International Journal of Production Research,
Vol. 44, No. 10, 15 May 2006, 1863–1880

Implementing theory of constraints in a traditional Japanese manufacturing environment: the case of Hitachi Tool Engineering

M. UMBLE*†, E. UMBLE† and S. MURAKAMI‡

†Baylor University, Department of Management, One Bear Place, PO Box 98006, Baylor University, Waco, TX 76798-8006, USA
‡HUSEI University, Japan Goal System Consultants, Inc, NK-1 Building 1-17, Kanda-Nishikicho Chiyoda, Tokyo, 101-0054, Japan

(*Received May 2005*)

This research presents a case study of a virtual 'textbook' application of the theory of constraints (TOC) in a Japanese tool manufacturing company. Hitachi Tool Engineering uses state-of-the-art technology to design and manufacture cutting tools known as End-mills. The plant described in this study is a classic V-plant and exhibited all of the standard problems of a traditionally managed V-plant, existing within the unique framework of Japanese work culture. Plant management applied the five focusing steps and used the operations strategy tools, including drum-buffer-rope and buffer management, to improve the system. Following the approach recommended by Eli Goldratt, the thinking process tools of current reality tree and evaporating clouds were used to help identify and resolve problems when the implementation encountered major obstacles. While the implementation was a huge success, the devastating effect of a core problem being left unresolved is well documented. The implementation generated significant improvements in work-in-process inventory, production lead time, on-time delivery, productive capacity, inventory turnover, product quality, sales volume, and profitability. Moreover, management has extended the introduction of TOC to the non-manufacturing functions and TOC is becoming the common company culture that bridges four culturally diverse manufacturing plants.

Keywords: Theory of constraints; Throughput accounting; Thinking processes; Japanese manufacturing

1. Introduction

The literature describes numerous applications of theory of constraints (TOC) principles in both manufacturing and non-manufacturing environments. The vast majority of these reported applications have occurred in the USA and most of the remainder have occurred in countries dominated by Western culture and business practices. In fact, Mabin and Balderstone (2000) describe 82 TOC case applications reported in the literature. Of these reported cases, 71 involved US firms, while 10 involved firms from Canada, the UK, Israel, and New Zealand. One case involves

*Corresponding author. Email: mike_umble@baylor.edu

International Journal of Production Research
ISSN 0020–7543 print/ISSN 1366–588X online © 2006 Taylor & Francis
http://www.tandf.co.uk/journals
DOI: 10.1080/00207540500381393

a Malaysian steel roll forming plant. The TOC-Goldratt.com web site identifies companies that have undergone TOC-based implementations who are willing to publicly share their results. This site currently contains 81 references, 62 of which involve US firms. The remaining 19 firms are from the UK, Ireland, Germany, Canada, Mexico, South Africa, Israel, Venezuela, Uruguay, and India. With few exceptions (e.g. Chaudhari and Mukhopadhyay 2003), the literature is clearly lacking in case studies of TOC applications in Asian organisations, and as far as the authors can ascertain, contains no case studies of TOC applications in Japanese firms.

Western firms have modified and adopted many proven manufacturing techniques and management philosophies from Japanese firms, and the cultural differences have sometimes hindered the successful implementation of Japanese-based improvement methodologies in Western firms. The natural question then is: 'Can the TOC management philosophy which has been widely and successfully applied in Western firms overcome the cultural barriers and be successfully implemented in a traditional Japanese firm?'

2. The theory of constraints approach

The theory of constraints (TOC) is composed of a considerable body of knowledge which may be summarized as including operations strategy tools, performance measurement systems, and thinking process tools (Cox and Spencer 1998, Gupta 2003). The operations strategy tools include the five focusing steps (see below), VAT analysis, and specific applications such as production management (drum-buffer-rope, buffer management, batching, and product mix analysis), distribution management, and project management. TOC performance measurement systems are based on the principles of throughput accounting (Smith 2000) which are incorporated through the implementation of concepts such as throughput, inventory, operating expense, throughput dollar days, and inventory dollar days. The thinking process tools include the various tree diagrams, evaporating clouds, and audit processes/guidelines such as the categories of legitimate reservation and the layers of resistance (Dettmer 1998, Scheinkopf 1999, Smith 2000).

The literature contains numerous case studies where various TOC elements are applied in a wide variety of combinations (Mabin and Balderstone 2000). However, in a recent presentation Goldratt (2004), emphasised that the basic TOC approach is embodied in the five focusing steps:

1. Identify the system's constraint(s).
2. Decide how to exploit the system's constraint.
3. Subordinate everything else to the above decisions.
4. Elevate the system's constraint.
5. If a constraint is broken, go back to step 1.

More specifically, these five focusing steps are utilised to guide the improvement process, incorporating the TOC knowledge embodied in VAT classification theory, the specific applications, and the throughput accounting principles as appropriate. In many cases, this approach is sufficient to generate significant system-wide improvements. However, Goldratt further suggests that when the five focusing steps process gets bogged down, then the various thinking process tools should be used. These tools can be utilised to describe the cause and effect relationships that characterise a system, identify core problems, identify and resolve core conflicts, develop a strategic plan, identify and overcome obstacles to the implementation of the strategic plan, overcome resistance to change, and successfully communicate any of the above concepts to key individuals.

This research documents the specific TOC tools and techniques utilised in a near 'textbook' implementation of TOC in a traditional Japanese tool manufacturer. However, two things make this case study unique in the literature.

1. The nature of the cultural obstacles encountered and the subsequent steps taken to successfully overcome these obstacles.
2. The strategic use of TOC techniques to focus the workers' substantial knowledge and capabilities to generate significant process improvements.

