Master Scheduling with Critical Chain[1]: A Remanufacturing Case Study

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ABSTRACT

This paper and presentation discuss the application of Critical Chain methodology to master scheduling for repair of complex military aircraft, a task considered by some to be a daunting challenge within even a sophisticated project management system. The application of Critical Chain to master scheduling of other complex industrial sectors would appear to offer similar benefits as appear in this case study in the remanufacturing sector. Experience with this approach within less than a year suggests the potential to reduce repair cycle time by as much as 50% or more. The history of the implementation and use of Critical Chain in this maintenance, repair and overhaul environment is described and observations drawn as they relate to using this approach for master scheduling. The roles of training, software and Critical Chain methodology are described. Critical Chain may profoundly impact on standards, bills of material structures and routers when implemented and used with an MRP II/ERP solution.

The Case Study Environment

This case study takes place in a complex project oriented repair and overhaul environment. Elements of the facility's repair processes include job shop, process and project-oriented operations. The DoD repair facility described is under increasing pressure to deliver superior value in terms of quality, cost, delivery, and service to its customers on a global basis.

Many repair and overhaul oriented organizations have traditionally used relatively simple operational planning and control methods along with home grown software programs to manage repair operations. MRP II and now ERP software developers have tended to favor the manufacturing environment, where a larger market appeared to be available and has tended to fall short of meeting the specific needs of repair and overhaul operations. In particular, the aspect of uncertainty as relates to probability of use of materials and operations to be performed, is a contrast to the relatively predictable consumption of materials and the straight forward assembly sequence in most manufacturing organizations. This complication provides additional difficulty to the master planning and scheduling of resources. Project management tools have been applied to master planning of remanufacturing operations with varying degrees of success, but tend to fall short in

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[1] A concept developed by Eli Goldratt and first described in his works such as the book of the same title, *Critical Chain*.

the area of managing capacity and priorities while scheduling across projects in process that share the same resources. Other emerging methodologies, such as Theory of Constraints, Critical Chain and Advanced Planning Systems have tended to be applied elsewhere and are just commencing to be applied to remanufacturing activities, such as maintenance, repair and overhaul.

This paper points out how an organization can take a step-by-step approach to implementing Critical Chain, as a master-scheduling tool, through an actual case study. The case study takes place at the Naval Aviation Depot Maintenance Facility at Cherry Point, North Carolina. NADEP Cherry Point has over four thousand employees, a budget in excess of $500 million and is a primary repair and overhaul location for complex Navy and Marine fixed and rotary wing aircraft, and to a lesser extent provides remanufacturing support to other US Department of Defense and international military organizations. The items in repair can be so complex that often this has been considered and managed as a project management environment. Often the aircraft, treated as separate projects, have been launched into the mainstream of repair and reassembly operations without recognition of impossible conflicts of interest for attention at work centers. This overload condition can easily result in extended lead times in the repair cycle and negative impacts on productivity.

NADEP Cherry Point, like other military repair facilities, is under increasing pressure to reduce costs, cut lead times and constantly improve quality. The number of Naval Aviation Repair Depots was cut in half in the 1990's, and survival of any one depot is not guaranteed, as budgets continue to tighten and commercial sector competition takes aim at portions of their workload. Both public and private sector organizations tend to be led to progressive concepts and tools by the pull of the felt need to improve and survive as in this case. The live case study in progress is used to illustrate how and what can be accomplished. Additional non-government organizations are commencing to use a similar approach to master scheduling.

Critical Chain

Critical Chain Project Management (CCPM) has the potential to substitute for both critical path and earned value project management for project environments and may become a valuable tool for master scheduling in a larger marketplace. It may be the next logical improvement step beyond earlier methods for insuring resource capacity and proper allocation where multiple projects share the same material and labor resources. In a single phrase, CCPM causes you to focus on project success. CCPM software is now available in the market and can schedule projects using the Critical Path methodology and also combine the schedule for multiple projects (items), respecting conflict of capacity for the same resource considerations. The concept of Critical Chain will be described as its methodology unfolds during the implementation sequence in the following real step-by-step implementation case study narrative.

