Identifying the Bottleneck in GM Assembly Systems

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Quality Reliability & Competitive Operations Implementation

Background

- Founded in 1908
- World's largest automotive corporation and full-line vehicle manufacturer.
- Employs more than 388,000 people
- Partners with over 30,000 supplier companies worldwide.
- Largest U.S. exporter of cars and trucks
- Manufacturing operations in 50 countries, has a global presence in more than 200 countries.
- Has substantial interests in digital communications, financial and insurance services, locomotives, and heavy-duty automatic transmissions.

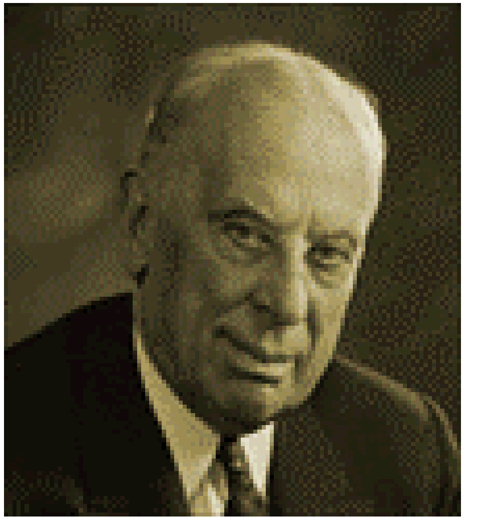
Before TOC in GM Manufacturing

- New or renovated plants started up poorly.
- Efforts to improve throughput were generating results slowly.
- Large investments were made in the plants to try and improve throughput.
- Overtime was extensively used to try and keep up with demand.
- RONA and profit targets were far below expectations.

History of TOC in Production

- Started in GM in1980 in Saginaw Division with a product call OP.
- GM develops C-Thru bottleneck identification tool in 1984 (Now called C-More).
- First successful implementation of C-Thru in 1987 at Detroit/Hamtramck.
- A divisional group was then started, which has grown from a few people to over 50 at corporate level.
- Other active groups in Powertrain, Supplier Development.

Alfred Sloan



"... we made the assumptions of the business process itself explicit. We presumed that the first purpose in making a capital investment is the establishment of a business that will both pay satisfactory dividends and preserve and increase its capital value.

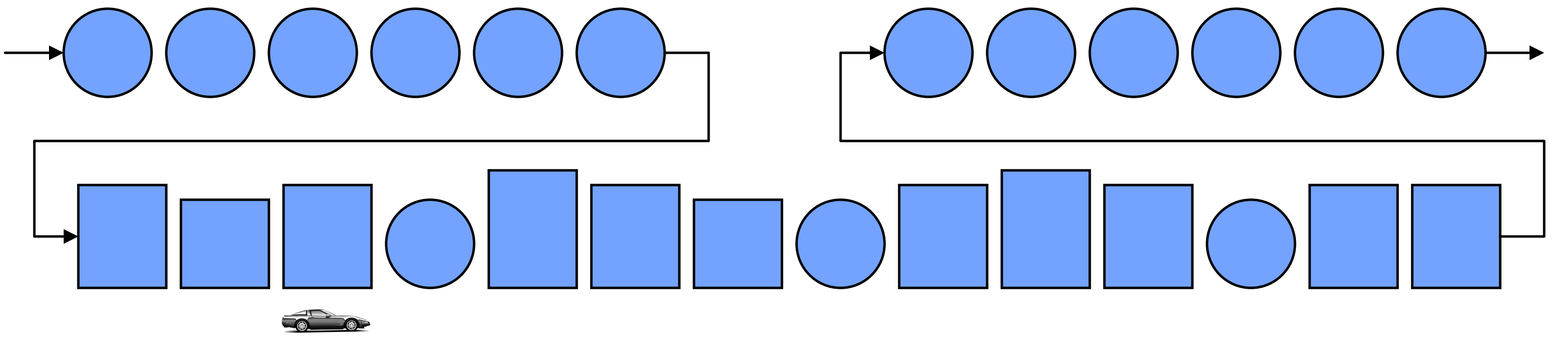
The primary object of the corporation, therefore, we declared was to make money, not just to make motor cars. Positive statements like this have a flavor that has gone out of fashion; but I still think that the ABC's of business have merit for reaching policy conclusions."

from "My Years with General Motors"

GM

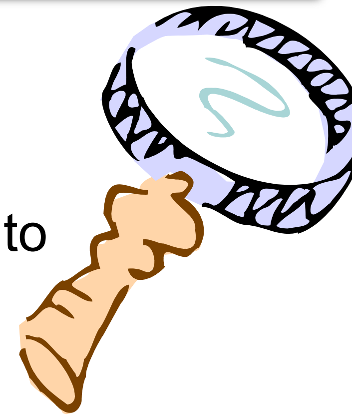
Comparison of Systems

Assembly Systems



Automotive assembly systems tend to be large, serial, highly balanced (all the cycle times and downtimes tend to be similar), with very small (0-1) job buffers on the floor, and small buffers overhead between systems. Finding the bottleneck in these tightly coupled systems is difficult.

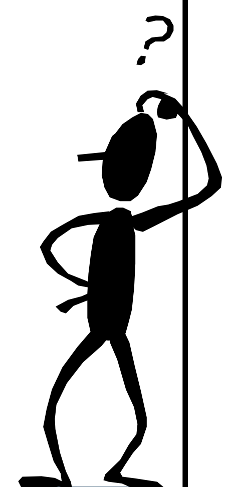
Bottleneck Identification Problems



- Downtimes are short
  - so an observer needs to be near the workstation to determine why it went down.
  - Looking for inventory here doesn’t work.
- There is significant blocking and starving.
  - Thus, the station is not running, but there is nothing wrong with it.
- The bottleneck may not be in the same place from shift to shift
  - although it tends to stay in the same place week to week.