3. Overview of the Yasu plant, Hitachi Tool Engineering Ltd.

Hitachi Tool Engineering Ltd. (HTE), originally founded in 1933, is the end product of a merger in 1987 and today has about 1100 employees. HTE is listed in the first section of the Tokyo and Osaka Stock Exchange, with company headquarters located in Koto-Ku, Tokyo and four plants located in the cities of Yasu, Narita, Uozu, and Nakatsu. The Narita and Yasu plants are the two main production facilities, accounting for 85% of total company production. This analysis focuses primarily on the Yasu plant. As the only comprehensive tool manufacturer in the Hitachi group, HTE designs and manufactures tools utilising emerging materials research and state-of-the art engineering. Since winning the Nikkan Kogyo Shimbun Best 10 New Product Prize in 1988, the company has solidified its lofty industry reputation and position. The development technology used to create the Yasu plant's family of products—the 'End-mill'—is ranked among the world's best and leads the tool manufacturing industry.

At first glance, an End-mill may not be easily distinguishable from a drill. While a drill is a tool used for boring a hole in metal, an End-mill is a cutting tool for scraping or grooving the surface or side face of metal—a sort of planer for metal. End-mills are mainly used in the processing of metal moulds for plastic products or for metal pressing. Two kinds of materials are currently used to produce End-mills. The older, more conventional technology uses high-speed steel, which adds carbon, tungsten, and chromium to iron. A more recent and rapidly expanding technology utilises a carbide alloy which is made by fire-hardening very hard tungsten carbide and the powder of cobalt or nickel. Since a diamond is the only natural mineral harder than carbide, this yields a harder and stronger cutting edge for the End-mills.

The Yasu plant produces somewhere between 12,000 to 20,000 distinct SKUs in a typical month each varying according to specific materials, configurations, and diameters. Like many industries, new product development is a source of competitive advantage in the cutting tool market. The competitive environment in the carbide tool market is particularly tough. Competitors typically launch a new product family about every six months. The availability of technologically superior carbide alloy cutting tools has enabled customers to develop more efficient production methods to produce high-precision metal moulds more rapidly. This only increases customers' demand for the development of newer tools designed with superior materials and technologies. The downside of new product development for the manufacturers is that every time a new product family with improved cutting tool quality and durability is launched, the older versions of the tools become obsolete. This, in turn, forces the manufacturer to heavily discount the older tools or to discard and write them off.

The Yasu plant is a classic V plant as described in the TOC literature (Umble and Srikanth 1990, Umble 1992, Umble and Srikanth 1997). V plants are characterised by divergence points in the production process, where a single material at one stage of processing can be transformed into a number of distinctly different products at the next stage. The three primary characteristics of V plants are:

1. The number of end items is large compared to the number of raw materials.
2. End items in the plant are generally produced in essentially the same way.
3. The equipment is generally capital intensive and highly specialised.

All of these characteristics are found in the Yasu plant. The raw materials used are very few in number. The general production process includes grinding of the edge of material, processing of the gullet, and processing of the tip of the edge of the blade. By the time materials are processed through the various processing steps, the resultant divergent combinations create the possibility of thousands of distinct end products. The Yasu plant has four processing lines—small diameter carbide combined grinding line, medium/large carbide normal grinding line, high speed steel small diameters line, and high speed steel medium/large diameters line. Each line has its own specialised equipment designed to be used for the specified product families. And the equipment in each line is laid out and sequenced according to the ideal processing requirements of the designated product families—even though the carbide lines may also be used to produce items from the high speed steel product families.

4. The Yasu plant prior to TOC implementation

The Yasu plant is primarily a make-to-stock operation with roughly 70% of items sold from finished goods inventory. Historically, the plant had been plagued by a high frequency of stockouts, delayed deliveries, high levels of inventory, and high levels of product obsolescence. In addition, the plant's production (replenishment) lead time was quite long—averaging about two months. Managers had been unsuccessful in resolving the seeming contradiction of high stockout frequency despite holding high levels of inventory. The stockout and delivery problems were jeopardising customer service and the inventory and obsolescence problems were increasing operating costs. The plant managers knew that these problems must be successfully resolved in order to ensure the plant's long-term survival. But the Yasu plant managers had made numerous attempts to address the stockout and delivery delay problems. They all ended in failure. The prevailing attitude of the production staff seemed to be that these problems could not be resolved.

In 2000, an improvement initiative led by deputy plant manager Akira Kosugi centred on a small lot production philosophy designed to reduce stockouts by increasing changeovers and reducing lot sizes. After starting the improvement initiative, a constant stream of complaints came from the production managers. Production efficiencies were dropping and, contrary to expectations, production lead times were increasing. Moreover, the plant's monthly shipment figures came in way under target. After two months, the initiative was dropped and the production lot sizes were reinstated to their original levels.

Makoto Fujii, chief of the quality assurance centre, clarified the situation by describing the work rules and informal shop priorities that existed at that time throughout the plant.

> The most important work of mine was to achieve the production value target as well as to inspect products. How could we secure the daily production value? The final process takes control of the output of the plant. An inspector routinely went to the site to pick up the products whose value was high. At the end of a month, he went to the site with a calculator and picked up products whose production values were high to secure the production value. At that time, there was work in process for 70 days in the processes and they made a habit of processing the largest lot preferentially in order to increase the production value in each process.

Production value refers to the accounting value of the products processed during a given time period. The practice of picking up products refers to the process of selecting products (with the highest earned production value) for final processing from among the available partially processed work-in-process inventory. Mr Fujii's description clearly indicates how both plant and individual departmental performance are based on the accounting measure of production value which is designed to achieve local optimization and to secure apparent earnings. One result of this approach is the existence of the well-known 'end-of-the-month' syndrome (Umble and Srikanth 1990). Unfortunately, this approach also did nothing to reduce stockouts, improve delivery performance, increase throughput, reduce inventory, or cut operating expense.

5. The TOC initiative

In June of 2000, Shigeaki Sato, the plant manager, along with Akira Kosugi, agreed on the necessity of a new course of action. Although the Yasu plant had been profitable, that performance could be largely attributable to their technological competitiveness and substantial growth of the market for carbide End-mills. They could not reasonably expect both of those conditions to continue indefinitely.

