APPLYING CONSTRAINT MANAGEMENT THEORY IN A WAFER FAB

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ABSTRACT

This paper will review National Semiconductor's experience in applying constraint management techniques at National's integrated circuit wafer fabrication factory in South Portland, Maine. The paper explains why constraint management was undertaken and the effect that constraint management techniques have had on product shipments, inventory, cycle times, and due date delivery performance. The process of identifying bottleneck tools, the methods used to increase tool output, and the synchronization of tool output and inventory will be described. The effect of factory indices and information systems on employee behavior and the strategies used to convince people to behave differently will also be described. Theory of Constraint concepts will be briefly reviewed.

I. INTRODUCTION

The National Semiconductor S. Portland, Maine fabrication facility is a high volume producer of many different integrated circuit products, including TTL, advanced schottky, CMOS, ECL, and LSI. The facility contains three fabs. Competition and the desire for increased profits cause the company to strive for improvement in product yield, increases in the volume of wafers produced (relative to the number of employees), improvements in on-time delivery of product, and decreasing manufacturing cycle time.

All fabricated wafers are shipped directly to a wafer sort facility. The sorted product is then either assembled and tested or placed in an inventory (die) store.

During the last decade, there has been a progression of manufacturing strategies. Ten years ago, control of work in process (WIP) did not exist. The factory was viewed as a black box into which raw materials were stuffed and finished product magically came out. WIP ballooned at one point to 80,000 wafers with one manufacturing operation registering inventory of an incredible 20,000 wafers. Important customer orders were hand carried by production control personnel through the manufacturing line. Over the years, inventory was gradually reduced and the number of "priority" or hot lots was limited. Hot lot processing was controlled by manufacturing. Manufacturing emphasized high volume output from all equipment.

In the early 1990's, management emphasis on improving cycle times and delivery to schedule prompted further inventory cuts. Management tried to balance the inventory and the line output by carving the line into hypothetical buckets and managing the buckets. The thinking was that even distribution of inventory would lead to maximum activity and output. Late lots were identified and vigorously pursued.

A "Kan Ban" like system was introduced to formalize the idea of steady and balanced flow. The system was modeled on the SEMATECH experiment. The hypothetical buckets or bins were transformed into physical entities via a manual "Kan Ban" card system. The "Kan Ban" system worked very well in the low volume, few product manufacturing line. It effectively balanced line inventory and lead to greatly increased activity and uniform shipments. Problems were quickly highlighted by work stoppage and subsequently fixed.

Unfortunately, the system did not work quite as hoped for in the large volume, many product manufacturing line. Inventory was evenly distributed, but the shipping rate and the overall activity level decreased. These problems were partially a result of the inability to design a system that handled many product flows, the inability to make the system easily understood and used, and the inability to convince the operators to talk to one another.

The needs to increase factory output and decrease cycle time remained in the large volume, many product manufacturing line. Constraint management was tried to achieve those needs.

II. THEORY OF CONSTRAINTS

The following is a gross and probably inaccurate simplification of Goldratt's constraint management theory. Please reference the bibliography for details.

Goldratt argues that 1) the goal of business is to make money, 2) the way to make money is to ship product that is in demand, and 3) inventory is evil. The principles supporting the theory are:

1) the output of the system is equal to the output of the process or tool that has the least capacity (bottleneck). That is, the system will produce only what the bottleneck produces.

2) Extra inventory in the system is necessary only to insure that bottleneck does not run out of work.

3) Inventory can be tied to bottleneck output.

An ongoing improvement process is recommended (figure 1).

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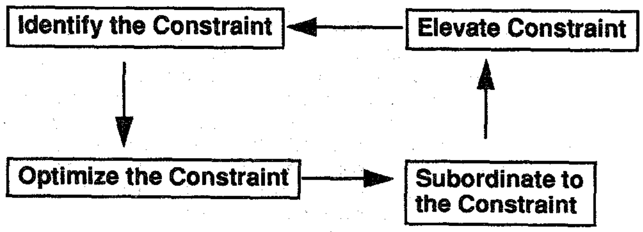

figure 1

The theory promotes an easier life. The entire system or factory must still run, but by focusing resources at the constraint, output of the entire system or factory may be increased or controlled.

