

Performance Measures for Product Development Utilizing Theory of Constraints Methodology

by

Matthew C. O'Leary  
B. S., Mechanical Engineering  
University of Michigan, 1977

Submitted to the Sloan School of Management on May 1, 1995 in partial fulfillment of the requirements for the Degree of

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Signature of Author .....

Certified by .....

Arnoldo C. Hax  
Alfred P. Sloan Professor of Management  
Thesis Advisor

Accepted by .....

Susan C. Lowance  
Director, Sloan Fellows Program

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## Abstract

Historical product development measures have included budget, timing, and milestone quality of event, but in today's rush to improve productivity and reduce product cycle times, more telling measures are required. At the same time, Theory of Constraints has been used successfully in revising manufacturing measures to improve throughput and create alignment with corporate strategy.

This thesis explores how Theory of Constraints (TOC) can be successfully applied to the product development process and provide the firm with a competitive advantage through the same characteristic increase in throughput and alignment that has been experienced in manufacturing.

First, firm-level measures are explored, along with the current trends that are impacting firm strategies and measures. Next, product development measures are reviewed and compared with the firm-level measures. Current product development trends are discussed to understand what changes are required in product development strategies and measures. After a brief tutorial and case study on Theory of Constraints, application of TOC to product development is explored, including real-world examples from leading product development companies.

Thesis Supervisor: Arnaldo C. Hax

Title: Alfred P. Sloan Professor of Management

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# Chapter 1 - Introduction

Product development (PD) is the core of manufacturing firms, providing a means for the company to take customer requirements and turn them into a product that provides value to the customer and profits to the firm. PD is a dynamic, complex process that requires constant attention to ensure competitiveness and responsiveness in the marketplace.

There are many marketplace changes that are impacting firms, and thus the PD process. Customers exposed to worldwide products are demanding more performance at lower prices, putting pressure on the PD process to provide more value to the customer without shaving profits for the firm. New markets are emerging that have unique requirements, challenging the PD process to develop products that meet multiple market demands and can be manufactured in a way that allows mass customization. Technology advances are occurring at a rapid pace, making products obsolete, and putting enormous time pressures on the PD process. In addition, as a response to the market pressures, many firms have moved from the traditional functional organizations to team-based organizations that rely on concurrent, or simultaneous engineering.

These changes are forcing firms to readdress the measures used to drive the behavior of the PD process. Many of the past measures worked fine for functional organizations, but they do not have the flexibility to meet the new team-based organizations. Keeping the same measures while trying to implement global thinking and mass customization is a formula for disaster as the measures will not drive behavior that aligns with a global strategy. Simply adding additional measures, a temptation given the advancement in information technology, will only create information overload and lack of focus.

Clarity and stability of goals are paramount to keeping an organization focused. Given the many changes that continually impact the

strategy of the firm, how can the clarity and stability be maintained? One answer may lie in the Theory of Constraints (TOC). TOC has been successfully used in manufacturing to improve the throughput of a manufacturing facility. Instead of the traditional focus on cost cutting, the denominator of efficiency, TOC focuses on throughput, or the numerator of efficiency. TOC considers resources in how work is focused in various activities to keep the pacing activity running at peak efficiency. TOC also uses buffers to guard against under-utilization or downtime of the pacing activity.

The question to be answered is "Can a rather simple model like TOC be applied to a complex process like PD?" The purpose of this thesis is to answer that question. First, Chapter 2 explores the performance measures at the firm level. Firm strategies and measures impact the strategies and measures for the PD process. Current trends that affect firms and their strategies and measures are briefly reviewed as background for the forces driving change in product development. Chapter 3 looks at PD performance measures and how they fit with the firm-level measures. Again, current trends in PD are reviewed for their impact on future strategies and measures. Chapter 4 reviews how TOC fits into the current measures, adding a third dimension -- resources. The five-step process of applying TOC is then briefly reviewed. A very simple case study in TOC is presented in Chapter 5 to demonstrate how TOC can provide more profitable (and sometimes counter-intuitive) alternatives than typical financial measures. Chapter 6 then considers applying TOC to the complex PD process -- first in general terms, then by way of three examples from the companies interviewed, each showing how TOC measures and methods helped provide insight into complex problems. Finally, conclusions and recommendations are presented (Chapter 7).

The research for this paper consisted of a literature search of the forces affecting firms, the PD process and its measures, along with numerous

discussions with consultants in the field, and in-depth interviews with five leading PD firms from various industries. The firms interviewed were reluctant to share specifics of their measurement systems, many viewing their metrics as competitive advantages. Even without the specificity, the discussions provide key insights into what works and what does not work, and how measures are being revised today.



## Chapter 2 - Firm-Level Performance Measures

Prior to reviewing the product development process and its measures, it is helpful to understand what is taking place at the firm level. Competitive pressures and changing environments at the firm-level will affect not only the firm-level strategy and measures, but will roll into the product development-level strategy and measures. Thus, this chapter briefly reviews the fundamentals of developing sound measures at the firm-level, beginning with the goal or mission of the firm.

*The Goal: Make more money now and in the future.*

*- Eliyahu M. Goldratt<sup>1</sup>*

Eli Goldratt states it so simply -- the goal of any profit-making corporation is to make more money now and in the future. This helps explain why many firm-level measures have been the same over several decades despite drastic changes in firm competition and strategy. That is not to say that measures have not changed, but that many of the changes have been refinements to improve the accuracy or timeliness of the measures, rather than a complete restructuring. However, the real challenge is not defining such a simple goal, but moving the firm toward the goal. The key to success is a robust strategy, and the key ingredient to successful implementation of that strategy is good performance measures.

This chapter will discuss the development of performance measures at the firm level and the role that strategy plays in that development. It is not intended to provide a deep understanding of how strategies are developed.<sup>2</sup> The process for establishing measures will be reviewed along with successful

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<sup>1</sup> Eliyahu Goldratt and Jeff Cox. *The Goal*. North River Press, 1992.

<sup>2</sup> See Hax and Majluf (1991) and Hamel and Prahalad (1994) for an in-depth look at strategy development.

measures used by firms today. A brief review of the current trends that are forcing firm-level strategy and measures to change provides background for the subsequent discussion in Chapter 3 on how product development strategy and measures are affected by these trends.

## **2.1 - Process to Establish Firm-Level Measures**

The starting place for all successful performance measures is the strategy of the firm. Beginning with strategy seems straightforward -- after all, measures are developed to track performance relative to the strategy. Hax and Majluf (1991)<sup>3</sup> provide an excellent process for developing a successful strategy at the firm level. The strategy process is a means of defining the organization's long term objectives, establishing plans to meet the objectives, and determining how best to allocate company resources.<sup>4</sup> Hax and Majluf emphasize the importance of communication in the strategy process -- that the strategy process is the means to communicate the firm's mission and goals to the rest of the organization. As that strategy process is being completed, one must begin the process of developing a set of performance measures that will align performance with the strategy and help monitor progress.

So how does one develop good measures? First, the measures must be linked to the strategy of the firm. The measures must ensure that the strategy of the firm will be properly implemented and provide management with ongoing feedback on the firm's performance. The feedback provides a way for managers to measure progress and make corrections to ensure that plans are meeting objective. Second, the measures must provide a balanced look at the firm's performance, both between financial and non-financial, and between short and long-term perspectives. Some firms use a version of the

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<sup>3</sup> A revised edition is due to be published in 1995.

<sup>4</sup> Hax and Majluf (1991), p. 2.

“Balanced Scorecard<sup>5</sup>” with measures covering the quality, financial, internal business, and learning perspectives. The key is to make sure that the measures provide feedback in all of the areas that are essential to achieving competitive advantage -- not just financial measures, and not just those that are easiest to measure.

Once the measures are selected, the short and long term goals for each measure must be established. Two considerations for this determination are the firm’s strategy and benchmarking. The objectives must align with the short and long term strategic intent of the firm. Obviously, if the strategy calls for market dominance, then the market share objectives should reflect that. Benchmarking<sup>6</sup> is the best way to establish short and long term objectives. First, competitive companies can be benchmarked to establish levels of performance within the firm’s industry. Second, benchmarking can also establish objectives for best-in-class performance. This type of benchmarking requires identification of firms, regardless of industry, that are best at a particular practice that are core to the strategic intent of the firm.

The measurements development process is not a trivial exercise and requires great care to ensure that the measures align with the strategy and provide the motivation for reaching the strategic intent of the firm. Measures development is a dynamic process that requires management’s commitment and determination to ensure the process is successful. As one executive from a leading firm put it, “Those who can block and tackle are those who really can drive these processes forward.”

In developing good measures, firms would be wise to avoid some of the pitfalls of measures systems that can result in failure to achieve desired results:

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<sup>5</sup> Robert Kaplan and David Norton. “The Balanced Scorecard: Measures That Drive Performance.” *Harvard Business Review*, January-February, 1992, Vol. 70, No. 1, pp. 71-79.  
<sup>6</sup> Robert C. Camp. “Learning from the Best Leads to Superior Performance.” *Journal of business Strategy*, May-June, 1992, vol. 13, No. 3, pp. 3-6.

- Misalignment with corporate strategy - the measures drive behavior that is inconsistent with strategic intent.
- Lack of balance - measures that drive only one element at the expense of others (e.g., cost at the expense of quality).
- Difficult to understand - measures that are difficult to understand will not drive predictable behavior, but random, chaotic behavior.
- Lack of credibility - either management does not believe in the measures or has unrealistic expectations, resulting in gaming to make the results look good.
- Lack of consistency in implementation - common measures not used throughout the organization.
- Short term focus - measures with short term focus will sacrifice long term performance.

The next section reviews some of the more common and successful measures used by firms today.

## **2.2 - Current Firm-Level Measures**

Firms today use a wide variety of measures depending on the industry they are in, the corporate strategy they use, the corporate culture, and the information systems capability of the firm. Table 1 displays typical firm-level measures grouped by the categories of Quality, Financial, Internal Capabilities, and People.<sup>7</sup> The following sections provide a brief discussion on each measure category.

### **2.2.1 - Quality Measures**

Quality and customer satisfaction are the cornerstone measures of most businesses today. Many of the US firms that were stung by quality

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<sup>7</sup> Adapted from Kaplan and Norton's "Balanced Scorecard." Meyer's *Fast Cycle Time* (1993), and interviews conducted as part of this research

products in the 1970s and 1980s and lost market share, keep quality in the forefront. The shift has been to put emphasis on customer satisfaction rather than just on the reduction of defects. Some of the more common measures used include:

- Customer satisfaction - as determined through customer surveys.
- On-time delivery - again, as determined by the customer.
- Quality - also determined through customer surveys of defects and of customer likes.
- Warranty - used mainly to track internal costs.
- Benchmarking - comparing measures with other competitors.

### **2.2.2 - Financial Measures**

Financial measures have evolved over time, and though information systems have allowed them to be more complex, the basic measures have not changed. What does change is the focus, with firms choosing one or two of the financial measures to zero-in on. The following are the most popular measures:

- Sales - either volume or revenue.
- New Products Percent of Sales - particularly important in consumer electronics, computers, printers, etc., where rapidly changing technology requires a high product obsolescence rate.
- Return on Assets (ROA)
- Return of Investment (ROI)
- Return of Equity (ROE)
- Cash Flow
- Market-to-Book Ratio
- Market share growth

- Breakeven Time (BET)<sup>8</sup> - the time from concept to a point in production where development costs are paid back. This is not a common measure, but an illustration of how some firms, like Hewlett Packard, are revising measures to fit their strategy.

Obviously, there are many other measures used, but these measures are typical for firms as a whole, and some of these measures may be cascaded down to a division level.

