Lecture 11: Critical Chain and the design process

Background

- These slides were borrowed from a presentation given by Steven Cook
- Based on work done in an LFM project with ITT

TOC Fundamentals

"The goal of a manufacturing organization is not to keep machines busy, employ workers, provide good customer service, or be at the leading edge of technology. It is to make money, now and in the future."

Dr. Eli Goldratt

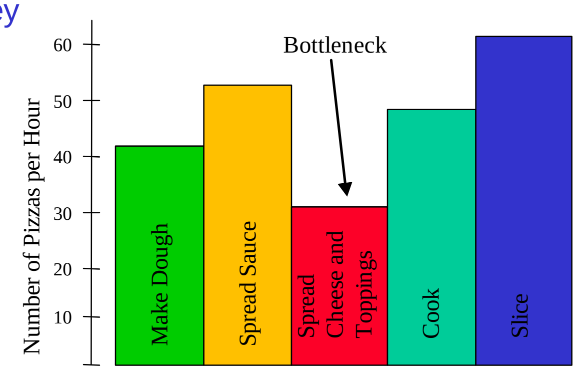
Conventional Wisdom...

- Inventory is an asset.
- Idle resources are wasteful.
- Big batches minimize cost.
- High product margins always mean higher profits.
- The most profitable plant is a balanced plant.
- To reduce cycle time we must increase capacity
- Overall performance is the sum of all "local performance."

Simplified Manufacturing Example

IPPD 3/14/00 Critical Chain

- An improvement to any area other than "Spread Cheese and Toppings" makes the pizza shop no more money



From presentation by Steve Cook

The Five Focusing Steps of TOC

IPPD 3/14/00 Critical Chain

- 1. IDENTIFY the system's constraint(s)
- 2. Decide how to EXPLOIT the system's constraint(s)
- 3. SUBORDINATE everything else to the above decision
- 4. ELEVATE (if necessary) the constraint
- 5. If, in the previous steps, a constraint has been broken, GO BACK to step one….but do not allow inertia to become the constraint!

From presentation by Steve Cook

"Typical" Project Management

- 50,000' level schedule
- Resources are given due dates, not task durations
- No buffer, later tasks are forced to make up any slide
- Local optimization
- Management attention on all tasks
- Resources not de-conflicted
- Judge resources on whether they completed by due date and quality of work

From presentation by Steve Cook

The Process is the Problem

The majority of all development projects fail to meet their time and cost targets, with the overrun typically between 40 and 200 percent.

Source:

Dr. Edward B. Roberts, Strategic Management of Technology:Global Benchmarking, December 10, 1992

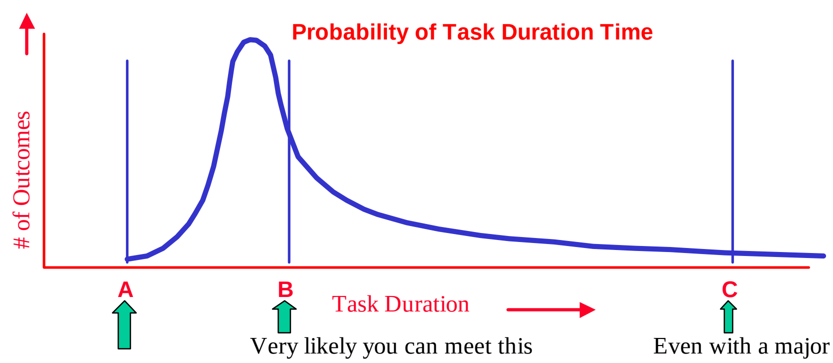
> "The system you currently have is designed to give you the results you are getting now."
>
> J. Covington

From presentation by Steve Cook

Critical Chain

- The goal of Critical Chain is to help projects finish on time, within budget, and without cutting scope.
- Main points-
  - Cultural change in how to manage projects and evaluate team members
  - Avoid multi-tasking while on the Critical Chain
  - Protect against uncertainty by aggregating all safety time at the end of the project
  - Concentrate on the constraint of the project: the longest chain of dependent tasks or resources

Which Time Are You Likely to Promise?



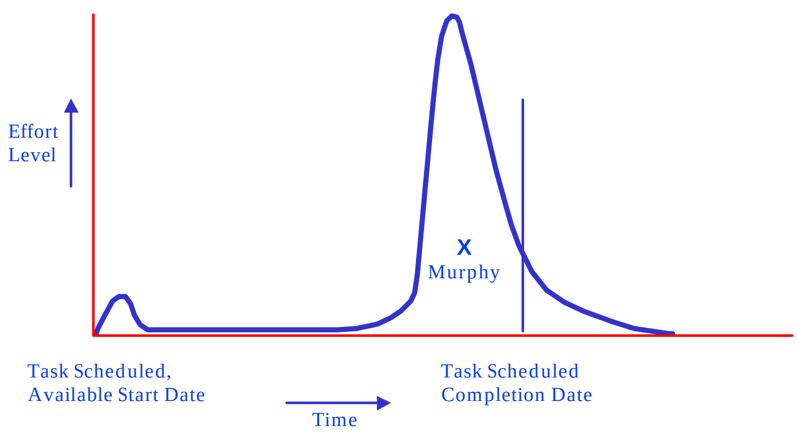
"Pure Success" basis-not likely to repeat

Very likely you can meet this time, even with some surprises. 50% of the outcomes are less than this, 50% are greater. This is the estimate CC builds into the schedule

Even with a major disaster this time is highly achievable, this is the time commonly used

The “Student Syndrome”

IPPD 3/14/00 Critical Chain



From presentation by Steve Cook

The Multiplying Effect of Multi-tasking

IPPD 3/14/00 Critical Chain

Task X
Project 1
One Week

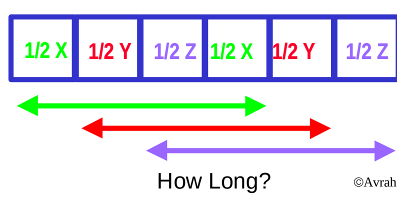
Task Y
Project 2
One Week

Task Z
Project 3
One Week

In order to keep each project on track, a resource does half of task X, then half of task Y, then half of task Z, then finishes task X then Y, then Z.