Step-by-Step Critical Chain Implementation

Sequence of Events:

Day 1 – The first day was devoted to preparation for onsite activity to commence with the H-46 Rotary Wing Team on Tuesday 7 Sept 99. Introductions and discussions took place between Vector Strategies personnel the Depot Commanding Officer, his staff program coordination manager, the project manager, and the external LMI observer/facilitator. This meeting was held at a nearby Holiday Inn on Labor Day, 1999. The depot personnel who would be participants were defined, a course of action for the week was discussed, and administrative issues were handled. A tentative objective was discussed for a pilot implementation and study of the H-46 rotary wing (helicopter) to achieve a dramatic 50% reduction in repair throughput time from an average of 185 days to 90 days.

Day 2 – The H-46 Team met with the Vector Strategies personnel for project startup. This session eased into education on the use of TOC and Critical Chain concepts while applying them to worthy depot issues. The Team and facilitators focused on defining the project, surfacing obstacles, conducting an exercise to demonstrate the effects of multi-tasking, reviewing simulations of project planning probabilities and introducing the concept of buffers. The basic questions dealt with were as follows:

1. What to change – identifying the core conflict
2. What to change to – constructing a solution
3. How to cause the change – devising an implementation plan

Sequencing was important in how the above questions were handled. The class gave feedback on obstacles in their repair processes and associated planning during this session.

Day 3 – TOC and Critical Chain concepts education continued. The core of the training message on this day was related to probability and buffer construction. For example, assume human nature tends to lead to estimated task times that have a 90% probability of success. If we pull out 50% as the safety time for tasks along the critical path and place at the end of the project as a buffer, then we can focus on fully utilizing resources upfront to stay on track, yet the protection is there and visible if we eat into the buffer. We can also protect the longest path from variability in connected shorter paths by creating feeder buffers at their intersection with the critical path (Critical Chain). Then we may be able to cut the buffers in half, as they probably overstate the risk, in that most likely only half of the 50:50 time estimates will be late. The result is a reasonably aggressively timed project plan with a safety net of buffers. Several of the basic concepts are described in more detail below as presented in this session:

The Student Syndrome

The student syndrome is characteristic of the typical work pattern of many people. They tend to do less than a third of the work on an activity during the first two thirds of the activity duration. Then they do two thirds of the work during the last third of the activity duration. Just think of how many students addressed term papers during their school years, by waiting until the day before, and consider that how this behavior tends to spill over into their adult lives. After consuming much of their available time without sizeable progress, even if they then work at 100% of their capacity to complete two thirds of the work in one third of the time remaining, there is no chance to keep to the planned project activity duration with a quality result. There is an opportunity to significantly accelerate a project, with no additional cost or complexity by just getting people to start early, and work at 100% until complete. This approach positively impacts quality, as there does not have to be a rush at the end to make a schedule at the expense of covering all the details.

Managers tend to use an early start schedule for non-critical path activities as well and earlier than is necessary to meet the schedule date. People working on such activities may realize that there is slack in their activity and this may well encourage the Student syndrome effect. This can also lead to confusion over what the real priorities should be and jam the process with too much work-in-process.

During one discussion, the H-46 team agreed that people probably give task durations they are likely to meet 90% of the time or more. The thought is that most people think the task duration they are asked for is expected to be met period, so they give times that they believe to be in the range of 95% + probability. Typically, they may give the longest time they can remember it taking them in the past, but certainly not one that is expected to be exceeded 50% of the time. The Team also perceived that the existing operational standards might be based on a similar perspective. Certainly the standards developers had not purposely set standards that would only be achieved 50% of the time. This then led to a mapping of current related repair processes and whether they could be rearranged to improve flow and utilization of constrained resources. This led to challenging of previously constructed routers for MRP II.
If we take a conservative case, fifty percent probability activity duration would be about half of the duration we normally experience. Therefore, we have at least a 100% contingency built into the initial activity duration estimates or even more.

Step-by-Step Buffer Methodology:

1. **Reduce task duration estimates by 50%:** Identify the project's network of activities and paths by unbuffered time and by resource. Collect activity durations as normal estimates, which are expected to have a high probability of success. Then estimate the 50% probability duration by cutting these estimates in half.

2. **Eliminate resource contentions and determine the Critical Chain:** Determine the Critical Chain as the longest chain of dependent events, task and resource. The Critical Chain is the constraint of the project. It is imperative that the resource contentions be deconflicted.

3. **Insert a Project Buffer sized and positioned to aggregate Critical Chain contingency time (normally 50% of the Critical Chain path length):** This step aims to exploit the constraint.