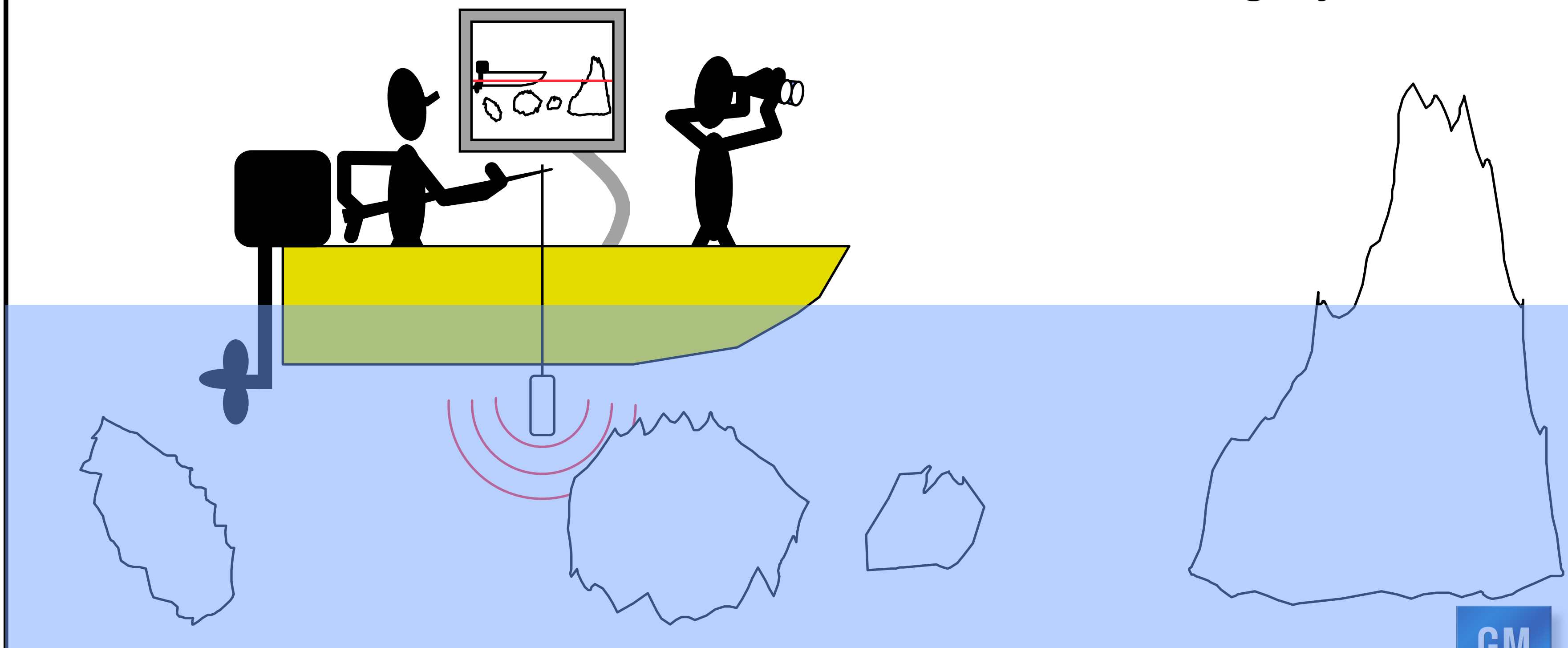
Bottleneck Identification Problems

- Stations that have a small amount of downtime, but are in an area of no buffers may turn out to be the bottleneck.
- Stations with high downtimes, but that are fast and have buffer may be perceived to be the bottleneck, but are not.
- Thus, there may be conflict in the plant over the bottleneck location.
- We needed a better way!



Solution - C-More

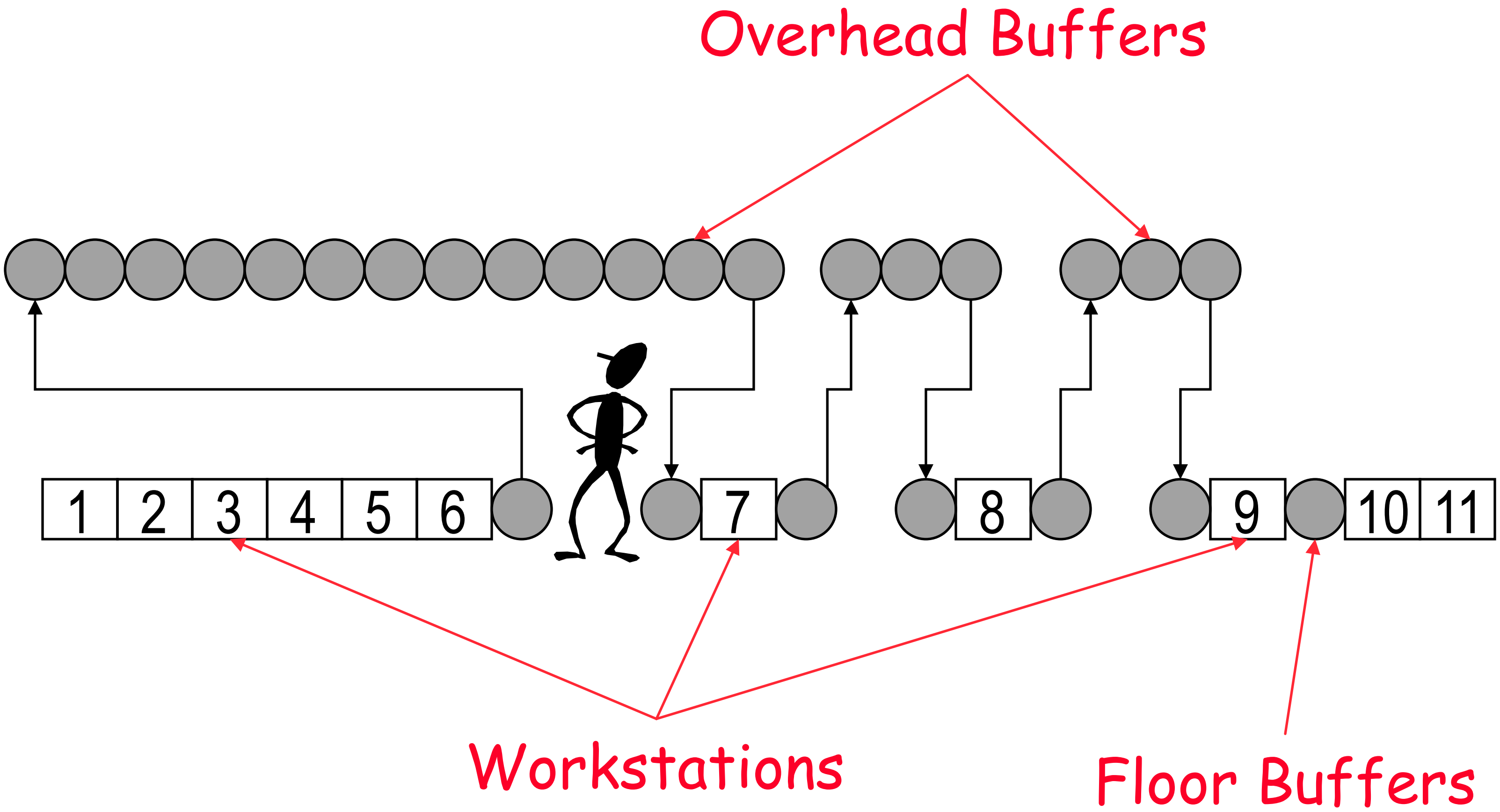
C-More is a GM Research developed proprietary software tool that predicts throughput, identifies the bottleneck and quantifies its impact, and can determine the best locations for buffers in a manufacturing system.



Causing the Change

- Training is the key. We have courses in Constraints Management, C-More (basic and advanced), and GM's Throughput Improvement Process.
- We distribute Goldratt books throughout GM without charge to individuals (The Goal, La Meta, The Race, It's Not Luck, Critical Chain, etc.)
- We install data collection in the plants to drive C-More.
- We do direct training with a plant that is installing this process or has a new manufacturing system.

