, is all of the manufacturing and logistics costs associated with converting raw material into finished product at the customer site.

[3] Expenses are the costs of running a business such as administrative, research and development, marketing, and sales.

[4] Non recurring items would be extraordinary income items such as gain on the sale of a business less any extraordinary expense items such as restructuring costs.

[5] Net Fixed Assets are plant, property, and equipment less accumulated depreciation.

[6] Inventories are the raw materials, intermediates, and finished products as well as other inventories such spare parts. Inventories are valued at cost; e.g. finished products located within the manufacturing facility are valued at manufacturing costs.

[7] Receivables are the monies customers owe.

[8] An example of an Other Asset is Good Will.

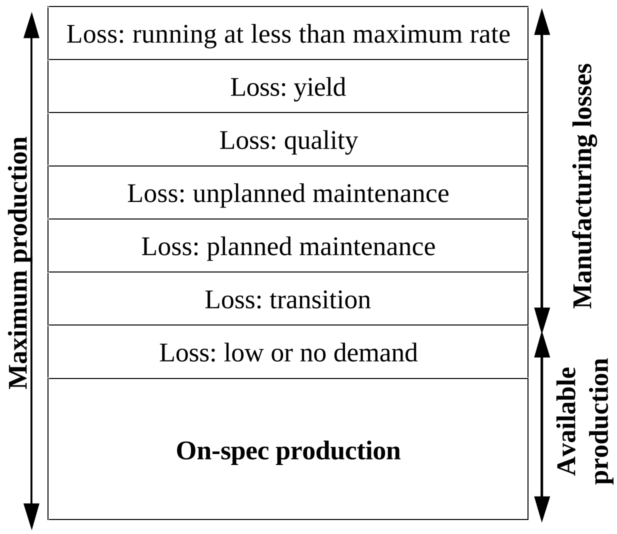

Figure 1. Relationship between Maximum production, On-spec production, and Available Production.

WHAT ARE THE DECISION SUPPORT NEEDS OF AGILE MANUFACTURING?

Agile Manufacturing seeks to create a supply chain that can respond quickly to changing market conditions. The type of decision support requirements will vary based on the market forces driving the implementation. Typically, the market forces are one of two basic types: Rapid Product Evolution and Variable Product Demand.

Rapid Product Evolution is characterized by relatively short product life cycles, with new products constantly replacing old, obsolescent products, such as in the high tech and pharmaceutical industries. Typically, the profit margins are initially high and deteriorate over the life cycle of the product. Agile Manufacturing is implemented to maximize the sales volume during the relatively short product life. Because of the high profit margins and short product lives, Rapid Product Evolution companies may have a strategy of holding capacity in reserve to shorten Time-to-Market or meet unexpected market demand. Increasing agility by holding capacity in reserve lowers Market Utilization. Holding too much or too little capacity in reserve will reduce profitability. *Appropriate decision support tools offer the ability to quantify the impact of Market Utilization, Manufacturing Efficiency, and inventory on profitability and Time-to-Market.*

Variable Product Demand is characterized by unpredictable demand over short periods or at the SKU[9] level and relatively predictable demand in aggregate. Mature industries such as pulp and paper or chemicals tend to be in Variable Product Demand markets. Agile Manufacturing is implemented to reduce the assets and costs associated with satisfying a demand that is unpredictable at the product level or over short time periods. *Appropriate decision support tools offer the ability to quantify the impact of Market Utilization, Manufacturing Efficiency, and inventory on order-to-delivery times and profitability.*

In addition, all companies share two additional decision support needs. First is the identification of reliability improvements that will have the largest profitability impact. *Appropriate decision support tools can identify the improvements that will have the largest impact on response time and profitability.* Second is determining the minimum investment that is required to meet the businesses needs. Minimum investment is a strong function of three factors, Manufacturing Efficiency, required response time, and ability to carry inventory. *Appropriate decision support tools can identify the minimum investment based on these three factors.*

WHAT ARE THE CHARACTERISTICS OF TOOLS THAT CAN PROVIDE DECISION SUPPORT?

A single tool cannot provide the ability to quantify the business and financial outcome of various strategies based upon these supply chain characteristics. Instead an integrated tool set that can perform both a financial and a reliability analysis is needed.

