Theory of Constraints Project Management in Aircraft Assembly

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Foreword

It has been the better part of two years since the subject paper was last edited, the title page bearing a retrospectively ominous date, September 10, 2001. How the world has changed since then! But that is not the subject of this message.

At the time of the original writing in early 2001, I wanted to capture the details of this development and application experience while they were still fresh. There was no demand for the story. No 'push' assignment or requirement to write, no request from elsewhere creating a pull. Using time between normal assignments and materials developed for presentations, the paper came together over several months. Circulating for critique and editing took more time.

TOC Project Management in Aircraft Assembly covers the timeframe from the spring of 1999 to fall 2000 – the purpose of this foreword is to provide the reader a current update and to give recognition to some of the key contributors to the success of the effort.

CCPM has been in constant use since the 'breakthrough' experience in April 2000, with factory wide implementation completed in November of 2000. The schedule management system preceding CCPM was Earned Value Management, driven by contractual customer requirements and also promoted by senior division leadership. While effective as a high-level indicator of program cost and schedule health, the EVM application was not effective at the factory level for improving daily performance or identifying critical issues. There was an assumption in place that since the customer required EVM, ***no other method of management was authorized***. When queried, the customer indicated that factory management methods were company business, but the customer wanted data in EVM reports. This response opened the door for CCPM schedules in conjunction with EVM reporting.

Earned Value Cost Performance Indices, CPI, (CPI = Actual Cost of Work Performed/Budgeted Cost of Work Performed) improved markedly with the CCPM application. Note that the Earned Value system and metrics were not changed to accommodate CCPM; CCPM was applied in a manner that supports heritage Earned Value systems while providing the factory unprecedented CCPM visibility into the needs of its projects. Since then, all deliveries have been made on schedule with healthy budget performance. Status meetings, once interminable, are now brief and focused on the key issues pacing performance. Factory performance has been routinely above historical benchmarks. The atmosphere is high focus, high energy, and low stress.

These results have attracted some outside interest. Feedback from EVM practitioners has run full spectrum, from understanding and acceptance to resistance based on the perception of two baselines. In fact, the EVM target is the baseline; the CCPM schedule is the work management plan and system that supports achievement of the baseline target. EVM sets the budget target, CCPM creates the work management plan to accomplish the target and manage the task variation. Cost is a result – in order to achieve

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cost targets we must manage the work associated with the project budget. When we manage work and schedule according to CCPM concepts, we can drive out non-value added time from our budgeted task estimates and improve cost performance. This is a subject well suited to a separate discussion.

No mention of this application of CCPM would be complete without recognition of the significant contributions of the Lean Manufacturing Initiative. Lean introduces a well-developed toolbox of practices and strategies for eliminating waste from our operations, and has been a continuing source of improvements. A fundamental strength of the Lean philosophy is its mandate to engage the workforce directly. Undoubtedly the greatest contributors to the success of improvement efforts have been the factory personnel themselves, who through the Lean workshops have developed belief and acceptance that their ideas and efforts are valued, and have new avenues of communicating and developing their improvement ideas.

We have found TOC and Lean concepts complimentary and synergistic.

The last several years have seen a continuous evolution of our technical application of the CCPM tool and the understanding we gain from the CCPM metrics. Technically, Information Technology development has linked internal data systems for improved information access and enabled an on-line, instant access, paperless reporting and status system.

We have gained unexpected new insights into our projects through the buffer chart metric. Such a simple metric, the buffer chart has proven a window to a new world of understanding and visibility of project drivers and process stability. In the paper, mention is made of the buffer chart's effect on cost control through area manager's recognition that completing a project in the 'green' zone is not necessarily desirable, and loaning a resource to an area needing help will reduce labor hours on the project and improve cost performance. In this recurring manufacturing project application, buffer consumption trends have also been found to provide insight into the nature of the problems facing the project. Early and/or rapid buffer consumption trends across multiple builds may imply a common root cause. Process problems, job sequencing, planning issues, and supply challenges have been identified and resolved after studying the trends of the buffer charts. Our drive for continuous improvement through the Lean Manufacturing Initiatives has elevated awareness of the value of standard work: performing the same tasks the same way every time. At the project level, the buffer chart effectively indicates our ability to ***achieve*** our standard work plan given the variation encountered in each build. As we identify, address and resolve the sources of variation, our processes become more stable and streamlined, more efficient and less costly. (It has occurred to me that this is the same intent of the Lean moving line philosophy, to identify and quickly resolve the problems preventing line movement. CCPM essentially models a virtual moving line, quickly identifying the issues pacing the project for resolution.) Implications for work management, cost control, process control, standardized work, performance to Takt time, and resource management visibility all come from one simple chart.

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Since our adoption and adaptation of the buffer chart, a number of advanced concepts for buffer reporting have been presented by various sources and in multiple forums. It appears from some models that the amount and complexity of information presentable in a buffer chart format is without limit. While complex formats may provide insight to the experienced, they may also quickly overwhelm the newcomer. Our buffer chart approach is unchanged from the original, and continues to serve well. Advanced buffer charting concepts may provide value given the necessary experience, need, and the demand of the application to make use of the additional information. I agree with an expert who advises using the tool appropriate for your situation.

Introduction of the buffer chart was not without challenges. In retrospect, I did a poor job of educating and communicating to the workforce the purpose of the buffer chart as an indicator of PROJECT health – when the buffer chart became standard fare in each area, numerous concerns were raised. The crews were working hard, why was their chart showing red? Accustomed to crew or individual performance metrics, the crews were taking the metric personally, rather than as a representation of the health of the project. Rarely if ever is a red condition the result of crew performance, it is generally the result of some support organization deliverable that has prevented work from completion. Special sessions were held to provide additional information on the use of the tool, and to emphasize the buffer chart's role in providing visibility to support organizations of the effect of their deliverables to the health of the project.

In studies of TOC and the Critical Chain approach, I have not found reference to an application quite like we developed for this factory. TOC Project Management was developed by the Avraham Y. Goldratt Institute (AGI) as a generic solution to the challenges of the project management environment. As taught by AGI, this generic solution must be tailored to the specific needs of each individual application. In the case presented here, several issues demanded early resolution.

First, what is the appropriate model for the solution? The traditional TOC model for 'production' applications is called Drum-Buffer-Rope, or DBR, and was proposed by some experts as the right model given the 'production' environment. However, the complexity of the processes did not appear to lend itself readily to the DBR model. A closer look showed clear parallels between the CCPM project model and the nature of the assembly work in this production facility. Hence CCPM was chosen over DBR. That's one.

Second, should the factory be modeled as one entity, or a series of related entities, or should the end product be the entity? Is each step buffered or is there one buffer for each tail number? In order for production to be successful, each step in the assembly process must be completed on time to allow it to move from its fixed tooling to allow the next product to begin work. Given these strong interdependencies, it became apparent that the individual steps in the process must be protected and managed to enable systemic success. Any delay in any step would paralyze the entire operation due to major tooling constraints. Hence our multi-single project scheduling model. That's two.