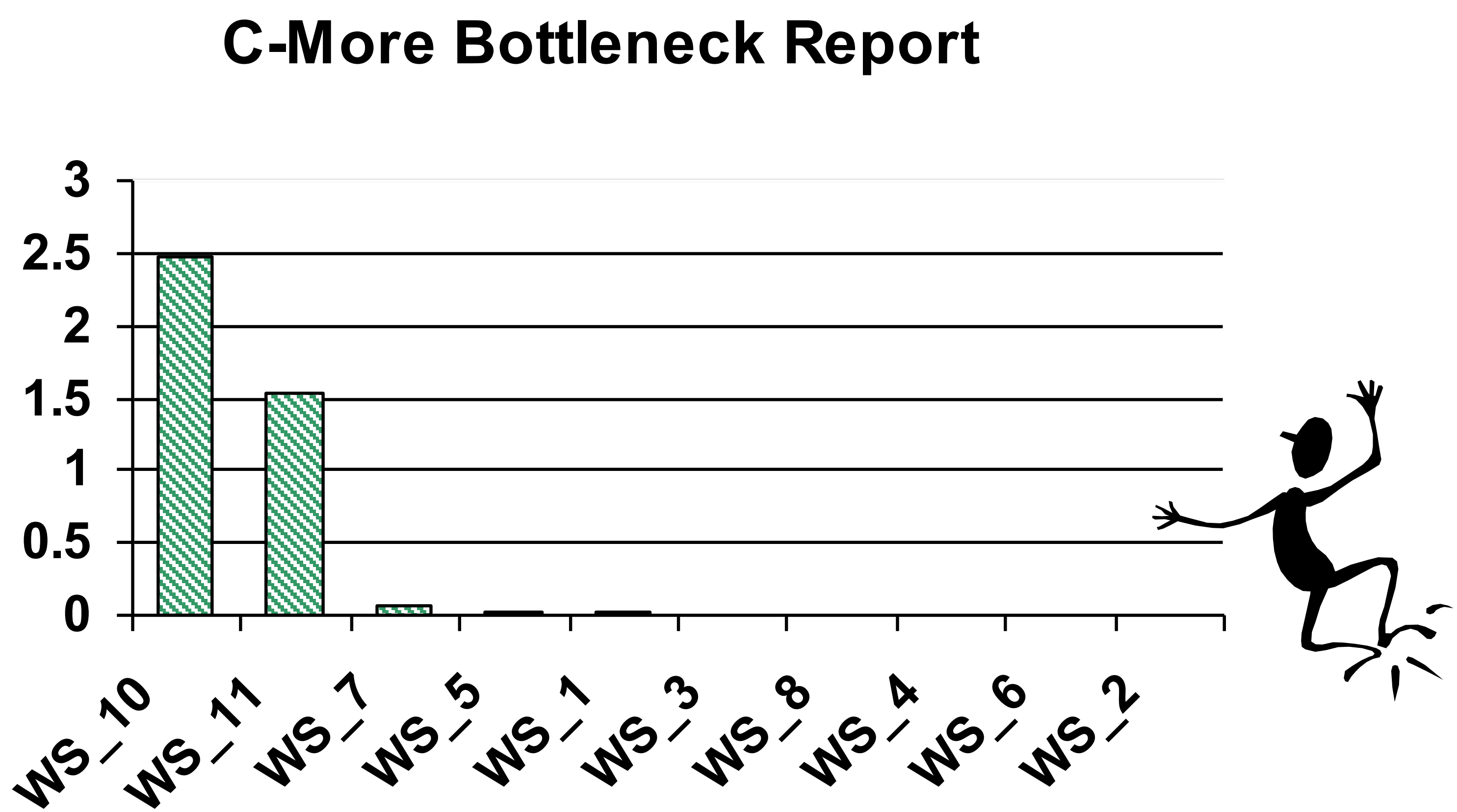
Training Example



Data

#	MCBF	MTTR	JPH	Buff	Cycle	Trgt	SAA	Down
1	92	4.3	58.7	-1	61.3	60	95.7%	383
2	58	1.7	64.8	-1	55.5	60	97.0%	261
3	86	2.7	59.6	-1	60.4	60	97.0%	264
4	76	0.9	57.1	-1	63.0	60	98.9%	101
5	100	3.3	59.7	-1	60.3	60	96.8%	281
6	94	0.2	56.8	15	63.3	60	99.8%	14
7	62	2.8	64.0	5	56.3	60	95.4%	403
8	398	0.3	56.1	5	64.1	60	99.9%	6
9	88	0.2	59.6	1	60.4	60	99.7%	24
10	15	2.5	56.5	-1	63.7	60	86.4%	1203
11	24	1.0	60.0	-1	60.0	60	96.0%	353

Sample C-More Report

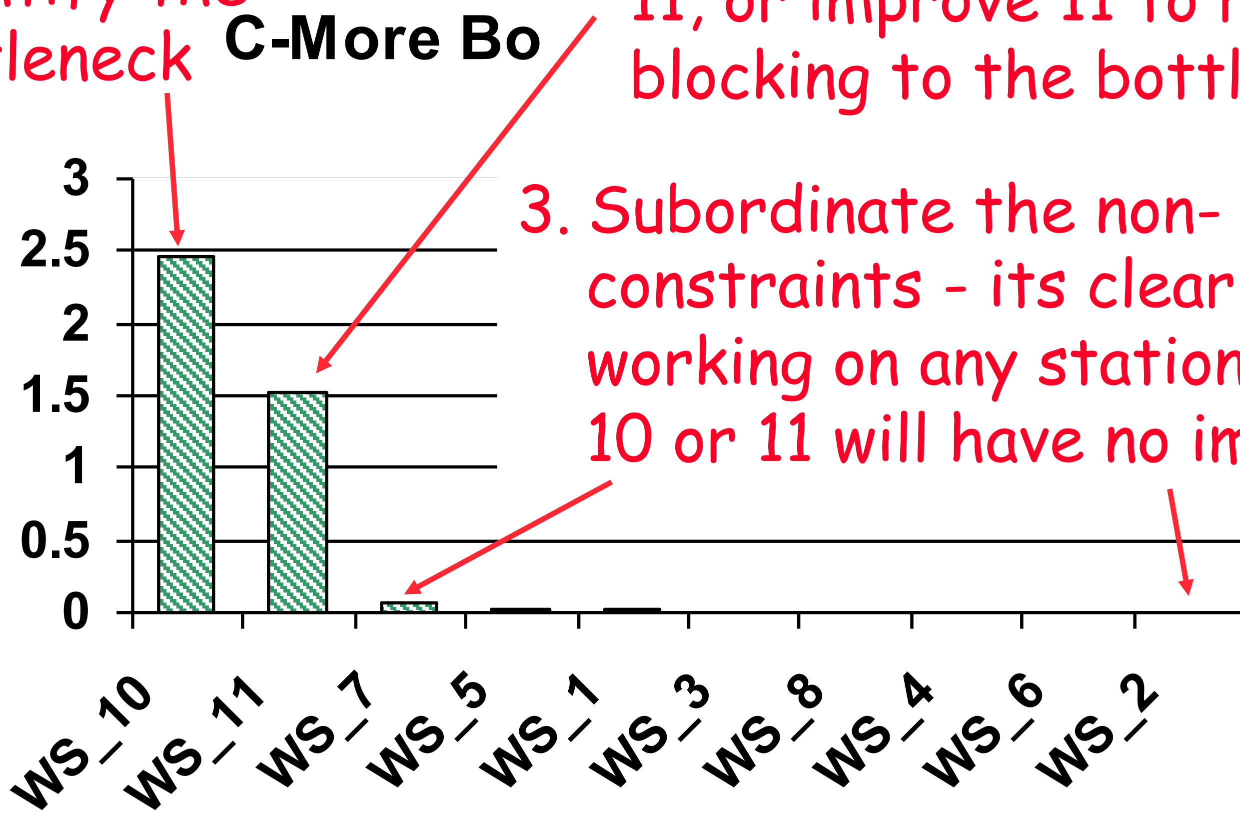


5 Steps & C-More

1. Identify the Bottleneck

2. Exploit the Constraint: Add buffer between 10 & 11, or improve 11 to reduce blocking to the bottleneck.

3. Subordinate the non-constraints - its clear that working on any station besides 10 or 11 will have no impact.



Elevate

4. Elevate the constraint - Workstation 10 fails frequently and is slow. Pareto charts from Monitoring Systems or from time studies. Solutions are typically not difficult to develop.