A financial analysis tool is needed to identify and select the projects based on their ability to improve profitability. To improve profitability, the results of an initiative must improve a financial variable[10]. The outcome of a financial analysis is a ranked criterion for strategies or projects based on their financial variable impact.

A reliability analysis tool is needed to quantify the benefits of managing or reducing unreliability. The benefits are either a direct improvement of a financial variable or an indirect improvement through reducing a response time. Reliability analysis tools are based on Discrete Event Technology. Using a reliability analysis tool, a simulation model is developed that can represent an entire supply chain or any of its components. These models predict the impact of failures, process variability, buffer capacity, operational strategy, and customer demand on throughput, inventory, and response time. All Discrete Event Models assume that random events are a dominant factor in predicting system behavior and function. A system is a collection of animate and/or inanimate objects that must work together to perform one or more functions. A system could be a pump, a manufacturing facility, an accounts receivable department, or a supply chain. Because a system is a collection of objects that must work together, failure of any system component can impair system function. The outcome of

[9] SKU, or Stocking Unit, is the number assigned to a specific product-container combination.

[10] Financial Variables include all of the individual terms in the RONA equation such as Sales Revenue or Inventory.

a reliability analysis is a prediction of how failures[11] and other unpredictable events[12] impact system characteristics[13].

HOW DO SUPPLY CHAIN CHARACTERISTICS IMPACT PROFITABILITY?

There are complex interactions between Manufacturing Efficiency, customer predictability, inventory, Market Utilization, response time, and profitability. These interactions may result in some unexpected outcomes after changing supply chain parameters. The following examples illustrate some of the unexpected outcomes.

- A Chemical manufacturer experienced deterioration of customer service after reducing inventory. Eventually, unhappy customers went elsewhere, reducing Market Utilization. When the customer service problem was finally resolved, total sales volume had dropped with associated declines in Market Utilization and profitability.
- A Durable Goods manufacturer launched a new product that was expected to be highly successful. Prior to the launch, the company did not change the inventory strategy for the other products sharing the manufacturing facility. Although initially stable, customer service for the older product began to deteriorate. Once again unhappy customers changed suppliers. Despite the new highly successful product, profitability did not improve because of lost market share in the other product lines.
- A Semi-Conductor manufacturer was rapidly expanding manufacturing capacity through capital additions. Although massive additions of manufacturing capacity reduced time to market, net income grew slower than the asset base. The company has yet to return to the profitability level enjoyed prior to the massive capital expenditures.

These outcomes could have been prevented if the decision-makers had been able to predict the impact of their decisions on key supply chain variables and profitability. The following case study illustrates how one type of decision support tools, Profit Driven Reliability® (PDR) Tools[14], provided this ability to decision-makers.

CASE STUDY

Starting in the late 1980’s profits for the largest business unit of a Fortune 500 company began to shrink. Profit loss was the result of a product mix shift away from the more profitable products toward the less profitable ones. Market share was lost in the more profitable products because of inconsistent customer service. To maintain sales volume, the business began accepting orders for the less profitable products. Since the company carried inventory in the highly profitable products to ensure rapid order fulfillment, manufacturing capacity restrictions were believed to be the culprit. Consequently the company continued to invest in new capacity despite dropping profits. The net effect was a rapid decline in business profitability over the next five years, as shown in Figure 2. This decline began to strangle the company since this business supplied the bulk of the cash flow for other corporate investments.

The results of an analysis of the 1993 Financial Statements are shown in Table 1. The analysis showed that profitability was relatively insensitive to changes in inventory and receivables. This result indicated that their current strategy for reducing these assets would have little profitability impact. Not surprisingly, the highest leveraged approach to improving profitability was to increase total sales volume with minimal capital investment. Obviously, if the sales volume increase could be concentrated in the more profitable products, the profitability impact would be even greater.

After assessing their current situation, the business decided to evaluate the potential of increasing capacity without capital investment at a single site. To provide decision support, a reliability model was developed. The reliability model served two purposes. The first purpose was to prove that incremental capacity could be obtained without capital investment. Local management did not believe that their site could produce more without additional investment. The second purpose was to select the improvements that would have the biggest capacity impact. The model predicted incremental production capacity associated with each proposed improvement.