### **2.2.3 - Internal Capabilities Measures**

These measures are for the most part firm or industry specific. Firms will target particular areas that need attention, or that are the core of the firms competitive advantage. The following are some examples:

- New Product Cycle Time - the time it takes to bring new products to market.
- Productivity - engineering hours per product, lines of software code per engineer, etc.
- Technology - identification of new technologies being utilized.
- R & D Effectiveness - what portion of R&D results in new product revenues.
- First-in-Class - the number of new product features introduced as market firsts.

### **2.2.4 - People Measures**

These measures are aimed at driving continuous improvement and typically are constantly changing as firms adapt to changing conditions. Some examples of these measures include:

- Employee Satisfaction - as measured through employee surveys.
- Employee Empowerment - decisions made at the lowest level

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<sup>8</sup> Wheelwright and Clark (1992). p. 47.

possible as measured by employee surveys.

- Training - funds committed to training or number of hours per employee.

Category	Measure
Quality	Customer Satisfaction On-time delivery Product Quality Warranty
Financial	Sales New Products - Percent of Sales Return on Assets (ROA) Return on Investment (ROI) Return on Equity (ROE) Cash Flow Market-to-Book Ratio Market Share Growth Breakeven Time (BET) Debt-to-Equity Asset or Inventory Turnover Cost of Capital
Internal Capabilities	New Product Cycle Time Productivity Technology R&D Effectiveness First-in-Class
People	Employee Satisfaction Employee Empowerment Training

**Table 1 - Firm-Level Performance Measures**

The measures outlined here are those currently being used by many firms, but competitive pressures and changing environments are bringing revised strategies to today's firms, and, thus, will bring changes to firm-level

measures. The following section will outline those trends to gain an understanding of how measures might be changing.

## 2.3 - Current Firm-Level Trends

What forces are driving changes in firm strategies and measures? Wheelwright and Clark (1993) highlight the changes PD firms are facing. Specifically, three critical forces are cited: intense international competition, fragmented demanding markets, and diverse and rapidly changing technologies.<sup>9</sup>

More and more business are competing on an international level, increasing competition for products and, as manufacturers take advantage of cheap labor markets, increasing cost competition. The competition leaves little room for slack in the system and firms must be flexible in adapting to environments in Europe, Asia, and North America.

With the global competition, customers have become aware of product features from around the world. Customers have become more sensitive and demanding, pushing firms to provide products that meet their individual needs. The days of mass produced, one-size-fits-all manufacturing are giving way to mass-customized, niche market products.

Technologies are migrating across products, allowing firms to meet widely diverse market needs. Electronics, materials, and biotechnology have the potential to dramatically transform products in a variety of businesses. Firms must be capable of finding, evaluating, adapting, and developing these new technologies to meet the more diverse and demanding market requirements.

International competition, diverse market needs, and rapid technology advances will require changes for firms to remain competitive. The most

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<sup>9</sup> Stephen C. Wheelwright and Kim B. Clark. *Revolutionizing Product Development*. Free Press. 1992. p. 2.



crucial changes will be required in the areas of speed, efficiency, and quality.<sup>10</sup> Let us review each separately.

Speed, or time, is by far the best way for firms today to gain a competitive advantage.<sup>11</sup> Firms must be able to quickly transform new technology into products that customers want, and the first firm to get those products to market is usually the firm that captures market share and sustained profits. Firms must also be quick at reacting to new markets, e.g., India and China, and adapting existing product to meet local needs. Again, first mover advantage is paramount to success.

Quickness alone will not make firms successful. With the expanding market, diverse needs, changing technology, and cost pressures, firms must learn to develop more product with the same or fewer resources. The computer and automotive industries are examples of the explosion of models being generated to meet niche market needs, with few, if any, additional resources to generate these models.

Quality in today's world means more than reliability and dependability -- it means total customer satisfaction. Products must also provide value or customer-perceived performance at a reasonable price. Finally, products must offer some distinction versus competition, surprising and delighting the customer with added features that are more than mere gimmicks.

Firms are responding to the global changes in a number of ways, but all are changing their strategies to cope with these new pressures. Whether it is reformulating current strategy to meet these new challenges, or striving to change the future of the firm's industry so that it provides a competitive advantage for the firm<sup>12</sup>, firms today are embroiled in significant

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<sup>10</sup> Wheelwright and Clark (1992). p. 4

<sup>11</sup> Peter M. Senge, *The Fifth Discipline*. Doubleday/Currency, 1990. p. 89.

<sup>12</sup> See Hamel and Prahalad (1994).

reformulation of their strategies. Not surprisingly, these changes in strategy will drive changes in performance measures.

## **2.4 - Pressures on Firm-Level Measures**

Measures used in the '60s, and in some cases still today (see Table 1) , were based on functional organization structures, manufacturing activities, and, for the most part, national, rather than international strategies. These measures were primarily financial in nature, and provided a historical perspective on where firms have been, not where they are going. The measures also prompted short term focus on profits rather than long term focus and reinvestment of capital. These measures seemed to work relatively well when markets were stable and there was little, if any, international competition.

As international competition develops and markets open globally, the old measures become obsolete. Increased time pressures necessitate predictive measures more and more. Competition is driving productivity improvements which many firms are not measuring on a routine basis. The focus on speed, efficiency, and quality will require more focused measures in these areas. Specifically, global competition will result in increased cost pressures and a view toward being the low-cost producer with high-quality products provided in the shortest amount of time. Firms must learn to do more with less, eliminate waste, improve productivity, develop mass-customization processes, and increase quality. So, how will the measures change? Clearly a focus on throughput of today's firms will be vital. A change from the typical "denominator" management, or emphasis on cost and asset utilization, must be replaced by "numerator" management,<sup>13</sup> or a focus

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<sup>13</sup> Gary Hamel and C.K. Prahalad. *Competing For The Future*. HBS Press. 1994. p.11.

on improving performance. This concept on numerator management will be explored in more detail in Chapter 4.

With some understanding of what is affecting firm strategies and measures today, one can begin the process of determining the impact on the product development process. The next chapter will take a view of the PD measures process similar to the methodology used in this chapter for firm-level measures.

## Chapter 3 - Product Development Measures

Developing product development performance measures that are aligned with corporate strategy and that drive individual behavior toward implementation of that strategy is more of an art than a science. Firms are constantly revisiting their process measures in light of changing priorities, restructuring, and reengineering, and those changes are rippled in the organizations, e.g., product development, that support the firm. Unfortunately, the measures do not really change much, as they seem to be driven more by what one *can* measure, then what one *should* measure. That is not to say that there are no cases where the right measures are being taken, but it stands as testimony to the fact that measures are difficult to define, communicate, and implement in a way that drives consistent performance across many activities of the firm.

This chapter will review how current product development measures have been established, what those measures are, and how they fit into the firm-level measures presented in Chapter 2. Next, a review of the current trends in product development and how those trends are affecting product development strategies and measures.

### 3.1 - Process to Establish PD-Level Measures

As with the firm-level process, the PD-level measures development process begins with strategy. First, strategy of the firm, as mentioned in Chapter 2, then with the strategy of the PD activity of the firm. In cases where there is no central PD activity, then the PD strategy is split between several functional activities. PD strategies operate on a somewhat different set of parameters than firm strategies. While firms are looking at long term financial stability, PD activities are looking at low-cost, high-quality programs

that support that financial stability. PD strategies are also more likely to focus on development and enhancement of the core competencies of the firm that are not as explicitly stated in the overall strategy of the firm.

Once the PD strategy has been established,<sup>14</sup> the measures development process begins. As with the strategy, it is critical to start with the firm-level and develop PD-level measures that support those higher-level metrics. Using the firm-level matrix as a guide will help ensure alignment with the firm measures, plus maintain a balance of measures that cover both long-term and short-term objectives. An important part of the process is to establish this linkage with the higher-level firm measures, reinforcing the firm strategy at the PD level. Many firms fail to make the linkage and find that their PD strategies and measures do not support the firm's overall mission, with disastrous results for the firm.

As with the firm-level process, benchmarking is used as a sanity check for the types of measures being used and also to help set performance objectives for the metrics. Benchmarking should be conducted on internal activities as well as external activities within and outside one's industry to provide the proper level of performance to support the strategy.

The PD measures development process is no more trivial than the firm measures development process. Linkage to both the PD strategy and the firm strategy and measures is crucial. The following section presents some of the measures developed by firms today.

### **3.2 - Current PD-Level Measures**

The literature search and interviews provided many different types of measures for PD activities -- not surprising given the wide array of products, competitive pressures, technology, etc. Table 2 outlines some of the more

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<sup>14</sup> Again, the reader is referred to Hax and Majluf (1991) for the details of developing robust business or functional strategies that support the overall strategy of the firm.

popular measures used by successful firms today, categorized using the same process as with firm-level metrics.

<b>Category</b>	<b>Firm-Level Measures</b>	<b>PD-Level Measures</b>
<b>Quality</b>	Customer Satisfaction On-time delivery Product Quality Warranty	Reliability Schedule Performance Engineering Changes Prototype Defect Rate Functional Performance Market Research Results
<b>Financial</b>	Sales New Products - Percent of Sales Return on Assets (ROA) Return on Investment (ROI) Return on Equity (ROE) Cash Flow Market-to-Book Ratio Market Share Growth Breakeven Time (BET) Debt-to-Equity Asset or Inventory Turnover Cost of Capital	Annual Budget Program Engineering Costs Product Costs Manufacturing Costs
<b>Internal Capabilities</b>	New Product Cycle Time Productivity Technology R&D Effectiveness First-in-Class	New Product Cycle Time Productivity Technology Patents R&D Effectiveness First-in-Class
<b>People</b>	Employee Satisfaction Employee Empowerment Training	Employee Satisfaction Employee Empowerment Training Skills Matrix

**Table 2 - Product Development-Level Measures**

### **3.2.1 - Quality Measures**

As shown in Table 2, the PD quality performance measures relate to the firm-level measures, but are not the same measures. For example, one

cannot measure customer satisfaction before a product is introduced to the public, thus one must establish alternate measures that ensure a product will meet customer wants. Market research results, coupled with reliability, prototype defect rate, and functional performance provide an early indication of customer satisfaction. The following briefly describes the measures highlighted in Table 2:

- Reliability - Mean-time-to-failure (MTBF) and B10 life (Weibull) are the most common measures. Correlation with real world experience is required to validate this measure as an early indicator.
- Schedule Performance - performance to the published program or project workplan.
- Engineering Changes - the number of changes required after the first prototype is built. Many add weighting to the changes to discourage late program changes.
- Prototype Defect Rate - based on a quality audit of prototypes. Trends are developed to predict production quality performance.
- Functional Performance - measure of the product's performance.

### **3.2.2 - Financial Measures**

PD financial measures are based on costs, and, in some cases, projected revenues. Activity-based costing<sup>15</sup> is used to ascertain the overall costs of a program and to assist in determining which projects or programs best utilize firm resources. Those presented in Table 2 include:

- Annual Budget - Labor, material, test, and other expenses. Most view this as the key measure for PD activities, since it is the one measure that is reviewed each year in performance appraisals.
- Program Engineering Costs - total costs for the program.

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<sup>15</sup> For a definition and example of activity based costing refer to Hilton (1994), pages 97-100 and 197-214.

- **Product Costs** - costs for supplied parts or transfer prices.
- **Manufacturing Costs** - all manufacturing and assembly costs not included in product costs.

### **3.2.3 - Internal Capabilities Measures**

As shown in Table 2, many of the PD measures are similar to the firm-level measures. For example, new product cycle time, productivity, R&D effectiveness, technology, and first-in-class are all the same firm-level measures applied at the PD-level. However, PD organizations will normally have different measures depending on their particular strategy, the diverse nature of the firm, etc. For firms interviewed as part of this paper, one unique measure was the number of patents applied for by the PD organization. This measure is typical for a firm with advanced R&D capabilities.