Sato and Kosugi investigated TOC and jointly decided the TOC approach was well suited to improve the Yasu plant's performance and to ensure future profitability. They selected Akihiko Niimi, a highly respected production chief to champion the TOC initiative. The implementation at Yasu would follow the five focusing steps (Goldratt 1986) and utilise the drum-buffer-rope and buffer management techniques (Goldratt 1990, Ronen and Schragenheim 1990, Umble and Srikanth 1990). Prior to the implementation, a series of introductory TOC education and training sessions were conducted to develop a good working understanding of TOC, how it applied to the Yasu processes, and how it could be implemented at the Yasu plant. These educational sessions emphasised the importance of identifying the system's constraint, applying the five steps, and implementing the logistical processes of drum-buffer-rope.

After two months, the training was proceeding smoothly enough, but Mr Niimi was concerned that the training sessions were not generating the necessary consensus, commitment, and energy required to drive a significant change initiative. This lack of consensus and commitment presented a huge cultural obstacle, which if not immediately addressed and eliminated, would likely scuttle the entire initiative. Therefore, it was decided that teams composed of all the involved staff and workers would use the thinking processes to help develop the necessary consensus.

Recent research illustrates how the thinking processes can be applied to generalised problems (e.g. Smith and Pretorius 2003) and to specific organisations (e.g. Chaudhari and Mukhopadhyay 2003, Scoggin *et al.* 2003). At Yasu, the thinking process was viewed as a methodology to

(i) carefully observe the whole system;
(ii) slowly and carefully figure out the structure of the system and the observed problems;
(iii) determine the appropriate change and reform measures to significantly improve the whole system with the least amount of resources.

To carry out this process, over the course of the next month, teams worked to develop a current reality tree (CRT). This exercise provided the structure for numerous lively discussions which uncovered many critical cause/effect relationships throughout the facility, and laid the foundation for consensus as to the nature of the core problem as well as the direction of the solution.

5.1 *The Yasu plant current reality tree*

The construction of the CRT begins with a list of undesirable effects (UDEs), and at Yasu included:

- finished goods shortages are common,
- finished-goods and work-in-process inventory levels are higher than necessary,
- replenishment lead times are longer than necessary,
- significant quantities of product becomes obsolete,
- costs are excessively high,
- some sales are lost,
- future sales volume is at risk, and
- current and future profit is lower than expected.

Using cause and effect logic and the categories of legitimate reservation, the CRT which was developed indicated that the core problem was plant and departmental performance at Yasu is primarily determined by production value. Notice that the core problem identified here is a policy which determines how both plant and departmental performance is measured. This performance measure directly influences people and generates dysfunctional behaviours that adversely impacts overall plant performance. The UDEs, core problem, and the cause/effect relationships are illustrated in the CRT shown in figure 1.