[11] Examples of failures include fouling of a heat exchanger, leaks, seal failure, and off-spec production.

[12] Examples of unpredictable events include bad weather, random customer orders, and product turnover.

[13] Examples of system characteristics include throughput, production capacity, inventory levels and response time

[14] Profit Driven Reliability® Tools are the RONAMAX proprietary decision support tools that predict the financial and business outcome of various supply chain strategies for managing unpredictability.

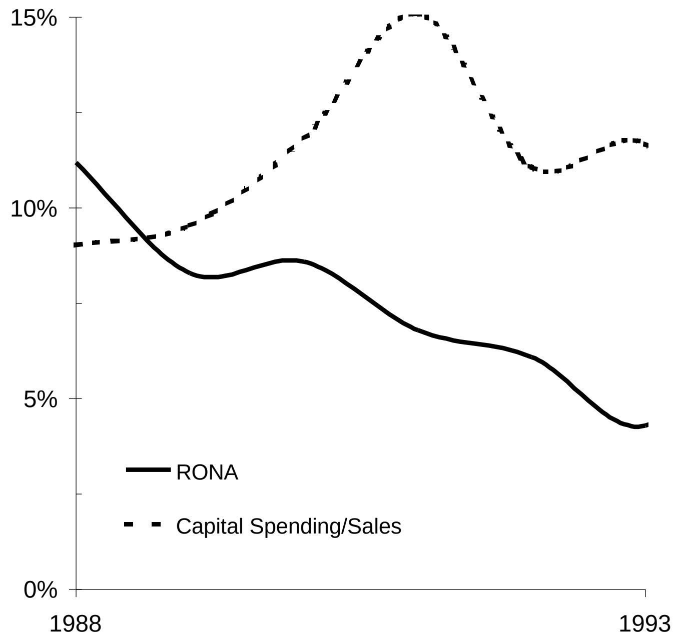

Figure 2. Erosion of profitability over time. Despite declining profitability, capital spending continued to climb.

TABLE 1. Results of analysis of 1993 Financial Statements

Financial Variable	Change needed to increase RONA from 4.6% to 5.6%
Fixed Assets	**Zero capital investment for one year** holding selling price, sales volume, costs, expenses, and other assets constant
Receivables	**Eliminate 69% of receivables** holding selling price, sales volume, costs, expenses, and other assets constant
Inventory	**Eliminate 87% of inventory** holding selling price, sales volume, costs, expenses, and other assets constant
Cost of Goods Sold	**Cut cost of goods sold by 2%** holding selling price, sales volume, expenses and assets constant
Sales Price	**Increase average selling price by 1%** holding sales volume, cost of goods sold, expenses and assets constant.
Sales Volume	**Increase sales volume by 3%** holding selling price, fixed cost of goods sold, expenses and net fixed assets constant. Variable cost of goods sold, inventory and receivables increased in proportion to sales volume.

The pilot was a success. Using the model as a decision support tool, the site developed and implemented a reliability improvement strategy that delivered the needed capacity. Analysis of the pilot project established that reliability improvements were a cost-effective source of incremental capacity. For this business, *the cost of incremental capacity purchased by reliability projects cost was approximately 10% of capacity purchased by capital projects*. A work process was developed to guarantee that the business would only use capital dollars as the last resort to purchase incremental capacity.

The work process consisted of one rule: no approval for capital expenditures over $100,000 if reliability could deliver the incremental capacity. To support the new capital deployment process, the business needed every site to be able to develop and use a reliability model similar to the pilot model. A Profit Driven Reliability® (PDR) Toolkit was developed and distributed to 20+ sites, worldwide. The toolkit allowed the sites to build reliability models to represent their multi-product batch operation.

The toolkit needed to be user-friendly for non-expert use. User-friendly tools match a user's frame of reference. In this case, matching meant the toolkit and models would resemble the manufacturing site in appearance, logic, and terminology. To facilitate easy use, a customized library was developed to support building and using reliability models.