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Finally, we'd decided to use CCPM in each step of the assembly process, now how do we apply CCPM to each step? Most reference and training materials reference CCPM applications where aggressive task estimates are used to ***shorten*** the overall schedule – but this was not our dilemma. We didn't want shorter schedules, and we wouldn't benefit from shorter schedules due to contractual payment milestones. The problem was we weren't getting the work accomplished in the scheduled periods. Our approach became to create buffered schedules that protected the existing commitment dates and provided closed-loop feedback reporting. It worked.

Another element of this experience that has attracted a lot of comment is the bottom up direction of the effort. It is commonly assumed that in order to have success, there must be top-down support and commitment to overcome the resistance to change normal to improvement initiatives. What was different about this example? We knew we had a better method. We believed that if we could demonstrate it, the users would find value in CCPM and create a demand that would spread through the operation. While most improvement initiatives are imposed upon the workforce, who typically resist them at first and may or may not find value in them, for CCPM to be successful it would have to prove itself FIRST to the workforce. In an environment turning its ear to the voice of the workforce under Lean practices, a method proving valuable to that workforce is likely to gain support and acceptance.

In January of 2001 I attended the first of two TOC Project Management courses at AGI, completing the series in January 2002. While the technical solution speaks for itself, the depths of understanding into the rationale behind the CC approach and the processes for developing an implementation roadmap have been particularly powerful influences. Most impressive to me are the fundamental principles behind the approach. In numerous conversations, presentations and messages, the truths within these principles have proven inarguable, withstanding tremendous scrutiny. Coordination with other scheduling improvement initiatives has shown the CC concepts to support the best intentions of every element of every initiative so far.

Following the coursework and additional review, AGI granted me license to teach their two-day "Introduction to TOC Project Management" within Boeing. Feedback to the course has been extremely positive, fostering additional applications and developing broader understanding of CCPM.

In closing, I would like to recognize a few of the key individuals responsible for this story. Thank you to: Michael T. Wagoner, for his vision and quiet leadership developing this application of TOC, and for introducing me to and mentoring me in TOC concepts and particularly Critical Chain; to Edwin T. Baker for his support in granting the opportunity for developing this application and promoting the success; to Dennis Wiley for recognizing value and grabbing onto the new approach, and for his new insights, endless enthusiasm and ongoing support for CCPM; to Bart Mickelson for overnight development of the EVM to CCPM bridge in use unchanged since 2000; to Bart and to Tammy Taylor for their understanding and forgiveness of my learning curve; and to

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George Masters for his vision and support for continued development and refinement of the CCPM tools and linking them to their heritage counterparts.

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August 19, 2003

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Abstract

A recently developed project management methodology is applied to an aircraft assembly environment. Cultural aspects of improvement initiatives are explored. Benefits in project status reporting, communications, morale, and overall performance are discussed.

Critical Chain Project Management (CCPM) is the Theory of Constraints (TOC) solution to the challenges of traditional project management. Dr. Eliyahu M. Goldratt has been credited with the creation and development of TOC, a continuous improvement management philosophy focusing on system constraints using logical analysis techniques and quantitative tools rooted in the philosophy of scientific enquiry. Details of TOC and CCPM methodology are not included in this report. To learn more on TOC and CCPM, the following books are recommended:

The Goal, by Eliyahu M. Goldratt and Jeff Cox, North River Press, Great Barrington, MA, 1992.
Critical Chain, by Eliyahu M. Goldratt, North River Press, Great Barrington, MA, 1997.
Project Management in the Fast Lane, by Robert C. Newbold, CRC Press LLC, Boca Raton, FL, 1998.

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Summary

In conjunction with Lean Manufacturing Accelerated Improvement Workshops, (AIWs) TOC Project Management has been implemented as a shop floor scheduling, tracking, and reporting tool in a major military aircraft assembly program.

- TOC PM and Lean Manufacturing concepts are complimentary and synergistic.
- TOC PM is used in conjunction with Earned Value metrics.
- TOC PM is successful in a bottom-up implementation.
- Substantial improvements have been realized in cost and schedule performance.
- Shop supervision reports clear visibility of each build's status and prioritization of problem issues.
- Shift to shift conflict is practically eliminated.
- Factory morale has improved dramatically.

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Background

Spring 1999 – Serious challenges face factory management as pressure builds to complete aircraft under the Engineering Manufacturing Development (EMD) contract. Program performance is measured using Earned Value. Cost targets are overshadowed by struggles to meet schedules that continue to be challenged due to complex producibility and parts supply problems. One hundred additional mechanics are added to the existing one hundred mechanics for a nine-month push to complete all deliveries during EMD.

Lean Manufacturing Team

A "Lean" office is formed to develop a strategic approach for applying Lean and TOC tactics. Accelerated Improvement Workshops (AIWs) are conducted to form the foundation for future improvements. (AIWs are designed to enhance performance through worker involvement in waste elimination, area organization, parts and tool kitting, and process improvements.) Due to the heavy demand on resources and pressure from the schedule, AIW efforts are directed away from major problem areas to avoid disrupting their intense build efforts.

A review of factory conditions and practices yields the following observations:

Work areas:

- Drill jigs and locating tools are often difficult to locate;
- Parts are delivered to assembly areas on large rolling shelving racks in shoeboxes, individually wrapped and sealed. Mechanics spend significant time sorting through boxes and unwrapping parts;
- Large parts are delivered to assembly areas in their wooden shipping crates;
- Part and tool crates are stored on or near aisles;
- Hand tools are standardized and in area specific carts.

Work force focus:

- Mechanics spend significant time gathering tools and supplies from support areas;
- Mechanics are assigned such that they often are in each other's way;
- Mechanics are often directed to work in areas they are unfamiliar with, impacting learning curve improvement;
- Mechanics are apathetic about improvement efforts, as they have seen no changes resulting from their repeated efforts to get problems addressed;

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- Support organizations are busy fire fighting and unable to resolve systemic problems.

Cost and Schedule Performance:

- 'Bar chart' scheduling software commonly used within Boeing is non-Y2K compliant and is discontinued in mid-1999;
- New MS Project schedules used in each area to display work sequence and record job progress are not readily accepted by factory employees used to traditional Boeing bar charts;
- Earned Value Tracking System used to measure factory performance takes progress information from the factory but does not provide the factory with the information they need to accomplish their objectives;
- Much work is traveled to the customer location;
- A large crew is maintained at the customer location to complete unfinished work at significant additional cost.

Summary status:

- Scheduled deliveries are frequently in jeopardy;
- Cost overruns occur: assigning additional resources is insufficient to resolve early challenges. Costs increase with minimal gains in schedule; (While the customer pays for overruns in EMD, inability to meet cost is a significant consideration in continued funding for the program.)
- Morale is low.

Initial Approach

There is significant pressure from inside and outside the program to quickly improve schedule and cost performance. The penalty for low performance could include cancellation of the program with significant loss of jobs, and a negative impact on potential future contracts. Program management needs rapid, sustained improvement in cost and schedule to make the program viable.

It is apparent from the factory review that the mechanics building the hardware do not have what they need, where they need it, when they need it. In order to yield the greatest immediate impacts, the initial approach will focus on improving mechanic's access to parts, tools, and supplies, and standardizing the work in each area.