### **3.2.4 - People Measures**

Again, the PD-level metrics tend to mirror those at the firm-level. There are some cases where the measures differ, depending on the strategy of the PD organization, or on the specificity required at the lower levels of the firm. An example for this paper is the skills matrix, which is a way for the PD organization to ensure it has the proper skills to maintain core competency. Human resource development and rotational moves are normally required to keep this competence and at the same time train high-potential individuals for broader assignments.

There is much flexibility in establishing performance measures that help the PD organization meet its strategy and that of the firm. The key is to start with the firm level first, so that alignment with the firm's mission is more likely to occur. The next section outlines some of the current PD trends that will put pressure on the current measures outlined in this section.



### 3.3 - Product Development Trends

Many books have been written about the PD process, with Clark and Fujimoto (1991) providing a comprehensive review of the automotive industry as an example of what many firms today are facing. American automakers closed the quality gap with the Japanese in the 1980s, but still lag on product development, both in terms of overall time-to-market as well as overall cost.<sup>16</sup> The push to improve the PD process can be likened to quality improvement efforts of the 1980s.

In response to these forces, many PD organizations have some form of multifunctional project teams that bring the products from concept to market. Wheelwright and Clark (1992) explore the various types of teams starting with the functional organization and its transition to lightweight and then heavyweight project teams.<sup>17</sup> This shift away from functional organizations puts a strain on the current performance measures, which are based on functions rather than overall or system performance. No longer can the design engineer on the team only consider function and cost in his design, but must also consider manufacturing, service, and customer needs.

Next, there is a trend toward a disciplined product development process, split up into different phases, each with a management level review prior to proceeding to the next phase. Examples from several leading product development companies participating in the Manufacturing Vision Group are chronicled by Bowen, Clark, Holloway, and Wheelwright (1994).<sup>18</sup> Ford Motor Company's Concept-to-Customer process, DEC's Phase Review Process, Kodak's Manufacturing Assurance Process (MAP), and Hewlett

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<sup>16</sup> Kim B. Clark and Takahiro Fujimoto. *Product Development Performance*. HBS Press, 1991, p. 309.

<sup>17</sup> Steven C. Wheelwright and Kim B. Clark. *Revolutionizing Product Development*. Free Press, 1992, Chapter 8.

<sup>18</sup> H. Kent Bowen, Kim B. Clark, Charles A. Holloway, and Steven C. Wheelwright. *The Perpetual Enterprise Machine*. Oxford Press, 1994, Chapters 11-14.

Packard's seven phase process are all reviewed for the lessons learned in specific applications. These phased gate processes require some predictive qualities in the measures, allowing senior management to determine if product teams are on track at each of the gateway approvals. Measures that are based solely on past performance, e.g., budget, will not serve as predictive indicators of future performance.

Meyer (1993) provides a more detailed solution for product development. His short list of musts<sup>19</sup> include a major focus on process improvement, customer-driven, flat organizations with multifunctional teams, stretch goals, and a learning environment as ways to improve performance in product development. In both cases, the reengineered PD organizations are attempting to drive different behavior. Different behavior requires different performance measures. One cannot expect different behaviors from the same old measures.

### **3.4 - Pressures on PD Measures**

The initiation of team-based product teams and simultaneous engineering requires more informal measures to meld the traditional functional measures into a whole system viewpoint. PD measures must no longer encourage the type of "chimney" or "silo" behavior common with functional measures. These informal measures provide flexibility and empower the teams to develop measures that provide a systems view of the team's performance. The difficulty is in establishing the validity of new measures, particularly as they relate to the functional measures they replace, and also to the competitive pressures that are forcing the change in measures.

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<sup>19</sup> Christopher Meyer. *Fast Cycle Time*. Free Press, 1993, p.271.

The phased gate process is also driving measures that are more informal, as well as more predictive than in the past. The predictive aspect is the most difficult to deal with, particularly when establishing new measures. Although the thought process for the new measures may be logical, it is difficult to prove the predictability of the measures until it is too late, thus management is more apt to support proven measures with which they have some level of comfort. Teams must not succumb to the pressures to stay with familiar measures if they know that the new measures drive better behavior than the old metrics. Teams must also be willing to recommend the elimination of management policies that prevent teams from meeting established measures and targets.

Finally, one note about the ability of organizations to develop accurate, consistent measures for product development activities. Organizations have successfully established measures in manufacturing, utilizing statistical process control and other tools to design predictive process measures of repetitive processes. For the PD process, work is not as repetitive or predictable, thus companies have not been as successful at establishing successful measures.<sup>20</sup> Further compounding the problem is the feeling of white collar workers that they cannot be fairly measured, thus performance measures are suspect and drive gaming practices to compensate for the suspected inherent unfairness.<sup>21</sup> This difficulty is something that teams should keep in mind as they encounter resistance to changing measures.

In summary, the PD process is undergoing significant change in strategy and measures, fueled by firm-level changes to adapt to global competitive pressures. Many firms have utilized crossfunctional product teams and are struggling with performance measures that drive the systems behavior desired. No one has yet discovered the “magic formula” that provides the right measures for all PD organizations -- or any for that matter.

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<sup>20</sup> Christopher Meyer, *Fast Cycle Time*, Free Press, 1993, p. 163.

<sup>21</sup> Dorsey J. Talley, *Total Quality Management*, ASQC Quality Press, 1991, p. 42.

Of course, one would be foolish to think that one answer would work for all, or that a great solution today would be a great solution tomorrow. What PD organizations need to do is to continue to try new ways of driving behavior that meet the changing needs of today. To that end, the next chapter will provide an introduction to the fundamentals of Theory of Constraints -- certainly not an end-all to PD measures, but a new perspective to help drive teams to faster, more efficient product development.

## Chapter 4 - Theory of Constraints

Theory of Constraints (TOC) first received attention with the publication of *The Goal*<sup>22</sup> in 1984. Since then, numerous companies have used TOC to boost manufacturing throughput and improve profits. But skeptics claim that TOC is too simple an approach for complex organizations. Further, many view TOC as a step backward in financial measures -- stepping away from the rigors of activity-based accounting back to a lumping of all overhead expenses. The skeptics may be right if taken at face value, but the success to date of TOC raises questions as to why and how it works. This chapter reviews the basics of TOC to begin the process of understanding -- its foundation principles; how it differs in perspective from traditional financial methodologies; and, the basic five-step methodology. A simple example will be reviewed in Chapter 5 to see how the methodology is utilized, with Chapter 6 providing the first look at applying this methodology to something as complex as product development.

### 4.1 - TOC Foundation Principles

TOC begins with the goal -- to make more money now and in the future -- and lets the goal drive the strategies and tactics to meet that end. In reality, the goal never changes -- it is the strategies and tactics that constantly change to adapt to competitive pressure. Customer satisfaction, low-cost producer, high-quality producer, etc., typically thought of as goals, are actually the means of attaining the goal. This demonstrates again why strategy is so powerful - it defines how the firm will attain its ultimate goal. TOC, which complements rather than replaces current measures systems, is based on two foundation principles:

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<sup>22</sup> Eliyahu M. Goldratt. *The Goal*. North River Press, 1984. A second revised edition was published in 1992.

1. View the organization through the “eyes” of throughput.
2. Develop an **aligned performance measurement system** derived from throughput.

The next sections will briefly review each of these principles.

#### 4.1.1 - Viewing Through the Eyes of Throughput

Viewing the organization through the eyes of throughput means viewing the capacity of the organization as the capacity of the pacing, or constraint activity. For example, if an organization were represented by a simple piping diagram, with the diameter of each pipe segment indicating the potential capacity of that activity to generate throughput, the piping diagram might look like Figure 1.

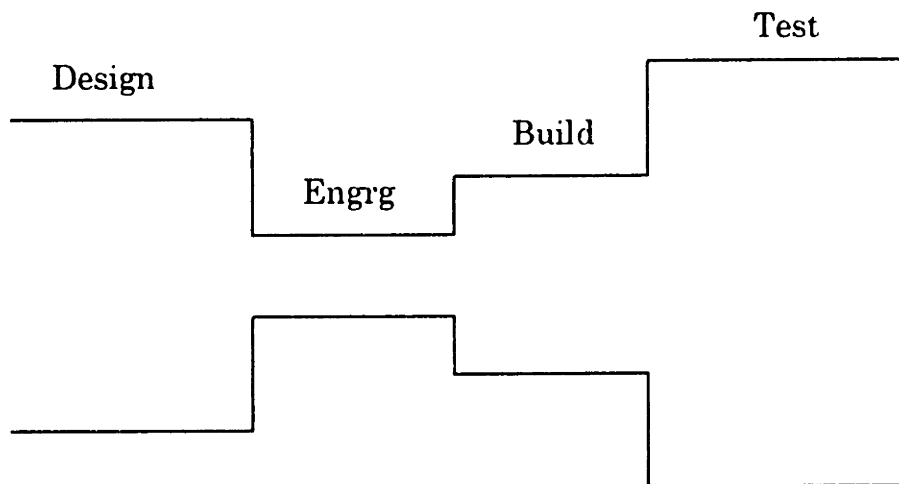


Figure 1 - Piping Diagram For an Organization

If one were to view the organization through the eyes of throughput, the system core capability would be as shown in Figure 2, where the limiting

factor for the entire organization is called the constraint. The constraint is defined as follows:

- **Constraint** - The element(s) of an organization that limits its ability to improve relative to Throughput.

Viewing through the eyes of throughput allows the organization to focus on system effectiveness, as opposed to system efficiency. Profitability is now equated with effectiveness vis-à-vis efficiency. Viewing through the eyes of throughput also provides a means to manage the system through the constraint and ensures that cost cutting is not done at the expense of throughput.

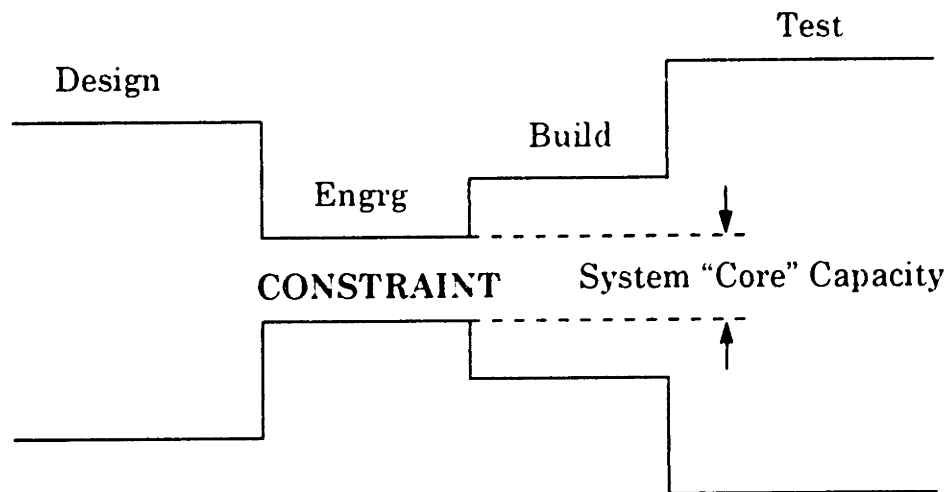


Figure 2 - Piping Diagram of Constraint

#### 4.1.2 - Develop an Aligned Performance Measurement System

The second foundation principle of TOC requires the development of an aligned performance measurement system derived from Throughput. As mentioned in Chapter 3, many organizations still use functionally based measures, resulting in "chimney" or "silo" behavior that optimizes the

functions and suboptimizes the organization. These measures also are typically not linked to one another, making it difficult to understand the interdependencies of these measures. Finally, it is difficult to determine linkage between each functions measures and the strategy of the firm, making implementation of the strategy difficult at best.

