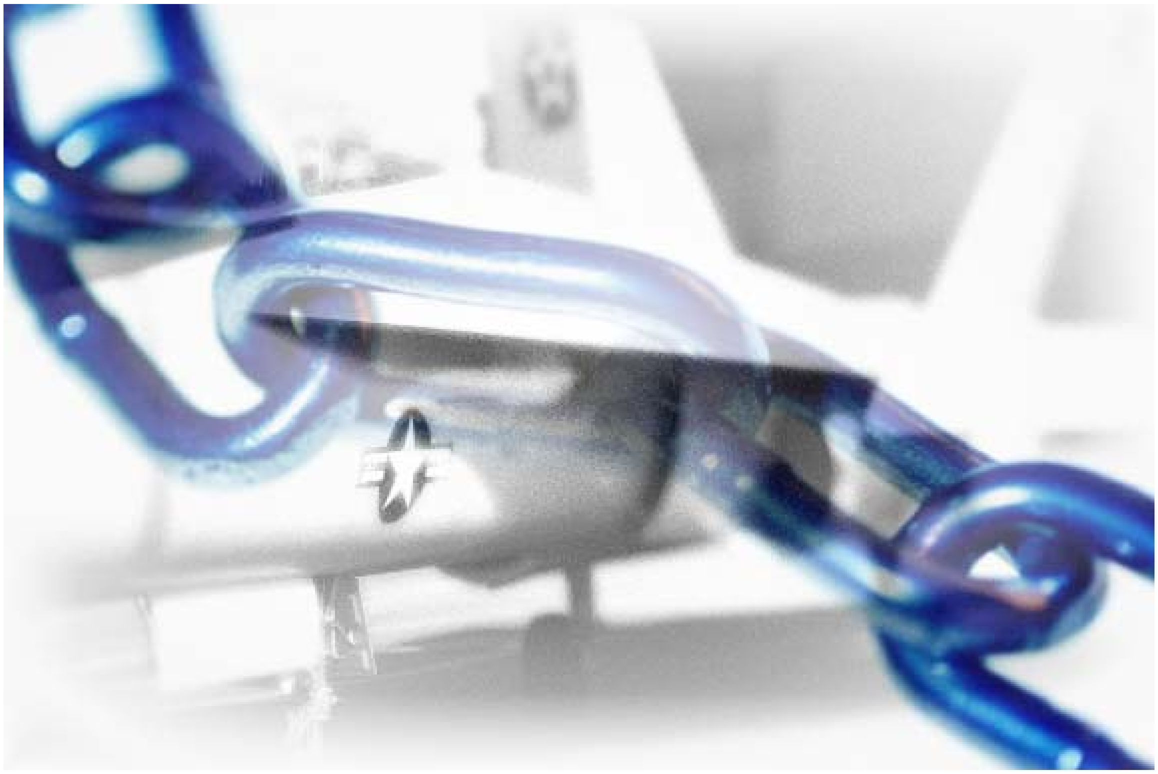
# CRITICAL CHAIN APPLIED TO AN MRO

## SURFACE REPAIR FACILITY

## CECIL FIELD, FL



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Prepared by:

Howard Kirk Rainer
Industrial Engineer
Jacksonville, Florida

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# EXECUTIVE SUMMARY

The project management methodology of Theory of Constraints, called Critical Chain, is examined for application to Scheduling, Planning and Control (SP&C) for a defense-related Maintenance Repair Operation (MRO).

The opportunities for Critical Chain, as an extension of Theory of Constraints (TOC), have been reported for well over a decade. With this proven record comes a proposal for similar application in the SP&C at the Surface Repair Facility (SRF) at Cecil Field, Florida.

The SRF has established reporting systems such as Earned Value Methodology (EVM)—mentioned here to distinguish the differences between execution and reporting in SP&C.

At the enterprise level, Lean (called Lean+) has been applied at the SRF with the following realized or potential opportunities:

1. Clear priorities for induction, processing and delivery of assets
2. Limits/controls on WIP in controlling inventory ready for processing
3. Immediate issues' resolution with concentration on constraints
4. Daily driven execution for working the plan and working the problems

Lean and Critical Chain have a long-standing, symbiotic relationship.

Critical Chain, as a common methodology in both the organization and the industry, offers the following opportunities for SP&C performance:

1. Supplementing Lean+ enhancements
2. Managing uncertainty and inherent process variability
3. Isolating and exploiting the current "critical constraint" of workflow
4. Reducing turn-around time (or time to repair) and WIP

Critical Chain Project Management (CCPM) not only supplements Lean but, as the proposal will describe, attacks the inherent variability of project/process duration.

At the submission of the proposal, the SRF is undergoing some changes that, pertinent to the paper, are described as integrated planning-scheduling. This recent development coupled with the success of CCPM (in maintenance and repair operations) is reason to consider the proposal, its content.

With the knowledge and approval of the management of the operation, the organization at Cecil Field, this proposal is submitted for the 2012 SCEA/ISPA Joint Annual Conference in Orlando Florida.

# MAINTENANCE REPAIR OPERATIONS (MRO)

Maintenance Repair Operations (MRO) characterizes the industry of the Surface Repair Facility (SRF). The MRO is described in further detail below.

## 1.1. Maintenance Repair Operations (MRO)

MRO is more of a general term or acronym applied to the servicing and repair of many products; or as described in Wikipedia:

> MRO may be defined as, "All actions which have the objective of retaining or restoring an item in or to a state in which it can perform its required function. The actions include the combination of all technical and corresponding administrative, managerial, and supervision actions."[1]

Of particular importance are the differences between maintenance and manufacturing, or the repair of an item versus its production.

## 1.2. Maintenance versus Manufacturing

At first glance, the MRO may look like manufacturing—as there are similarities and shared processes; but perhaps more difficult to discern, are the differences due to uncertainty and variability. The differences can be simply described: in repetitive manufacturing, variability is reduced through the control of processes, both design and production (e.g. Six-Sigma); but in maintenance, such opportunities and effects are offset by uncertainty surrounding the product (or service) infiltrating the processes of this project-type industry-environment.

Reliability engineering, as a sub-discipline of systems engineering, deals with this uncertainty in addressing risks.[2] But even with such methodologies as Design for Six-Sigma DFSS) and Failure Mode Effects Analysis (FMEA), uncertainty (uncontrollable risks and unknowns) can be replete in the repair of product—unlike the industry and environment of manufacturing or production.

This uncertainty is inherent in product-service, and is ever-increasing over the product life cycle[3]; it occurs in such areas as:

- Technological developments, and the limits of replaceable parts
- Product attrition and the shrinking supply of repairable items
- Limited, irregular demand and the availability of materials
- Skill’s retention due to dying technology and limited need

[1] From the on-line encyclopedia, Wikipedia: Maintenance Repair Operations (MRO).
[2] From Wikipedia: Reliability engineering.
[3] Product life cycle extends from initial production through retirement or disposal.