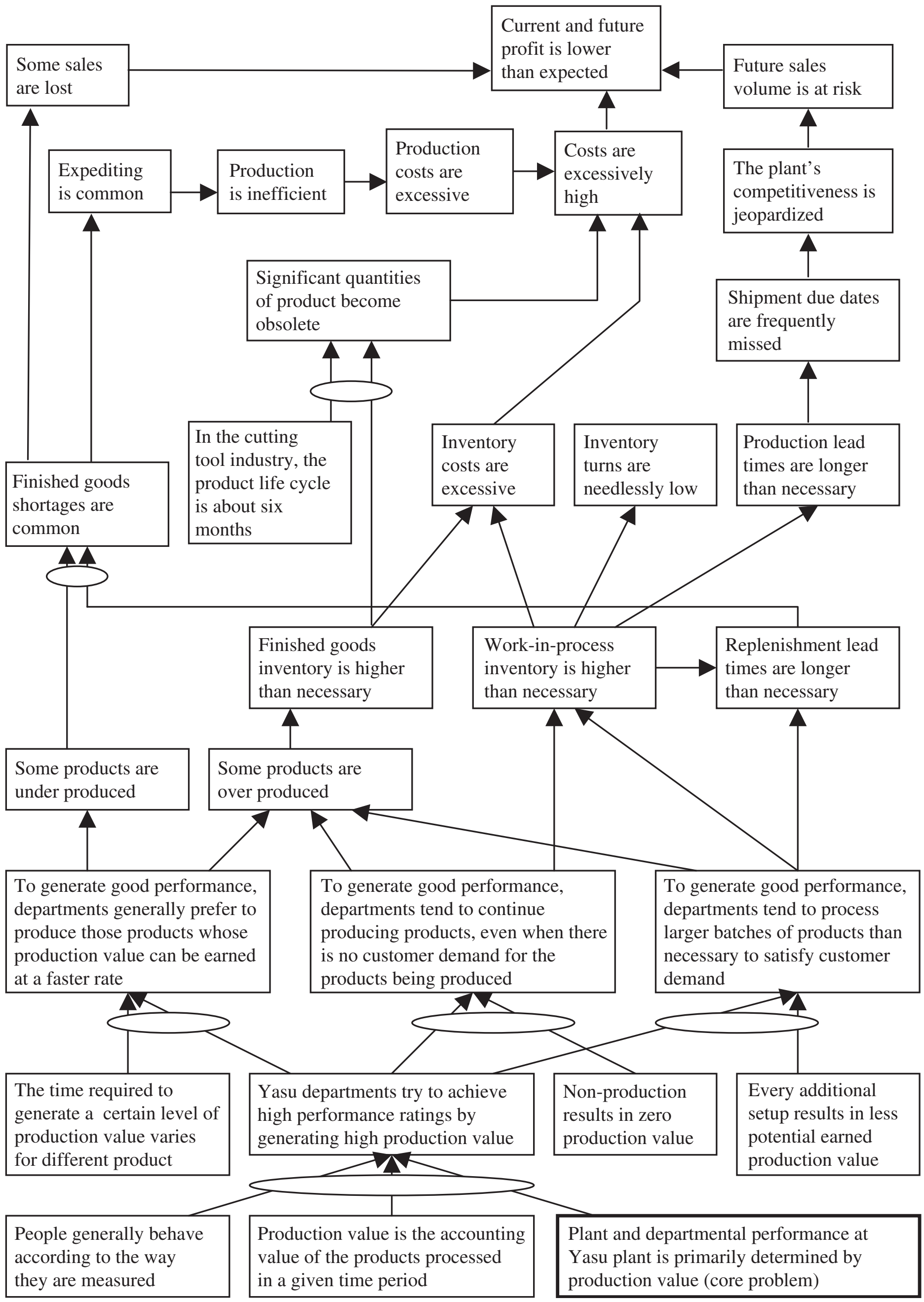

Figure 1. Current reality tree for the Yasu plant.

The statements in figure 1 are read as 'if . . . , then' statements where the statement at the base of an arrow is the 'if' (or cause) statement and the statement at the tip of an arrow is the 'then' (or effect) statement. The elliptical shapes in figure 1 are called 'bananas' in TOC speak and represent 'logical and' connectors which means that any multiple causes that are connected by the banana to the effect must all exist in order for the effect to exist. The reverse is also true—if any of the connected causes are eliminated, then the effect will not occur.

By examining figure 1, it should be clear that if the core problem of using production value to measure performance is successfully resolved, each of the previously identified undesirable effects should be significantly improved or eliminated. The meaning of core problem is that if this issue is successfully resolved, then overall plant performance should improve. On the other hand, attempts to resolve the undesirable effects by making quality improvements, installing better information systems, cutting batch sizes, etc., without addressing the core problem, are doomed to fail.

5.2 *Implementing the first three focusing steps*

By September of 2000, the initial educational and training sessions had been conducted. The exercise to develop the CRT had generated the necessary consensus among the production staff and workers that the systematic evaluation of plant and departmental performance through the production value mechanism was the plant's core problem. The direction of the solution was widely accepted and the implementation was ready to commence. Management thought that they could sufficiently cope with the core problem by following the five focusing steps and implementing a new logistical system with its own set of operating rules and procedures. The following subsections describe the implementation of the first three focusing steps. However, it will become clear that management underestimated the insidious nature and power of a core problem left unresolved.

5.2.1 Step 1: Identify the system's constraint. The first step was to find the primary constraint for the Yasu plant. To do this, it was decided to select one of the four product lines—the high speed steel small diameter line—to serve as a model. (The implementation activities were conducted on this line first and later systematically implemented on the other three lines.) The product flow for the high speed steel small diameter line was specified and information on the theoretical and actual processing capability of the equipment, the work load status, and the work in process status collected. A variety of inaccuracies in the data made the identification of a bottleneck resource difficult. But it was eventually concluded that the resource responsible for grooving the End-mills at a slant and attaching the end cutting edge was the bottleneck, since it appeared to be the only resource which had insufficient capacity relative to its work load. Follow-up discussions with the production floor workers and supervisors confirmed the hypothesis that grooving the End-mills and attaching the end cutting edge was indeed the bottleneck.

5.2.2 Step 2: Exploit the system's constraint. After identifying the grooving and attaching process as the system's bottleneck, the next step was to ensure that this resource was utilised to its full available capacity. However, management was careful to exploit only the bottleneck equipment, not the workers. Management and team leaders related to the workers the importance of their work and emphasised the need for them to 'work lively' and take ownership of the process of improvement.

The workers enthusiastically responded to the challenge and committed themselves to keeping the equipment fully utilised.

Work sampling was used to scrutinise the existing work procedures at the bottleneck process. This analysis revealed a number of inefficiencies which were quickly remedied by modifying existing work procedures and workers schedules. As a result, within a short period of time, the processing capability of the bottleneck was substantially improved. The work sampling analysis also revealed that the setup time required for changeovers was excessively long, so a renewed importance was placed on set-up reduction activities.

5.2.3 Step 3: Subordinate everything else to the constraint. This step requires that all operating rules and procedures be set so as to fully support the optimum performance of the bottleneck process and the overall system. This subordination is designed to result in the total synchronization of all non-bottleneck resources with the bottleneck and also to synchronize the material release schedule with the production pace and schedule of the bottleneck.

A rudimentary drum-buffer-rope system was soon established in the Yasu plant to facilitate the subordination step. Specifically, in order to ensure that the bottleneck has sufficient materials to process, a buffer consisting of three days worth of bottleneck production was established prior to the bottleneck operation. This constraint buffer was implemented by utilising a shelf system, where the required materials for one day's worth of production was set separately on each of three shelves. In addition, an operating rule was established that material inputs into the system should proceed according to the general production speed of the bottleneck. Finally, each of the non-bottleneck processes was asked to process materials on a first-in, first-out basis.

5.3 *The first crisis*

To facilitate the smooth implementation of TOC, management decided to conduct two-day workshops every month. The purpose of these workshops was for leaders and team members to share the progress of activities taking place during the previous month, identify emerging problems, develop solutions to remedy any identified problems, determine future implementation activities, and design implementation strategies.

It was nearly three months after the initiation of TOC activities in the plant when Yuji Mori, the leader of the high speed steel small diameter line, encountered the first critical obstacle which threatened to derail the whole implementation. Data which had been collected from the various processes in the high speed steel line indicated that the amount of work-in-process inventory in the system was not being reduced as planned. The various planners, leaders, and work teams had all agreed about the need to synchronize all work and material inputs to the capability of the bottleneck process. The analysis indicated that material inputs were, in fact, being released into the system according to the production capability of the bottleneck. However, all that did was maintain the level of work-in-process (WIP) inventory already in the system, which was quite excessive.