Using the toolkit, site engineers could build reliability models of their facility. The first step in building a model was to define the process flow. Defining process flow is similar to creating a process flow diagram using a CAD program. As in CAD, blocks representing an operation or equipment are copied from a library and pasted onto a worksheet. The output of one block connects into the input of another. Material flows through the blocks according to how they are connected, as shown in Figure 3.

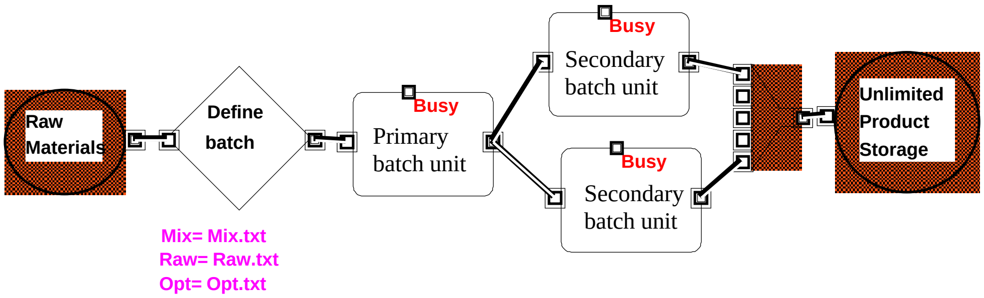

Figure 3: Reliability Model of a Single Manufacturing Facility. Material flowed from raw material storage through a block that defined the batch characteristics. The "Define Batch" block assigned a product code and cycle times to the batch. The product code assignment was based on the mix file that defined the probability that a batch would be a specific product code. After the "Define batch" block the batch flowed into the primary batch unit. After processing in the primary unit, material flowed into one of two secondary batch units for final processing. After final processing material flowed through a piping manifold into finished product storage. Detailed input and output for any of the blocks was accessed by double clicking on the block.

The next step to building a model was to load the model with data that would define the product mix and product cycle times associated with the facility. Since there was extensive data defining product specific step duration, the model was developed to use the existing "batch card" data. The batch card data did not explicitly capture lost production time or attribute a lost production time to a symptom. For example, batch card data for the first batch of Product A might show that the second processing step took 13 hours. The reliability model predicted capacity given data defining product mix and actual batch cycle times. To predict capacity losses resulting from cycle time variability, an optimum cycle time database was developed. The optimum cycle times were based on shortest cycle times posted for a product specific step in similar equipment.

After developing a work process for increasing the capacity of existing sites, the business began evaluating methods to regain market share in the more profitable product lines. A key success factor to regaining market share was to offer the market consistent, short order-to-ship times. The capability of the original PDR Toolkit was expanded to provide decision support in developing the supply chain strategies that would result in consistent, short order-to-ship times with minimal investment in inventory and capacity.

On the surface, the expanded model was identical to the original site model. The only visual difference was the replacement of the "*Unlimited Product Storage*" block with a "*Limited Product Storage*" block. This change altered how the model scheduled production. In both models, an empty primary batch unit would request starting a new batch. In the site model, a new batch was always started immediately in response to the request. Consequently the production facility always ran at peak instantaneous capacity. In the supply chain model, new batches were scheduled in response to product-specific customer orders and inventory levels. Insufficient customer orders would result in an idle primary unit.

The supply chain model required additional input data[15]. The additional data included

- Probability distributions defining order frequency and size.
- Desired order-to-ship time.
- Scheduling parameters such as planning horizon and freeze period. The planning horizon is the number of days forward that the model would look in creating a schedule. For example a planning horizon of fourteen days means that the model would consider actual and forecasted orders due to arrive in the next fourteen days. The freeze period is the time period after developing a schedule that it is frozen. For example, a one-day freeze meant that a schedule could not be changed for one day, regardless of the arrival of new orders.
- Inventory management parameters for each product (and container) such as maximum storage capacity and safety stock targets. Products were scheduled for production when projected (or actual) inventory levels fell below its safety stock target.