## 1.3. Depot Repair, Overhaul and/or Upgrade

The term "Depot Repair" is the defense-related equivalent of an MRO. As the title of this section suggest, "Depot Repair" can include a full array of life-cycle support-services for military assets; some of the services are:

- Preventive maintenance
- Corrosion evaluation, treatment and removal
- Surface and structural repair
- Functional and non-functional parts replacement
- Retrofit, upgrades and similar modifications
- Re-assembly, testing, and other services prior to re-deployment
- Retirement, scrapping of obsolete, antiquated or dysfunctional assets
- Spares and associated logistics services

Depot facilities provide services' support both directly through the Defense Department, as "organic" operations, and from the private sector. Relevant to the subject (of this paper), Critical Chain Project Management (CCPM) has been applied successfully in both sectors with "Stories" provided in the appendix.

## 1.4. MRO and CCPM

MRO and CCPM have a sound relationship; as mentioned previously, Critical Chain has found success in a host of defense and commercial MRO and depot operations. My own awareness of this success was coincident to working at another aircraft depot operation[4]; there, I learned of a key-success story in South Georgia, at the Marine Corps Logistics Center:

> The Maintenance Center for the Marine Corps Logistics Base, Albany, Georgia, launched a program in 2001 combining principles drawn from the Theory of Constraints and Lean thinking. The Center had been constantly plagued by apparent capacity shortages.... An analysis using Theory of Constraints (TOC) revealed that there was, in fact, more than adequate capacity to handle the workload. The perceived lack of capacity was due to policy constraints imposed on the Center as a result of a push scheduling mechanism. By implementing a pull system....

More details on the Marine Corps Logistics Center and other studies are provided in "Stories" in the appendix.

[4] The author's awareness occurred while working at the former Pemco Aeroplex, Birmingham Alabama as a scheduler in 2004.

# SURFACE REPAIR FACILITY (SRF)

At Cecil Field, the SRF provides depot-services' support for the repair of flight controls of several fighter-aircraft programs.

## 2.1. History

Prior to Cecil Field, the SRF was located in Mesa, Arizona. The fact of geography seems of lesser importance than the understanding that this prior location was higher performing notwithstanding the current Cecil Field SRF being less than three years in operation.

Early efforts had limited effect on ramping-up the re-located operation; the first year or so was marked by limited deliveries and prolonged cycle times (RTAT). More recently, the efforts have paid dividends as statistics bear-out a steady delivery of flight controls (assets) per a generally-described three-month schedule.

Both capacity and agility have been enhanced through increased facility and capital spending with proportional hiring and training programs. Further gains have occurred through the support of such areas as:

- Programs
    - Contracts
    - Customer relations
    - Communication
- Quality
    - Compliance (AS9100)
    - Coordination (of single-point inspection)
    - Continuous improvement (Lean application, events, training, etc.)
- Engineering
    - Standardization/simplification of routine dispositions
    - Strengthening of organization relations and request response
- Supply Chain
    - Prioritization by demand profile
    - Long-term commodity forecasting of discrete parts
    - Coordination of flight-control carcass inventories to delivery demand
- Integrated Planning, Scheduling & Control (SP&C)
    - Integration of operational requirements and capacity
    - Requirements/constraints against growth opportunities/markets
    - Visibility for customer-supplier coordination and communication

## 2.2. General Surface-Controls (Asset) Workflow

The general workflow of an asset is shown in Figure 1; further explanation is provided below.

On arrival or receipt of the asset ("carcass"), the records are reviewed; and if data is missing or questionable, Logs & Records makes the necessary corrections. Depending on the program, an asset may be inducted (into the repair cycle) de facto arrival, or the unit may be retained in receipt pending records or an internal request to induct (i.e. a PULL system).

The description of PUSH and PULL applies in these optional inductions: one program is more of a customer-PUSH with immediate induction (on arrival or receipt); the other falls mutually to the SRF and customer to PULL the asset into the repair cycle from the warehouse post-arrival or receipt.

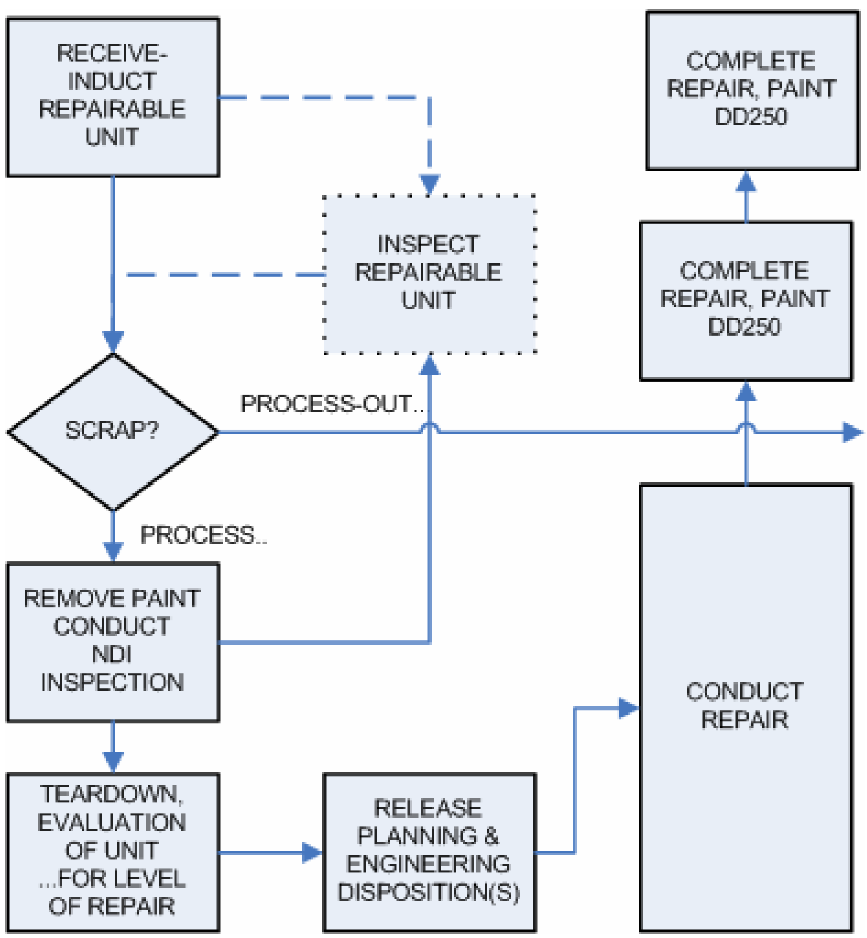



**Figure 1 – General Asset Repair Workflow for the SRF.**

A local warehouse serves as pre-induction, receiving-storage, and as an exception, a preliminary inspection point. Preliminary inspection (before induction) can be a hedge against *throwing good money after bad*; but in general, it is used on a limited basis to assess the extent of repair. Otherwise—and much more often—the assets-carcasses are either inducted on receipt (PUSH) and/or are deferred for inspection following induction (PULL).