Part, tool, and consumable kits dramatically improve area organization and improve access to supplies. Kits also provide clear visual indications of missing tool locations and

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part shortages. Time is given to the mechanics to develop their own kits in accordance with the Lean/TOC strategy.

Standardizing the work in this case refers to the project level of detail, and involves building new precedence networks and removing conflicts between task instructions. The precedence network, or precedence diagram (PD), forms the foundation of the schedule by defining the necessary and preferred sequence of operations required to build a product. Defining the PD by task provides visibility of conflicts between task instructions. Once identified, these are rewritten to remove the conflicts. Once the PD is defined with task duration estimates, schedules can be modeled with varying resources to determine what level of effort is required to make schedule and budget. The PD foundation of the schedule assures the product is scheduled to be built the same way every time.

Kitting/PD/rewrite focused AIWs are different than the traditional AIW approach. Traditional AIWs supported and practiced by the company's central Lean office are centered around a broader scoped, general "waste reduction" focus associated with waste in time, movement, inventory, processes, travel, etc. Philosophical disagreements arise over the non-traditional AIW approach. The program's Lean manager and program management maintain the focused approach in spite of some opposition.

First Application

Program management uses a cautious approach toward the unproven application of CCPM in the factory. The program cannot afford to lose ground with a new concept that doesn't work.

A wing tip subassembly is the first area addressed. This pilot is run to learn more about the dos and don'ts of kitting. Management makes a significant and visible commitment by purchasing large amounts of kitting materials.

Large, rolling shelving racks used for part delivery and storage are replaced with custom built rolling display racks. Original racks stored parts in wrapped shoeboxes, making identification and access difficult, and required unwrapping by the mechanics, which wasted mechanic's time and generated a lot of trash in the area. New display racks present bare parts, and display them as they physically relate to one another, essentially an exploded view of the complete assembly. Each part display location is identified with its associated part number.

Tooling is moved from under benches to ergonomic stands for ready access.

The precedence diagram is developed with the guidance of the two experienced factory mechanics. This approach is new to the participants and requires several iterations spanning two days. The affected parties agree upon the final version.

A critical chain schedule is developed using the new PD. Application of resources is an issue. An approach is adopted and proves suitable.

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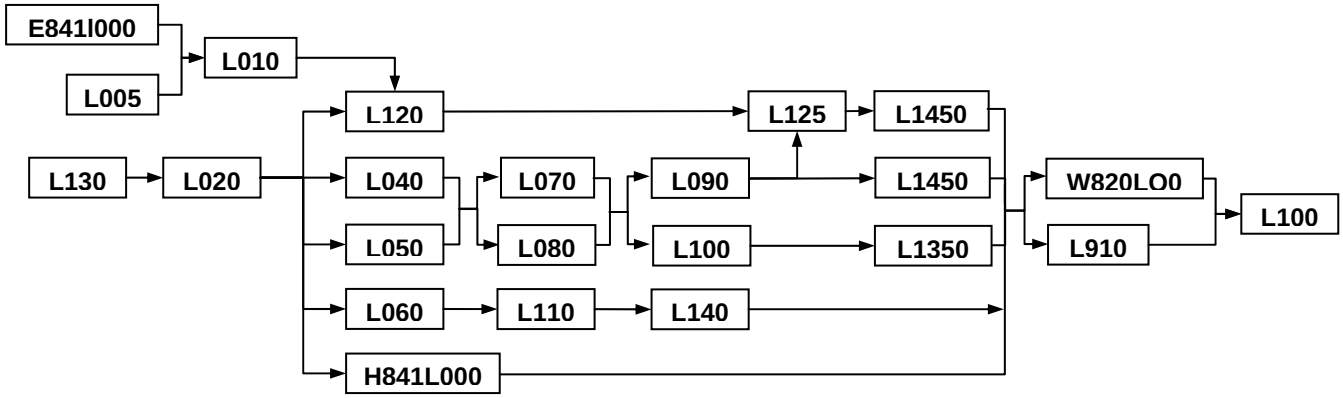
Figure 1. AIW - First Application

Figure 2. Workflow Analysis: Revised Precedence Network



Note: Original work sequence was linear

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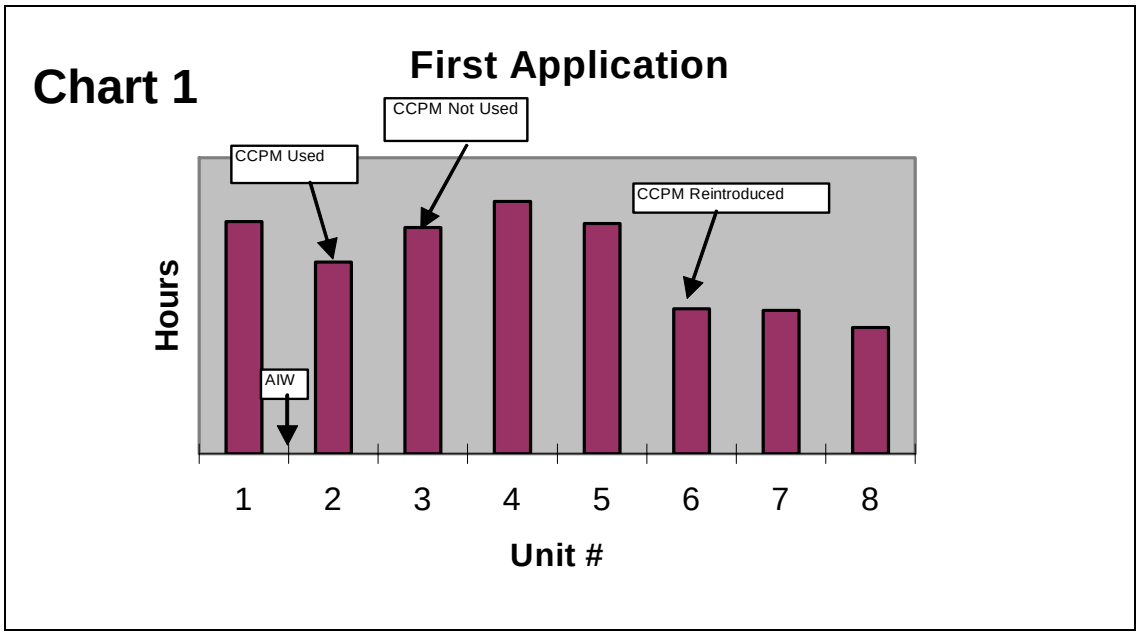
Two wing tips are built using Critical Chain schedules. Cost and schedule results are the best to date. Reference Unit #2, Chart 1 below.

Supervision in the area changes. The contribution of the scheduling tool to the performance improvement is not readily apparent. Traditional schedules are restored to the area. Most of the documented improvement is lost in subsequent builds. When CCPM is applied across the entire factory, Unit #6 is the first built with the new schedule. Improvement is apparent.



Second Application

A fuel tank is the second component addressed. During the AIW, substantial improvements in area organization are realized.

Literally hundreds of small drill fixtures are carefully organized and catalogued for ready accessibility. Conflicts between build tasks are resolved through planning changes. Special carts are made for mechanic's use in confined areas.

The precedence network is developed with the guidance of mechanics and lead mechanics. Coordination between first and second shift personnel results in cross-shift agreement on a preferred build approach. Resource application is directly associated with the physical configuration of the product, which greatly limits access to the majority of the work.