How long does each task take to complete?

What happened to the safety time?



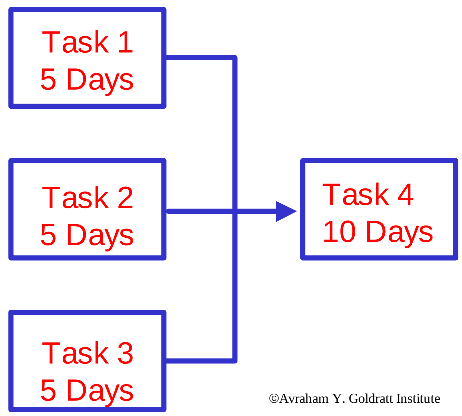
From presentation by Steve Cook

Delays Are Passed on – Gains Are Not

IPPD 3/14/00 Critical Chain

Merging paths don't allow us to benefit from tasks completed early.

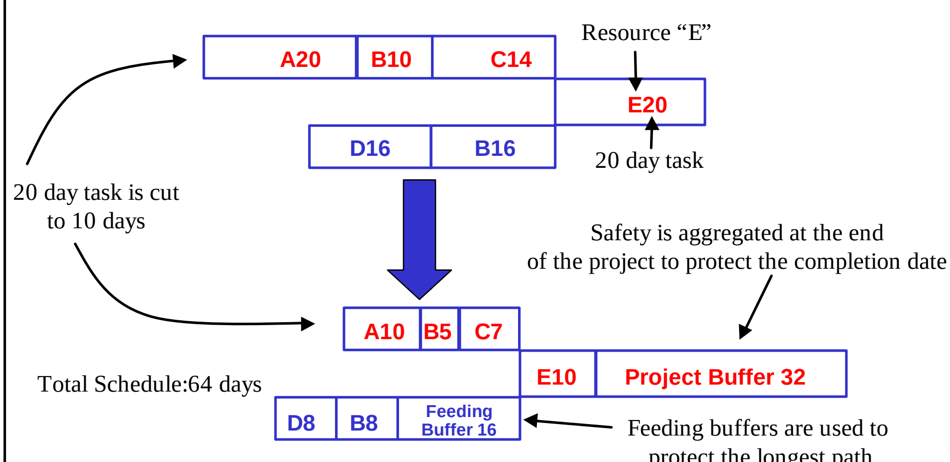
- What's the impact on the total project if Task 1 is done in only 3 days?
- What if Task 3 takes 8 days?
- What if Tasks 1, 2, and 3, through some miracle, all get done in 2 days? (Will Task 4 be ready to start 3 days early?)