If the asset is deemed a BER/BPR, it is processed-out of the repair cycle and held, pending DCMA approval to scrap. An important factor is that the BER/BPR can occur at any point along the repair cycle; late-finds or related factors can lead to such decision late in the repair cycle. The value of such decisions as early as possible has obvious benefits.

At induction, an asset is stripped (PMB) for visual surface examination, or Evaluation and Examination (E&E). Afterward, the asset undergoes NDI followed by Teardown & Inspection (T&I); followed by Planning and Engineering (P&E), Repair, and finally, Painting and DD250.

P&E and Repair can constitute the bulk of labor and other resource demand—as is common for maintenance—and is where the largest variability occurs to schedule performance. This variability stems from the Planning and Engineering process, the supply chain or material acquisition, and other less frequent or impacting sources. Relevant to the subject of this paper, these sources of variability are also constraints (to schedule performance).

One other alternative (to on-site repair) involves programs (contracts, terms, etc.) where there is another, partnering repair operation. In such exceptions, the repair processing includes asset shipment to a partnering supplier for repair followed by on-site paint and DD250 to close the cycle.

## 2.3. Planning, Scheduling & Control (SP&C)

SP&C has limited application at the SRF: effort and progress have been largely applied to recent developments; namely, an effort toward integrated planning that encompasses an extended planning horizon of multiple years and integration of requirements and developments by resource and location.

Prior to “recent developments”, SP&C has occurred consistently at the operational level for a planning horizon of about three months; called the 30-60-90, this schedule aligns work-in-process to monthly objectives by asset type and serial number (SN). In this horizon, the operations’ managers are given lead-way to substitute assets both within and beyond the planned delivery. Within the contractual criteria, managers have the flexibility to make last minute changes—a privilege that works amazingly well as a hedge against uncertainty and variability.

At this time (coinciding with the completion of this paper), integrated scheduling is underway—driven to some degree by prospects of market, defense and programmatic opportunities for the SRF. As each asset type, by program, has been assessed in terms of growth opportunity, a scheduling team has been chartered to outlay delivery expectations, capabilities, and capacity requirements/limitations. Integrated scheduling (SP&C) describes the area of concentration for Critical Chain Project Management (CCPM).

## 2.4. SRF and CCPM

Application for TOC/CCPM in the MRO (section 1.4) is echoed (here) with the addition of further detail. But as a primer for this detail, consider the following on the SRF as it relates to project management and specifically CCPM.

Each asset received-inducted at the SRF is a project; it is unique with a definite beginning and end, composed of many tasks distributed among activities and phases (as a network) generally described in section 2.2. The inducted "project" joins the work-in-process (WIP) or a multi-project environment; indeed, the SRF manages perhaps hundreds of projects (as WIP) at any one time.

Here, in a qualified project-setting, is where CCPM can produce 20 to 40 percent improvement in throughput—concurrently driving-down variability while increasing schedule-delivery reliability and integrity.[5]

Whether an asset is scrapped *right out of the gate* or is repaired and shipped, the workflow (or flow) must be managed from receipt and induction. Again, CCPM proves applicable as it focuses on managing and streamlining flow through multiple gates[6]. This focus on flow has several benefits that address current and inherent problems at the SRF:

- Reducing WIP by deferring induction until the work can commence...and continue with the least amount of uncertainty
- Integrating contingency or buffers to counter the effect of uncertainty and variability
- Allowing individual tasks to be late while, more importantly, managing the buffer as a measure of performance (rather than the tasks' performance)

[5] These performance statistics were obtained from "Multi-Project Critical Chain: Three Vital Points"; a publication of the professional firm, Realization Technologies, 2009.
[6] See "Terms" in the appendix for more on gates.

In addition to the benefits, CCPM is said to "attack policies" as a second strike toward increased performance. The policy changes recommended (or required) are:

- Replacing metrics that require individual tasks to complete on-time with metrics that drive down WIP
- Mandating a minimum amount of protection, about 50 percent of the sum of the task's duration, to assure uninterrupted flow [7]
- Engage Repair-To-Cycle-Time (RTAT) as a true and applied metric in support of throughput improvement and, as a percent, WIP
- Purge the SRF of all assets that are decisively *dead-on-arrival* [8]
- Deploy CCPM (and Buffer Management) to every aspect of SP&C from long-term integrated planning to daily schedule control[9]

Policy changes will not be easy: policy may be required per contract modification, internal or industry governance; it could require *an act of congress.*

In a multi-project environment, CCPM addresses the multi-project constraint. One example of a multi-project constraint (at the SRF) is the supply chain; where the aging-aircraft (program) incurs increasingly more constraints in with the resources called suppliers, materials, and technology (or knowledge).

In dealing with these constraints, the organization has increased emphasis and development on demand modeling and forecasting of critical, discrete[10] parts (refer to section 2.1, Supply Chain). Such internal measures are paying dividends on proactive (versus reactive) acquisition as a hedge against known long-lead time and limited inventories.

Still, the programs must contend with contract and policy that dictate such purchases on an as-need, or incidental basis, rather than as anticipated. Such policy clearly requires change in order to reap the benefits of demand modeling. From the effort already applied in mitigating the effect of this multi-project constraint, the organization can (or has) pursued some form of mutual-investments (customer and supplier) to increase inventories of such critical items.

[7] In the planning of a project, CCPM drives down multi-tasking by delaying task starts, cutting tasks' estimates, passing the cuts to buffers. More information is presented in the next section. This policy change would necessitate some data collection and analysis regarding activities unique to asset types, direct and support functions in the SRF.

[8] The use of "dead-on-arrival" is metaphorical to a patient arriving to triage; the use of the term is not meant to be morbid but rather, to emphasize immediate removal of "bad assets".

[9] An example of CCPM applied to daily schedule control is found in the appendix.

[10] Here, "discrete" is used to denote detailed parts, critical components and the like.

# CRITICAL CHAIN

CCPM is an extension of Theory of Constraints (TOC); it is based on principles that help to identify impediments to your goal(s) and effect the changes necessary to remove them. The keystone resource for TOC is *The Goal* by Eliyahu M. Goldratt.[11]

## 3.1. Theory of Constraints (TOC)

In TOC, a "chain" represents the collection of steps or activities of a system; the strength of the chain is dependent on the weakest or "critical" link (task or activity). For any significant improvement in the system, the critical constraint must be identified and "exploited" to effect substantive improvement.

With the common and universal goal of making money or profit, TOC outlines the means toward "the goal":

1. Increase Throughput
2. Reduce Inventory
3. Reduce Operating Expense

To increase throughput offers unlimited opportunity.

Further, TOC emphasizes the feedback mechanisms of a system to re-examine all actions and measurements of the goal using:

- The Socratic Method
- Five Focusing Steps
- Evaporating Clouds
- Reality Trees

These mechanisms are essential to CCPM applied to Scheduling, Planning and Control (SP&C). Some details of each, along with sources of information, are provided in the appendix.