Immediately before the start of the next build sequence, factory management approached the critical chain scheduler with their coming challenge, to build two units in the time it normally takes to build one, without increasing their budget.

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A critical chain schedule is developed to address these objectives. The schedule is developed using aggressive task durations equal to 50% of the traditional durations.

The critical chain schedules are presented to the factory with a brief informational overview of critical chain methodology. Traditional schedules are not posted. Posted task durations are explained as aggressive estimates, not actual targets. Mechanics, leads, and supervisors are instructed to focus on the sequence of the scheduled tasks and to do the best they can with each job.

Two fuel tanks are completed in the time normally allotted for one. Direct hours charged in assembly are reduced dramatically. Reference Unit #2, Chart 2.

Tool Storage

BEFORE AIW

AFTER AIW

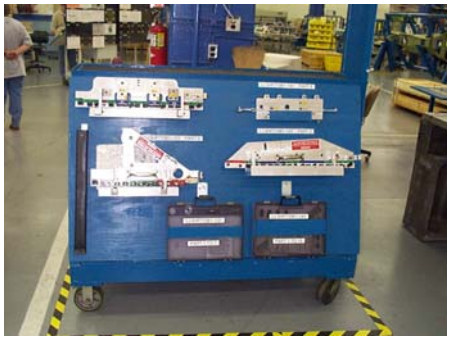

Figure 3 - AIW - Second Application

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Second Application - Precedence Network with Critical Chain

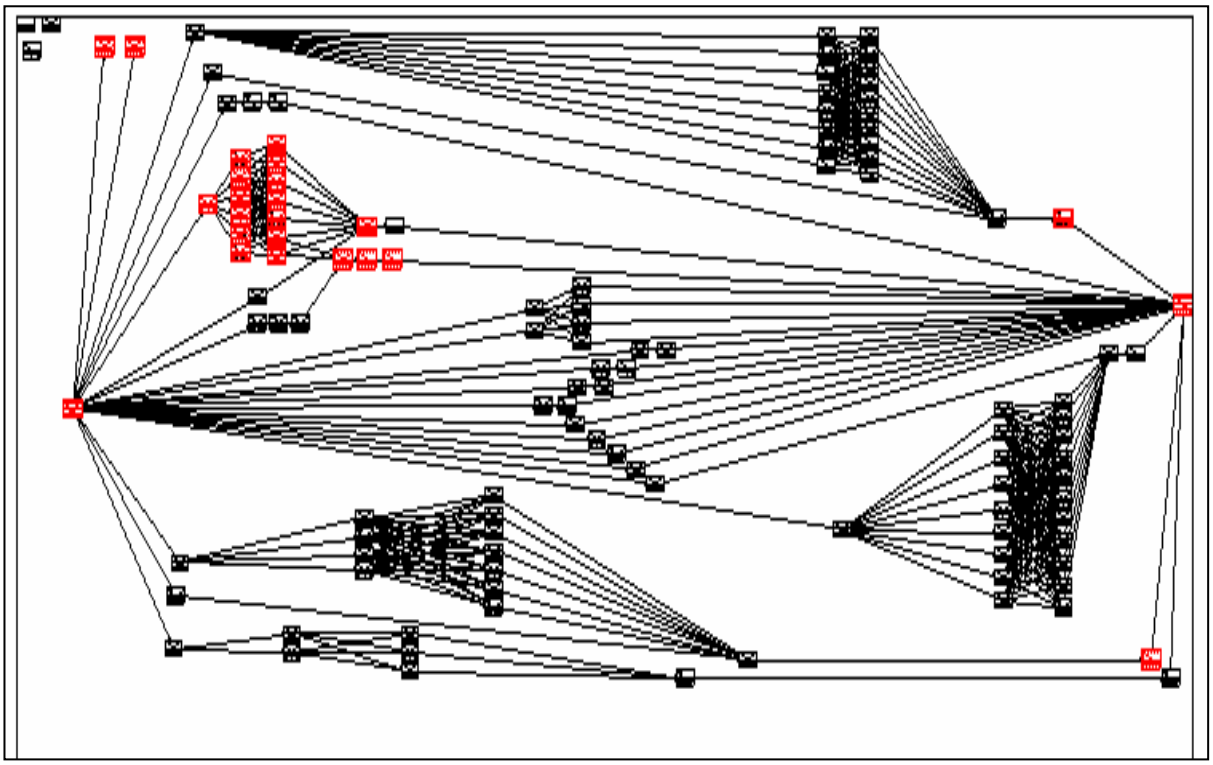

Figure 4 - Workflow Analysis: Revised Precedence Network

Another ambitious build cycle is required for the following units. Another critical chain schedule is developed. Once again, supervision in the area changes. The contribution of the scheduling tool to the performance improvement is not readily apparent due to multiple improvement efforts and a delay in data processing. There is pressure to start work early because the major parts have arrived. Traditional schedules are re-introduced. Most of the documented improvement is lost in subsequent builds.

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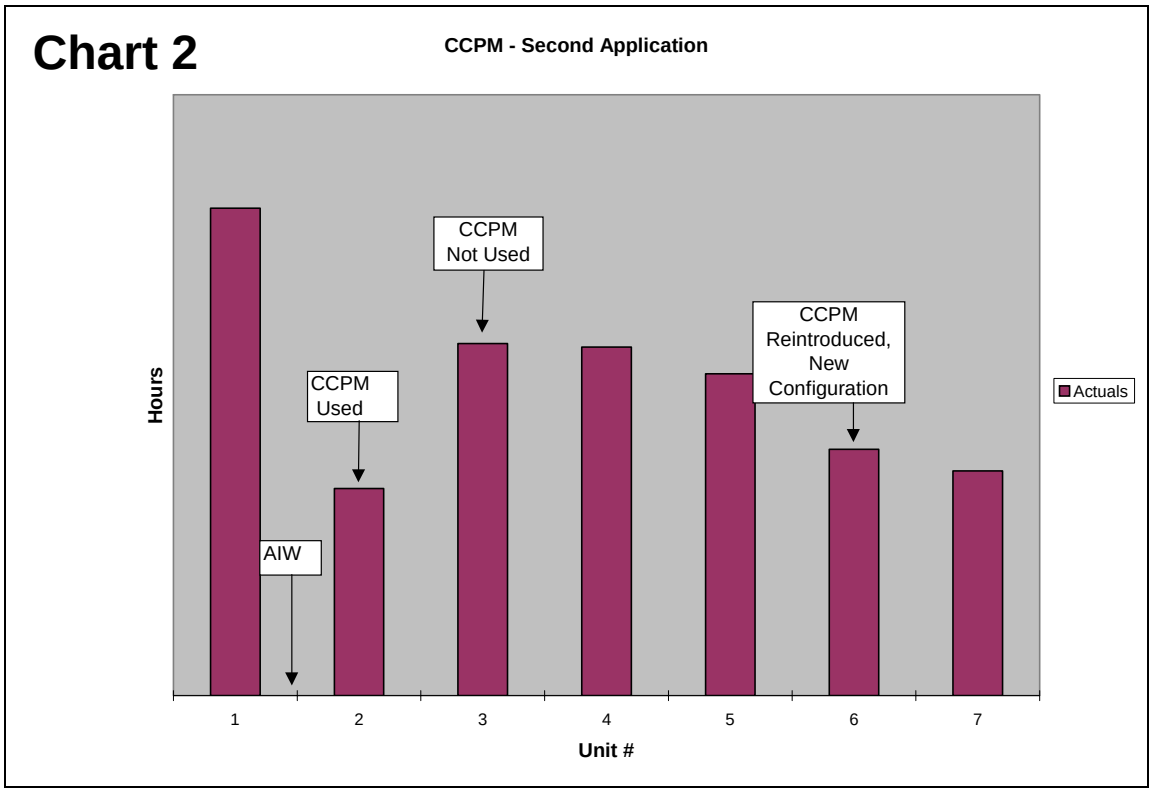

This chart seems to indicate some of the impact of the scheduling tool. Unit 2 had the benefit of the AIW and CCPM; units 3, 4 and 5 had the AIW benefit alone.