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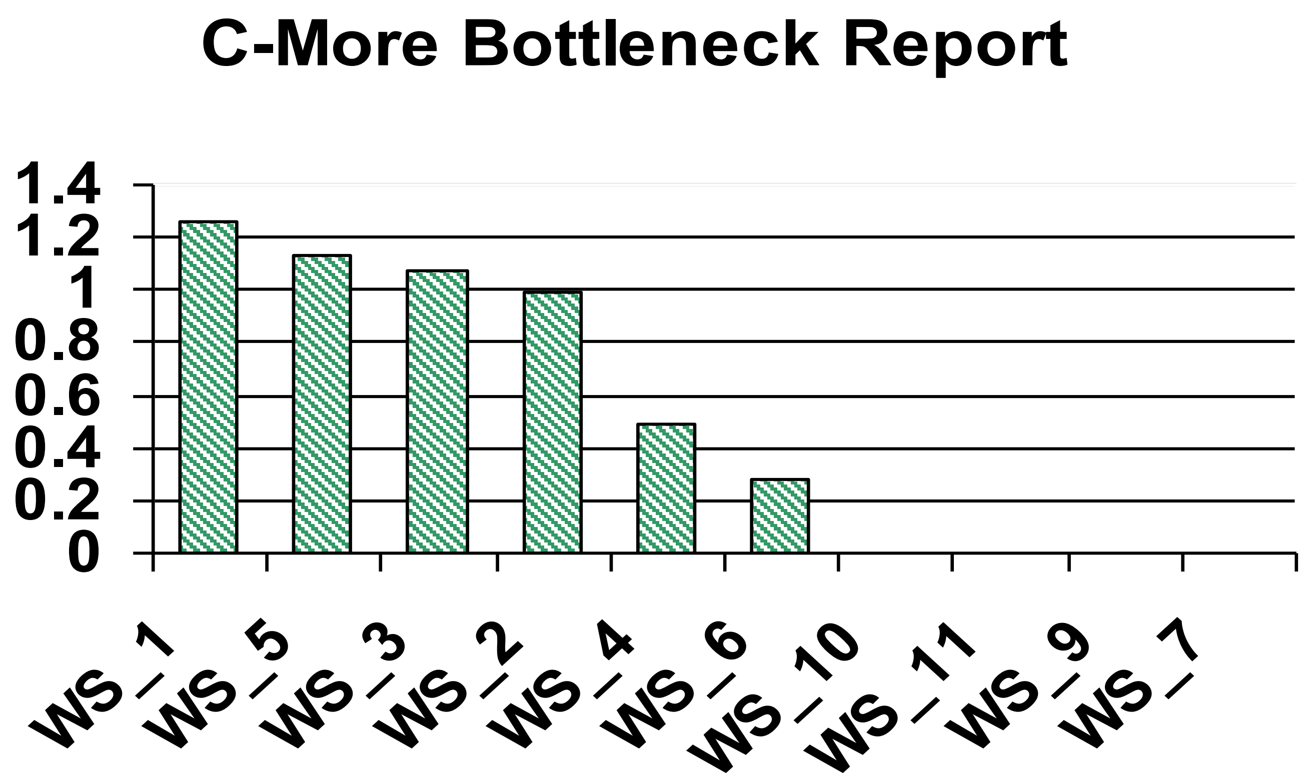
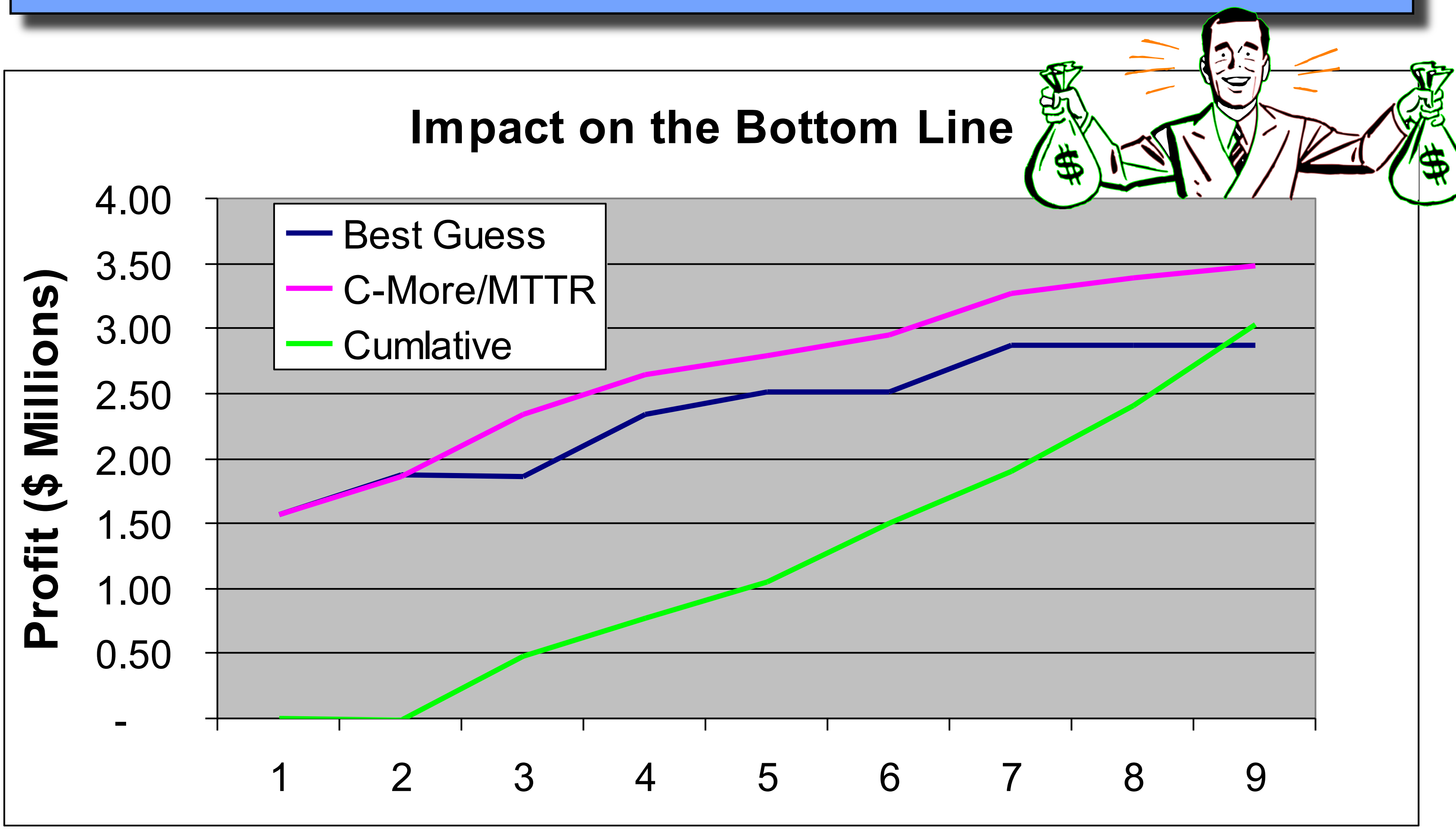
Restudy