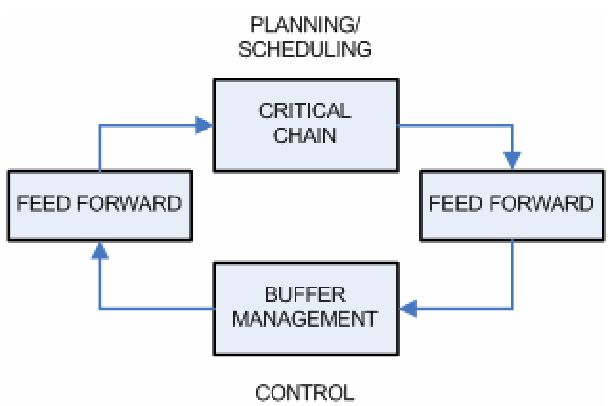



**Figure 2 – Basic Project SP&C Feedback.**

[11] Goldratt's theories aim at improving manufacturing processes by finding the "bottlenecks" in the manufacturing process and then exploiting those bottlenecks to either increase the flow of product through it or bypass it with other systems. *The Goal* was originally published in 1984 with revisions every few years, once in 1992 and again in 2004.

## 3.2. Critical Chain Project Management (CCPM)

Critical Chain is common to organizations and industries such as: NASA, the USAF and USN, and a multitude of defense and military contractors (including BOEING). Programs, projects and similar "systems-level" developments general represent opportunities for application; for example, Boeing has realized significant benefits in R&D projects among other areas. [12]

As to projects (or programs), Critical Chain resolves conflicts of cost, schedule and quality on the basis that: time or duration to complete any single activity or series of activities is predictable, of course; but it is also probabilistic: the estimate, the duration, has inherent variation as illustrated in Figure 3.

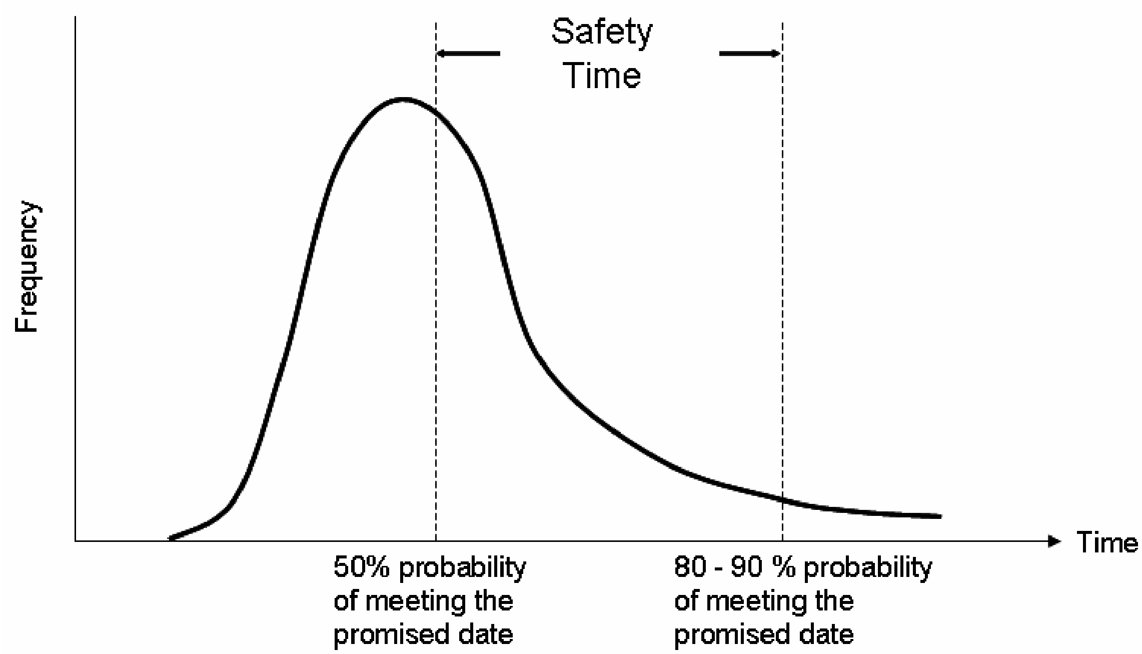



**Figure 3 – Activity Time/Duration is Probabilistic; Inherent Variation.**

Yet even with the *certainty of uncertainty*, estimations of duration are often treated as discrete or non-probabilistic; and in this treatment, each group or team is held to "their" due date—as a PUSH system! And what is wrong with a discrete estimate, a singular completion date, or PUSH system? Well, as applied commonly to manufacturing processes, a PUSH system (as opposed to PULL) produces waste in the form of increased WIP, idle time, and other workflow disruptions.

[12] Other areas include, by program: 777 Airframe, Interiors Design; F/A-22 Assembly; 777 Assembly (CC303); 747 Section 41; F-18 Support Equipment; and 7E7.

From *The Billion Dollar Solution* by Robert C. Newbold, the following on the uncertainty of time, it's many classes:

> There are many classes of uncertainty with respect to time. Variability can be measured through the range of possible durations for a particular task. The "known unknowns" include various risks that you can take into account and that may or may not happen. The "unknown unknowns" are completely unexpected.

These classes (or complexity) of variability underscore the danger—the engineered risks—of relying on discrete durations and dates.

To answer the question (of PUSH versus PULL) in the scope of Project Management is to understand that, since variation is inherent, **the probability of completing the activity on a particular date is not realistic**; and with activities in series, the problem is compounded as illustrated in Figure 4: as the project commences and deadlines expire (as common occurrences through delays and extensions), the response is typically "crashing" or compressing the series' durations.