Also noteworthy is unit 6, which represents reintroduction of CCPM during the factory wide implementation in conjunction with a new design configuration. When a new design is introduced, it is normal to see an increase in hours as personnel acclimate to the new configuration. In fact, the area management anticipated a jump in hours. In this instance the improvement trend accelerated.

Third Application

Wing systems installation is struggling with cost and schedule. An AIW is performed in the area.

Area organization is greatly improved. Very large carts are constructed to provide work surfaces on top with part and tool storage underneath.

First iteration of the PD is generated with leads and supervisor. This work package has never been completed by the factory due to many factors associated with development efforts such as late parts, engineering changes, etc. As a result, a significant portion of work travels to the customer, and there are areas of uncertainty within the initial PD. Task duration estimates are obtained from the mechanics. These estimates are generally equivalent to 70% of the ‘standard’ duration. The method of resource application used by the regular scheduler is quite different than other schedules, yet very well suited to this product.

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First results

Inaccuracies in the PD corrupt the accuracy of buffer reports. Factory customers express mild interest in the reports but essentially maintain a business as usual approach. Some improvement is seen attributed to the sequencing of the work. Reference Unit #2, Chart 3.

Second results

Refined PD.

The build is progressing well to schedule when a labor dispute interrupts schedule maintenance and reporting. The wing was very nearly complete when shipped, on time, to the customer. Reference Unit #3, Chart 3.

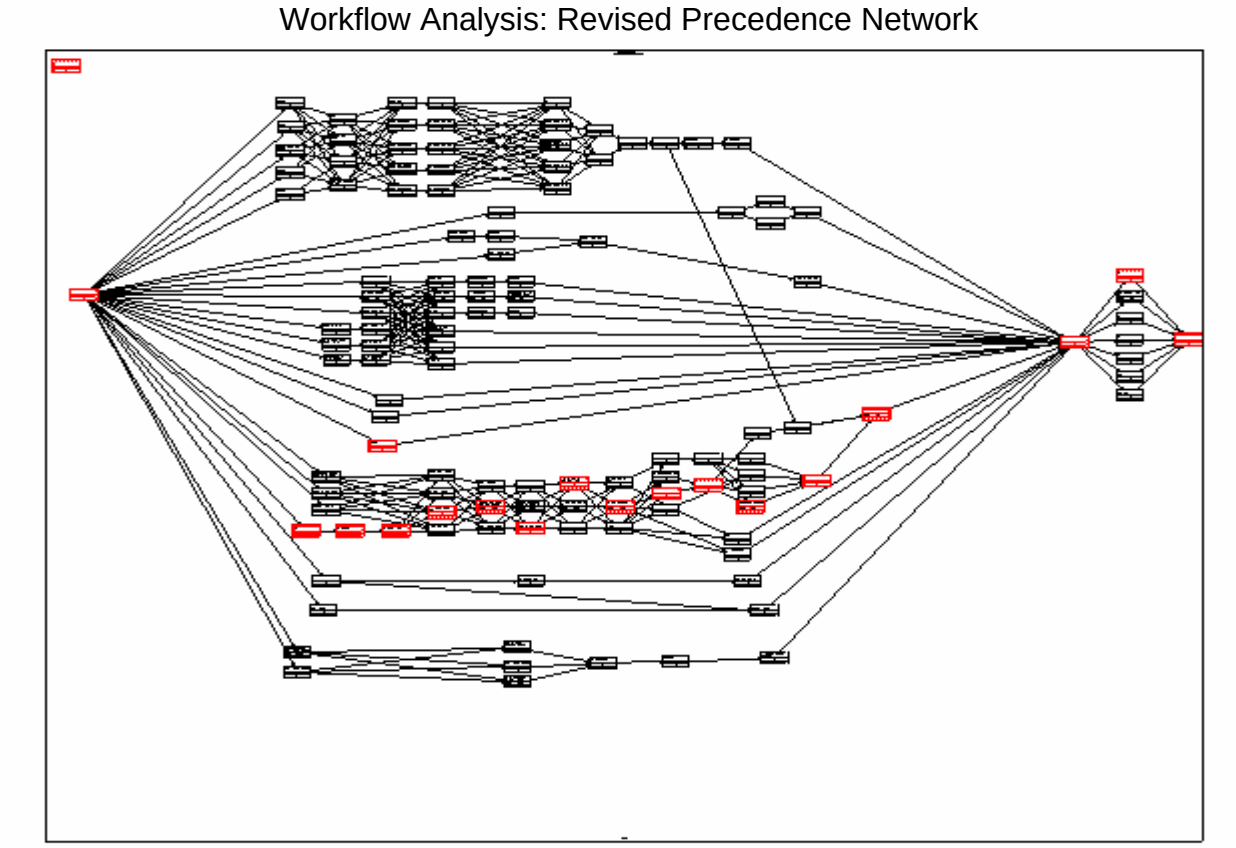

Figure 5. AIW - Third Application

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Third time's a charm

At the end of the labor dispute, another wing was in work. A critical chain schedule was developed and compared with the traditional schedule already in use. Both schedules used the same PD. The first day comparison indicated the project was on track according to both schedules.

A few days later the critical chain schedule was updated, showing significant project buffer consumption. Immediate notification was made to the supervisor, area manager, and methods analyst that the project was in danger. Alarm was evident in all parties, as the traditional metrics indicated the project was healthy.

Investigation by the area supervisor and focused detail reports from the critical chain software confirmed that while work was being accomplished at a rate satisfactory to the earned value system, the work along the critical chain was NOT being accomplished, threatening the completion date.

From this point forward the critical chain buffer reports were accepted as fact and work was assigned according to the buffer reports first. As the project buffer recovered, the traditional metrics showed the project falling further and further behind. At one point a decision had to be made to confirm or delay a military cargo plane reservation for delivery of the finished wing to the customer. The critical chain reports showed the project on track to complete on time, while traditional metrics showed a late completion. This major decision was left up to the area supervisor, who confirmed the reservation based on the critical chain reports.

The wing delivered on time, at a new high % complete, and a new low budget hour expended. Reference Unit #4, Chart 3.

This build is considered the breakthrough needed to validate the critical chain approach in this major assembly environment.