From presentation by Steve Cook

General Critical Chain Approach

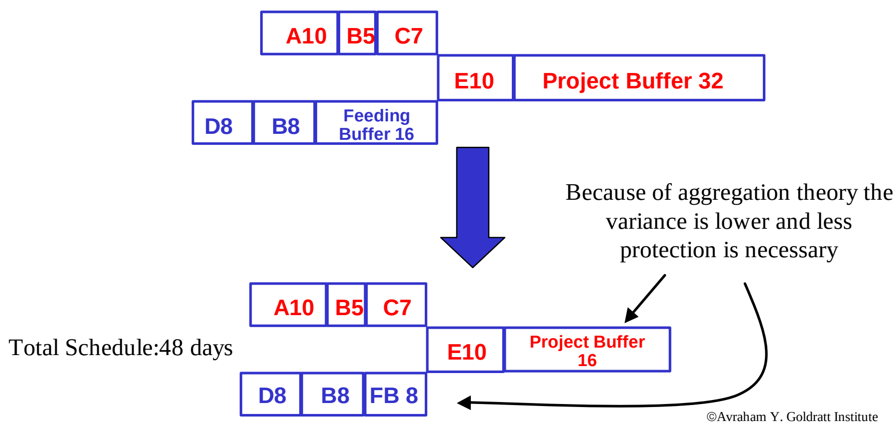
IPPD 3/14/00 Critical Chain



From presentation by Steve Cook

The Aggregated Buffers Can Be Smaller Than the Sum of the Individual Safety

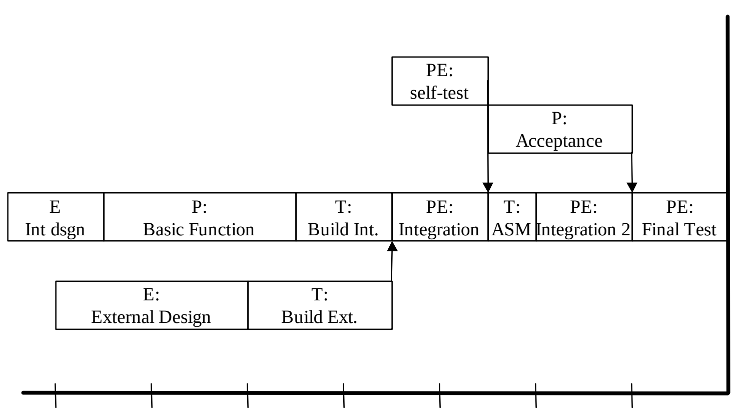
IPPD 3/14/00 Critical Chain



From presentation by Steve Cook

Create the initial plan

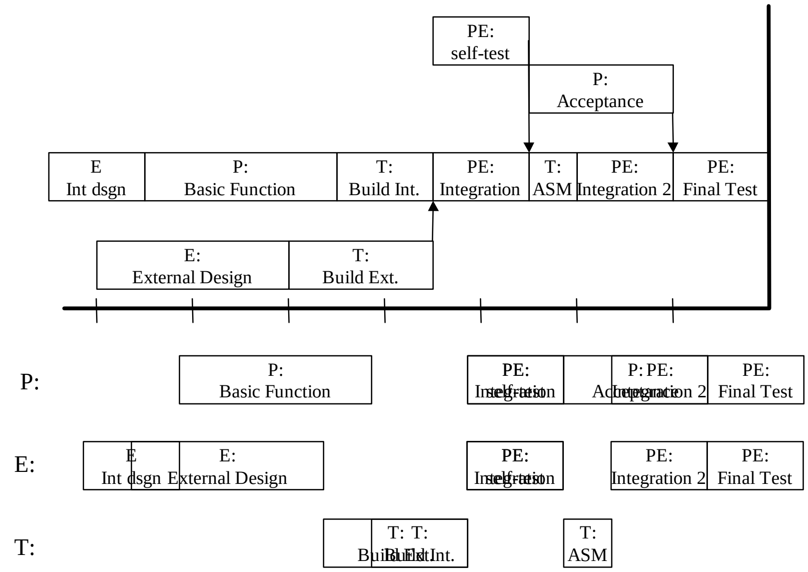
IPPD 3/14/00 Critical Chain



From presentation by Steve Cook

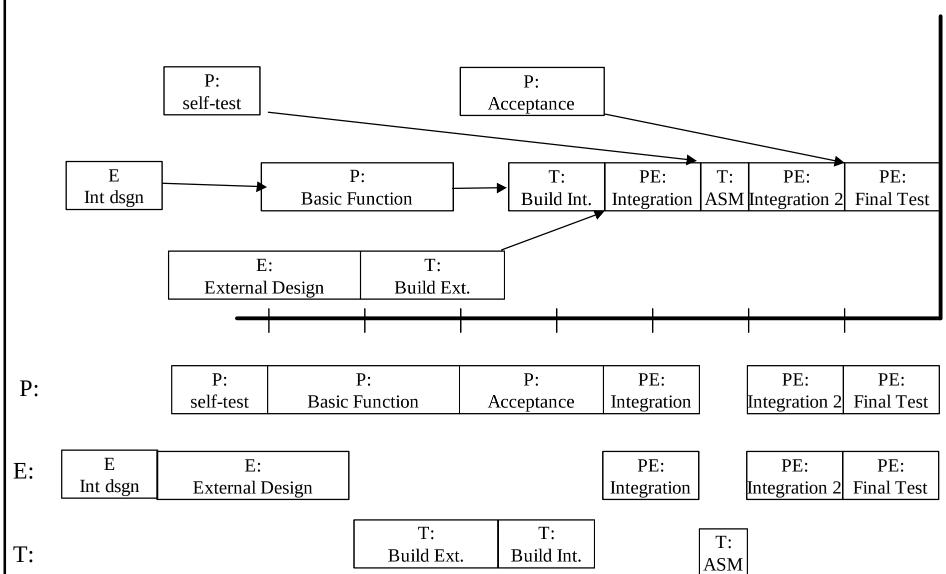
Check for resource conflicts

IPPD 3/14/00 Critical Chain



Level Resources

IPPD 3/14/00 Critical Chain



Notes about leveling resources

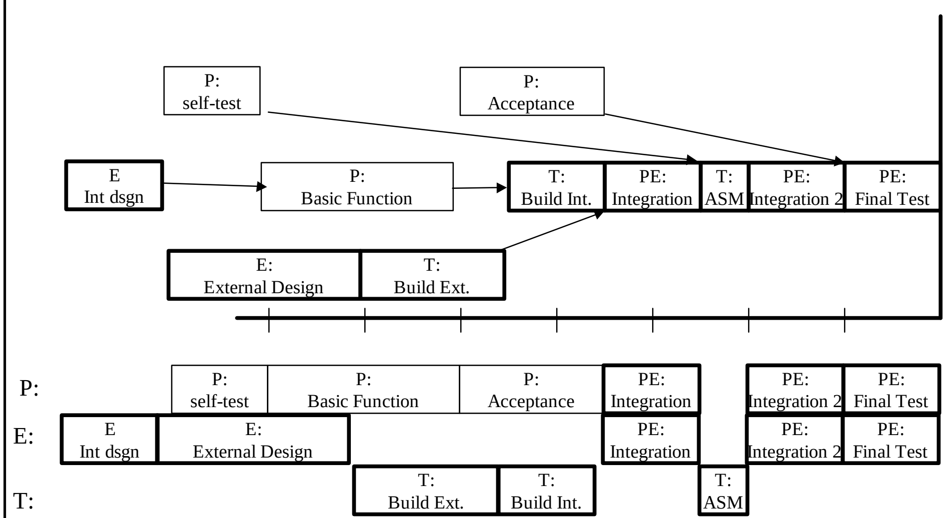
IPPD 3/14/00 Critical Chain

- There is no one solution
- There are many algorithms to do this
- Very important in critical chain not to just put people on who approve or have minimal input.

From presentation by Steve Cook

Identify Critical Chain

IPPD 3/14/00 Critical Chain

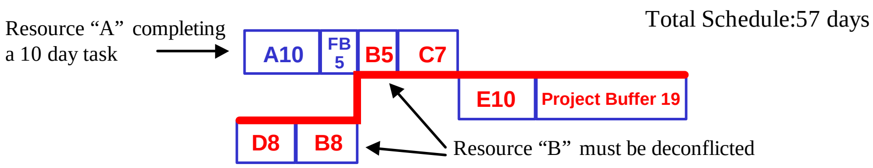


From presentation by Steve Cook

What Is the Constraint of the Project?