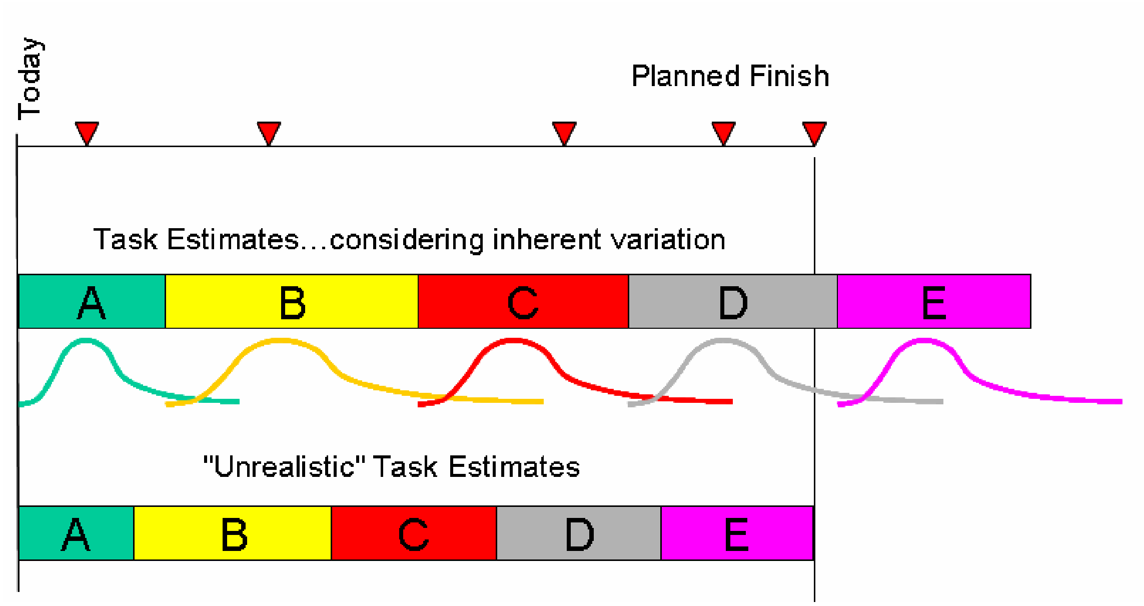



**Figure 4 – Series of Activities Treated as Discrete Durations is Unrealistic.**

But as early as estimates are developed and submitted, such conventions of discrete estimates and schedule "crashing" are cause for the estimating sources to "pad" their estimates as a form of risk planning. To "pad" or inflate estimates, both duration and effort, becomes contagious and pandemic.

Further, and as the plan is executed, a consequence (of the PUSH) is to work out of sequence…and on multiple jobs or work packages. Each and all of these practices are counter-productive and inefficient as Steve Holt adds:

> "Done" often means "I've reached the due date" instead of "I've completed the task to my customer's satisfaction." This results in passing on incomplete work or "throwing work over the wall" to the next group even if it is not usable in its present form.

Further, a "Date Driven" approach, rather than execution to plan, contradicts the basic tenants of Lean:

- Make to use (pull)
- Eliminate waste
- Defects are not made, passed, or accepted

CCPM exposes these causes for unrealism by accepting the inherent variation and, in turn, planning accordingly as shown in Figure 5: rather than driving the series (PUSH), CCPM establishes a PULL via "Schedule flexibility" in the form of Buffer and purposely delayed or deferred activity starts.

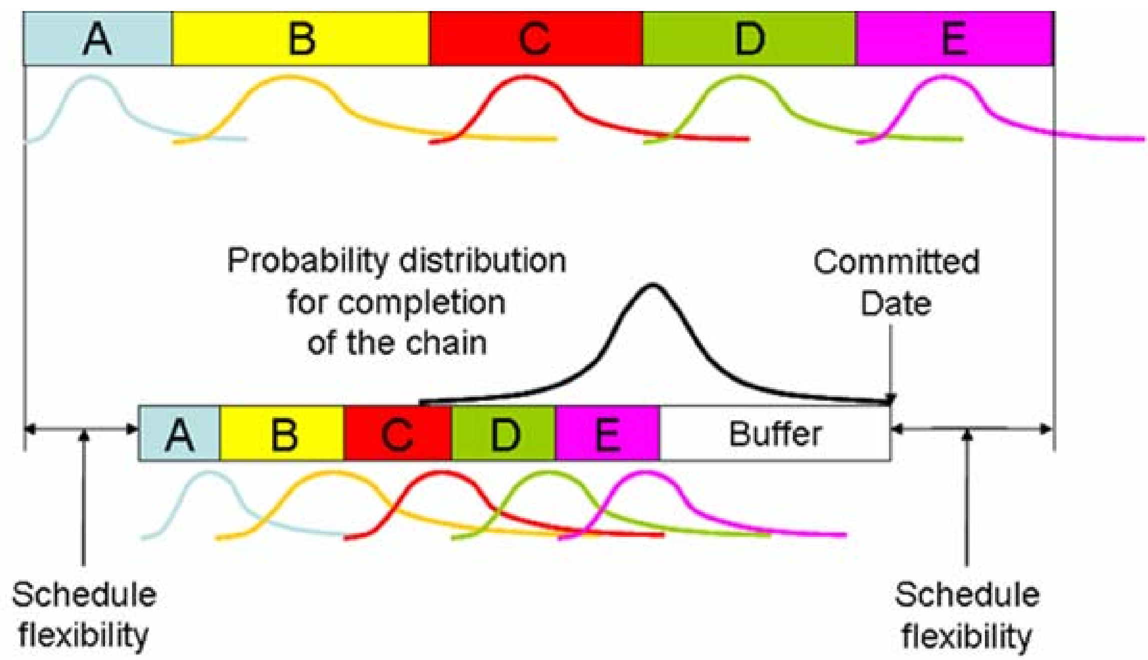



**Figure 5 – Buffer and Deferred Activity Starts result in "Schedule flexibility".**

Using the analogy of a 400 meter relay team, CCPM places much emphasis on a smooth, timely transition—in keeping with the plan and logic. While the variation is curtailed by limiting planned duration to half the estimated duration, buffer management is employed to effectively manage some of that expected variation. These buffers are illustrated in Figure 6, and are used tactically at the following network locations:

- the beginning of a series, as Feeding buffers
- at the end or terminating point of one or more series
- on the Critical Chain—or the longest series of activities in terms of duration

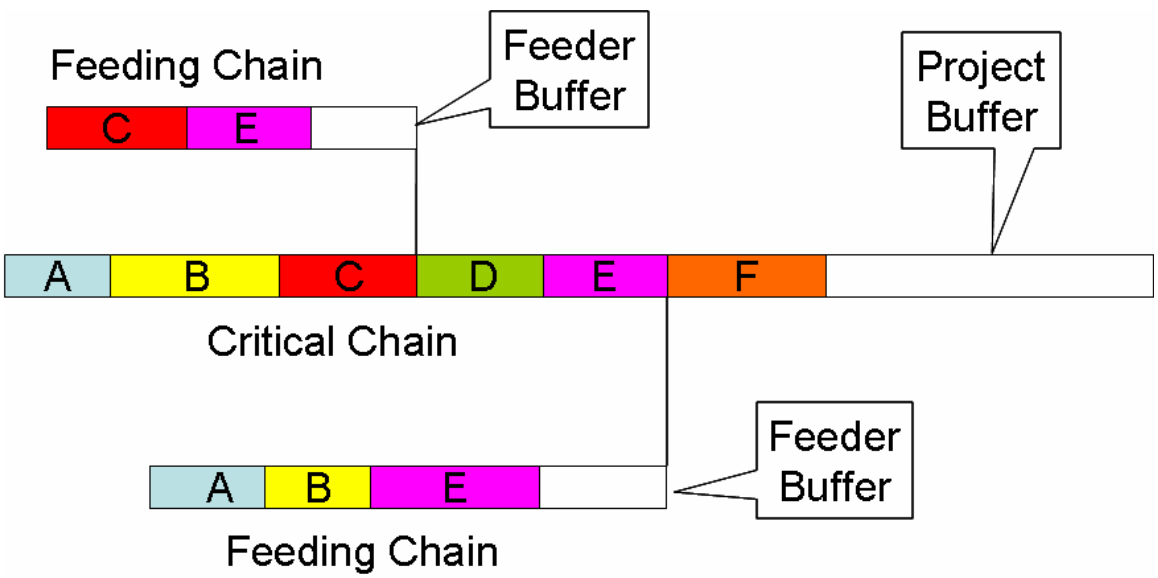



**Figure 6 – Buffer applied to the Feed and Critical Chain, and the Project**

Buffer (Management) is a process too; it is part of data collection and feedback on progress against schedule. The buffers subordinate the tasks to the total project completion time and ensure that the team is able to fully exploit reductions in completion time.