Prior to using the reliability model, the business had applied rules of thumb based on forecast accuracy to arrive at safety stock targets. The purpose of safety stock is to ensure an acceptable customer service level. For this site, an acceptable customer service level was defined as shipping 99% of the orders within two days of order receipt. As shown in Figure 4,

[15] The additional data needed to represent an entire supply chain will vary based on supply chain strategy.

eight of the thirty-eight products had unacceptable customer service levels despite an average site inventory of 17 days.[16]

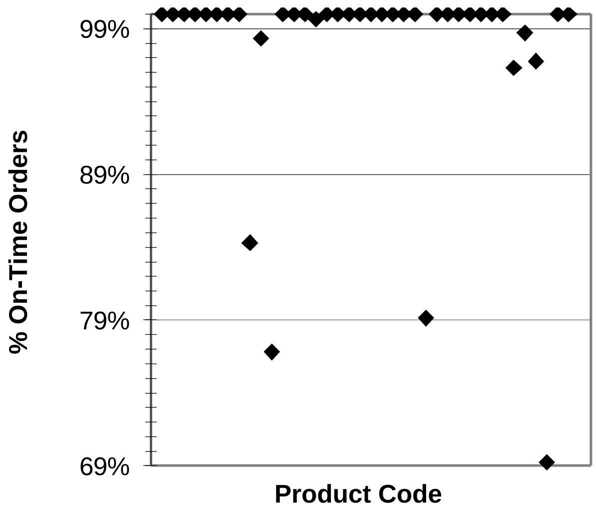

Figure 4. On-time orders as a function of product code for a single site that manufactured 38 products. The Market Utilization for this site was 75%.

Using the model, the business was able to quantify the relationship between safety stock targets and on-time shipments as shown in Figure 5. Through a trial and error process, the model was used to find new safety stock targets. *These targets allowed shipping 99.5%+ of the orders for individual products in 2 days or less, without increasing average site inventory*.

Safety stock targets are a function of manufacturing reliability, customer predictability, desired customer service, and Market Utilization. To maintain constant customer service with increasing sales requires either increasing capacity[17] or inventory.[18] Increasing inventory is sufficient up to a point; then, capacity must increase. The model allowed prediction of when new capacity must come on-line in order to maintain customer service level. Figure 6 shows that new capacity should come on-line by the time that Market Utilization is forecasted to be 93%.

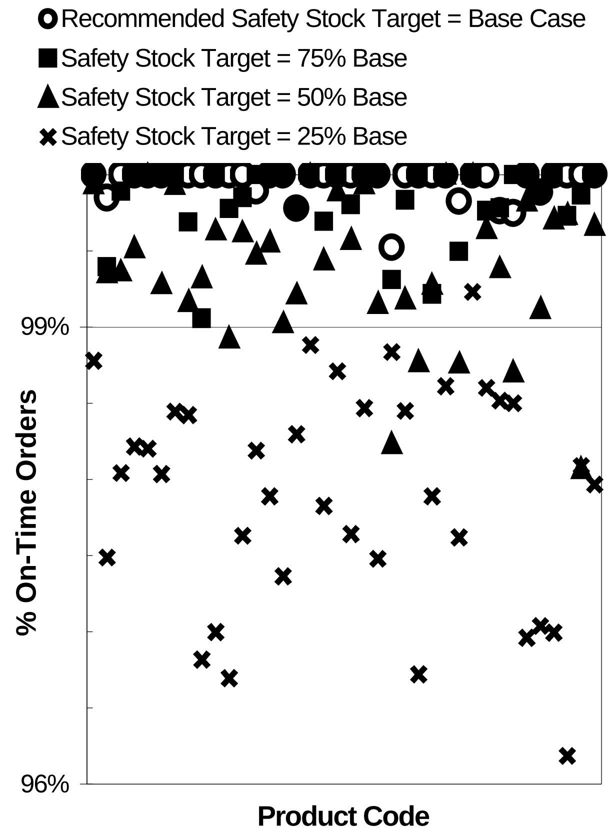

Figure 5. On-time orders as a function of safety stock targets for a site with a Market Utilization of 75%.

The model also assisted in the design of new sites. To maximize profitability of new sites required the ability to predict impact of facility design parameters on customer service, initial Market Utilization, and investment. These design parameters were a function of product mix, customer predictability and manufacturing reliability. Using the model, the business was able to reduce capital investment by approximately 25% through determining facility design parameters such as

- Size of primary units, secondary units, and storage tanks.
- Ratio of secondary units to primary units. Secondary units are optional and only installed to increase capacity. The value of increasing the number of secondary units varied dramatically with product mix.