5. **Size and position the Feeding Buffers on all paths that feed the Critical Chain:** Use Feeding Buffers to protect the Critical Chain from accumulation of negative variations on the feeding chains. The other project paths are thereby subordinated to the constraint.

6. **Plan scheduled activities to start as late as possible, protected by buffers:** Subordinate further the other paths to the constraint by allowing the Critical Chain to normally start first, with possibly a few other paths.

7. **Resources deliver optimal performance (eliminate multi-tasking and the student syndrome):** The resources work as quickly as possible, as soon as the schedule triggers their activation, on their activities and pass their work on as soon as they complete, rather than looking to use all of the time available whether it is necessary or not.

8. **Provide resources with activity durations and estimated start times in the master schedule:** Encourage resources to pass on their work when done. This results in elevating the constraint.

9. **Use buffer management to control to plan:** The project and feeding buffers provide the information to trigger the master scheduler and other users as to when to plan for recovery and when to take recovery actions. It provides visibility when the project or system is in control and simply experiencing acceptable fluctuation. As the workers performing the tasks report their progress, it becomes evident where slack and shortfalls are developing. These can be charted and compared to probability durations and remaining available buffer time. Now take appropriate action as warranted when part of the project buffer or feeder buffers have been consumed:

Methodology:

1. Establish the size and placement of the Project and Critical Chain Feeding Buffers.
2. Determine the daily status of buffers by asking performing activities to project activity completion.
3. Develop action plans if the Buffer penetration exceeds one third.
4. Implement corrective action if Buffer penetration exceeds two thirds.

Day 4 – The overall objective of the Critical Chain implementation in the H-46 area was established and intermediate objectives (IOs) were identified.

The team determined that the goal would be: *By increasing throughput, NADEP Cherry Point will remain the preferred H-46 source by producing high quality aircraft, under cost with a turnaround time of 90 calendar days.* Obstacles to achieving this goal were identified by the team in detail. This was a preparatory step for day 4.

Day 5 – The obstacles to achieving the project's goal were used by the team to develop intermediate objectives that would resolve the obstacles and insure success.

Day 6 – The network for the overall project was constructed, using the intermediate objectives. Specific individuals were assigned to be responsible for achieving each identified intermediate objective. The network was fed into a Critical Chain software tool, and project buffer and feeder buffers were automatically calculated. This was a team activity to create the implementation plan for the project.

The afternoon was dedicated to commencing the network creation for the H-46 repair process. Yellow stickies were used to identify tasks with the following information required in each case:

1. Task
2. Description
3. Number and type of resources required
4. 50% and 90% duration times for each task.

The intent is to pull one thread at a time out of the total process, study it and put it in its proper relational position. This effort purposely starts with a clean sheet as the groupings of activities and related timing may differ from other efforts in the old paradigm. It was determined that the last task in an H-46 repair project is closing out the aircraft logbook. From this point on, the team worked backward to deal with all required tasks. This effort was continued into the second week with the completion of scheduling three aircraft and input as separate projects into the Critical Chain software. Then the multiple projects were combined into one portfolio stream through the software and schedules developed that were subordinated to the available resources. With this accomplished, the model was established to continue adding new aircraft items proceeding into repair, until a complete transition from the old to the new method of master scheduling would be complete.

During the following weeks and months after startup, the previously inducted workload was completed and every new H-46 aircraft has been introduced into the CCPM software and related master scheduling process.

OBSERVATIONS

H-46 Critical Chain master scheduling appears to be proceeding as planned with a trend of improving throughput performance. The first aircraft, initiated and completed under CCPM, was completed in approximately 130 days, as contrasted with an average recent experience of 190 days under the old planning approach. The H-46 program had just accepted a major increase in the content of the work package and was given an additional

30 days to complete. Therefore, the benchmark turnaround time was 220 days. The trend suggests a continuous improvement in turnaround times with a goal of 90 days. The depot now inputs separate aircraft into the CCPM software tool, then combines multiple aircraft into multi-project networks with multi-chaining in the CCPM software, utilizing the Critical Chain methodology for both induction and process planning, and create a multi-item network of events in desired order of priority sequence. As a result of lessons learned during implementation, they have restricted the number of aircraft in the flow from an average of 26 to now 14. The reduction in work-in-process inventory has resulted in lead-time reduction and increased overall throughput.