In the most basic example or description, the data-collection process would include the following questions:

- What task are you working on?
- How long until you're done?

**To follow the path of collecting percent complete is engineering further risks or waste; the end-date becomes illusive**—the last small percent of completion inflated much as estimating described previously.

To support of buffer management, CCPM employs the "Fever Chart". This chart, as illustrated in Figure 7, provides a first-alert regarding risks to schedule completion. Question considered in the use of the chart include:

- What's going on?
- What are you doing about it?
- Do you need any help?
- What can we do to keep this from happening again? [Promotes organizational learning]

Using an almost-universal color scheme, the Fever Chart is the early warning of potential or certain problems. Each color carries the following description-action:

- **Green**: Don't worry, Be happy
- **Yellow**: Watch/ready risk-response plan
- **Red**: Deploy risk-response plan (overtime, extra people, etc.)

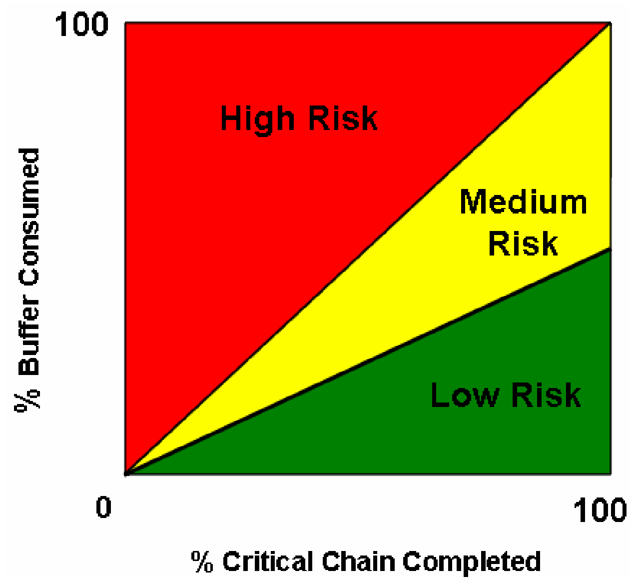



**Figure 7 – Fever Chart for Buffer Management.**

## 3.3. "The Goal" and the SRF

In addition to the title of his first book, "The Goal" is basically defined as "making money…both now and in the future".

The means (to the goal) involves the three earlier stated measurements of throughput, inventory and operating expense. Increasing throughput while decreasing expense maximizes net profit; and if inventory (expense) is also reduced, then ROI is maximized.

Specific to maintenance or repair (and the SRF), "The Goal" is making money while maximizing value to the customer. This value—though not necessarily measured in ROI[13]—does encompass cost and schedule metrics both within EVM and specific to the contract, the customer's requirements.

After arriving at and confirming "The Goal", an organization proceeds with "The Five Focusing Steps":

1. Identify the factor limiting the system's performance (the constraint)
2. Decide how to exploit (get the most out of) the system's constraint
3. Subordinate everything else to that decision
4. Elevate (get more of) the system's constraint
5. Note: this is the first step that costs any money If the constraint has been broken, go back to Step 1 and start again in a process of on-going improvement

Some details of "The Five Focusing Steps" are provided in the appendix.

Applied to the SRF, these "Steps" would be routine for each project (or each asset in WIP) and intermittent at the multi-project environment—both with the program as well as across all programs at the SRF and the larger enterprise to include any and all potential constraint sources:

- Cecil Field operations, support and services
- Regional and Divisional Boeing supply chain, engineering and other support resources
- External supply chain, governance (DCMA), subcontractors, partners and similar co-ops.

For where *the rubber meets the road*, a scenario of the daily routine (the Boardwalk) under the influence of CCPM is provided in the appendix.

[13] ROI does not apply because, as a rule, the defense department's performance does not include profit.

# CONCLUSION

As an MRO, the SRF represents the type of industry and environment for which CCPM is applicable and valuable: the effect of inherent variability and uncertainty that is part and parcel maintenance is acknowledged and treated through this extension of "The Goal".

Time and again, the success of CCPM has been proven in both the industries public and private sectors and through some divisions at Boeing:

- Throughput has increased,
- WIP has decreased,
- ROI (where applicable) has been raised

Hence, the value of establishing a probabilistic (versus discrete) based plan complete with risk response planning (e.g. buffer management).

Integrated SP&C is increasingly taking hold through the effort to grow the operations' services and expand market share. This development has much bearing on the consideration of CCPM as a PM methodology—as integrated planning has and will explore a horizon far beyond....

Whether considering the discrete material requirement for an asset—as a type of project—or furthering the horizon for planning capacity, the organization must exploit the constraint and subordinate all other, lesser issues. CCPM is the methodology that fosters the discipline to *separate the forest from the trees*—to focus on the single, current constraint rather than peripheral issues.

Continuing to counter uncertainty and variability with expedience (crashing, multi-tasking, date-driven, estimate inflating) is futile—as such practices are counter-productive and inefficient. The methodology of the "The Goal" is data-driven—with the accepted and realistic advent of probability into the planning process from the single project to all projects collectively called WIP.

As probability becomes the accepted—and respected—condition, the SRF can begin to realize increased scheduling integrity in conjunction with the necessary agility necessary for responding to inherent and uncontrollable uncertainty. Residual capacity will always be necessary as part of the organization's risk response plan, but in the presence of CCPM, is treated as an asset—rather than liability—as part of buffer management.

Resources are replete at Boeing; thus enabling the SRF to leverage CCPM with minimal costs and risks. Steve Holt—as a resident subject-matter expert—has not only been a major contributor to this paper but stands ready to champion the cause for CCPM within and beyond the rank and file.

Finally and farewell, my appreciation goes to the SRF, Cecil Field and the Boeing organization for their support in my completion of this paper—and my journey along pathways with its own forms of uncertainty and variability.

# APPENDICES

## Acronyms

| | |
|---|---|
| **BER-BPR** | Beyond Economic Repair-Beyond Physical Repair |
| **DCMA** | Defense Contract Management Agency |
| **MRB** | Material Review Board |
| **MSR** | Maintenance Service Record |
| **NDI** | Non-Destructive Inspection |
| **PMB** | Plastic Media Blast |
| **RTAT** | Repair Turn-Around Time |
| **SOW** | Statement of Work |
| **SRF** | Structural Repair Facility |
| **RTAT** | Repair Turn-Around-Time |
| **WIP** | Work in Process |

## Basic Game Rules

- ✓ Work on the high priority project
- ✓ Critical chain tasks have priority over feeding chain tasks
- ✓ Earlier scheduled tasks have priority over later scheduled tasks
- ✓ The above rules are subject to buffer management decisions
- ✓ Work as quickly as possible - at a sustainable rate
- ✓ Hand-off the deliverable as soon as it meets requirements - to the next resource in the chain

## Boardwalk (CCPM applied to daily schedule control)

Within the vein of Lean, Boardwalks are carried-out at the SRF and Cecil Field. The following scenario applies strictly to the SRF...as the subject of this paper. As an introduction:

Format of the Boardwalk focuses on the schedule-delivery status; for each/all programs (multi-project) and each asset (project) for a period from one to as many as six months.