By contrast, TOC measures functions by what can be done to improve the throughput of the organization, instilling a systems view of performance. This systems view motivates all functions to help the constraint activity, and thus the organization, perform better -- as determined through the eyes of throughput.

There are three distinct measures that TOC utilizes:

- **Throughput (T)** - The rate at which the organization generates and contributes new money, primarily through sales.
- **Investment (I)** - The money that the organization spends on “short and long” term assets that can ultimately be converted into Throughput (T).
- **Operating Expense (OE)** - The money that the organization spends converting the Investment (I) into Throughput (T).

Throughput (T) as defined here is sold goods, not finished goods inventory, avoiding the problems with false inventory profits. Throughput is not simply sales, but the rate at which money is generated through sales, i.e., sales revenue less out-of-pocket expenses. Investment (I), includes all materials (e.g., raw materials, work-in-process materials, etc.) captured by the firm, as well as the traditional capital assets (e.g., plant, property, equipment, etc.).

Operating Expense (OE) differs significantly from traditional accounting terminology. All direct labor expenses, indirect labor expenses,



overhead expenses, sales and general administrative expenses are lumped together. Does this mean that TOC ignores the improvements in defining product costs from methods like activity-based costing (ABC)? Absolutely not! Knowing the costs of one's products is essential in making product mix decisions to maximize products, but TOC provides another perspective -- capacity or resources (see next section).

Using the definitions for (T), (I), and (OE), one can define more familiar measures. Throughput (T) was defined as "new money generated and contributed primarily through sales," yet sales revenue alone does not provide the right answer. Those expenses that are truly variable must be subtracted from sales to get throughput. Truly Variable Expenses (TVE) include only those expenses that are truly variable such as overtime, subcontractors, raw materials, marketing, commissions, shipping, etc. TVE does not include labor expenses (included in OE).

One can now define (T), (I), and (OE) in terms that are more familiar as measures of the goal (making more money now and in the future):

$$\mathbf{T = Sales - Truly Variable Expenses (TVE)}$$

$$\mathbf{Net Profit (NP) = T - OE}$$

$$\mathbf{Return on Investment (ROI) = \frac{\Delta T - \Delta OE}{I}}$$

Another important measure is productivity, which is defined as:

$$\mathbf{Productivity = T / OE}$$

Or, the productivity of an organization is described as the T dollars generated for each OE dollar spent.

Chapter 6 will provide a comparison of these TOC measures with those PD measures presented in Chapter 3, allowing a better understanding of the differences between TOC and current measures.

## **4.2 - TOC's Different Perspective**

Current financial measurement systems are two-dimensional, viewing the organization through financial (e.g., ROA, ROI, ROE, etc.) and market (e.g., market share, sales volume, etc.) measures. TOC provides a third perspective or dimension to performance measures -- the perspective of capacity, or resources. This additional perspective provides depth not realized in traditional or activity-based costing (ABC). As the example in Chapter 5 will demonstrate, ABC is fine if all resources or capacities are treated equally (i.e. a constant diameter pipe in the previous example), however, if a constraint is present, ABC may not provide the most profitable answers. In short, TOC is not a replacement for ABC, but another filter to aid in making the right product decisions.

Traditional accounting systems require uniformity across all business activities, providing little or no flexibility, and potentially leading to poor managerial decisions. Activity-based costing (ABC) has been an improvement, but it is sensitive to how cost pools and drivers are established, and it assumes all resources and capacities to be the same. The result can cause misguided behavior. For example, if all costs for design changes were collected in a cost pool and allocated based on the number of engineering changes, managers would be tempted to batch engineering changes together to make their costs look better than they actually appear. The batch process would slow down response time for customers, overload the design resources when the lumped change goes through, however it would provide the

intended short term reduction in the product line manager's overhead allocation.

Whereas ABC focuses on cost allocation, TOC focuses on profitability through the measures of throughput (T), investment (I), and operating expenses (OE) as mentioned earlier. The primary focus is on Throughput because it provides a relatively boundless measure compared to Investment and Operating Expenses. In most organizations, OE is the prime measure, not necessarily because it should be, but for some of the following reasons:

- OE is the easiest measure to control
- OE changes can be implemented rapidly
- OE includes the cost of labor, an easy target
- Productivity improvement projects focus on OE reduction
- and so on.....

This type of “denominator management” puts focus on asset utilization instead of growth and makes it difficult for management teams to make the transition to a growth, or “numerator management.” Perhaps another way to view this is by looking at how each measure must change to improve the organization's performance. Organizational performance toward the goal is achieved when: T increases; I decreases; and OE decreases. Efforts to decrease I and OE are bounded by some minimal operating level of expense and investment, and thus reach a point of diminishing returns. T, on the other hand, is relatively unbounded, and focus on this measure will maximize the organization's progress toward the goal.

Focusing on T, or viewing opportunities *through the eyes of T*, does not mean that I and OE are to be ignored -- quite the contrary. Viewing through the eyes of T means that one can still pursue I and OE opportunities as long as they do not negatively impact the T of the organization. More

importantly, viewing through the eyes of T allows all in an organization to focus in a positive direction with common measures. This change in focus is easy to understand, but can be difficult to implement as it requires a shift in the traditional OE paradigm that has been the model for most of this century.

In summary, TOC provides a third perspective, capacity, to performance measures, and focuses the organizations efforts on increasing Throughput. Table 3 provides a comparison of TOC versus traditional accounting practice.

Traditional Perspective	TOC Perspective
Focus on Everything Measure Element Efficiency Micro-Manage Functions Conflicting Measures Profit = Efficiency Strategies/Tactics = Goal 2-Dimensional Decision-Making  <div style="display: flex; justify-content: space-around; align-items: center;"> <div style="border: 1px solid black; border-radius: 50%; padding: 5px; text-align: center;">Market</div> <span style="font-size: 2em;">---</span> <div style="border: 1px solid black; border-radius: 50%; padding: 5px; text-align: center;">Financial</div> </div>	Focus on the Constraint Measure System Effectiveness Manage System vs Constraint Aligned Measures Profit = Effectiveness Goal Drives Strategies/Tactics 3-Dimensional Decision-Making  <div style="display: flex; flex-direction: column; align-items: center;"> <div style="border: 1px solid black; border-radius: 50%; padding: 5px; text-align: center; margin-bottom: 20px;">Capacity</div> <div style="display: flex; justify-content: space-around; align-items: center;"> <div style="border: 1px solid black; border-radius: 50%; padding: 5px; text-align: center;">Market</div> <span style="font-size: 2em;">---</span> <div style="border: 1px solid black; border-radius: 50%; padding: 5px; text-align: center;">Financial</div> </div> </div>

**Table 3 - Traditional Versus TOC Perspective**

The next step in understanding the basics of TOC is the five-step process to implement TOC as presented in the following section.

### 4.3 - TOC's Five Step Process

TOC's Five Step Process is best seen by referring to the pipeline analogy previously presented. As discussed, increasing the performance of the organization is directly linked to improving the performance of the constraint. A more complex piping diagram is shown in Figure 3.

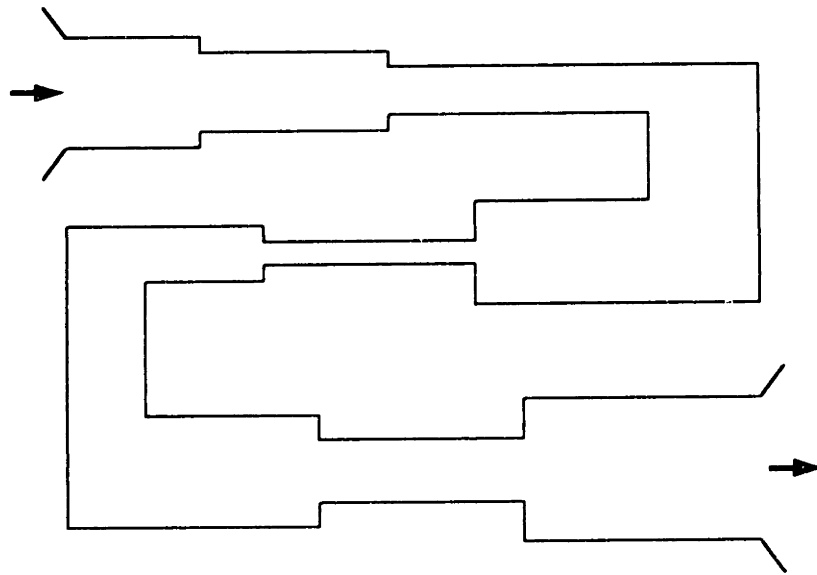


Figure 3 - Piping Diagram

The overall performance of this system is measured in terms of  $T$  (the rate at which water is delivered to the end of the pipe). If the amount of water being generated is no longer sufficient, the easiest way to generate more throughput would be to widen the limiting pipe section to increase flow. This same concept can be applied to an organization's product development process as shown in Figure 4.

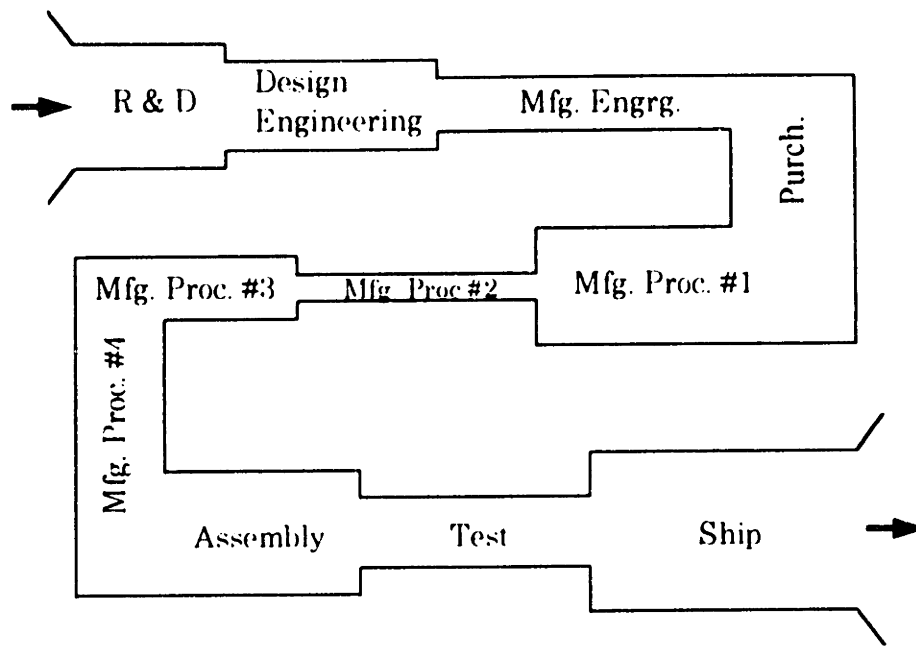


Figure 4 - Piping Diagram for a Manufacturing Firm

First inspection of this system would point to Manufacturing Process #2 as the constraint. As with the water analogy, the narrowest pipe, Manufacturing Process #2, limits the throughput of the entire organization.

Viewing this diagram through the eyes of T provides some insight into why traditional across-the-board cost-cutting does not provide the projected benefits. For example, if Manufacturing Process #2 is the constraint, or pacing activity, then reducing its OE might have a negative impact on the T of the firm. OE reductions in Assembly or Shipping, on the other hand, would most likely not impact the T of the firm. Similarly, improvement actions aimed at Assembly or Shipping probably would not improve the T of the firm, however, improvement actions aimed at Manufacturing Process #2, the constraint, would likely have a tremendous impact on the T of the firm.