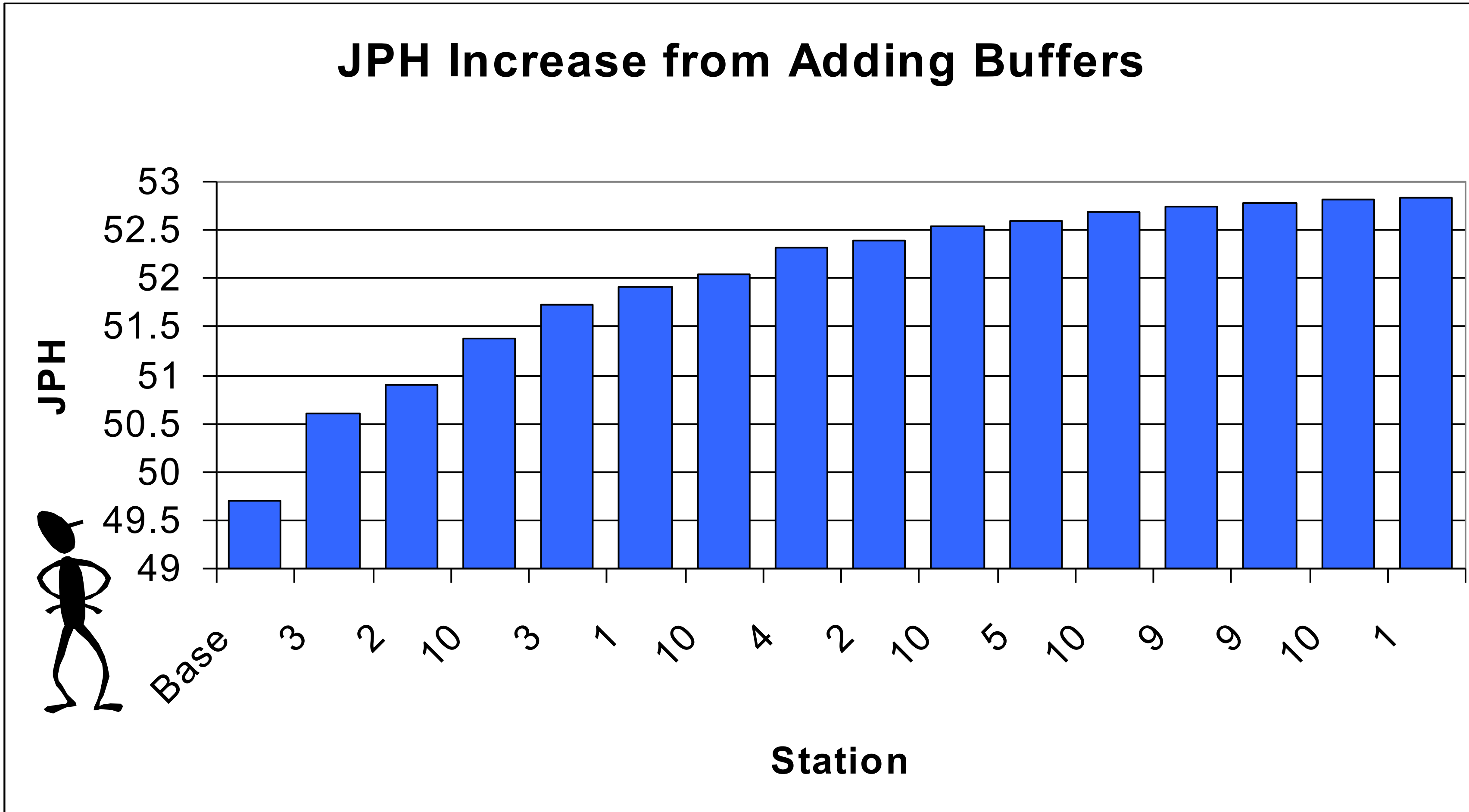
5. Restudy - or, in this case, predict the location of the next bottleneck.



Typical Training Results

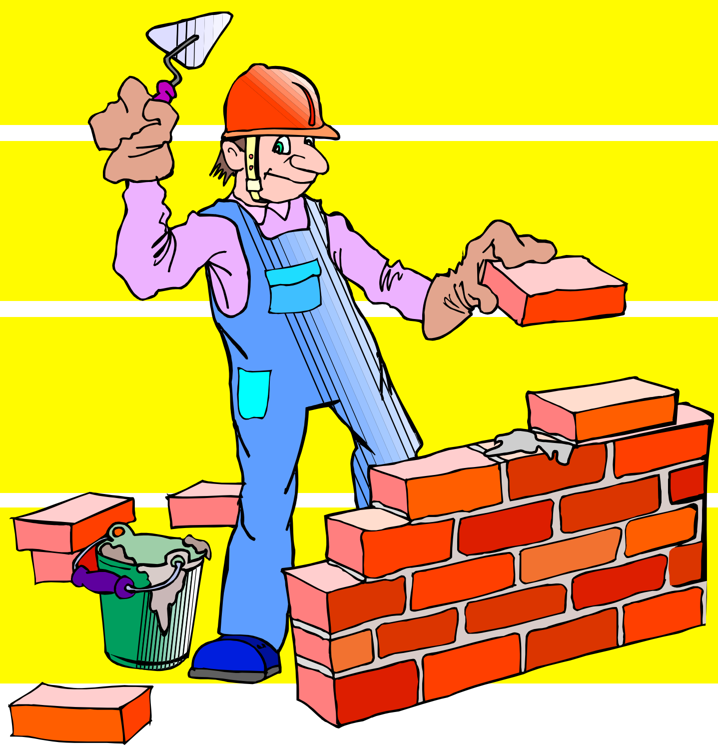


Buffer Analysis



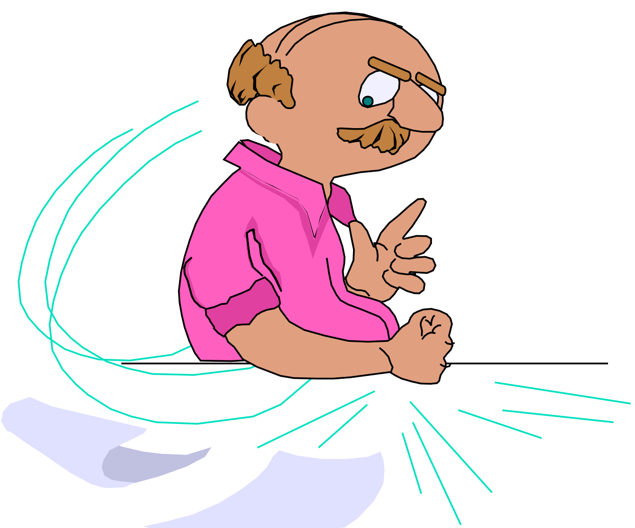
Production

Identify	Evaluate "Pull"
Collect Data	Plant Floor Monitoring
Analysis	C-MORE Simulation
Plan/Select	Team Meetings
Implement	Plant Personnel
Evaluate	Track Throughput