IPPD 3/14/00 Critical Chain

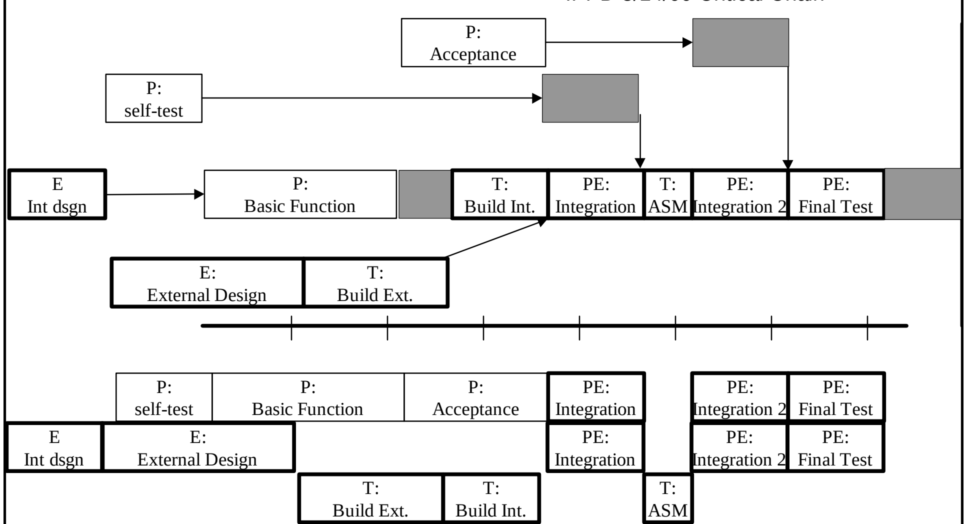
- **The longest chain of dependant resources**
  - ***Time***
  - ***People***



From presentation by Steve Cook

Add buffers

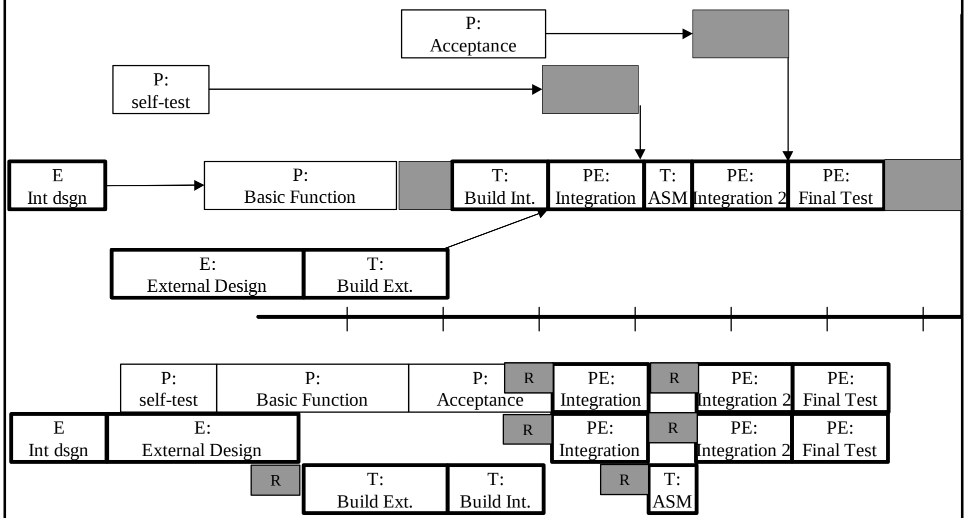
IPPD 3/14/00 Critical Chain



From presentation by Steve Cook

Insert resource readiness alerts (called resource buffers)

IPPD 3/14/00 Critical Chain



From presentation by Steve Cook

Resource Readiness alerts

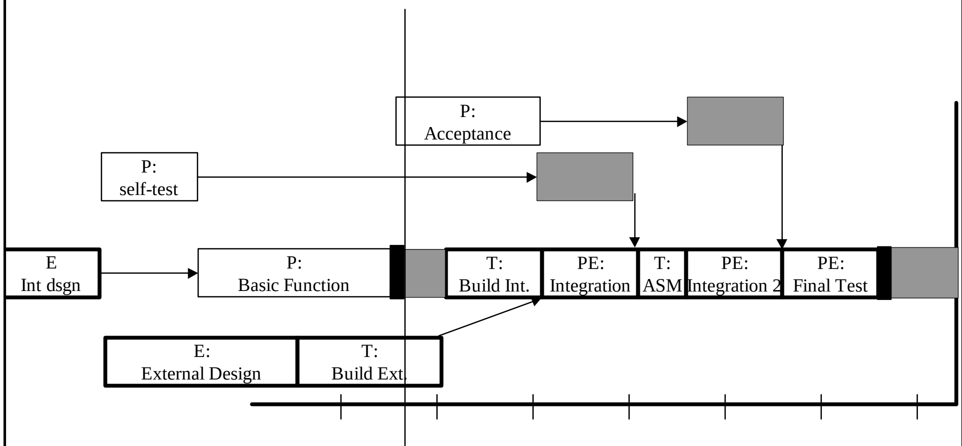
IPPD 3/14/00 Critical Chain

- Used to inform people that they are about to go onto critical chain
- Should clear their desk of other tasks
- Should not be asked by others to do tasks
- Physical “marker” on the door to indicate critical resource