Although some organizations have tried it, it appears to be too complex to reasonably use CCPM, without computer and CCPM software, in a complex master-scheduling environment. There are too many calculations to be performed across all items to create a multiproject Critical Chain and then update the entire network in a reasonable timeframe. Experience suggests that the multi-project Critical Chain does not have to be recalculated, but rather sticking to the priorities already established is more important as variation in actual time to perform tasks occurs. Obviously there are emergency exceptions to this, but every effort is made to eliminate constantly changing priorities where it is not necessary.

This project's results continue to be measured in observed reduction in turnaround time and reduced operational costs related to more effective plan execution as a result of improved resource identification, acquisition and usage. These metrics are easily measured with existing reporting systems. There is a trend toward the lessened need for overtime, and particularly unanticipated overtime, which has always been a sore point for workers and supervisors alike. Total repair lead-time (TAT) is trending in a downward direction. Reducing lead time for repair will result in fewer aircraft required in the repair pipeline at any one time and result in an increase in operationally available aircraft, possibly offsetting the need for additional asset purchases.

The implementation of Critical Chain for master scheduling challenges whatever standards, bills of material structures and routers exist. It takes a leap of faith to re-determine task durations, based on an expectation of missing it 50% of the time, until you consider that the other 50% is placed in a buffer and available if really necessary. This is a philosophical twist to traditional standards setting and the process by which they are determined. It is very likely that groupings of tasks may be restructured and modified, as processes are improved, regrouped and unnecessary delays are eliminated. A change in the way bills of material and routings are developed and how their completion is controlled and reported is likely to change in a CCPM environment. Standards and their related costs may decline significantly as the process is viewed differently and multitasking issues related to more than one item in repair are resolved in the upfront master planning phase. Cultural resistance to this new way should not be underestimated.

CONCLUSIONS

CCPM is emerging as a tool for the master scheduling of multiple items, especially where individually planned items tend to trip over each other to use the same resources (materials, equipment and work skills). In many companies using MRP II/ERP, the master scheduler performs the initial master scheduling somewhat manually. CCPM can provide a real boost for these organizations. The question becomes what to do after the schedule is constructed and input to the MRP logic processor. MRP may try to reschedule sequences of operations and time phasing as feedback is received. Several potential approaches are suggested:

1. Use the CCPM tool for planning and scheduling and use MRP only for material acquisition. The rest of the MRP II/ERP system can still be used to collect costs and communicate information throughout the central nervous system of the organization for integrated resource functions.
2. Seek an Advanced Planning System solution (APS) that incorporates CCPM logic and integrates with your MRP II/ERP system to provide ongoing dynamic updates of the master schedule.
3. Use the CCPM tool for initial master plan development, input to MRP and then allow MRP to manage beyond that point with occasional sanity checks by replanning through the CCPM software.

At this point both options one and two appear to be the likely candidates, with a thought preference for option 2 for the depot environment. APS with CCPM logic is currently being explored for inclusion in ERP implementation within NADEPs like Cherry Point.

The H-46 Team has now embraced the Critical Chain master scheduling template as their own and are recommending continuing changes. Some reflect actual man-hour corrections due to having an accurate work history, some recombinations of tasks are being suggested because they make good sense, and some adding of a few smaller tasks for clarity of explanations is occurring. The depot is having a good exchange in capturing real world hours without extending the turnaround time (TAT). The workers are beginning to actually believe that lower TAT is possible. The manager of H-46 repair operations has identified the 10 Top Parts Constraints. These are being tackled one at a time. Using TOC tools and the philosophy, they then present their findings. The shop personnel are seeing exactly how they fit into the CCPM and the impact they have on the sell date of the A/C. They then report directly their progress and constantly see the big picture as to what the next task and priority is. As the backlog of aircraft in the repair cycle becomes smaller, the reduction in cycle time allows them to start delivering in a timelier manner. The necessary changes that they are implementing in order to achieve these improvements are transparent to their customers. Now they clearly understand and see that driving the turnaround times down significantly improves their cost basis. This in turn makes their rates more competitive, which in an era of uncertainty is the key to survival. Now there is real management help being provided to solve workers' problems (constraints) as they surface as rocks in a stream. As one manager recently commented, "It is fun to watch the expression of people's faces when they are told they need to improve their processes because the A/C are now selling 40 days faster. I tell them that this is the good news and that the A/C line is continuously improving and so must we. This is more about working smarter, than working harder."

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