III. METHOD

The initial project objectives were to 1) introduce and have the work force adopt constraint management theory, 2) increase factory output by 15%, and 3) reduce work in process (WIP) by 25%. The project was limited to the high volume, many product integrated circuit fabrication line. The project was authorized by the fab manager for six months. A project team was formed that included people from production control, training, computer systems, fab supervision, technicians, and production operators. The project team was authorized to do anything necessary to achieve the project goals. A budget of $35,000.00 was authorized. A consultant who was a certified associate of the Goldratt Institute was hired. The consultants' role was to advise and assist with training.

The project consisted of three major thrusts: 1) behavior change, 2) constraint management, and 3) development and implementation of a supporting information system. The purpose of the thrusts was to establish a new means to measure success, to have the work force adapt specific behaviors that lead to the achievement of the measure, and to provide information that both encourages correct behavior and shows progress to achieving the measure.

(a) Measurement

The first step taken was to change the primary production supervisor measure from fab wide activity to three indices: 1) the amount of product shipped, 2) constraint tool activity, and 3) buffer fullness. The purpose of the change was to attempt to focus people on the primary goal (product shipment) and the means to get there (constraint tool activity).

The fab wide activity measure continues. The measure, which National calls "absorption", is the primary measure for the top factory management. The measure rewards every wafer moved by reporting a financial gain.

The "absorption" measure is a manifestation of a standard cost based financial system. Constraint management promotes a "throughput" based system. The throughput based system promotes ships. The two systems conflict. Short term decisions are made to improve the financial measure at the expense of system output.

(b) Constraint Management

The identification, optimization, and subordination of the constraint is the core of the project.

(b1) Identification

The constraint was identified by conducting a survey of factory employees and through development of a static tool capacity model. The results were reviewed by engineers and production personnel, consensus reached and the constraint was formally anointed.

A random survey of twenty-five people was conducted. The people were asked to identify the tool they felt was the factory bottleneck. The results clearly identified the factory constraint and many near constraints.

An attempt was made to identify the constraint by looking at the historical high inventory points. Analysis of the data was inconclusive.

A static model for each tool set in the factory was created. The results were compiled in a spread sheet. The model used as inputs the theoretical capacity of the machine, the number of machines, the average downtime over the last 3 months and the manufacturing demand being placed on the machine. A graph was created that plotted the number of wafer moves of protective capacity (capacity above demand) against each tool set. The low points on the graph clearly identified constraint and low protective capacity equipment.

The static model identified the constraint to be Perkin Elmer Model 340 aligners. These tools require lots of labor to run and maintain. To add additional tools will be very expensive because of a lack of space.

The spread sheet model also identified a rather alarming number of tools with low protective capacity. In other words, the factory had many pieces of equipment with a relatively low and equal capacity. Disruptions at these tools increase the likelihood of constraint starvation. They have less capacity to catch up if they fall behind. Luckily, many of the low protective capacity tools were inexpensive (for example wet stations, inspection stations, and grinders). Projects were initiated to expand the capacity of these tools.

A significant outcome of this process is the understanding of the need for unbalanced factory capacity. Allocation of capital and engineering projects to increase capacity have changed due to this understanding.

(b2) Optimization

Optimization is the process of squeezing as much out of the constraint as possible. This was achieved by focusing attention and resources on the constraint equipment. This focus is the core new behavior. The following steps were taken to increase constraint output:

1) Production supervisors were dedicated to the constraint tools. Their job is to make sure that the tool is up and available, manned, and running product at all times. They are held accountable for the tool output. 2) Work schedules were changed so that the tools continued running over lunch and dinner breaks. 3) A list of available backup workers was developed so that the constraint supervisor has a pool of resources to draw upon. The supervisor was given the authority to temporarily move non-constraint workers to the constraint. 4) Additional workers were assigned to the area. 5) Back up workers were trained. 6) Maintenance technicians and engineers were trained to run the equipment. These people are used when no one else is available. 7) Maintenance priorities were rearranged so that constraint equipment was the first priority. 8) Adequate spare parts for the constraint equipment were permanently stocked. 9) Engineering efforts were directed to increase equipment reliability and quality.

(b3) Subordination

Subordination is the synchronization of manufacturing to the pace and needs of the constraint. The factory inventory is tied to the constraint activity. Non-constraint activity should suborn to the needs of the constraint. An attempt was made to synchronize manufacturing.