From presentation by Steve Cook

Managing by buffers

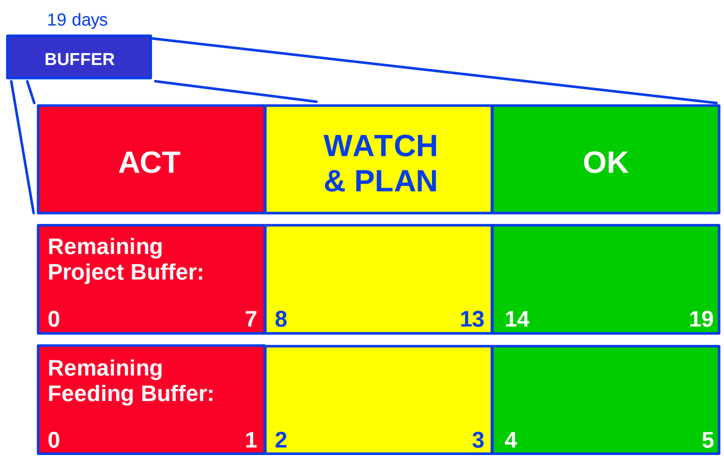
IPPD 3/14/00 Critical Chain



From presentation by Steve Cook

ITT approach

IPPD 3/14/00 Critical Chain



From presentation by Steve Cook

Training Your Team

IPPD 3/14/00 Critical Chain

- Recommend at least 1 day of training with most of the team JIT, use Goldratt the first few times
- All team members should have at least a 1-2 hour intro.
- Senior management needs to be trained and fully support the effort
- Its useful to have a CC champion or guru who can take over training and running the schedule workshops
- Other Program Managers should have intro. to understand new vocabulary

From presentation by Steve Cook

Dealing with Suppliers

IPPD 3/14/00 Critical Chain

- We found it very useful to partner with major suppliers and pay for their CC training
- If a supplier is a major part of the CC they should be part of the schedule workshop
- Otherwise, pay expediting surcharges only when the task will impact the Critical Chain
- Overall, CC allows you to be a much better customer to suppliers because you are not always “crying wolf”

From presentation by Steve Cook

Putting Together the Schedule

- Intense workshop with all key team members and possibly suppliers
- Start by spending a few hours to very clearly define the final objective of the team
- Starting at the final objective, work backwards to determine what task dependencies are necessary
- Break large tasks down to maximize task overlaps
- Two ways to deal with necessary iterations
  - try to pick 50/50 number of iterations and lay out all tasks (recommended)
  - conglomerate all iterating tasks into one summary task and use Eppinger's methods to choose appropriate 50/50 time

From presentation by Steve Cook

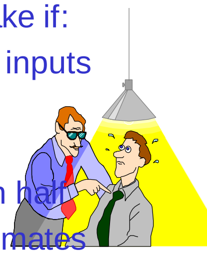
Assigning Resources

- Assign resources as a team, this really helps to clear up confusion down the road
- Identify the minimum people necessary to complete each task (don't capture if <10% of resources time is required)
- Avoid "Systems Engineer" who wants to be assigned as a partial resource in all tasks
  - this slows down primary resources
  - break out identifying system interfaces as a separate task

From presentation by Steve Cook

Assigning Task Times

IPPD 3/14/00 Critical Chain



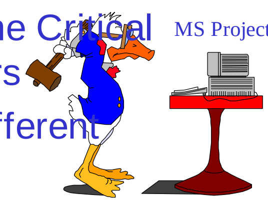
- Time ground rules- How long will this task take if:
  - 1) You have all necessary resources and inputs
  - 2) You only work on this task non-stop
  - 3) Either give best estimate of 50/50 time or give 85%-90% time and cut this time in half
- Peer pressure really helps to get honest estimates
- With the above ground rules team members can give much more accurate estimates
- We feel this will really help in the bid baseline

From presentation by Steve Cook

Working with ProChain

IPPD 3/14/00 Critical Chain

- During schedule workshop enter network and task data into MS Project in PERT format
- Recommend avoiding numerous summary tasks and milestones
- Ensure there is only one task with no successors (unless you want more than one project buffer)
- Level the resource load, identify the Critical Chain, create buffers, insert buffers
- Use numerous file saves under different names



From presentation by Steve Cook

Maintaining the Schedule with ProChain

IPPD 3/14/00 Critical Chain

- Ask all resources currently working on tasks how much longer the task will take to complete (not date)
- Enter the current date and task completion times
- Monitor the buffers only
  - buffer reports will direct management attention to the most high leverage tasks
  - attempt to work back to the original schedule
- As the dynamics of the schedule dictates, re-baseline by calculating CC, buffers, etc.
- Only use the ProChain icons

From presentation by Steve Cook

Intangible Benefits of Critical Chain

IPPD 3/14/00 Critical Chain

- Acts as a team building tool
- Improves employee morale
- Improves relationships with suppliers
- Clear communication between
  - team members
  - project managers with each other
  - project managers with management
- Improves bidding process
- Identify where additional resources
- Reduces the “everyone in on the weekend” problem

From presentation by Steve Cook

Cultural Keys to Successful Implementation

IPPD 3/14/00 Critical Chain

Tell me how you measure me and I will tell you how I will behave

From presentation by Steve Cook

Cultural Keys to Successful Implementation

IPPD 3/14/00 Critical Chain

- How team members are evaluated
  - Team is evaluated as a unit on overall project completion success
  - Individual task completion due dates and milestones must be de-emphasized to avoid suboptimization
- Management must hold up their end of the bargain- don't force multi-tasking
- Need support from the top
- All key team members must be trained and participate in putting together the schedule
- Need very clear communication between the schedule keeper and team members