Information or data in within the *7 Flows* [14] of Lean with a concentration on material and engineering support: material requirements (shortages) are identified , assigned action & reported; engineering issues (or Non-Conformances) are address on a singular basis and a collective basis—where an asset has multiple issues—with similar action & reporting.

Attendance includes all functional areas; active participation is concentrated between the asset manager(s) and the SRF manager with incidental participation by other attendees.

In the table below, a scenario for CCPM

| Facilitator | Asset Manager | Constraint Resource |
|---|---|---|
| Okay, Asset X-1; are we on schedule? | Yes; will deliver as scheduled | |
| Okay, Asset Y-2; are we on schedule?<br><br>NCR Y-2; engineering, what is status and response plan?<br><br>Okay; please provide updates—if something changes.<br><br>Is there another potential constraint? | No; the asset is held for engineering; this **could be** the critical constraint<br><br>No; everything else is okay. | Y-2 is on the watch-list; a disposition should be delivered no later than next Friday.<br>Okay; if something changes... |
| Next asset....on schedule<br><br>Okay; what is the response plan for this critical constraint?<br><br>Okay; move this item to Red and proceed with a schedule change notice. | No; that material need—that is Yellow has slipped again—and by all indication—will not arrive until....<br><br>Okay on the schedule change | We contacted the supplier via the purchaser; a rush order is being applied to offset the delay; still, the item will not arrive until at the earliest....<br><br>Okay on the item status... |
| Next asset... | | |

[14] *7 Flows* (of Lean) include: raw material, WIP, finished goods, operators, machines, information, and engineering.

# Feedback Mechanisms

Feedback mechanisms include: The Socratic Method; Five Focusing Steps; Evaporating Clouds and Reality Trees.

**The Socratic Method**: is a form of inquiry and debate between individuals with opposing viewpoints based on asking and answering questions to stimulate critical thinking and to illuminate ideas. It is a dialectical method, often involving an oppositional discussion in which the defense of one point of view is pitted against the defense of another; one participant may lead another to contradict him in some way, strengthening the inquirer's own point.

It searches for general, commonly held truths that shape opinion, and scrutinizes them to determine their consistency with other beliefs.
Source: http://en.wikipedia.org/wiki/Socratic_method.

**Five Focusing Steps:** these steps are for on-going improvement; each is briefly described.

1. **Identify** the system's constraint - Like a doctor assesses symptoms and draws a conclusion that they come from a common source, a review of the undesirable symptoms that an organization suffers from can quickly lead to a diagnosis of the system's constraint.

2. **Exploit** the constraint - to exploit it translates to making sure that we are squeezing the most we can out of it. Utilization and productivity of the constraint must be maximized.

3. **Subordinate** everything else - subordination suggests that our use of the constraint itself should not be allowed to be limited by anything else that's outside of its control, including policies, habits, and assumed requirements of non-constraint.

4. **Elevate** the system's constraint – with the "everything else" subordinated, it is commonly found that there is far more untapped capacity than previously thought.

5. **Prevent inertia -** If, in a previous step, a constraint has been broken, go to step 1 and begin again. The new constraint demands a whole new view of the system.

By using your organization's current constraint as the initial target, you will be able to apply your efforts in the most effective place, getting the most bang for the buck in the short term and setting the stage for a process of truly on-going improvement.
Source: http://www.focusedperformance.com/poogi1.html.

**Evaporating Clouds:** a solution to conflict between two parties or two points of view, it requires a 'win-win' solution where both parties are trying to reach the same ultimate goal.
Source: http://en.wikipedia.org/wiki/Evaporating_Cloud

**(Future) Reality Trees**: a future reality tree test the future outcome using known cause and effect to check that what is wanted will be the outcome or effect; it is the tool of choice in gaining understanding and agreement that the solution will account for all of the undesirable effects in the current tree.
Source: http://www.dbrmfg.co.nz/Thinking%20Process%20FRT.htm

## Getting Started (with CCPM)

1. Identify precedence of tasks and critical path.
2. Identify resources required to complete each task.
3. Plan to an aggressive 50% confidence schedule.
4. Move all tasks as late as possible.
5. De-couple conflict with resource constraints.
6. Select a critical chain (can be a precedence path or a resource path).
7. Insert the project buffer.
8. Insert the feeder buffers.
9. Insert the resource notification buffers.
10. Initiate and Control using Feedback Mechanisms, Buffer Management, etc.

## Metrics

A metric is a measure, made over time, which communicates vital information about the performance of a process; here are some common types:

**Quality**: is a key performance category that supports process performance in meeting or exceeding customer expectations. It is a measure of conformance or non-conformance to requirements or expected performance. Typically a quality metric is captured as a ratio of good/total or bad/total.

**Delivery Time**: a key performance category that supports process performance in meeting or exceeding customer expectations. It is a measure of success in meeting a schedule event or commitment. Typically a delivery time metric is captured as a ratio of on-time delivery/total or late delivery/total. In EVM, an example would be the Scheduling Performance Index (SPI).

**Cost/Efficiency**: a key performance category that supports process performance in achieving superior business results. It is a measure of cost or efficiency to process or process step output. Typically cost/efficiency metrics are captured as a ratio of cost/time to output. In EVM, an example would be the Cost Performance Index (CPI).

**Cycle Time**: a key performance category that supports process performance in achieving superior business results. It is a measure of the total process time starting when all required process inputs are available and ending when the product or service is received by the customer. Typically cycle time metrics are captured as the elapsed time between two events.

## Quotes

***Planning and scheduling accuracy…***

"The problem with expecting project scheduling to produce an accurate forecast of the future is it is impossible to accurately forecast or control the future. The solution to effective project delivery lies in a different direction…."
"The critical role of the schedule is to inform decisions being made by people about their future actions so that the optimum decisions are made to drive the project to a successful conclusion."

- "Scheduling in the Age of Complexity", Patrick Weaver, PMI-COS May 2009

***Power for project management…***

"I like to think of Critical Chain Project Management as a performance engine for projects. And, by "engine" I don't mean the thing under the hood of a bright red Ferrari, I was thinking more of the 4000-6000 horsepower turbo-charged diesel engine that sits under the long hood of each locomotive at the front of a North American transcontinental intermodal freight train."