Clearly, the only way to reduce the WIP was to drain the inventory out of the system by restricting the material input to less than the production capability of the

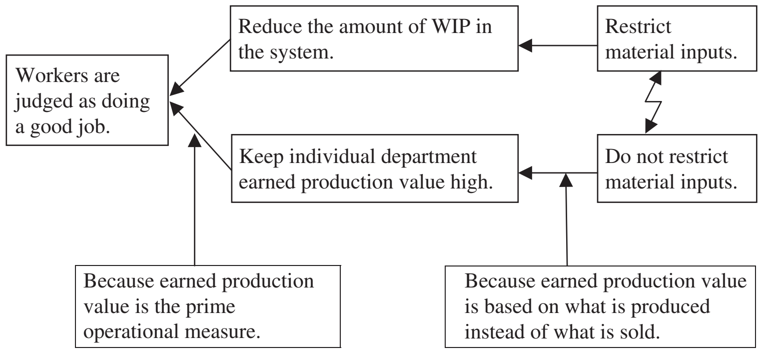

Figure 2. Evaporating cloud describing the material input conflict.

bottleneck. But this did not happen! Why not? There were many older, skilled workers in the work force who had learned over the years how their performance would be evaluated by the company. The prevailing sentiment about significantly reducing WIP inventory and shortening lead time among these workers was clearly expressed by one of the longer tenured workers who declared, 'it is (an) absolutely unreasonable goal'.

The TOC thinking process tool known as the evaporating cloud reveals that the workers were stuck on the horns of a dilemma. Appropriately, the objective for workers in the high speed steel line was to be judged as doing a good job. On the one hand, in order to do a good job required that they should strive to reduce the amount of WIP inventory in the system, and in order to reduce the amount of inventory in the system, the release of material inputs must be restricted. On the other hand, in order to be judged as doing a good job the workers must keep their individual departments' earned production value high (because this is the primary performance measure used by the company), and in order to keep earned production value high, the release of material inputs must not be restricted. This cloud and two critical assumptions are shown in figure 2.

Each of the five pairs of statements connected by arrows has at least one assumption which logically ties the two statements together. To resolve the dilemma, the logical connection between at least one pair of statements must be broken. This is done by revealing a connecting assumption which can be invalidated.

This cloud reveals the pervasive power of the core problem (plant and departmental performance is primarily determined by earned production value). Even though taking the steps necessary to reduce the WIP was understood by the workers as the right thing, many years of experience conditioned them to resist operating rules that would reduce earned production value. You can ask workers to do the right things for the good of the company, but you should not ask them to cut their own throats to do it.

The best way to resolve this dilemma would be to eliminate earned production value as the primary way of evaluating performance, thus removing the primary incentive for workers to release excess material inputs. But Mr Mori did not have the authority to change the performance measure.

However, encouraged by the team leaders and a TOC consultant who was working with the plant, Mr Mori became convinced that he must take decisive action. Given the excessive amounts of WIP already in the system, he decided to call for a temporary halt to the release of all material inputs for one week! Mr Mori and the high speed steel team soon realised that using lead time offsetting to determine when to release materials was flawed because standard lead times were too long. These long lead times became a self-fulfilling prophesy that ensured large amounts of work in process and long lead times. Thus, the standard lead times used to determine the timing of the input materials were reduced. It was also decided that instead of releasing large quantities of materials at the same time (the previous practice) only one day's worth of material would be released each day. The immediate result of these changes was that the WIP inventory decreased sharply and lead time was proportionately shortened by the next monthly workshop, while maintaining the same level of throughput.

5.4 *Elevate the system's constraint*

The two-day workshops that were conducted every month were voluntary and highly interactive. This structure resulted in active learning from others' experiences, changing workers' attitude from passive to participatory, and improving organisational effectiveness through increased understanding of the system's interdependencies and dynamics. Once the bottleneck resource had been identified, many of the discussions focused on how to elevate the performance of the bottleneck.

One major source of improvement involved the reduction of set-up times at the bottleneck. Since a large variety of products are processed on each of the different lines in the Yasu plant, numerous changeovers are continuously required. If relatively small process batches and high productivity are both to be achieved, then fast set-up times are indispensable. Worker teams divided the set-up activities into off-line and on-line activities and carefully scrutinised ways to reduce the amount of on-line setup time required. Worker teams eventually succeeded in reducing the on-line set-up times at bottleneck resources on all of the processing lines by at least 50%. On one line, the on-line set-up time was cut by a remarkable 90%.

Another major source of improvement focused on the fact that much of the equipment utilised in the plant was quite old and subject to breakdowns and defect-generating malfunctions. In some cases, it was determined that the best course of action was to purchase new equipment, which quickly paid for itself at the bottleneck resources. In other cases, preventive maintenance efforts focused on the bottleneck resource also generated handsome returns in the form of creating additional effective capacity, especially capacity that generated higher quality products.

6. Implementing system-wide improvements

Numerous sources in the literature describe how TOC principles can be used to focus improvement efforts for maximum benefit (for example, Chakravorty and Atwater 1994, Chakravorty and Atwater 1998, Umble and Srikanth, 1990). Following standard TOC procedure, it was easy for team leaders to decide that improvements designed to enhance bottleneck performance should receive top priority. But how should the priorities for all other activities be determined?

In most Japanese manufacturing plants, workers are generally well trained and quite proficient at reducing variability, but not as well versed in how to focus their efforts for maximum impact. The lively discussions in the monthly workshops generated numerous potential improvement activities in addition to those carried out at the bottleneck. However, following TOC principles helped the teams focus on those activities which held the greatest promise for improving system performance.