From presentation by Steve Cook

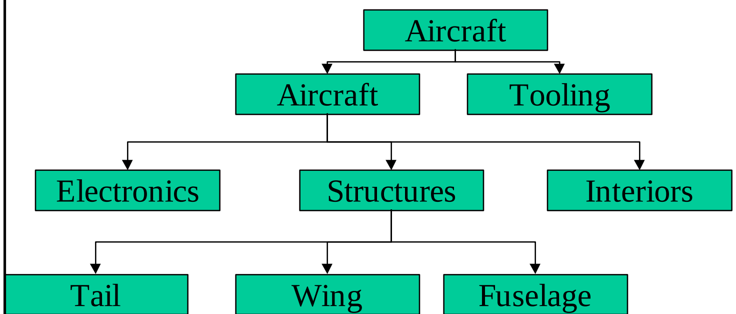
Design Processes

Product Development Time

- **Japanese**
- 1.7M hours dev. time
- 46 Months dev. time
- 1 month ramp

- **American**
- 3M hours dev. time
- 60 months dev. time
- 4 month ramp

Work breakdown structure



- Product is broken down into sub-systems
- Each sub-system is a “work package” and is assigned to a given group

Problem with WBS

- No system view of the product
- Assumes that if the parts are designed correctly the product will assemble correctly
- Does not include tools to highlight and identify risk of failures at the part or system level

Best Practices

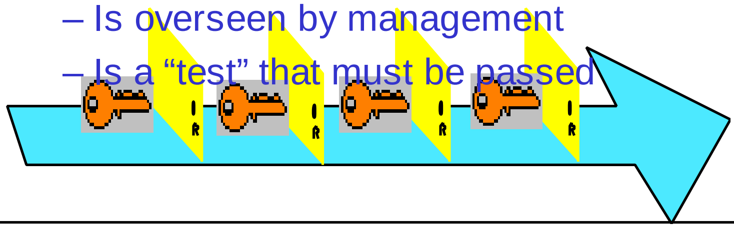
IPPD 3/14/00 Critical Chain

- Use an appropriate stage/gate process
- Simultaneous/concurrent engineering
  - Clear tasks
  - Tasks ordered correctly
- Cross functional teams

Stage/Gate process

IPPD 3/14/00 Critical Chain

- Systematic way of breaking up the product into a set of stages
  - Made up of a series of tasks
  - Each task may be performed by one or more groups
- Each stage is separated by a gate that must be passed.
  - Is overseen by management
  - Is a “test” that must be passed



Generic Stages

- Concept Generation
- Concept Development
- Detail Design (engineering and production)
- Verification
- First Unit Production
- Production

	Space	Automotive	Imaging
Concept Generation	Mission feasibility	Concept	Define Market
	q	q	q
Concept Development	Mission definition	Approval	Define Product
	q	q	q
Detail Design (engineering and production)	System Definition	Vehicle design	Detail Design
	q		
	Preliminary Design		
	q	q	q
	Final Design		
	q		
Verification	Fabrication	Pilot	Demo
	q		
	Prep for deployment	q	q
	q		
First Unit Production	Deployment and ops verification	Launch	Deliver
	q	q	q
Production	Mission	Production	Production

q = Gate

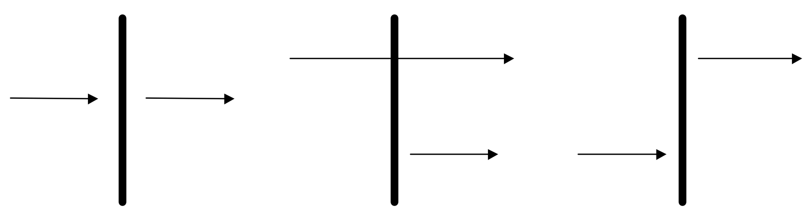
Gates

IPPD 3/14/00 Critical Chain

- Subjects
  - Did the tasks get done?
  - How well did they get done?
  - How are the metrics going?
  - Assess the important risk factors
- Reasons for Gates
  - Ensures accountability
  - Ensure risks are low prior to major resource expenditure (tooling, etc.)
- Tools
  - Prototypes
  - Business cases
  - Analysis

Types of gate reviews

IPPD 3/14/00 Critical Chain



Fixed Gate

Everything must be finished

Task delay

Non-critical elements can be left undone

Early Task initiation

Tasks that require an early start (tooling) can be begun before gate finished

Gate subject: risks

- Schedule risk
  - are the tasks that are required being done
- Customer risk
  - will the customers like the product
- Technical risk
  - can the specifications be met
- Robustness risk
  - it the product going to be robust enough
- Production risk
  - will production be able to build the product
- Cost risk
  - will the product come in under cost

Typical Gates

- Braun
  - *Company concern* - customer perception
  - *Metric* - Customer acceptance
  - *Gate* - Tooling expenditure okayed subject to functional model tested with the customer
- PCB -
  - *Company concern* - Care if the product can be produced at a low enough cost
  - *Metric* - Yield
  - *Gate* - Board release from stage to stage subject to yield calculations being on target
- Space
  - *Company concern* - System performance and lack of failure
  - *Metric* - Failure probability
  - *Gate* - Check the ability to achieve the required system performance
- Copiers
  - *Company concern* - Will the copier meet customer requirements
  - *Metric* - Technology S/N
  - *Gate* - Measure if the technology can meet specifications
- Automotive (1)
  - *Company concern* - Will we meet delivery schedule
  - *Metric* - % tasks complete
  - *Gate* - Ensure that the tasks are on on schedule
- Automotive (2)
  - *Company concern* - High quality product
  - *Metric* - Functional performance of the car
  - *Gate* - Check the prototype for achievement of goals and the absence of problems