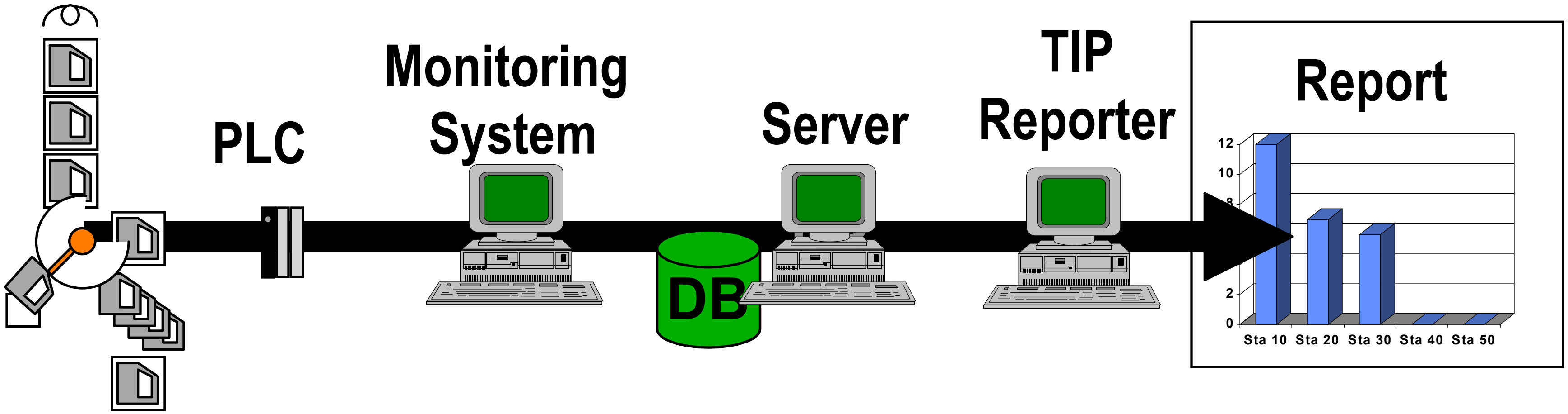
Identify the Goal - Production

Key factors in selecting plants for Throughput Improvement.

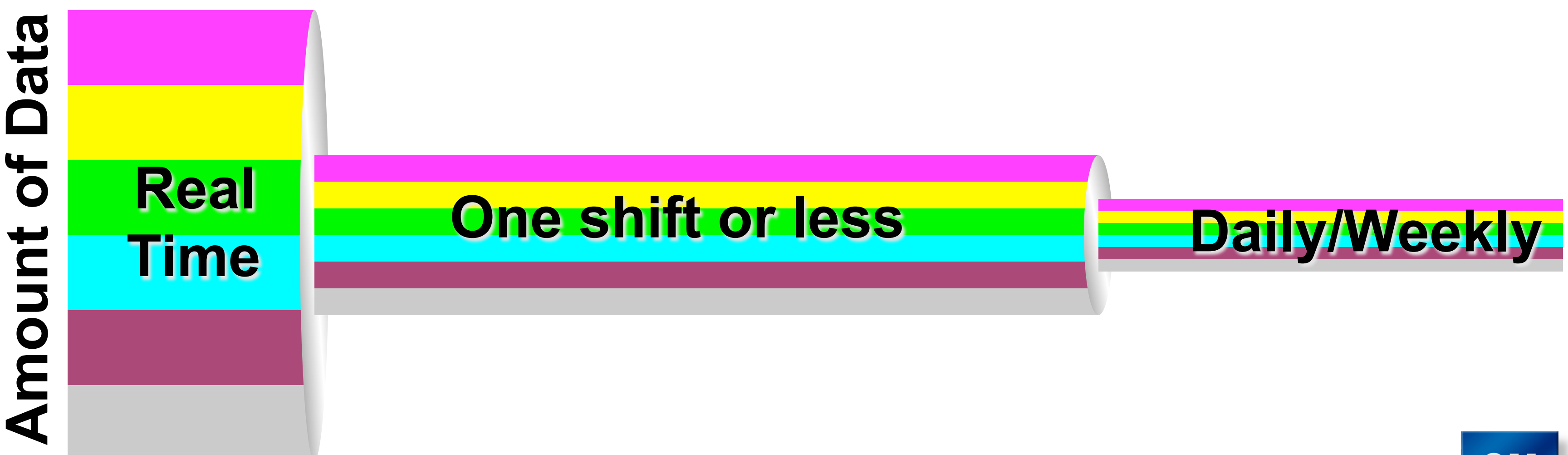


- Demand exceeds capability.
- Inability to make schedule.
- Excessive overtime & premium shipping.
- Willingness to change.
- Data collection capability.

Data Flow



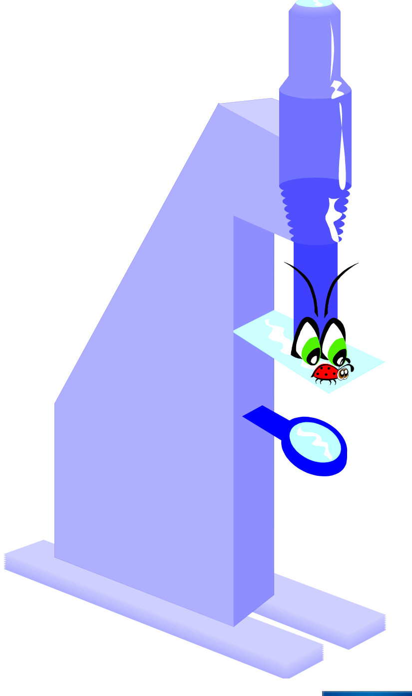
PLC
Monitoring System
DB
Server
TIP Reporter
Report
12
10
8
2
0
Sta 10
Sta 20
Sta 30
Sta 40
Sta 50



Amount of Data
Real Time
One shift or less
Daily/Weekly

Data Collection Issues at GM

- “All data is wrong - some of it’s useful.”
- Data is being collected to find the bottleneck in the plant, but can also be used for simulation of future systems.
- C-MORE analysis and data rarely matches our perceptions, unless we are willing to go down to the floor and stare at one workstation for at least a shift.
- Perceived need to “micro-analyze” the data - challenge its validity instead of attacking the problem.