Buffer management (Goldratt 1990, Schragenheim and Ronen 1991) provided the necessary focus for directing many of the improvement efforts. Once the basic drum-buffer-rope system was in place, then buffer management controls were established. One control mechanism was to determine whether the original three-day buffer was appropriate. By visually monitoring and manually analysing the buffer, the size of the buffer was adjusted so that it could perform its function of protecting the bottleneck with a minimum amount of inventory. Another control mechanism was to monitor the arrival status of materials to the buffer. When materials are sufficiently late to the buffer, this triggers an effort to track down and identify the source of the problem. Identifying the major sources of problems affecting the buffer led to the development of a prioritised action list for improvements, including such items as setup reduction, preventive maintenance, and removing inappropriate operating rules.

6.1 *Ensuring proper product flow*

One of the major process improvement efforts focused on the enforcement of a first-in, first-out rule which helps maintain proper product flow in a drum-buffer-rope system. Shop floor control data indicated that instead of following a first-in, first-out rule, the workers in each process tended to 'cherry pick' the lots of materials they would process, and typically chose those products which would generate the highest earned production value for their particular process. (Once again, the effects of the core problem are evident.) The team leaders, including Mr Niimi, determined that such practices caused significant distortions to the desired product flow and had to be eliminated. Thus, they issued a 'compliance with first-in, first-out' edict which became the slogan for production control.

6.2 *Quality improvement initiative*

Another major improvement effort involved quality issues. Prior to the implementation of TOC, the Yasu plant experienced product quality defects which was costing several million yen per month. Moreover, in an attempt to sort out the defective material, quality inspections costing lots of time and money were conducted at virtually every step of the various processes. Nevertheless, significant amounts of defective products were slipping past the inspections and were reaching the customer, resulting in numerous customer complaints—which would certainly impact the potential future throughput.

The workshop team leaders decided to address the quality issue and assigned the problem to worker teams to investigate. The causes of defective products were divided into two main categories:

(i) defects caused by careless mistakes or inappropriate work methods and
(ii) defects caused by the functional deterioration of equipment, jigs, and tools.

The worker teams first developed work rules and measures designed to drastically reduce the incidence of careless mistakes. Analysis further revealed that a particularly troubling type of defect occurred when the tip of a processed product was nicked, referred to as 'nicked edge defect'. This type of defect was likely to occur throughout the process, and small nicks in the product were very difficult for workers to see, resulting in defective products slipping through the inspection process. The teams systematically identified the human causes of nicked edge defects in each process and developed procedures to reduce the incidence of defects. For example, in the process which treats the blade edge, the repacking operation was modified so that repacking could be conducted more quickly and without causing defects.

As the human causes of defects were resolved, it became increasingly evident that a significant number of nicked edge defects were generated by causes related to the equipment. For example, one major source of machine-related nicked edge defects was the cutting equipment. Thus, the worker teams devised new procedures for inspecting jigs and maintaining operation standards in this process. By implementing similar measures in each of the processes, nicked edge defects were cut in half in a short period of time. Eventually, the worker teams developed quality improvement measures for additional causes of defects throughout the process.

7. Summary of first year achievements

By September of 2001, significant gains had been achieved in all four of the high speed steel and the carbide lines. The workers had wholeheartedly embraced the TOC philosophy and were working enthusiastically to continue to implement improvements. Setup times had been reduced throughout the plant, improving the product flow through the system, and at the various bottleneck resources, on-line setup times had been cut by more than half. Overall productivity had increased significantly and the Yasu plant was shipping about 20% more product than one year earlier. WIP inventory and lead times had both been reduced by nearly 50%. On-time deliveries had improved substantially. The first-run quality rate increased from 93% to 97%, and the overall loss due to defective products decreased by 50%.

In addition, the information system had been significantly upgraded. Prior to the implementation, there were serious doubts about the credibility of the performance data. But now, materials and products could be continuously tracked and system updates were being made four times a day to allow for almost real time information. This system provided the information necessary for establishing a more sophisticated drum-buffer-rope scheduling system in the second year.

We note that in June of 2001, Shigeaki Sato was transferred to the Narita plant to assume the duties of plant manager of that plant (presumably because of the significant transformation that occurred at the Yasu plant). In turn, Akira Kosugi, the deputy plant manager who had overseen the Yasu TOC implementation was promoted to Yasu plant manager.

8. The second crisis

By the end of 2001, the joyous mood that had developed throughout the plant was disappearing. The worldwide economic recession that was occurring at that time was exacting a heavy toll and the plant's business was quickly declining.

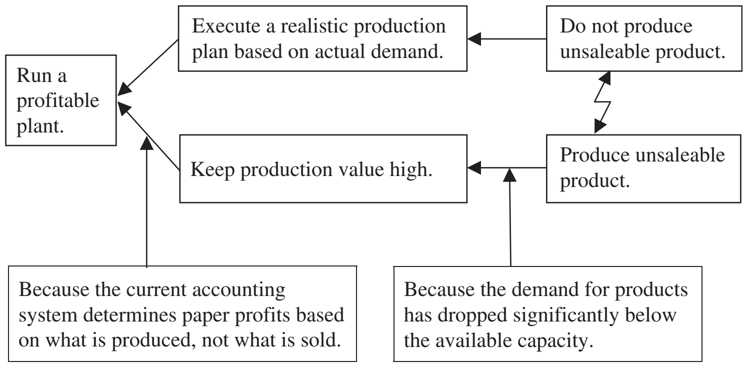

Figure 3. Evaporating cloud describing the production of unsaleable product conflict.

Despite the plant's enhanced competitiveness due to improved product quality and on-time delivery performance, there were simply not enough new orders to utilise all of the plant's hard-earned increased capacity.

At the beginning of the business slowdown, Akihiko Niimi, the production leader who had been selected to champion the TOC implementation, had a tough decision to make. System-wide process improvements were continuing to be implemented, but Niimi now wondered to what purpose? How could he continue to ask his workers to improve productivity when there were not enough orders to be produced and jobs could be lost?