One more time

Based on these results, the area supervisor demanded critical chain scheduling for his future wing schedules. An immediate challenge was to build the next two units in a compressed schedule with fewer mechanics than thought possible. The supervisor realized he now had a tool that gave him feedback to meet schedule, and decided to use it to focus on cost improvement.

Budgeted for twelve mechanics per shift per wing, the schedule estimated nine mechanics per shift per wing would be required. Taking this into account, the supervisor applied six to eight mechanics per shift per wing, using two crews, one for each wing.

The buffer reports became the supervisor and lead's focusing tools. A conscious decision was made to accept variations from daily earned value targets in order to focus on working the right sequence, because rigidly meeting daily earned value targets had been

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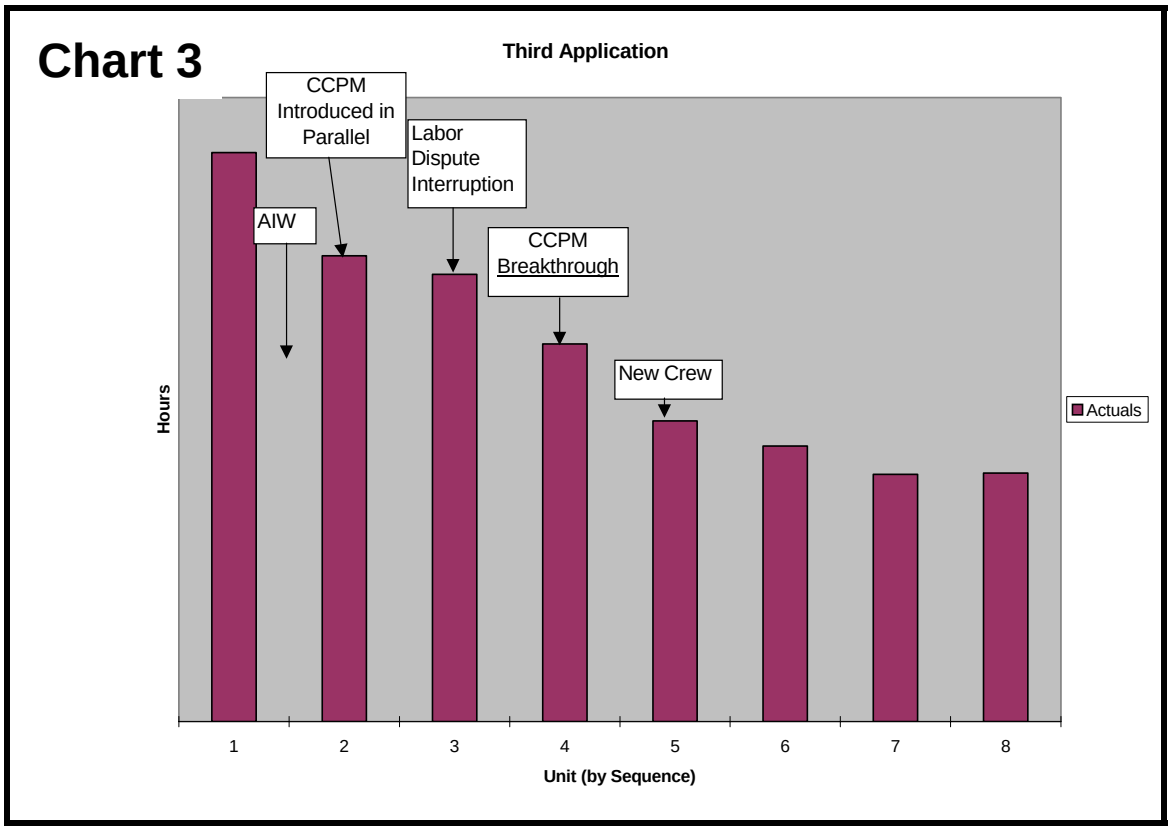
found to encourage working out of sequence. The supervisor chose to take the heat in earned value status meetings when targets weren't met.

By focusing on the right sequence, both wings were completed on time and dramatically below previous labor hour results.

The crew building Unit #5, Chart 3, had never done the systems installation work before. Following the critical chain schedule and reports, they completed the work package in fewer hours than the previous unit. The experienced crew completed their wing in fewer hours than that. Reference Unit #6, Chart 3.

And Another

Improvement continues. Area management has been consistent and critical chain scheduling has been continued. On the next cycle additional improvements were achieved on the two wings. Reference Units #7 and #8, Chart 3.



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What Happened?

The supervisor found value in the critical chain buffer reports that is not available in the traditional performance metrics.

Maintaining consistency of supervision promoted use and understanding of buffer management.

Use of the buffer reports greatly simplified the supervisor and lead's workloads, allowing them to focus on those tasks most important to their ability to complete the build on time.

Standardizing the work through the PD guided the build sequence to be consistent unit after unit.

Next Step

Performance improvement in this area was so pronounced and widely visible that it caught attention throughout the factory. Based on the improvements and stated benefits of the buffer management system, the factory manager decided to implement CCPM across the factory.

Factory Wide Implementation

Earned Value

A significant concern to program management regarding a Critical Chain implementation was the contractual requirement to report program status to the prime contractor using Earned Value (EV) metrics. Before implementing CCPM across the factory, some resolution must be agreed upon between the two systems.

In an effort to improve program status visibility, earned value reporting was being done daily. While daily EV showed projects behind schedule and over cost, it did nothing to indicate which work on any project was the most important to that project. As a reporting tool, EV takes status from the factory floor and reports upward, providing no guidance or feedback to the floor. Supervisors were in the unenviable position of gathering reports showing negative performance, presenting the reports, and then suffering the feedback on negative performance, without receiving any assistance from the reports.

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Reconciling the metrics

The objective of any project management tool is to complete on schedule within budget. With this in mind, a consolidation of methods was proposed, evaluated and adopted.

The critical chain schedules would be developed using 50% project buffers within the existing boundaries of the master schedule start and finish dates. Hence, the project finish date becomes the end of the project buffer. See Figure 6. In this particular application, there is no advantage to an early finish. Pay points are fixed, based on contractually agreed milestone dates. The objective is to meet the milestone dates, at or below budget.