[16] Days of inventory is a relative measure of inventory. It is equal to the average inventory divided by annual Cost of Goods Sold multiplied by 365 days.
[17] Increasing site capacity reduces the Market Utilization at that site.
[18] Raising safety stock targets increases inventory.

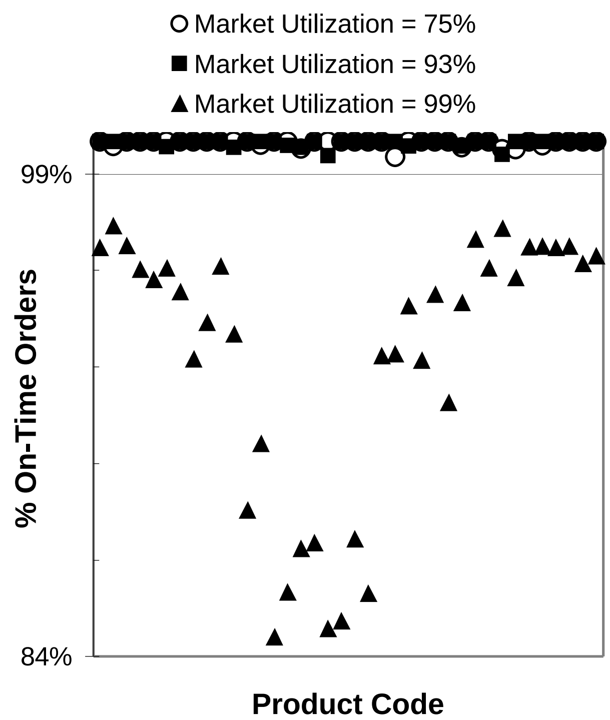

Figure 6. On-time orders as a function of Market Utilization, holding relative safety stock targets[19] and maximum storage capacity constant.

Today the business reaps the rewards of their new integrated supply chain strategies. Figure 7 shows the increase in profitability and the simultaneous decline in capital spending.

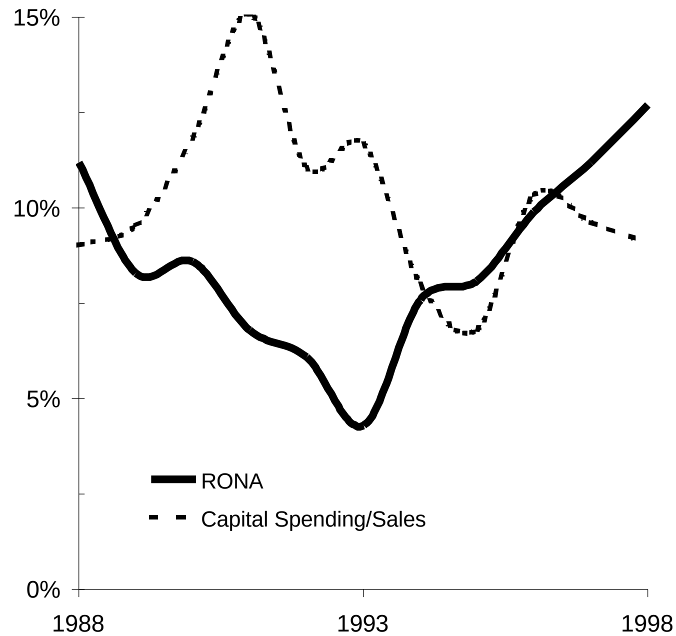

Figure 7. Return to profitability after implementing new supply chain strategies in 1993.

CONCLUSIONS

Every aspect of a business contains unpredictability from instantaneous production capacity to customer demand. Agile Manufacturing offers a philosophy for dealing with this unpredictability. Implementation of Agile Manufacturing will require development of supply chain strategies. The profitability impact of Agile Manufacturing can be improved with appropriate decision support tools that predict the impact of various supply chain strategies on response times and financial variables. These tools should ideally include both a financial analysis tool and a discrete event simulation tool similar to the Profit Driven Reliability® Tools.

[19] Safety stock targets increased in proportion to customer demand.