One might assume that, in looking for the constraint, all activities would have some anxiety about being named the "constraint." In fact, the activity that is the constraint is the most valuable resource in the firm and the scarce constraint resources are to be cared for so that the firm's T is

maximized. Somehow, “scarcest, most valuable resource” is a better label than “constraint.”

Traditional measures are aimed at optimization of each element of the process, and at across-the-board cost reduction. As the piping diagram demonstrates, this suboptimization may have a small impact on OE reduction, but can have a negative impact on the T of the organization. Assume that TOC measures are implemented in the piping diagram. What type of behavior would be evident? First, each activity must understand where the overall constraint is. This can be accomplished by process mapping or looking for long queues where work is building. Second, the organization would try to improve the constraint activity’s efficiency and capacity, first in the short term, and then in the long term. Third, each non-constraint activity would need to understand how to positively impact the constraint activity and what actions might taken to keep the constraint activity running smoothly. Finally, once the short and long term improvement actions have been taken, the firm should check the process again to see if the constraint has now moved to another activity.

Summarizing these steps:

1. **Identify** the organization’s constraint.
2. Develop a plan to **subordinate** the constraint, i.e., maximize the T utilizing existing constraint resources.
3. **Subordinate** all other activities to the implementation of the plan developed in Step #2, i.e., ensure that all non-constraint activities give full support to the plan implementation.
4. **Elevate** the constraint, i.e., lift the restriction of the constraint.
5. Once the constraint has been broken, go back to Step #1, but be sure to communicate to the system that the constraint has now moved (otherwise the system inertia will continue subordination to the old constraint).

Above are the **Five Steps of Theory of Constraints (TOC)**.<sup>23</sup> These steps guide an organization in managing constraints through common measures and viewing through the eyes of T. As noted earlier, these measures do not supplant current measures, but provide a different focus and crossfunctional linkage to meet changing environments.

To better understand these five steps, Chapter 5 will provide an example of how current measures may lead to poor decisions, and how TOC measures can enlighten the decision-making process.

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<sup>23</sup> Eliyahu M. Goldratt. *The Haystack Syndrome*. North River Press, 1990. pp. 57-63.



## Chapter 5 - TOC Case Study: The P/Q Company<sup>24</sup>

The P/Q Company case study allows a demonstration of the concepts of TOC by comparing the current measures with TOC measures and reviewing the actual outcomes of those decisions. To make matters simple, assume that there is no uncertainty in customer orders, production schedules, material delivery, machine efficiency, etc. -- in other words a near-perfect world. This simple approach provides a good building block to understanding how to apply TOC to a more complex system.

### 5.1 - Identify the Constraint

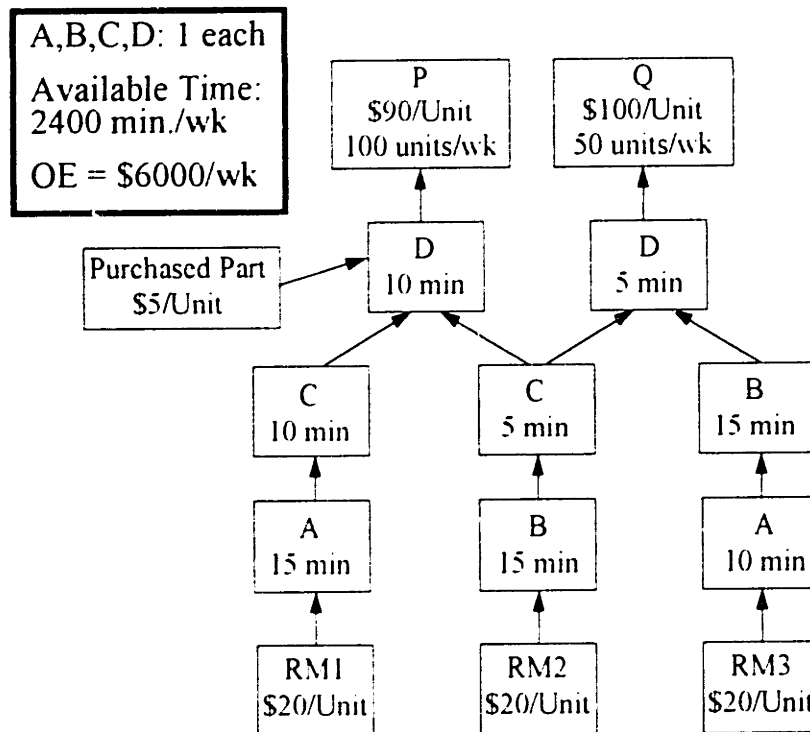


Figure 5 - The P/Q Company

As shown in Figure 5, the P/Q Company currently makes two products, P and Q. Product P sells for \$90 per unit and has a market demand of 100

<sup>24</sup> Adapted from Goldratt's *The Haystack Syndrome*, pp. 64-99.

units per week. This product is an assembly put together by Resource D, which requires 10 minutes to make one Product P. The assembly is composed of a purchased part that cost \$5, plus two manufactured parts. The first of these parts starts at Resource A which uses Raw Material 1 (RM1), and after a 15 minute operation moves to Resource C which takes 10 minutes to complete its work. The second part starts at Resource B which uses Raw Material 2 (RM2), and after a 15 minute operation moves to Resource C which takes 5 minutes to complete its work.

The second product, Q, sells for \$100 per unit and has a market demand of 50 units per week. This product is an assembly also put together by Resource D which requires only 5 minutes to make Product Q. The assembly is composed of two manufactured parts. The first part starts at Resource B which uses Raw Material 2 (RM2), and after a 15 minute operation moves to Resource C which takes 5 minutes to complete its work. The second part starts at Resource A which uses Raw Material 3 (RM3), and after a 10 minute operations moves to Resource B which takes 15 minutes to complete its work.

There is only one Resource A, one Resource B, one Resource C, and one Resource D, each working no more than 40 hours per week or 2,400 minutes per week. The operating expense is \$6,000 per week. The computation of the profit potential of the plant is shown in Table 4.

	<b>Product P</b>	<b>Product Q</b>	
<b>Sales Potential</b>	100 units	50 units	
<b>Sales Price</b>	\$ 90	\$ 100	
<b>Material Cost</b>	\$ 45	\$ 40	
<b>Gross Margin</b>	\$ 45	\$ 60	
<b>Operating Profit</b>	\$4,500	\$2,000	\$ 7,500
<b>Operating Expense</b>			<u>\$(6,000)</u>
<b>Net Profit/Week</b>			<b>\$ 1,500</b>

**Table 4** - Profit Potential for P/Q Company

The profit potential of the plant is \$1,500 per week. The next question is whether there are sufficient resources to meet sales volume for each product. The utilization of resources can be calculated as shown in Table 5.

<u>Resource</u>	<u>Process Load/Wk.</u>	<u>Available Time/Wk.</u>	<u>Percent Load/Wk.</u>
<b>A</b>	$15 \times 100 = 1500$ $10 \times 50 = \underline{500}$ 2000	2400	83%
<b>B</b>	$15 \times 100 = 1500$ $15 \times 50 = 750$ $15 \times 50 = \underline{750}$ 3000	2400	125%
<b>C</b>	$10 \times 100 = 1000$ $5 \times 100 = 500$ $5 \times 50 = \underline{250}$ 1750	2400	73%
<b>D</b>	$10 \times 100 = 1000$ $5 \times 50 = \underline{250}$ 1250	2400	52%

Table 5 - Resource Loading

### Step 1 - Identify the organization's constraint

- Calculate the process load for each resource.
- Determine the number of setups that can be accomplished.

Table 5 clearly shows that, given the market demands for Products P and Q, this particular plant is capacity-constrained. Furthermore, the plant throughput is constrained by Resource B, thus Resource B is the constraint.

### 5.2 - Exploit the Constraint

The next step is to determine the most profitable mix of product. Product Q has the higher margin (\$60 versus \$45 for Product P) and requires less labor (50 minutes versus 55 minutes for Product P). Thus, assume that all the orders for Product Q are completed first, then Product P is produced

with the time remaining. We can determine the amount of Product P by looking at time used at the constraint B. Product Q uses 30 minutes of B per unit for a total of 1,500 minutes. With the remaining 900 minutes remaining, we can make 60 units of Product P (15 minutes per unit). The profit for this product mix is shown in Table 6.

	<b>Product P</b>	<b>Product Q</b>	
<b>Sales Potential</b>	100 units	50 units	
<b>Actual Production</b>	60 units	50 units	
<b>Sales Price</b>	\$ 90	\$ 100	
<b>Material Cost</b>	\$ 45	\$ 40	
<b>Gross Margin</b>	\$ 45	\$ 60	
<b>Operating Profit</b>	\$2,700	\$3,000	\$ 5,700
<b>Operating Expense</b>			<u>\$(6,000)</u>
<b>Net Profit/Week</b>			<b>\$ (300)</b>

Table 6 - Profit Using Conventional Approach

This particular mix seems to defy conventional wisdom since the highest margin profit with the least amount of labor time required was chosen, yet the firm is losing money. Something was missing in the conventional approach: viewing through the eyes of T. In the conventional approach, all of the labor time was assumed to be equal. Although the labor rate is the same, the throughput for each labor unit is not the same. As stated earlier, the constraint is the scarcest, most valuable resource, thus, for this example, Resource B's time is the most valuable. Product Q uses 30 minutes of Resource B and has a gross margin of \$60, thus Product Q generates \$2 for every minutes of Resource B. Product P uses 15 minutes of Resource B and has a gross margin of \$45, thus Product P generates \$3 for every minute of Resource B. Product P, therefore, generates the most revenue per minute of the constraint Resource B.

Redefining the product mix in terms of the constraint, all of Product P should be made first, then the remaining time should be used for Product Q --

the exact opposite of what was called for in the conventional approach. The product mix now becomes 100 units of Product P and only 30 unit of Product Q. Table 7 shows the new net income per week for this product mix.

	<u>Product P</u>	<u>Product Q</u>	
<b>Sales Potential</b>	100 units	50 units	
<b>Actual Production</b>	100 units	30 units	
<b>Sales Price</b>	\$ 90	\$ 100	
<b>Material Cost</b>	\$ 45	\$ 40	
<b>Gross Margin</b>	\$ 45	\$ 60	
<b>Operating Profit</b>	\$4,500	\$1,800	\$ 6,300
<b>Operating Expense</b>			<u>\$(6,000)</u>
<b>Net Profit/Week</b>			<b>\$ 300</b>

Table 7 - Profit Using TOC Approach

Viewing the organization through the eyes of T allows an organization to maximize profits by considering the constraint resources and their ability to generate revenue.

**Step 2: Develop a plan to exploit the organization's constraint.**

- **Determine the most profitable mix by maximizing T performance of the constraint.**

### **5.3 - Subordinate The Organization To The Constraint**

Producing product is not the only measure for most organizations. There are usually efficiency objectives which generate several cost reduction projects each year. Assume a project that will cost \$5,000 investment actually adds time to the process, increasing the labor minutes required to make part #2 from 20 to 21 minutes. Most would flatly refuse the project because it adds labor time and provides no quality improvement. Upon further inspection, the project reduces time on Resource B from 15 to 14

minutes, utilizing additional time on Resource C to perform the same operation, thus process time at C increases from 5 to 7 minutes as shown in Figure 6.