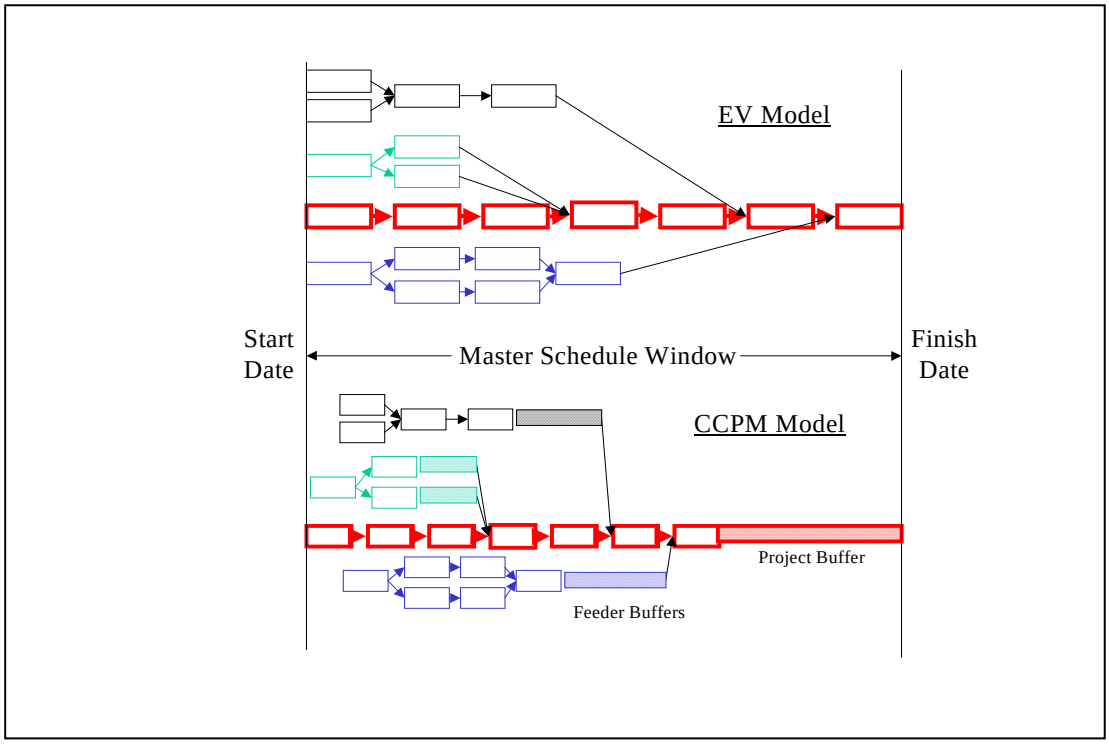

Figure 6. EV and CCPM Project Models

The aggressive task estimates of the critical chain schedule essentially compress the earned value scheduled tasks, then add the project buffer. Since the end of the critical chain schedule equals the end of the earned value schedule, delivering to the critical chain schedule meets the earned value schedule target. In turn, achieving critical chain tasks according to the critical chain schedule would show improved earned value performance.

Project visibility

As a supplement to the buffer report, and in order to display project status at a glance, a red-yellow-green 'wedge' chart was developed. See Chart 4. Earned value % complete is tracked on the x-axis and project buffer consumed on the y-axis, a line showing daily progress of the combined metrics. The upper right hand corner, on the boarder of yellow-

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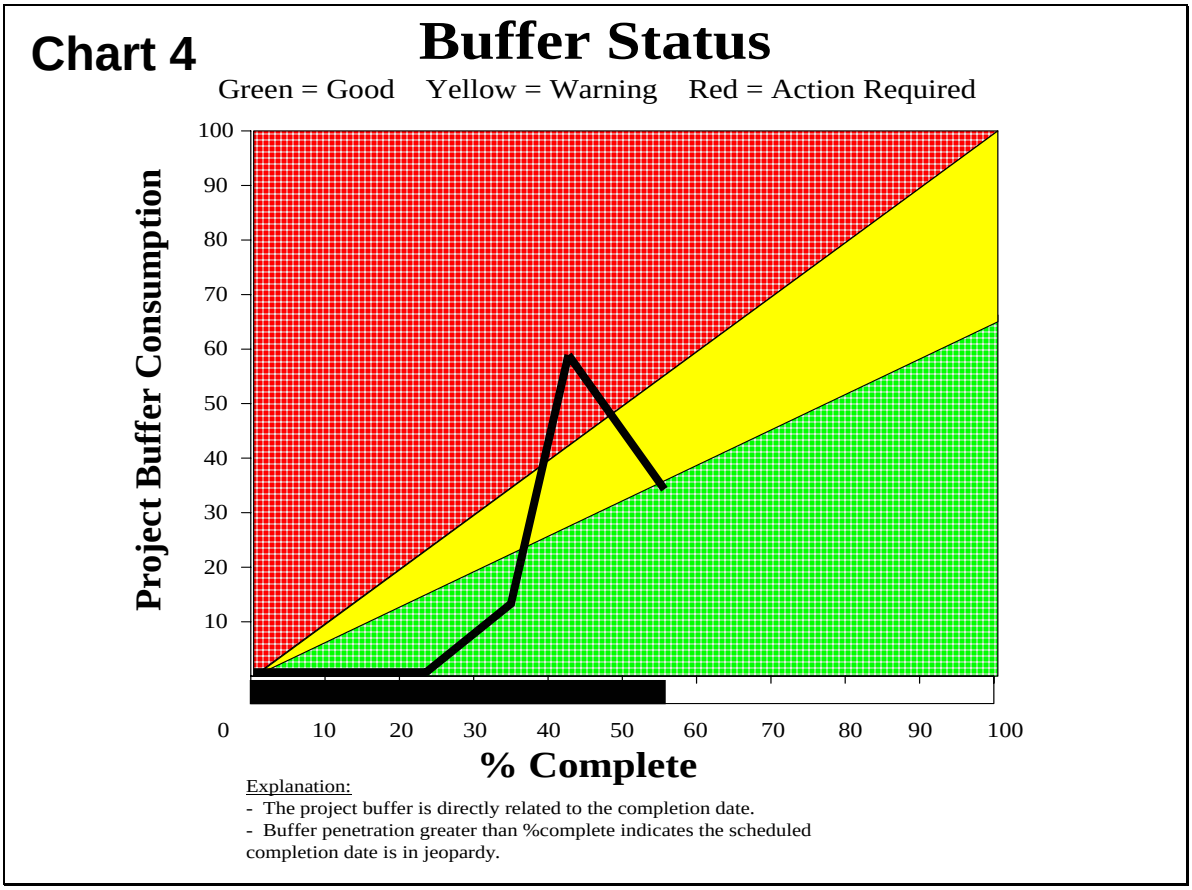
red, indicates the master schedule completion date. This corner is the target. Steady progress along the green baseline indicates a probable early completion, while rapid penetration of the red zone indicates the completion date is in jeopardy.



When an early completion is anticipated, the supervisor can determine whether there is advantage in the early completion, or whether there is a resource that can be shared with another area in need.

When buffer consumption exceeds % complete, the printed buffer report clearly indicates which specific tasks in the project are causing the consumption. The supervisor and lead can focus on resolving issues with these specific tasks to recover buffer and maintain the schedule.

Cultural Issues

Change is difficult. Initially, none of the potential users of the critical chain tool were interested in any new systems tools, scheduling or otherwise. Factory support systems were already developed, in place, and in use. Support personnel were too busy to take on other projects. In the factory, scheduling wasn't perceived as the problem, the problem was the missing parts and not having enough people. The entire workforce was working

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too hard to entertain unproven “improvement” concepts that would require them to invest any time, since time was the commodity in shortest supply.

Facing this challenge was the factory manager, who had learned of the dramatic improvements achieved in another factory using constraints management tools, and the former leader of that other factory’s improvements who had been brought in to lead the Lean manufacturing effort.