Material is processed in the factory according to a schedule. Every lot released in the line is assigned a date when it is to be processed at the constraint. Since a lot passes through the constraint multiple times, each lot has multiple due dates. Work is processed at the constraint according to the schedule. Efforts were made to maintain sufficient inventory at the constraint so that it never starved. Non-constraint workers process work so that it arrives at the constraint on schedule. Production supervisors identify and expedite late lots.

Early attempts to tie overall factory inventory to constraint output failed. Material released into the factory on a daily basis was supposed to equal constraint output. A correct starts equivalent could not be calculated. The incorrect calculation twice caused severe constraint starvation.

Today, material is released into the line based on the number of ships expected from the factory. The start rate is not allowed to exceed the expected constraint capacity.

(c) Behavior Change

This thrust was and continues to be the most difficult. People do not readily change the way they act. Supervisor and operator ingrained behavior is to move the largest pile of work as fast as possible. As previously mentioned, the standard cost system measure supports this behavior.

An attempt was made to change the behavior to moving the right work at the right time. This was done by crafting a simple message, convincing people that it was correct, and repeating it over and over.

This is the message.

The output of the factory is equivalent to the output of the constraint tool. Therefore, we will run the factory by focusing on the constraint. The constraint tool needs to be functioning, manned, and producing all of the time. People working at the non-constraint tools need to do whatever it takes to make sure that 1) the constraint does not run out of work, and 2) that the work gets to the constraint on schedule.

This message was delivered through various methods. Brief introductions to the concepts were delivered to all employees in large groups. The message was delivered the second time via small group seminars. The third and forth time each employee was told in one-on-one training sessions on how to use the information system. Finally, each production supervisor was charged to speak with each employee to encourage conformance to the system. These repetitions of the message occurred over a six month time frame.

The small group seminars were the linchpin of the education effort. Every production, engineering, and support employee was required to attend a seminar. The purpose of the seminars was to explain constraint management theory, why the project was being undertaken, and specific behavior that was expected. Exempt employees attended a two day course. Non-exempt employees attended a four hour course. Both courses used simulations or games to illustrate the effects of bottlenecks on factory output.

The two day seminar was taught by the consultant. The four hour course was taught by the project team. The course curriculum was developed with the help of the consultant. The courses have been made part of the overall fab training that new hires go through.

(d) Information System

The information system was enhanced to provide production employees with an understanding of what had happened and with information on what to do next. National's manufacturing execution system is based on the Consilium Inc. Workstream product. Many site specific improvements have been added.

The basic report used by fab supervisors, the line management report, was modified to support the new factory measures. The report summarizes factory inventory and activity by operation. The report was enhanced to include constraint tool output versus goals and constraint on-hand inventory. The report also displays the location and status of late lots.

Dispatch lists were created for each tool set in the factory. The dispatch lists are used by operators to determine what to work on. The dispatch lists are accessible directly from the line management report or independently. A tool dispatch list orders all work available to be processed. The list order is based on when each lot is due to be processed at the constraint. The dispatch lists are the daily work schedule for constraints.

Following the dispatch list has been a cause of friction. It has sometimes causes unbalancing of the line. Unbalancing of the line results in wild, but temporary activity swings. The activity swings almost always cause concern among senior management.

Finally, a supervisor tool is available which identifies the latest lots. It provides a means for supervisors to trace, identify, and fix disruptions.

IV. RESULTS

1) Constraint tool optimization resulted in significantly increased output. The increased output was achieved by focus, not by adding additional equipment.

2) The ability to maintain output and achieve cycle time goals was demonstrated at lower inventory levels.

3) Recent data shows gains in ship to schedule performance.

V. CONCLUSION

Significant improvement in factory performance has been achieved by using constraint management theory. The increases in output were attained primarily by focusing attention and resources at the factory bottleneck. An inventory reduction was achieved by maintaining excess inventory only in front of the constraint tool set. Better on-time delivery was achieved by scheduling the constraint. A change in behavior was required to achieve the improvements. The behavior change was, and continues to be difficult. Constraint management is a fundamentally different method of management. It conflicts with the standard cost system and requires new measures. Because of the conflict, organization buy-in is important. Information systems highlighting and supporting attainment of the new measures and that support constraint focused behavior have been integral.

VI. REFERENCES

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