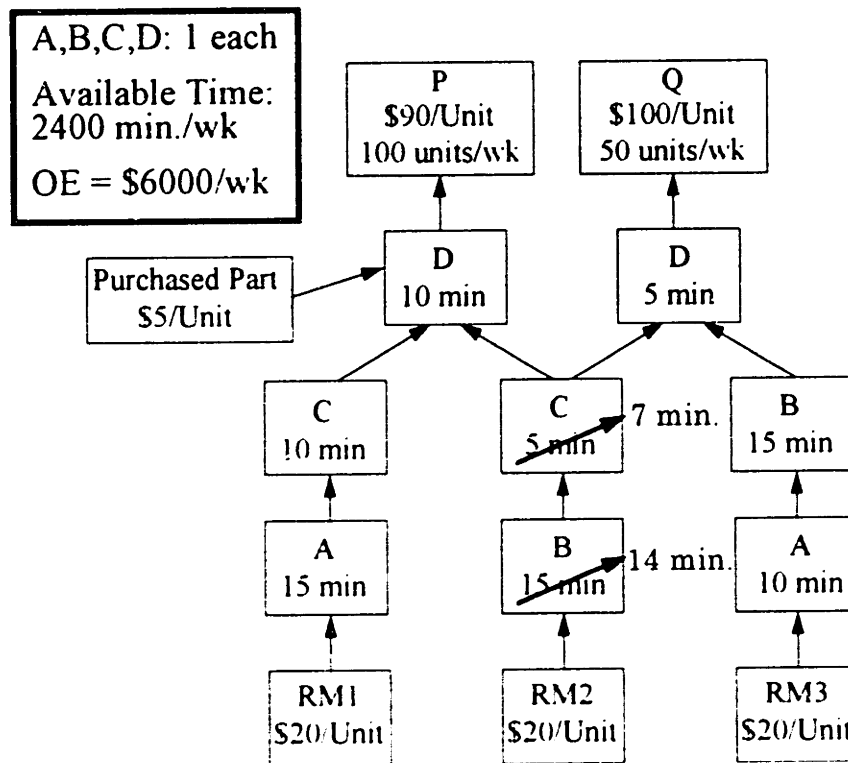


Figure 6 - P/Q Improvement Project

In conventional accounting, this project would still be rejected. However, when viewed through the eyes of T, a different decision is rendered. The key is to determine what the project does to constraint time, as was accomplished with the product mix. First, the resource loading of C must be checked to ensure that the added process time does not utilize all of the C time permitted. To produce all of the demand for Product P requires 1700 minutes of C time with the new process. The time to produce all of Product Q is unchanged at 350 minutes, thus the increase in C process time is still within the 2400 minute constraint.

Now the project is reviewed for its impact on the constraint resource B. Since time on Resource B is reduced 1 minute, it now takes 1400 minutes to make all of Product P. With the remaining 1000 minutes, a total of 34 units of Product Q can now be produced. The increase in profit due to the added 4 units of Q is \$240 per week!

This project shows that even if a non-constraint resource performs a constraint resource function less efficiently, total profit can be improved. The reason is that the constraint resource is being unloaded and allowed to produce more product than before. In the conventional OE method, this type of sacrifice in efficiency would not be allowed because each activity is measured on its own efficiency. TOC provides a means for non-constraint resources to contribute to T by helping the constraint resource run more efficiently, even if it means a less efficient resource. Why? Because all resource activities are measured on the total system T.

**Step 4: Elevate the organization's constraint.**

- **After squeezing the most T from the existing constraint, reduce its limitations on the organization's performance.**

The final step on the TOC method occurs if and when a different resource becomes the constraint. The process starts all over again with determining the constraint, exploiting the constraint, subordinating the organization to the constraint and elevating the constraint. As previously mentioned, communication is crucial when transitioning to a new constraint. TOC aligns the organization to optimize T by concentrating the organization's focus on the constraint activity. Changing to a different constraint requires extensive communication to maximize the organization's performance.

## 5.4 - Controlling Inertia

Assume now that there is a market demand for product P (100 units) and Q (50 units) in Japan, however the price would have to be reduced to \$72 for a P and \$80 for a Q. The question is: Should the products be exported to Japan? As with the previous example, the product mix decision should be based on the throughput dollars generated per constraint time unit as shown in Table 8.

	<b>P</b>	<b>P(J)</b>	<b>Q</b>	<b>Q(J)</b>
<b>Sales Potential</b>	100 units	100 units	50 units	50 units
<b>Selling Price</b>	\$90	\$72	\$100	\$80
<b>Material Cost</b>	\$45	\$45	\$40	\$40
<b>Gross Margin</b>	\$45	\$27	\$60	\$40
<b>Min. of Res. B</b>	15	15	30	30
<b>\$ / Min. of Res. B</b>	\$3.00	\$1.80	\$2.00	\$1.30
<b>Product Mix Ranking</b>	<b>1</b>	<b>3</b>	<b>2</b>	<b>4</b>

Table 8 - Product Mix Ranking

Given the figures in Table 8, one would not choose to market in Japan. The T generated per unit of constraint time would have to be greater than \$2.00 for it to be worthwhile to export to Japan.

Now assume that a second B resource can be purchased for \$100,000 and would add \$400 per week to operating expenses. Should the firm buy the machine? First, adding a second B resource breaks the current constraint. Referring back to Table 5, one can see that Resource A is the next most utilized resource at 83%, and thus, A would become the constraint. With the Japanese product included, the total resources loading for A at sales potential would be 4000 minutes (200 units P at 15 minutes each plus 100



units Q at 10 minutes each). Since Resource A is limited to 2400 minutes, it now becomes the constraint.

	<b>P</b>	<b>P(J)</b>	<b>Q</b>	<b>Q(J)</b>
<b>Sales Potential</b>	100 units	100 units	50 units	50 units
<b>Selling Price</b>	\$90	\$72	\$100	\$80
<b>Material Cost</b>	\$45	\$45	\$40	\$40
<b>Gross Margin</b>	\$45	\$27	\$60	\$40
<b>Min. of Res. A</b>	15	15	10	10
<b>\$/ Min. of Res. A</b>	\$3.00	\$1.80	\$6.00	\$4.00
<b>Product Mix Ranking</b>	<b>3</b>	<b>4</b>	<b>1</b>	<b>2</b>
<b>Previous Ranking</b>	1	3	2	4

**Table 9 - Product Mix Ranking with New Constraint**

Table 9 shows the new ranking for product mix which says that all of Q should be made first, then Q (J), then P, and finally, P (J). Note the drastic difference in the ranking as the constraint changes from resource B to resource A.

Next, the net profit must be calculated to determine if the \$100,000 investment for an additional resource B is worthwhile. Using the ranking in Table 9 and the constrained time of resource A to determine the actual production numbers, one determines that all 50 Q and 50 Q(J) can be made, as well as 93 P, with no opportunity to make P(J).

As shown in Table 10, the new net profit per week is \$2785, which is a \$2485 per week improvement versus the previous optimization in Table 7. This profit improvement would allow payback of the \$100,000 investment in 41 weeks. The profit improvement was made possible by making an investment to break the constraint, and shifting the organizational inertia to the new constraint, resource A.

	<u>P</u>	<u>P(J)</u>	<u>Q</u>	<u>Q(J)</u>	
<b>Sales Potential</b>	100 units	100 units	50 units	50 units	
<b>Selling Price</b>	\$90	\$72	\$100	\$80	
<b>Material Cost</b>	\$45	\$45	\$40	\$40	
<b>Gross Margin</b>	\$45	\$27	\$60	\$40	
<b>Min. of Res. A</b>	15	15	10	10	
<b>\$ / Min. of Res. A</b>	\$3.00	\$1.80	\$6.00	\$4.00	
<b>Actual Production</b>	93 units	0	50 units	50 units	
<b>Gross Profit</b>	\$4185	0	\$3000	\$2000	\$ 9185
<b>Operating Expense</b>					\$(6400)
<b>Net Profit/Week</b>					<b>\$2785</b>

Table 10 - Profit Summary with New Constraint

**Step 5: Once the constraint has been broken, go back to step #1, but beware of organizational inertia.**

## 5.5 - Examples of TOC in Manufacturing

TOC has been used in many firms for manufacturing. Of the 5 leading companies studied for the paper, 2 had used TOC extensively in their manufacturing activities with great success. Lockamy and Cox (1994)<sup>25</sup> explore the successful usage of TOC in the manufacturing activities of everything from industrial electronics to pet care products. These case studies reveal how financial and performance measures were revised according to TOC principles. The result was an alignment with the organization's strategy, and successful implementation of that strategy.

<sup>25</sup> Archie Lockamy, III and James F. Cox, III. *Reengineering Performance Measurement*. Irwin Professional Publishing, 1994. Chapters 8-13.

Other studies have shown drastic improvements utilizing TOC in different aspects of their operations. For example, Proctor & Gamble, first to use TOC for distribution, has reported a \$600 million reduction in inventory using TOC.<sup>26</sup> Kent Moore Cabinets utilized TOC and reduced their lead time to two days versus an industry standard of four weeks. This reduction was achieved without raising their employment levels and resulted in a 40% (\$4 million) increase in sales over two years.<sup>27</sup>

Each of the cases sighted dealt primarily with the order entry-through-customer delivery process. Although successful in these downstream activities, TOC has yet to be expanded to the product development area. The next chapter will demonstrate how the same TOC principles that have been successfully used in manufacturing can be successfully applied to product development.

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<sup>26</sup> Stanley C. Gardiner, John H. Blackstone, and Lorraine R. Gardiner. "The Evolution of the Theory of Constraints." *Industrial Management*, May, 1994, Volume 36, No. 3, pg. 13.

<sup>27</sup> Gardiner, Blackstone, and Gardiner (May, 1994).

## Chapter 6 - Applying TOC to Product Development

The previous chapter demonstrated how TOC can be applied to a manufacturing environment, but the question is whether TOC can be applied to the product development process. As mentioned in Chapter 3, measuring white collar workers is difficult at best. Unlike manufacturing, where tasks are repetitive and easy-to-measure, product development is a complex system made up of tasks that are rarely repeated. There are many tasks that cannot be timed for a completion date, particularly if they require conceptual or creative thinking such as packaging or styling. Even if measures are put in place, companies have not been very successful in developing repeatable process measures.<sup>26</sup> However, there are similarities. Manufacturing processes material through shared machinery as shown in the P/Q example. Product development processes information (electronic drawings) through shared resources.

Despite the difficulties, developing measures is key to the organization's success in implementing strategy. Measures drive behavior, and poor measures will drive behavior that is unsynchronized with the corporate strategy. The alignment provided by TOC's common measures would provide the focus and cross-functional linkage for a product development group. What should the measures be? Given the complex nature of product development, how does one determine the constraint? This chapter will try to answer these questions by comparing product development to the factory and demonstrating how to apply the five step TOC process. Three examples of actual application of TOC will be interwoven in the presentation: one example using a constraint activity; one using a non-constraint upstream activity, and one using a non-constraint downstream activity. The companies and products have been disguised, but

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<sup>26</sup> Christopher Meyer, *Fast Cycle Time*, Free Press, 1993, p. 163.

present real world examples of successful application of TOC to the PD process. The new measures for PD will then be compared to the current measures presented in Chapter 3.

## 6.1 - Determine the Constraint

As with the manufacturing example, it helps to start the constraint identification process with a process map of the organization which shows how the work flows from one activity to another. A process map for a typical product development organization is shown in Figure 7.