Concurrent engineering vs. Cross-function engineering

- Concurrent engineering = design task sequencing
- Cross-functional engineering = who is involved in the design tasks

Cross-functional engineering

- Shortcomings
  - time intensive
  - meeting intensive
- Benefits
  - reduce rework later
  - improve the quality
  - increase the impact of design for manufacturing
    - earlier in design it is easier to change

Functional groups

- Systems engineering
  - in charge of ensuring that the system works together
  - interface design and management
- Marketing
  - Define and explore the market
- Supplier liaisons / Materials
  - Work with and negotiate with suppliers
- Research and Technology
  - bring the new technology up to speed
- Quality
  - in charge of testing and validation of the product
- Legal
- Finance
- Engineering functions
  - Aircraft: structures, electronics, hydraulics, etc.
  - Automotive: suspension, body, interior, controls
  - Copiers: toner, paper feeds, image processing, etc.
- Manufacturing
  - Tooling designers
  - Assemblers/hourly labor
  - Advanced manufacturing
  - Process designers

Concurrent Engineering

- Simultaneous execution of tasks that would normally be done sequentially
- Tasks are started early using partial information
  - Start to cut dies before design is done
  - Begin to procure materials before final drawings are available
- Benefits
  - Shortens design time
- Problems
  - Decisions made based on partial information
  - Risk that work done in downstream task will need to be redone based on inputs from upstream task

	Planning	Product Definition	Process definition	Production
Concept Generation	Intense			
Concept Development	Some	Intense	Minimal	
Detail Design		Intense	Intense	
Verification		Some	Intense	
First Unit Production		Minimal	Some	Intense
Production				Intense

Intense Activity

Some Activity

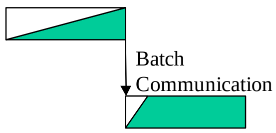
Minimal Activity

Concurrent and cross-functional categories

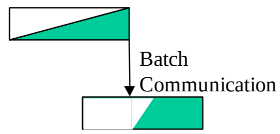
		Concurrent engineering	
		Sequential	**Overlapping**
Cross-functional engineering	**Functionally oriented**	- Traditional hand it over the wall - High risk of expensive late design fixes - Long design cycle	- Hand partial information over the wall - Risk of late design fixes - Risk of design changes affecting downstream tasks - Short design cycle
	Cross-functionally oriented	- Long design cycle - Lower risk of expensive design fixes - Lower risk of design changes impacting downstream tasks	- Short design cycle - Lower risk of expensive design fixes - Higher risk of design changes impacting downstream tasks

Four modes of Upstream-downstream interaction (Wheelwright and Clark)

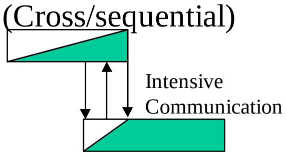
Serial/Batch
(functional/sequential)



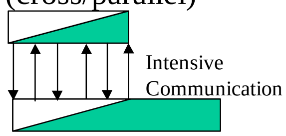
Early Start in the dark
(functional/parallel)



Early communication
(Cross/sequential)



Integrated problem solving
(cross/parallel)



Serial

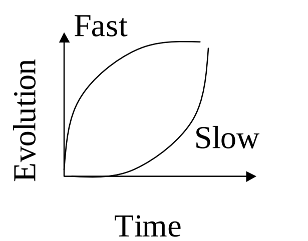
- Time consuming
- Lower risk of design iteration

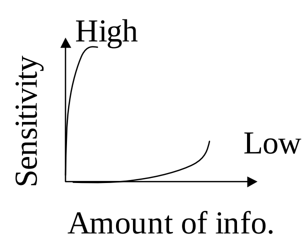
Parallel

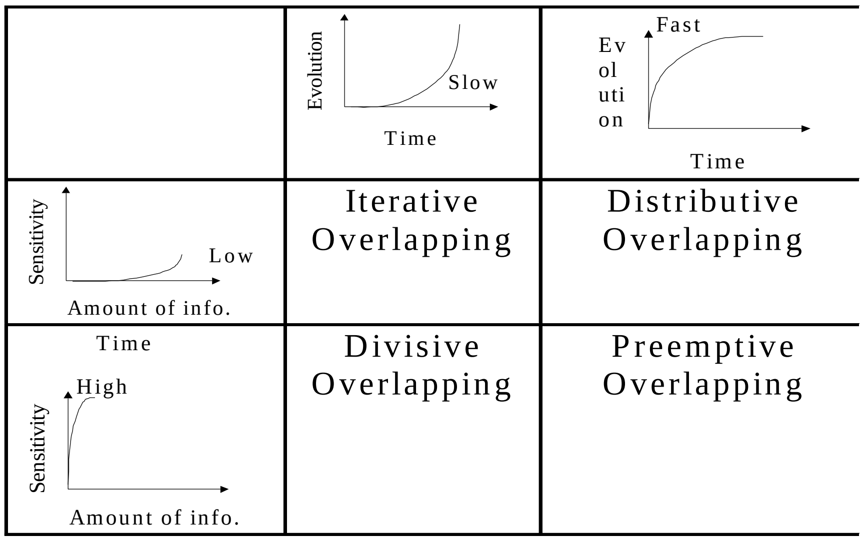
- Saves time
- High risk of design change

Evolution vs. Sensitivity

- Upstream
  - Evolution
  - How fast is the design completed
- Downstream
  - Sensitivity
  - How sensitive is the task to changes in the upstream data