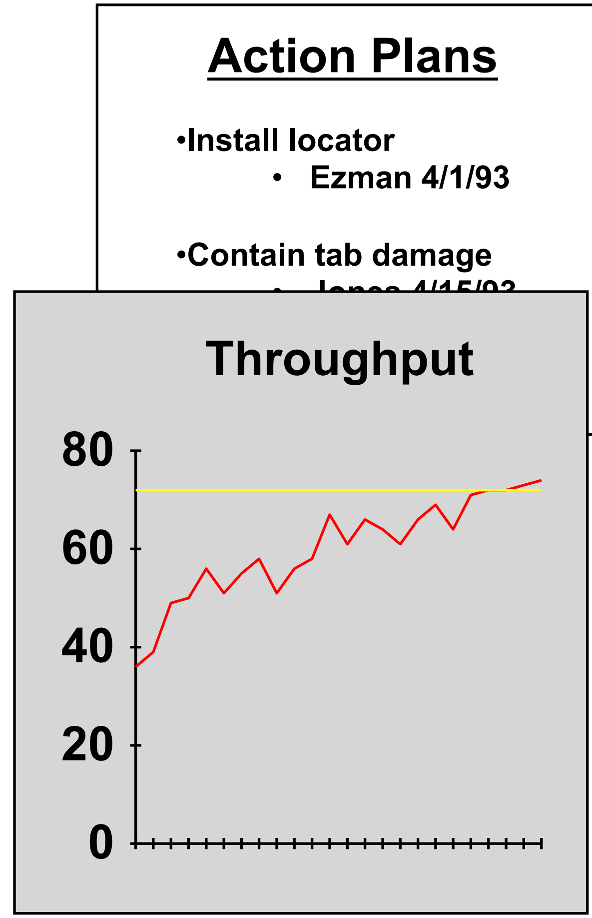


Analysis - Production

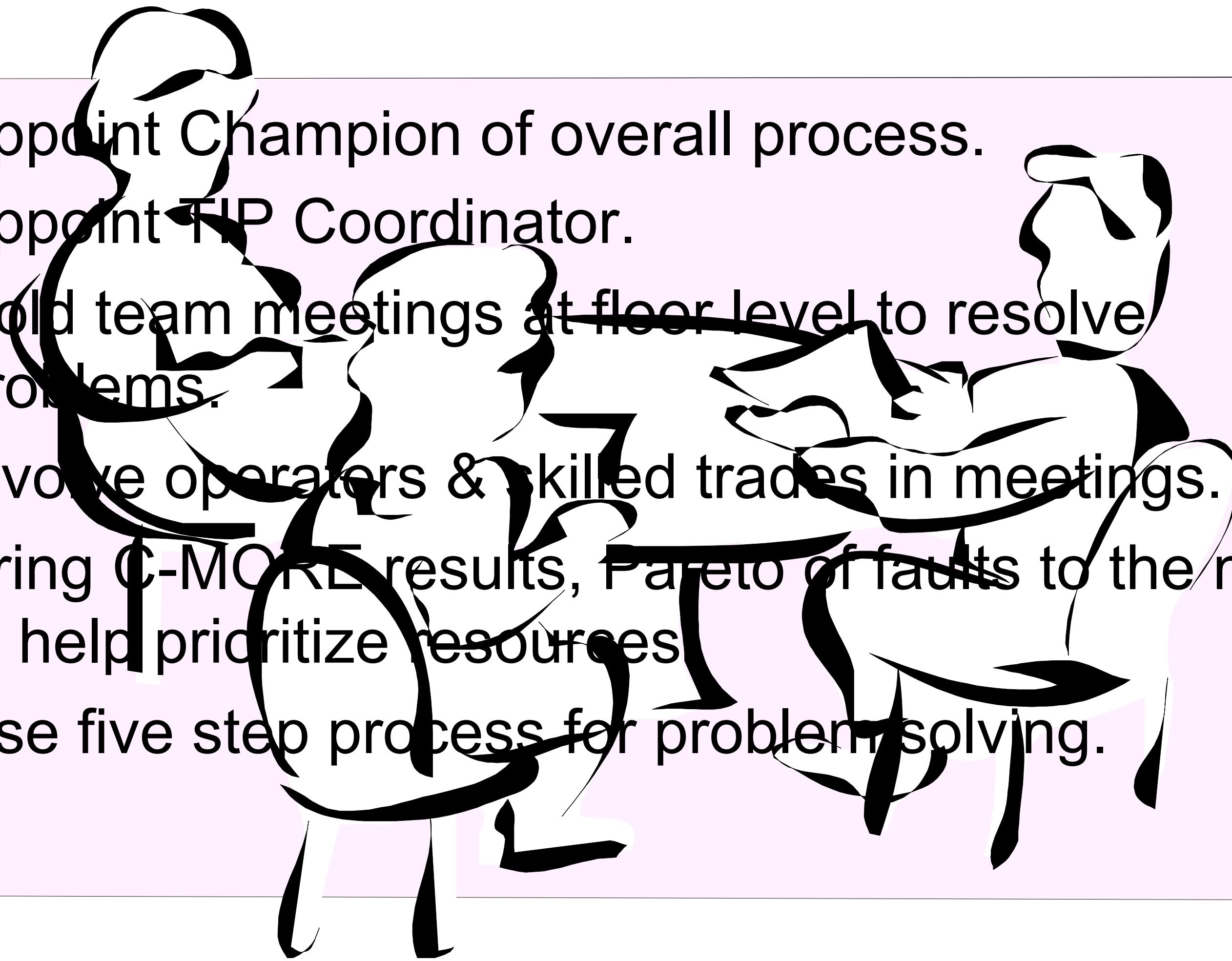
- C-More for finding bottlenecks, setting priorities, basic "what-ifs."
- Add Selling Price, Raw Material Costs, Operating Expense to help determine Net Profit impact.
- Emphasize that buffers, while "Non-Value Added," can be "Net Profit Added" if properly located.
- Simulation for production strategies, detailed "what-ifs."
- Use Pareto analysis & delay studies for breakdown of problems on the Bottleneck.

Implement/Evaluate - Production

- Insure the actions plans are recorded, and their progress is tracked.
- Bottleneck changes generally have priority after health, safety, and quality issues (These are "necessary conditions").
- Productivity suggestions can now be effectively evaluated.
- Work on overtime, then operating expenses, and then inventory after throughput goals are obtained.



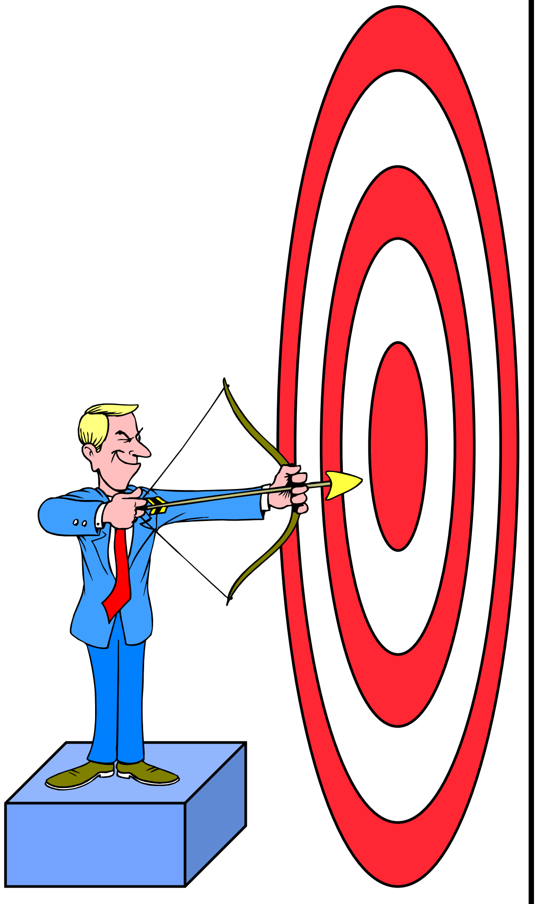
Team Meetings - Production



- Appoint Champion of overall process.
- Appoint TIP Coordinator.
- Hold team meetings at floor level to resolve problems.
- Involve operators & skilled trades in meetings.
- Bring C-MORE results, Pareto of faults to the meeting to help prioritize resources.
- Use five step process for problem solving.

Status in GM

- To date Net Profit improvements, validated with internal customers, exceeds $2 billion.
- All GM assembly plants have been allocated a throughput improvement coordinator position.
- Impact is large, so even having a few action plans focused on the bottleneck yields results.



Current Status

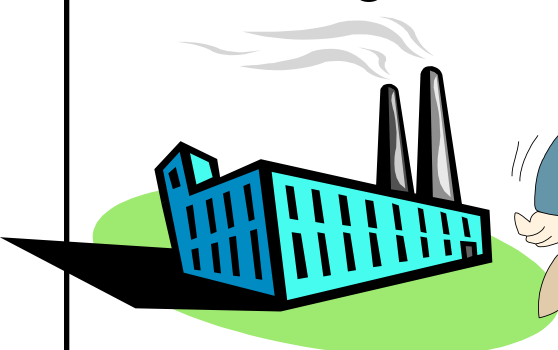
- Have one Throughput Coordinator position in every Truck and Car plant.
- There are 56 engineers working in or around this area of data collection, bottleneck analysis, bottleneck resolution, or new system design.
- TOC classes are taught as part of the General Motors University Curriculum. As of 6/9/2000, over 600 of our GM people have attended a 2-day course.