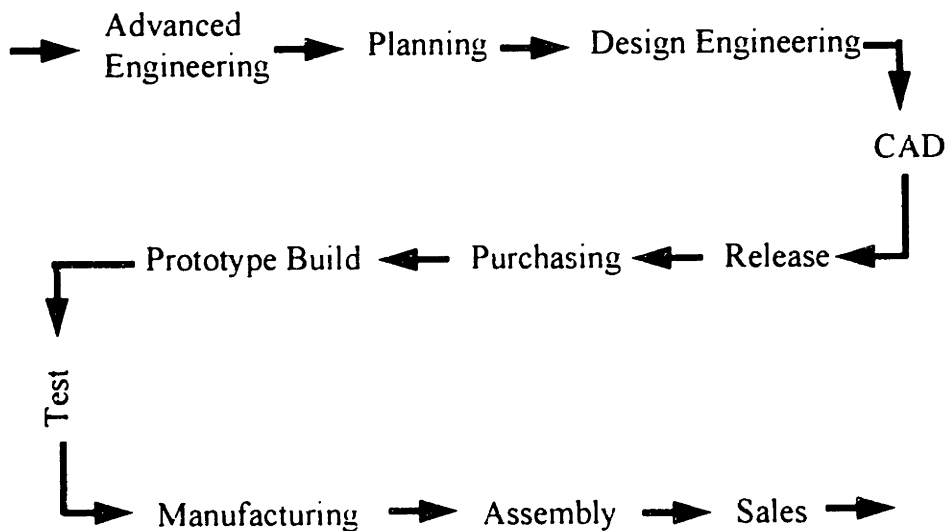


Figure 7 - Process Map for a PD organization

How does one find the constraint once the map is complete? Finding the constraint may not be as difficult as it first appears. First, most have an intuition for what the constraint might be, and these hunches will at least provide a good starting point for investigation. Another way to start the process is to look for work-in-process building in front of an activity. One only need look in an engineer's file tray to determine the work-in-process for

that individual. A careful review of the activities workloads and workflows will allow one to construct a piping diagram. Initially the pipe diameters will be a guess as to the capacity of each activity to do work. At this stage, the actual size is not important. What is important is to identify the constraint to the organization so that the next step in the TOC process -- exploitation of the constraint -- can take place. A piping diagram that corresponds with the process map is shown in Figure 8.

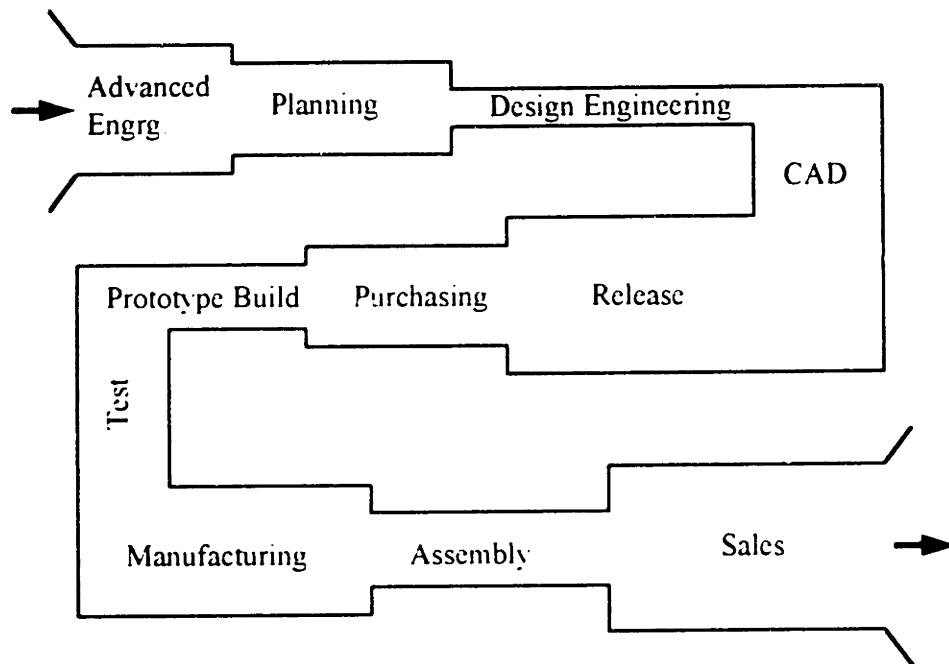


Figure 8 - Piping Diagram for a PD organization

Note that for this organization, Design Engineering is the constraint activity -- the scarcest and most valuable resource. Now that the constraint has been identified, what might be done to exploit the constraint?

## 6.2 - Exploit the Constraint

For design engineering, one needs to look at what is limiting the pipe diameter, or capacity, of the activity. Work flowing through the pipe can be

categorized into three categories: value-added work that contributes directly to the final product, non-value-added work that contributes nothing to the final product, and non-value-added work that is the result of rework.

The value-added work can be thought of as drawings that become actual parts in production. One might think that the value-added work would be a high percentage of the capacity, but recent studies have shown that the actual throughput can be as low as 10% for aerospace projects to 90% in software projects.<sup>29</sup> This wide variance in throughput is attributable in part to the amount of uncertainty in the technology and the length of the product development cycle time. The best way to determine if one's company is competitive in this attribute would be to benchmark other firms.

The non-value-added work that does not contribute to the final product is pure waste in the system and should be eliminated. All of the companies interviewed for this paper had some form of value-determining process whereby the work done is evaluated for its contribution from the customer's viewpoint.

The third category, non-value-added work that is the result of rework, provides some real potential for improvement, and would significantly improve the throughput capacity if reduced (as referenced in Cooper's Rework Cycle). Total elimination of this rework is desired, but not likely to occur. Eliminating rework would mean that drawings would only be done once -- no changes. Although this is possible, it is not practical. Changes are always required to resolve problems found in testing, manufacturing, and assembly. Eliminating changes would require designs that are highly overdesigned, costly, and require a longer time-to-market, thus defeating the overall purpose.

Both categories of non-value-added work can be thought of as "rust" in our pipeline analogy -- both reduce the throughput of the pipe and should be

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<sup>29</sup> Kenneth G. Cooper. "The Rework Cycle. Benchmarks for the Project Manager." *Project Management Journal*. March, 1993. Volume XXIV, Number 1.

minimized to the extent possible. In one of the companies interviewed, Company A, TOC had been applied to design engineering, which, for this firm, was the constraint activity. Based on this firm's pilot, the following set of measures was developed utilizing TOC:

- **Throughput:** The rate at which saleable part drawings are created.
- **Productivity:** Saleable Parts / Operating Expense, where Operating Expense is a cumulative total for the program.
- **Schedule Adherence:**  $\{T^{\text{put}}(\text{planned}) - T^{\text{put}}(\text{actual})\} * \text{Days Late}$ , weighting dates late by throughput.
- **Design Effectiveness:** Saleable Parts / All Parts, where all parts includes all part drawing updates for prototype or experimental use.
- **Engineering Efficiency:** Value Added Time / Total Cycle Time

How do these compare with the previous PD measures for this activity?

Table 11 makes the comparison for measures that are different from those shown in Table 2. Of particular note is the revision from Budget to Throughput -- a real shift in the cost-driven paradigm, although total program costs still capture the amount (albeit on a total program versus annual basis). These changes in measures are still in the pilot phase and the benefits gained have yet to be determined. But what can clearly be seen in the TOC measures shown in Table 11, is the change in focus from the traditional cost reduction, to one of throughput increases. What is also apparent is that TOC has not totally replaced the previous measures, but complements most measures while giving a perspective on the impact on the critical constraint resources.



Previous PD Measure	TOC Measure	Revision for TOC
Budget	Throughput	Throughput versus Cost
Program Engineering Costs	Operating Expense + Truly Variable Expenses (TVE)	Operating Expense does not include truly variable expenses (e.g., prototype material costs)
Schedule Performance	Schedule Adherence	Adherence weighted based on throughput.
Productivity	Productivity	Throughput versus Cost
---	Engineering Efficiency	Not previously measured.
Design Efficiency	Design Effectiveness	Based on saleable parts - previously not a performance measure (for info only)

**Table 11 - Comparison of Current and TOC Measures for Design Engineering**

### **6.3 - Subordinate the Organization to the Constraint**

How does one subordinate the activities shown in Figure 9 to the constraint activity (Design Engineering in this case)? Each activity must review how it can impact the throughput of the constraint. For purposes of illustration, an upstream and a downstream activity will be reviewed.

The upstream activities, Advanced Engineering and Planning, can have a significant impact on Design Engineering. In the companies interviewed, most regarded these upfront activities as crucial to the success of the design. First, Advanced Engineering must ensure that the technologies being used for the product are ready. Ready here means feasibility has been established, technology has been tested for robustness,

manufacturing and assembly assessments have been made, and all key issues have been identified with action plans in place. Pushing forward a technology that is not ready will significantly increase the amount of rework that Design Engineering must do, thus reducing the capacity of the constraint. The result is costly in terms of development monies, but, more importantly, in adding more time-to-market.

Planning has a similar responsibility to specify what the customer wants in a product including function, quality, life, appearance, price, etc. As with pushing poor technology, late changes to meet customer wants will add to the "rust" in the Design Engineering pipeline. Planning must therefore ensure that the customer has been identified and researched to determine what the customer specification should be, resulting in reduced rework for the constraint.

Company B experienced this dilemma between Advanced/Planning activities and the downstream product design activity (again the constraint for this firm). Company B found that the upstream activities can have a tremendous impact on the downstream activity, and the overall cost of the program. Company B had two similar product launches. In the first program, call it B1, the Advanced Engineering and planning activities had been criticized for taking a longer-than-normal time to develop the technology and finalize the customer specifications. While B1 was still developing, product B2 had launched its product engineering phase, however, B2 ran into difficulties downstream. Technology problems not forecasted or planned were requiring tremendous resources to resolve. This extensive rework slowed the implementation process and caused costs to soar. B1 completed its development and specifications, and, after a late start, found relatively smooth sailing in the product development phase. The two programs were compared for their timing and use of resources. A graph showing the results is reflected in Figure 9.

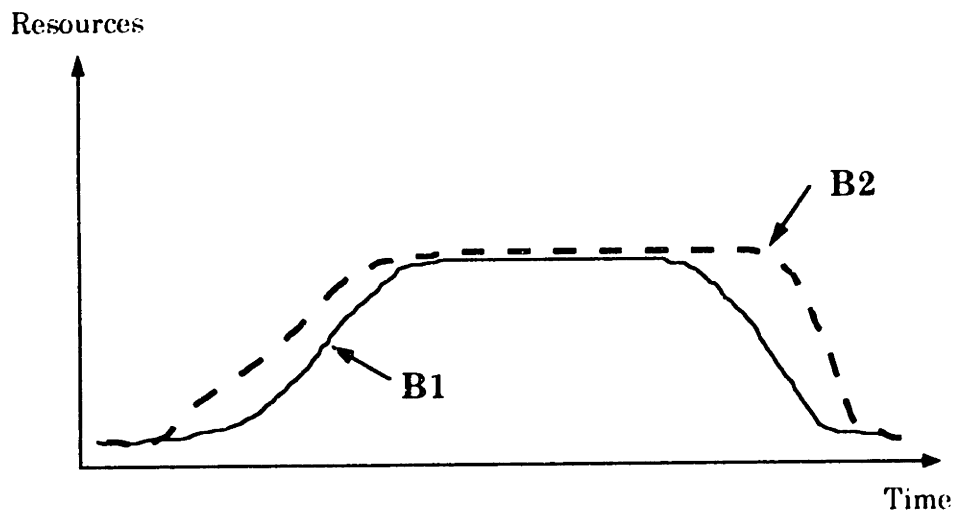


Figure 9 - Comparison of Program B1 and B2

Although both programs took the same amount of time, B2 clearly used more resources. Worse yet, the resources used were the constraint resources, robbing precious capacity away from the firm. Company B did not use TOC in this case, but TOC would have forced the upstream activities to define their output in terms of the downstream impact on the constraint activity. TOC would have clearly helped management understand why waiting for technology to be ready (as defined earlier) instead of wasting valuable constraint resources on rework.. As one frustrated executive in Company B put it, "We've always erred on the side of pushing technology too soon. Just once I'd like to see us push it too late, just so we understand what the other bounds are."