- "A Guide to Implementing the Theory of Constraints (TOC)"; http://www.dbrmfg.co.nz/Projects%20Critical%20Chain.htm

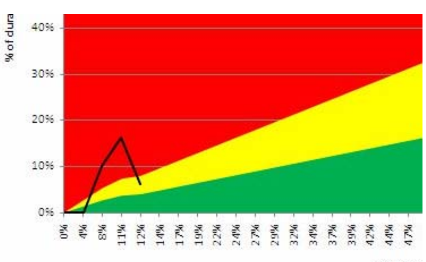
***Contrast to traditional Project Management…***

"A Critical Chain project network will tend to keep the resources levelly loaded, but will require them to be flexible in their start times and to quickly switch between tasks and task chains to keep the whole project on schedule."

- http://it.toolbox.com/wiki/index.php/Critical_Chain_Project_Management

***Catching the fever…***

"The buffer penetration line crept up with renewed intensity. Worse, this was the second week it remained in the Red zone. My earlier conversations with the powers that be did not appear to help. Developers were being pulled into higher priority tasks. But now I had data. A week of people unable to work to the plan meant the project was going to be delayed by a month; and we had just kicked off the project. Sigh! … Some time later … "What I like about the fever chart is that it highlights a project **heading into a ditch** long before it gets near a ditch." Did a non-believer just get converted?"

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## Stories

**"ON TIME, ON BUDGET, THE CHALLENGE"**

If you want to improve the strength of the chain, concentrate your efforts on strengthening the weakest link. To do this, first identify the weakest link, which is the constraint. Then concentrate on improving the weakest link without subjecting the organization to too great a load. Eventually, the weakest link will improve to the point where it is no longer the weakest link, thus eliminating the constraint and maximizing throughput.

Source: http://www.goldratt.co.uk/Successes/full/bae.pdf

**"APPLYING THEORY OF CONSTRAINTS PRINCIPLES AND LEAN THINKING AT THE MARINE CORPS MAINTENANCE CENTER"**

The principles in Theory of Constraints can be used in conjunction with Lean thinking to leverage even more benefits for the enterprise. Like Theory of Constraints, Lean thinking is a means of enabling a growth strategy.4 Unlike Theory of Constraints, which primarily focuses on the bottleneck, Lean thinking is focused on reducing waste at all levels and in the process of doing so, it uncovers additional capacity that could be deployed for further growth.

Managing a maintenance, repair, and overhaul (MRO) facility is a more challenging task than managing most manufacturing facilities because of the high degree of uncertainty that prevails in repair operations….

In the MRO facility, the work scope of a product that arrives at the facility is not known unless the product is disassembled and inspected. There is a tremendous variation in the work scope even for the same type of product… and it is difficult to accurately predict the percentage of parts that must be replaced and the percentage of parts that should be repaired. To add to the complexity, the original manufacturer may no longer produce the parts that have to be replaced.

Source: http://www.dau.mil/pubscats/PubsCats/AR%20Journal/arq2004/Srinivasan.pdf

**"KEEP THE CHAIN INTACT"**

On the commercial satellite program, "We made a commitment to adopt CCPM as our new operating mode, and this decision really paid off by helping us identify and focus on the most important tasks at any given time,"

The result: The team is on track to complete the system design phase in 15 months, compared to the 36 months it took on a similar program.

Source: http://www.boeing.com/news/frontiers/archive/2007/july/i_ids01.pdf

## Success Factors

- Successfully applying CCPM requires two critical success factors:
  - You must have a good enough project plan (precedence network, resources)
  - You must have the right execution behavior
- Execution in CCPM follows the principles of the ***10X Lean+*** Disciplines
  - Establish Clear Priorities
  - Eliminate Bad Multitasking - Focus and Finish
  - Limit the Release of WIP to Deliver Earlier
  - Prepare! Start Finish
  - Use Checklists to Prevent Defects & Traveled Risk
  - Face-Into and Resolve Issues Quickly
  - Drive Daily Execution
- Imperatives
  - Leaders **must not** remove the buffer because it is necessary to pay for unknown unknowns, unplanned work, and quality
  - PM cannot beat up team for late deliverables – **expect that ~50%** of deliverables will be late (what matters is buffer consumption!)
- Team Operating Mode
  - Plan to 50% aggressive schedules
  - How long will it take to do each task if we have all the inputs/resources when we need them?
  - Disciplined preparation so you are ready (i.e. baton in relay race)
  - Get work done as quickly as possible with necessary quality
  - Handoff items immediately when task is complete
  - Communicate progress in time remaining
  - Make progress very visible
  - Use fever chart to communicate the progress of the team

## Terms

**Bottleneck**: the primary constraint in a flow; the most limiting capacity process step.

**Buffer**: durations placed strategically in a project to protect against unanticipated delays or uncertainty; a buffers is **not** slack, but is contingency interjected as a feed to a series of activities and for the project overall.

**Critical Chain**: the longest chain of dependent activities in a project.

**Flow Time**: the amount of time it takes to accomplish the processing sequence, including queue and move times

**Gating Task**: or Gate, it is a task not yet started and that has no predecessors.

**Lead time:** total time a customer must wait to receive a product after placing an order. When a scheduling and production system is running at or below capacity, lead-time and throughput time is the same. When the demand exceeds the capacity of a system, there is additional waiting time before the start of scheduling and production, and lead-time exceeds throughput time.

**Lean Manufacturing**: a set of Principles and practices which focuses on eliminating waste and non-value added activities in manufacturing and support processes

**Multi-tasking**: not that this term is not common today, but applied to PM, it is an inefficient and therefore undesirable interruption of one task to complete another—the consequences of which is much longer to complete a single task.

**Parkinson's Law**: put simply, the demand upon a resource tends to expand to match the supply of the resource—but the reverse is not true.

**Pull Production (JIT)**: a system where parts, supplies, and information are pulled by internal and external customers exactly when they are needed.

**Push Production**: a traditional inventory system where parts are processed by their schedules and pushed on to the next process regardless of whether they are needed at that time.

**Stabilized Process**: a process producing consistent output as verified by facts and data; a stable process is one in which no special cause variation exists…it is in statistical control.

**Student Syndrome**: waiting until *the 11$^{th}$ hour*, to complete the task (or cram for the exam).

**Task Engagement**: the opposite of multi-tasking, it offers greater efficiencies through by reducing/eliminating the waste of task shifting and juggling.

**Variation**: a change in data, a characteristic, or a function that is caused by one of four factors: special causes, common causes, tampering, or structural variation.

**Waste**: anything that does not add value to the product or service in the eyes of the consumer; pertains to waste of materials, defective goods, errors, idle materials, time transportation, energy, space, overproduction, labor, and complexity.

## What CCPM is…and is not

- Is NOT a substitute for Program Management Best Practices
- Is NOT a substitute for leadership or technical competence
- Serves as an intuitive & logical approach to managing project uncertainty
- Serves as a methodology to facilitate consistent project management
- Helps to focus on what is truly important
- Helps to facilitate team communication and coordination
- Creates high visibility to the critical chain for the project
- Provides a leading indicator as to when projects will complete
- Aims to increase customer trust by improving schedule confidence