As profits continued to drop because of the lack of orders, Niimi made an anguished decision. In order to protect his workers' jobs, he broke his own rules and decided to start producing product for which there was no current demand. He knew this would unnecessarily inflate WIP inventory and production lead times and would cause finished goods inventories to increase. He also knew that this would keep his workers busy and artificially maintain earned production value. Because of his actions, the apparent profits for the plant increased. But many understood how misleading the paper profits were and also knew that in the long run such actions would lead to disaster.

The team leaders were called to meet and analyse the problem. They all inherently knew the conflict—whether or not to keep producing products for which there is no demand—but initially there was nothing but silence. Finally, an elderly staff member commented that 'profits will drop off if stocks and work-in-process are reduced'. This started an avalanche of discussion.

In order to summarise the arguments presented and clarify the dilemma, an evaporating cloud was constructed (this is shown in figure 3). Essentially, the objective is to run a profitable plant. In order to run a profitable plant, the workers must execute a realistic production plan based on actual demand, and in order to execute a realistic production plan, they must not produce unsaleable product. On the other hand, in order to run a profitable plant, the workers must keep production value high (because the current accounting system calculates 'paper profits' based not on what is sold but what is produced). In order to keep production values high they must produce unsaleable product (because the demand for products has dropped significantly).

Once the cloud was written and the assumptions behind the logical connections were exposed, everybody agreed that all of the pressure to produce more product than could be sold was based on a flawed system of accounting and performance measurement. Responding to the leaders' impassioned plea for a resolution to this conflict, Mr Kosugi announced to all workers that 'from this time . . . one will not be called to account for unachievable production value. Bear in mind that unsaleable product should not be produced'. Instead, performance at the plant level would be based on actual bottom-line profitability, and performance at the individual and departmental level would be based on contribution to meeting the established production plan and operational budgets.

Finally, the core problem had been formally addressed at the plant level and earned production value was no longer to be used to evaluate plant, departmental, or individual performance! Mr Kosugi intuitively knew that it was critical to convince the senior workers of his commitment to eliminating the earned production value trap, because the junior workers would follow the lead of the senior workers. So he visited with all of the senior workers in the plant and discussed the new policy.

9. The process of ongoing improvement

Many additional improvement activities were initiated in the Yasu plant during the second year of the TOC implementation. The more significant activities included the development of a realistic scheduling system designed to increase due date delivery performance, a workspace management activity, and an activity designed to further improve equipment maintenance.

The Yasu plant management and TOC team leaders knew that to enhance their competitiveness in the marketplace they would need to improve their on-time delivery performance. To that end they established 'DD100', which indicated their goal of meeting delivery deadline 100% of the time. This goal became feasible with the development of a more sophisticated drum-buffer-rope scheduling system fed by more accurate capacity and performance data. A necessary condition to achieving this goal was the elimination of the earned production value performance measurement and mentality from the plant environment, which was accomplished. Equally important was the new-found commitment to enforce the necessary synchronisation rules, including rigid control of material inputs according to the market-driven production plan based on bottleneck capacity as well as a first-in, first-out processing rule for all non-bottleneck resources. In addition, the enhanced drum-buffer-rope system increased the benefits from using buffer management to guide the improvement activities.

An initiative referred to as 'My Machine My Space' was created as a way to encourage workers to take personal ownership of, pride in, and responsibility for the general work environment and performance of their work station. The My Machine My Space initiative was supported by the implementation of the 5S programme, which stands for Seiri (sorting out), Seiton (arrangement), Seisou (cleaning), Seiketu (cleanliness) and Shituske (discipline). The 5S programme simply emphasises the necessity of maintaining appropriate work place environment practices. The logic is based on the premise that without the 5S programme in place, it becomes more difficult to carry out necessary activities like efficient equipment changeovers and first-in, first-out processing. The 5S programme was enforced by a group consisting mainly of junior workers who would routinely patrol the production site to evaluate adherence to the 5S principles and provide assistance where needed to help workers upgrade their work station environment.

Prior to the implementation of TOC, there was no organised equipment maintenance programme. However, bottleneck performance analysis and buffer management indicated that equipment in poor operating condition was causing costly equipment downtime and quality problems. In particular, the high speed steel lines contained many older pieces of equipment that were in a state of disrepair. Thus, during the second year of the TOC implementation, a comprehensive equipment maintenance initiative was begun. Vital components of this initiative were a training programme coupled with a change in attitude and capability from 'I produce, you repair' to 'I produce and repair'. This increase in worker ownership and responsibility dovetailed well with the 5S programme. The results from this programme were quickly visible. The amount of lost throughput caused by bottleneck downtime showed significant improvement. Plant wide, work stoppages due to equipment downtime decreased significantly. Moreover, partially due to the repair and replacement of older equipment, product quality continued to improve.

10. Company-wide implementation and results

After the successes at the Yasu plant, Hitachi Tool Engineering became fully committed to TOC and introduced TOC throughout the rest of the company. Shigeaki Sato, who started the TOC initiative at the Yasu plant and became the plant manager at the Narita plant, also initiated the implementation of TOC soon after his arrival at Narita. By February of 2002, the TOC implementation at the Narita plant was fully underway and they soon experienced improvements similar to the Yasu plant. TOC implementations were also initiated at the Nakatsu plant in 2002 and the Uozu plant in 2003. The other plant implementations generally followed the processes used at Yasu but had the advantage of learning from some of the mistakes and problems encountered at the Yasu plant.

Today, the TOC philosophy is found throughout the organisation. Even the non-production activities in HTE now fall under the TOC umbrella. For example, the monthly closing is now calculated by both the conventional accounting and TOC-based throughput accounting methods and the differences are reconciled. Future sales plans are developed through a process which includes the profitability contribution of products based on throughput analysis. In addition, by order of the president of HTE, Makoto Takeuchi, manufacturing budget meetings were discontinued. Mr Takeuchi wanted the company to have 'fruitful meetings leading to the improvement of throughput rather than meetings dedicated to developing and modifying budget plans that would never be achieved'.