Downstream activities must also play a role in assisting the constraint. The testing activity should first look for ways to reduce test completion time (Testing throughput) to provide timely feedback to Design Engineering. Secondly, Testing should review its own capacity relative to Design. Testing should have enough overcapacity to enable Design Engineering to catch up with design changes required for unforeseen events. A tradeoff must be

made, however, between the cost of increasing testing capacity and the time it takes for Design Engineering to complete their work.

Company A conducted a TOC pilot on one of their test activities. This test activity had always been measured on performance to budget, and had been a strong performer based on that measure. However, testing seemed to drag on for a long time, and the design activities were finding it difficult to get the valuable testing information they needed before the next prototype level design was due to be completed. A small, crossfunctional team was established to conduct the pilot. The team determined the following measures:

- **Throughput:** Completed tests.
- **Productivity:** Throughput / Operating Expense
- **Test Cycle Effectiveness:** Ideal Test Time / Actual Test Time
- **Schedule Adherence:** Percentage of Vehicles Completed on Time

Use of these and other lower level TOC measures, coupled with the Five Step methodology, significantly reduced the time required to complete testing, with a 47% reduction in the first nine months of the pilot. Curiously, budget measures were continued during this process, and in spite of the tremendous increase in efficiency (and more importantly the quick feedback to design activities), the test activity was being criticized for being 5% over budget. Realistically, the 5% can be attributed to merit increases. The moral of the story is that the measures must be bought into by management if they are to be effective.

Other downstream activities need to take steps similar to Testing to improve the throughput of the constraint activity. In some cases, it is merely serving on the design team early in the process to provide input and prevent

late changes to accommodate the downstream activity's function, e.g., manufacturing and assembly.

## **6.4 - Elevate the Constraint**

How does one increase the capacity of the constraint activity in the long run? The obvious answer for the product development organization is to add resources, but that is not always possible nor desirable. Adding resources not only adds costs, or OE in TOC terminology, but it also adds time. Time, as mentioned earlier, is the enemy, or a possible competitive advantage if one can find a way to be fastest. If adding resources is not the answer, then what is?

Some of the remedies are already being pursued, as discussed in Chapter 3. One clear way to reduce the "rust" in the pipeline of the constraint is to eliminate the need for non-value-added work through reengineering or some other value enhancing process. Again, this may not elevate the constraint to the desired level. This hits on a more fundamental issue -- how does one know the desired level? At what point does one stop adding capacity?

Let us review the pipeline from Figure 9. Adding capacity to the pipeline adds OE to the organization, but it provides valuable flexibility for the firm, and more directly, for the constraint activity. One could imagine a situation where capacity is increased in the constraint activity which causes the constraint to move to another activity, and on and on. Adding the additional capacity will increase OE and may slow down the process time. At some point a decision must be made as to whether additional capacity should be added. To answer this question, one must decide where in the organization to strategically place the constraint. Which activity should serve as the pacing activity -- the scarcest and most valuable resources?

For most product development firms, design engineering makes the most sense as the constraint activity. Design engineers provide the core competency for the firm and allow the firm to take technology and customer specifications and turn it into product that generates more money now and in the future -- the goal of the firm. Thus the firm must first decide how much capacity it requires in the design engineering process, find ways to generate the throughput rate with the least amount of "rust" in the pipe, and then start to systematically determine how much overcapacity to have in both the upstream and downstream non-constraint activities. As the world becomes more competitive and firms require more flexibility, the firm that can balance the capacity of both the constraint and non-constraint activities will have a competitive advantage in quickly developing high quality products.

## 6.5 - Common Measures

Managing constraints is only possible by implementing common measures that focus and align the organization toward the common goal. As mentioned in Chapter 4, there are three basic measures for TOC: throughput (T), operating expense (OE), and investment (I). These three measures work for product development organizations as well as manufacturing firms.

OE and I are relatively straightforward measures, requiring only some minor modifications of current financial measures. T is more difficult to understand in a product development firm. Unlike manufacturing firms, where the T is readily visible and easy to measure, T in a PD firm is more elusive, but not as elusive as one might first suspect. Each activity must determine what their T is relative to the firm's T. For a PD firm, T is generated when product is produced. For the Design Engineering activity, T is a drawing (or information in today's electronic drawings) that results in a production part. Design Engineering should therefore measure its T in terms of production level drawings that actually get produced and sold, thus

prototype drawings that are for test only eat up the T of the activity and must be done only with the most deliberate planning.

How would other activities in a PD firm define their T? Let us look at Advanced Engineering and Planning. These activities provide technology and customer specifications that the design engineers turn into product. T for these activities can be measured in terms of technologies and customer specifications that require no changes to implement. In other words, the technology implementation uncovers no major issues that were not addressed in the advanced activity, and the customer specifications do not change because planning did not properly address the right market or customer wants. This is not to say that technology and customer specifications should be perfect -- perfection takes too much time and is not possible given today's uncertainties. Rather, Advanced Engineering and Planning must, in conjunction with their downstream customer Design Engineering, strike a balance that provides high quality products in the shortest time.

Downstream non-constraint activities should likewise define their T in terms of the final product, being mindful of their impact on the constraint activity. For example, Testing T would include the tests that verified production parts, and Testing should be looking for ways to improve their T, especially if it can be done in a shorter time period. Lab testing, accelerated vehicle testing, and computer simulation are all tools that Testing could use to improve T. Other downstream activities should likewise define their T in terms of the final product, keeping the constraint activity in mind.

Table 12 provides a comparison of PD measures before and after implementation of TOC. As discussed earlier, it is important to notice two particular characteristics. First, that TOC does not replace all the measures that have previously been developed. In many cases, if no constraint is active, TOC provides no additional insight to current measures. However, with today's resources being squeezed, constraints are becoming more and more noticeable. Second, TOC measures complement current measures by

changing the focus from cost to throughput, and providing the additional perspective of capacity.

<b>Category</b>	<b>PD-Level Measures</b>	<b>TOC Measures</b>
Quality	Reliability Schedule Performance Engineering Changes Prototype Defect Rate Functional Performance Market Research Results	Reliability Schedule Adherence Engineering Effectiveness Prototype Defect Rate Functional Performance Market Research Results
Financial	Annual Budget Program Engineering Costs Product Costs Manufacturing Costs	Throughput Operating Expense + TVE Product Costs Manufacturing Cost
Internal Capabilities	New Product Cycle Time Productivity Technology Patents R&D Effectiveness First-in-Class	New Product Cycle Time Productivity (def. by Tput) Technology Patents Engineering Effectiveness and Efficiency First-in-Class
People	Employee Satisfaction Employee Empowerment Training Skills Matrix	Employee Satisfaction Employee Empowerment Training Skills Matrix

**Table 12 - TOC Measures Versus Current PD Measures**



## **Chapter 7 - Conclusions and Recommendation**

Theory of Constraints is based on two foundation principles: viewing the organization through the eyes of throughput and developing commonly derived performance measures. Use of this methodology has proved successful in manufacturing and can be applied to product development as shown in this report. TOC provides a third dimension (capacity) to current financial and market measures, giving product development firms a potential competitive advantage. Another compelling reason to apply TOC is that it embodies the success factors for good measures. This section will elaborate on those success factors and how TOC has those factors built in.

### **7.1 - Start with Strategy**

Successful measures are a means to drive behavior and implement strategy. If the measures do not tie to the strategy, the strategy is doomed to failure. The best strategy in the world is useless if not implemented properly, and measures are the cornerstone for good implementation.

For a product development activity, the strategy going into the 21st century will be to create a fast process that can quickly adapt and integrate changing technologies into a product that satisfies global customers at a reasonable price. That strategy requires an increase in the throughput of the product development process without an increase in resources. The increase is only possible with some form of reengineering, and a change in the performance measures to drive behavior, and, more importantly, to align the organization toward a common goal.

Long term strategy requires some stability and thus the goal of the company must have sustainability as the company moves forward. TOC provides an unchanging goal: Make more money now and in the future.

This stability keeps the organization focused on more than short term profits, and allows the strategy to become a key part of the organization's culture. The culture becomes part of the long term sustainability of the strategy.

## **7.2 - "Keep It Simple, Stupid"**

Focusing on too many things at one time leads one to lose focus altogether. With today's growing capabilities in information systems, the tendency is to overwhelm managers with information that confuses rather than provides insight. Detailed metrics can drive micromanagement of the PD process, slowing it down and disempowering employees.

TOC provides a single focus, throughput, making it easier for those in the PD process to make the right tradeoff decisions. TOC can easily be adapted to the current measures used for PD as it complements the traditional measures by providing an additional perspective -- capacity, or resources. Since TOC is not a revolution, implementation and training are easier than a complete overhaul of the current measurement system.

## **7.3 - Balanced Measures**

Measures must provide a balanced view of the organization's performance, including financial and non-financial as well as short-term and long-term measures. The measures should include quality, financial, internal capability, and people measures that keep management attention focused on core capabilities.

The balance of performance requires some tradeoffs. These tradeoffs need to be made in light of what is considered to be the driving force for the company. For product development firms in today's competitive environment, throughput is the means of achieving competitive advantage.

## **7.4 - Training and Communication**

Good strategy requires extensive communication to the organization in order to provide alignment and buy-in. Measures keep that alignment going over time, and thus, communication and training of all employees in the measures and their use is necessary for success. The level and intensity of training will vary from department-to-department and through various levels of the organization.

TOC provides relatively simple measures that complement current measures, thus training for the "mechanics" of TOC measures is comparatively straightforward.

## **7.5 - Pilot Programs**

Successful implementation of new measures is best achieved by establishing a series of pilot programs that prove out the concepts, adapt them to the specific requirements of the activity, and build successes that encourage other activities to adopt them. As with the firms interviewed, management commitment is key to successful pilots, by providing protection, support, and guidance to the team. Once fully supported, the resultant laboratory environment allows teams to experiment with what works best, with minimal risk to the organization as a whole.

## **7.6 - Shortfalls of TOC**

As with any new system of measures, there are no magic formulas, and one system's advantages can be offset by its disadvantages. For TOC, one warning is to be wary of the means of achieving the goal. The means of achieving the goal, e.g., quality, market surveys, diversification, etc., all

change over time. A firm must provide a mechanism for sensing changes in means that will provide a competitive advantage for the firm.

A second warning is that TOC requires a paradigm shift from the current cost view of measures. This shift can be overcome with some of the training and communications mentioned earlier, but real success will only come with strong management commitment and persistence.

Finally, TOC does not provide a cookbook of improvement actions that one can take to improve throughput. There are no tools that one can use to ensure continuous improvement. Managers must rely on their experience and tenacity to make improvements on an ongoing basis. TOC is still relatively new, so tools may become available as more and more application experience is gained.

## **7.7 - Recommendation**

Product development activities that require high-quality products which include the latest technology, driven by customer needs, and developed in ever-shrinking timeframes would benefit significantly from application of TOC measures to their performance process. TOC provides a means of implementing common measures and focusing the organization on the goal: To make more money now and in the future. TOC has been successfully applied in manufacturing, providing sufficient experience and insight on which to build from and implement in product development organizations. TOC could provide a significant competitive advantage in the number of products that a firm can produce, and on the time it takes to produce that product -- all without increases in the current level of resources.

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