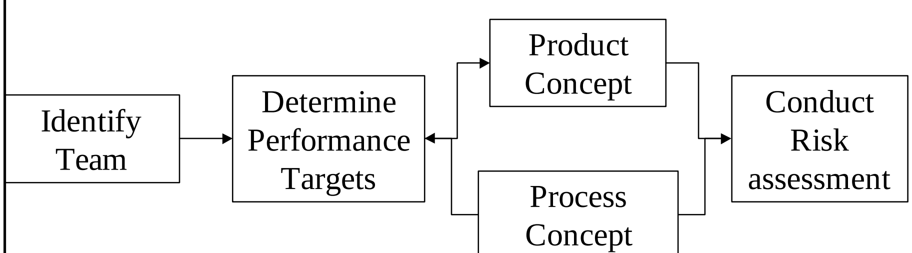




Krishnan "Managing the Simultaneous Execution of Coupled Phases in Concurrent Engineering"

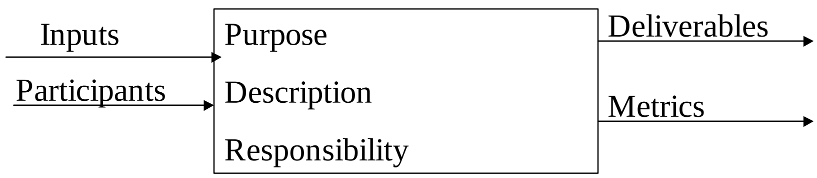
Each Stage is made up of a series of tasks

IPPD 3/14/00 Critical Chain



Task structure

IPPD 3/14/00 Critical Chain



- Inputs - What data does the task need
- Participants - What functions are involved
- Purpose - What is the reason why this is being done
- Description - What are the sub-tasks and tools
- Responsibility - Who is responsible for the deliverables and metrics
- Deliverables - What gets fed to the next task
- Metrics - How do you measure how well you have done

Responsibility Matrix

IPPD 3/14/00 Critical Chain

Tasks	marketing	design	manufacturin	quality
Define the market	A			
Product Concept	I	A	C	I
Quality validation	I	I	C	A

- C (Concurrence) - identifies the function required to agree/disagree to proposed decision or action; response is mandatory
- I (Input) - identifies the functions require to make input to a proposed decision or action
- A (accountable) - identifies the accountable function/organization

Typical Tasks

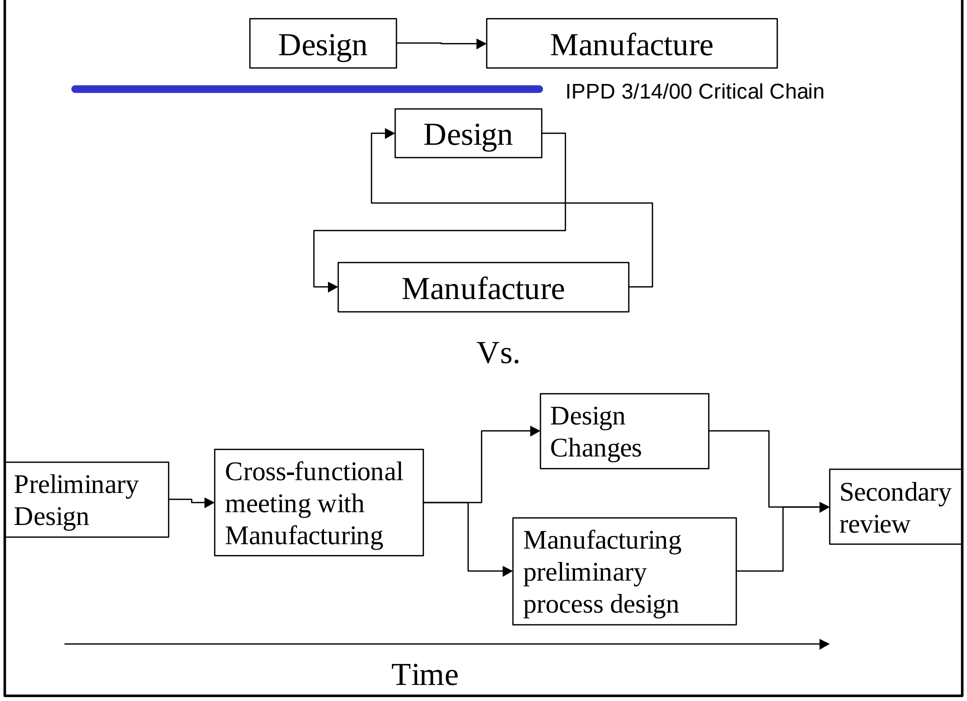
- Critical path
  - Drawings
  - Manufacturing planning
- Identify Risks
  - systematically highlight the possible failures and assign responsibility
  - bring cross functional people together to identify problems
  - Examples: FMEA, DFM, prototypes
- Assess Risks
  - Used to monitor how well the design is

Generic Stage Gate process

Stage						
Goal						
Gate						
Approval						
	Task 1	Task 2	Task 3	Task 1	Task 2	Task 3
Market.						
Design						
Mfg						
Quality						

Automotive Example

Stage	Concept		
Goal	Define the Vehicle Program to meet customer requirements and be profitable		
Gate	Assess the program scope to assure that they are consistant with long-range goals		
Metrics	How close does the concept match the goal		
Approval	General Managers		
	Identify Pre-sourced suppliers	Process Concept	Product Concept
Design	C	C	A
Suppliers	A		
Mfg		A	



Lecture 12: Teams and motivation

- Wheelwright, S. C. and K. B. Clark (1992). Chapters 8 : Organization and leading product teams. Revolutionizing Product Development: Quantum Leaps in Speed, Efficiency, and Quality. New York, The Free Press: 188-217.
- Aghion, P., and Tirole, J. 1994. "The management of innovation." Quarterly Journal of Economics, 1185-1209.
- Holmstrom, B. 1989. "Agency costs and innovation." Journal of Economic Behavior and Organization, 12(3): 305-327.