Changes in four key performance measures from before the introduction of TOC in 2000 to October 2004 show the degree of improvements at the Yasu plant. Production lead time decreased from 40 to 16 days. Due date performance increased from 40% to 85%. Production capacity (not including new investment) increased by 20%. Inventory turns for all assets increased from 7.02 to 10.17. Although performance improvements at the Uozu plant has lagged behind the other plants, the performance improvements at the Narita and Nakatsu plants are similar to those disclosed for the Yasu plant.

Global economies began to emerge from the worldwide recession in 2003. And HTE—with its improved inventory management, lead time reductions, quality improvements, improved on-time delivery, and productivity gains—was well positioned to dramatically increase sales and profitability. Recently released financial data illustrates the overall gains experienced at HTE. From 2002 to 2004, company sales increased from approximately 15.3 billion Yen to 20 billion Yen. More important, HTE bottom line profitability increased from 921 million Yen in 2002 to over 4 billion Yen in 2004, which was an all-time high. Profit as a percentage of sales exceeded 20% in 2004. Moreover, HTE's stock price more than doubled from 400 in October of 2002 to 920 in October of 2004.

11. Future directions and lessons learned

The four plants that comprise HTE are the result of repeated mergers and they each have a different company culture. One major goal is to allow TOC to be the common culture shared by all entities in the company. This process is well underway.

The management at HTE understands that as production capacity increases, the organisation's constraint typically moves to the market. In order to effectively exploit the market constraint, the plants and the company must be able to keep up with changing market demands and requirements. Thus, HTE has declared that increased manufacturing flexibility and further reduction of lead time is indispensable. In addition, to further exploit the market constraint, top management has increased the emphasis on new product development. Since June of 2002, management has championed the introduction of TOC to the product research and development division in an effort to significantly reduce new product development lead time.

The HTE case study presented in this research highlights two important lessons learned. One lesson is that the TOC philosophy works very well in a traditional Japanese manufacturing environment, in both the manufacturing and non-manufacturing functional areas. In fact, HTE is virtually a textbook study in following the five focusing steps, using the operations strategy tools such as drum-buffer-rope and buffer management, and resorting to the thinking processes when encountering critical obstacles to overcome or conflicts to resolve. A second important lesson highlighted by this case study is the typically insidious and all-pervasive nature of a core problem. That is, a core problem is likely to cause dysfunctional behaviours throughout the organisation. Furthermore, when a core problem—such as using earned production value to evaluate performance—is discovered, that core problem must be resolved before proceeding with further change initiatives. Otherwise, until the core problem is resolved, it will continue to wreak havoc throughout the entire system.

References

Chakravorty, S.S. and Atwater, J.B., How Theory of Constraints can be used to direct preventative maintenance. *Indust. Manage.*, 1994, November/December, 10–13.

Chakravorty, S.S. and Atwater, J.B., Implementing quality improvement programs using the focusing steps of the Theory of Constraints. *Int. J. Tech. Manage.*, 1998, **16**, 544–555.

Chaudhari, C.V. and Mukhopadhyay, S.K., Application of Theory of Constraints in an integrated poultry industry. *Int. J. Prod. Res.*, 2003, **41**, 799–817.

Cox, J.F. and Spencer, M.S., *The Constraints Management Handbook*, 1998 (CRC Press LLC: Boca Raton, FL).

Dettmer, W.H., *Breaking the Constraint's to World-Class Performance: A Senior Manager's/Executive's Guide to Business Improvement Through Constraint Management*, 1998 (ASQC Press: Milwaukee, WI).

Goldratt, E.M., *The Goal*, 1986 (North River Press: Croton-on-Hudson, NY).

Goldratt, E.M., *The Haystack Syndrome: Sifting Information out of the Data Ocean*, 1990 (North River Press: Croton-on-Hudson, NY).

Goldratt, E.M., Presentation at the 2004 TOC-ICO International Conference, Miami, FL, 2004.

Gupta, M.C., Constraints management—recent advances and practices. *Int. J. Prod. Res.*, 2003, **41**, 647–659.

Mabin, V.J. and Balderstone, S.J., *The World of the Theory of Constraints: A Review of the International Literature*, 2000 (CRC Press LLC: Boca Raton, FL).

Ronen, B. and Schragenheim, E., Drum-Buffer-Rope shop floor control. *Prod. Invent. Manage. J.*, 1990, 3rd quarter, 18–23.

Scheinkopf, L., *Thinking for a Change: Putting the TOC Thinking Processes to Use*, 1999 (CRC Press LLC: Boca Raton, FL).

Schragenheim, E. and Ronen, B., Buffer management: A diagnostic tool for production control. *Prod. Invent. Manage. J.*, 1991, 2nd quarter, 1867–1877.

Scoggin, J.M., Segelhorst, R.J. and Reid, R.A., Applying the TOC thinking process in manufacturing: A case study. *Int. J. Prod. Res.*, 2003, **41**, 767–797.

Smith, D., *The Measurement Nightmare: How the Theory of Constraints Can Resolve Conflicting Strategies, Policies, and Measures*, 2000 (CRC Press LLC: Boca Raton, FL).

Smith, M. and Pretorius, P., Application of the TOC thinking processes to challenge assumptions of profit and cost centre performance measurement. *Int. J. Prod. Res*, 2003, **41**, 819–828.

Umble, M.M., Analysing manufacturing problems using V-A-T analysis. *Prod. Invent. Manage. J.*, 1992, 2nd quarter, 55–60.

Umble, M.M. and Srikanth, M.L., *Synchronous Manufacturing: Principle for World Class Excellence*, 1990 (South-Western: Cincinnati, OH).

Umble, M.M. and Srikanth, M.L., *Synchronous Management: Profit-Based Manufacturing for the 21st Century: Vol. 2, Implementation Issues and Case Studies*, 1997 (Spectrum: Wallingford, CT).