The support organization responsible for developing schedules had a well-organized system and had worked with the factory to document build sequences. Generally, however, the factory could not follow these schedules due to the many variables normal to development programs such as part shortages, engineering changes, etc. Often, posted schedules reflected master schedule dates already in the past because of delays and schedule changes common to development programs. Schedule targets that cannot possibly be met have a negative impact on mechanic’s morale. Factory personnel sometimes worked tasks they were most familiar with regardless of the schedule. As a result, confidence in posted schedules was low, each build followed a different sequence, and the schedules were used primarily to record and track progress on individual tasks.

In lieu of an automated schedule reporting system such as buffer reports, a manual method of project tracking had been developed, and was considered a substantial improvement over its predecessor. See Figure 7. All task numbers in a build sequence were listed in numerical order below a status bar showing key milestone target dates. The status bar indicating progress toward milestone dates was filled in manually based on the number of tasks complete and the supervisor’s intuition. These reports provided a relative measure of project status though heavily reliant on an individual supervisor’s intuition. Supervisors routinely checked status of every task in every area every day in an attempt to keep tabs on their projects, a very time consuming effort.

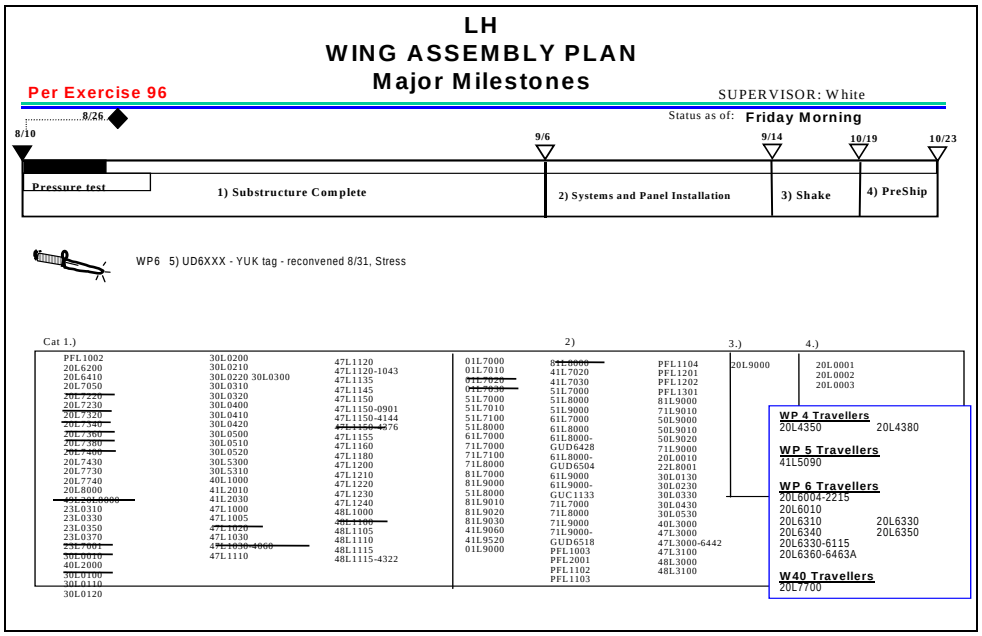

Figure 7. Old Project Status Form

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In order for the critical chain schedule to be successful, it would be necessary to demonstrate that critical chain scheduling would provide the users more time to accomplish the scheduled work and more time to resolve the problems that always arise during a build. This time must come not by lengthening build cycles, but by somehow finding time hidden within the existing cycle.

In order to properly demonstrate the schedule tool it would be necessary to re-establish some confidence in the schedule to ensure it would be followed. Development of the precedence network with the factory mechanics during each AIW created a direct link from the floor personnel to the schedule itself. Linking the precedence network, task estimates and resource loading generated robust schedules based on resource capacity. These relationships were reinforced when formally introducing the new schedule to factory personnel in each area. The importance of the sequence was reiterated, with focus on giving each task a best effort instead of meeting rigid milestone objectives.

Following a set plan showed dramatic results in the initial application examples given. Significant time within each build schedule was ‘found’ and saved.

Buffer reports provided to supervision and lead mechanics focused attention on the tasks most important to achieving the project completion date. Instead of finding status on many tasks, it became necessary to focus on only a few specific tasks delaying progress. Instead of simply reporting EV status upward, the new tool also provides closed loop feedback based on progress. The time found in the simplification of project status was well utilized in addressing the specific issues affecting progress. The stress relief provided by the reports is clearly visible in the faces of the leads and supervisors. As one lead put it, “I know how we’re doing, what to focus on, and that we’re going to finish on time. Life is good!”

Based on the results and proven improvement associated within areas where critical chain had been demonstrated, the factory manager directed that critical chain buffer management be implemented across all factory areas.

The benefits of the buffer management approach perceived by the factory were instrumental in convincing the scheduling organization that the new tool was adding value to the scheduling process and improving factory performance. These individuals then began resolving process and integration issues specific to their applications in scheduling in order to accommodate the buffer management approach.

Since implementation the good relations between the schedulers and the factory have only improved. Schedulers are often approached to model work around scenarios for an area to determine the potential effect of identified variation factors.

Factory supervisors performing well under the traditional system protested the shift to buffer management the most. When a supervisor’s knowledge, experience, and intuition of an area proved sufficient to meet most objectives, the appearance of a new tool seemed a nuisance. The buffer reports did not tell the supervisor anything they did not already

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know from intuition, since that intuition was used to build the schedule. Two primary points of agreement about the new approach have been made: it provides real insight to a temporary or replacement supervisor, and it provides an automated status to raise visibility to support organizations responsible for problem resolution.

Supervisors struggling under the traditional system generally accepted the new approach and quickly appreciated the value of the buffer reports. Some of their areas included hundreds of tasks making intuition based decisions very difficult. Automating their intuition relieved the stress associated with rapid decision making by providing clear insight into the build.

Conclusions

- Critical Chain Project Management has been successfully demonstrated in an aircraft assembly environment to reduce cost, improve schedule performance and increase morale.

- Lean Manufacturing AIWs and Theory of Constraints CCPM practices have been successfully demonstrated as complimentary concepts that can work well together.

- CCPM affects the Lean 'standard work' concept at the project level. Where standard work by definition applies to a task or process, CCPM guides the project through a standard sequence.

- Robust schedules considering resource capacity, work sequence, and task variability, with visibility provided by buffer reports, simplify complex projects and provide management time to identify and address problems as they arise.

- Earned Value and Critical Chain can be adapted to work together successfully without conflict.

- Critical chain project management can be successful in a bottom-up implementation with minimal management support.

- Involvement of the parties responsible for schedule performance in the development of the schedule fosters ownership, acceptance, and belief in the schedule. The best place to get the details of a precedence network is from the people doing the work.

- Successful demonstration of critical chain project management is not necessarily sufficient to create acceptance of the method. A key to gaining acceptance is the user's realization that the buffer report information adds value by simplifying their workload and creating time to address project issues.

- The job of the consultant (change agent) is to provide visibility through tools that clearly indicate where the project is, where it needs to be, and specifically where to focus to correct or improve the current situation. The consultant does not lead the change; only the user can lead the change by their acceptance and use of the tools.

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- Given an understanding of the environment and resource applications, addressing the greatest problem area provides the best opportunity for rapid, visible demonstration and acceptance of the power of the critical chain approach.

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