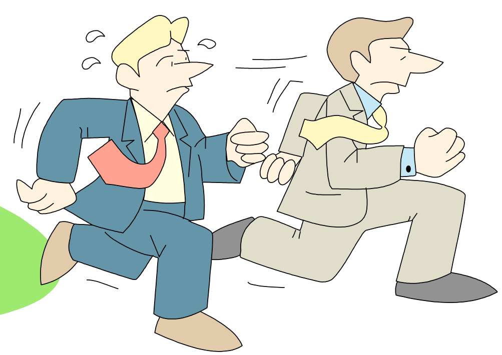
GMU General Motors University

GM

Relentless Pursuit of the Constraint

- While we were learning how to improve throughput once that plant was running, it became apparent that the root cause was in process design. Designs for new manufacturing systems were not capable of reaching throughput targets.
- So, were started to pursue the constraint into the design world....

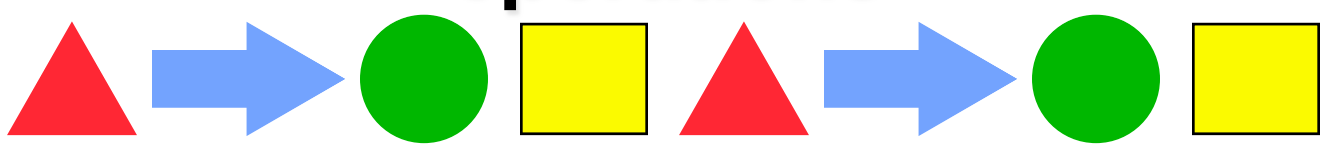




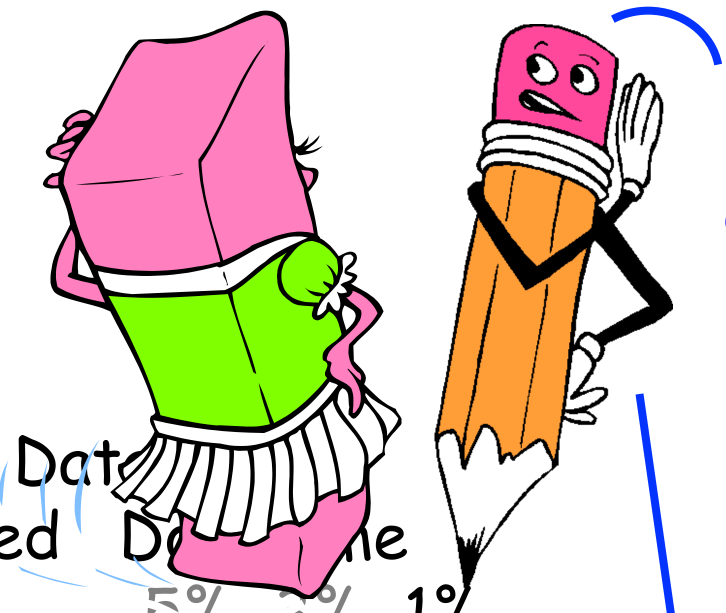
Manufacturing Engineering →

Design of Manufacturing Systems

Manufacturing: A series of material handling steps we occasionally interrupt with value-added operations



Data Problems in Design

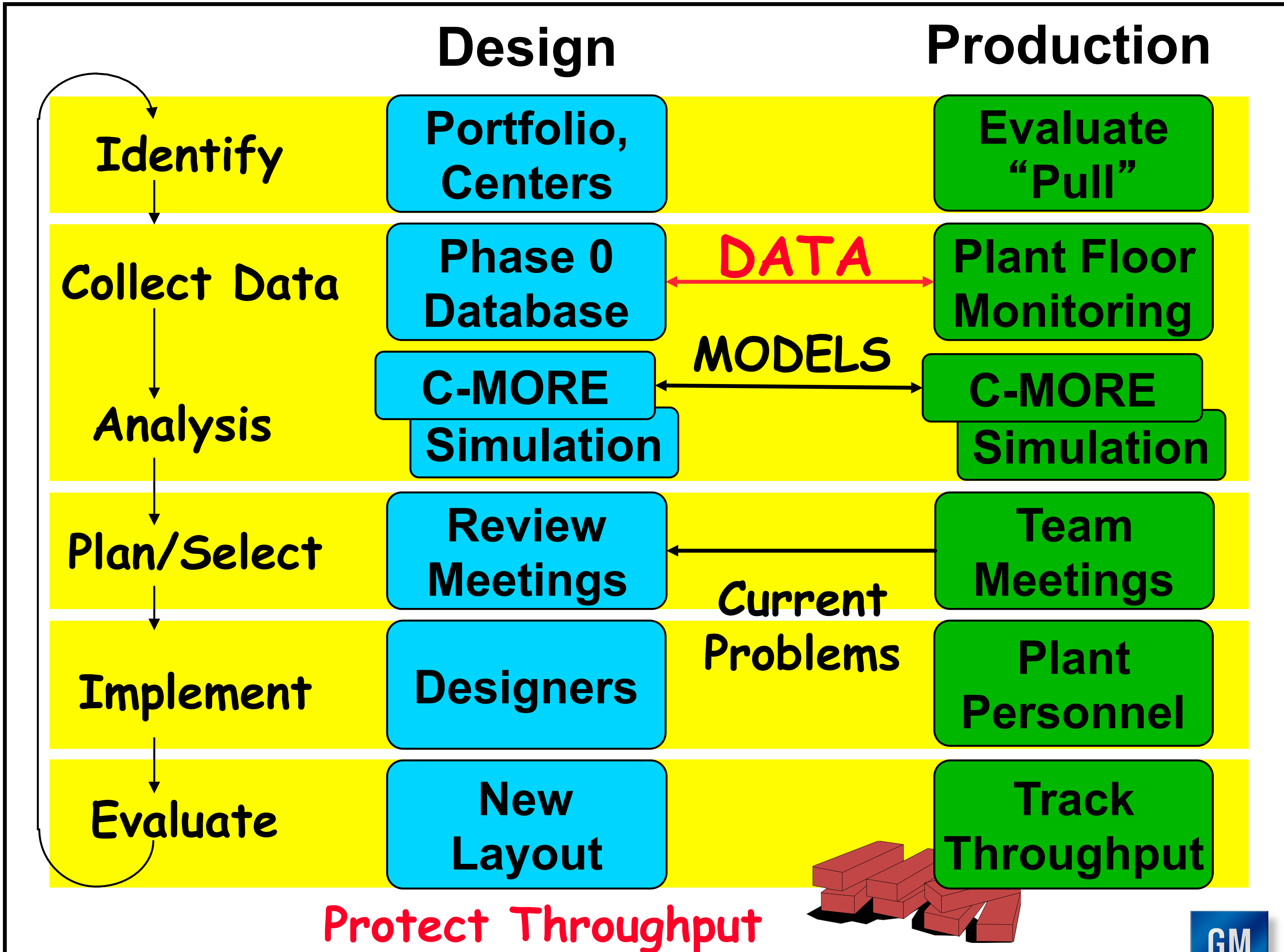


This is a technique I learned in my college engineering labs -- if you don't get the right answer, keeping changing the data until you do!!

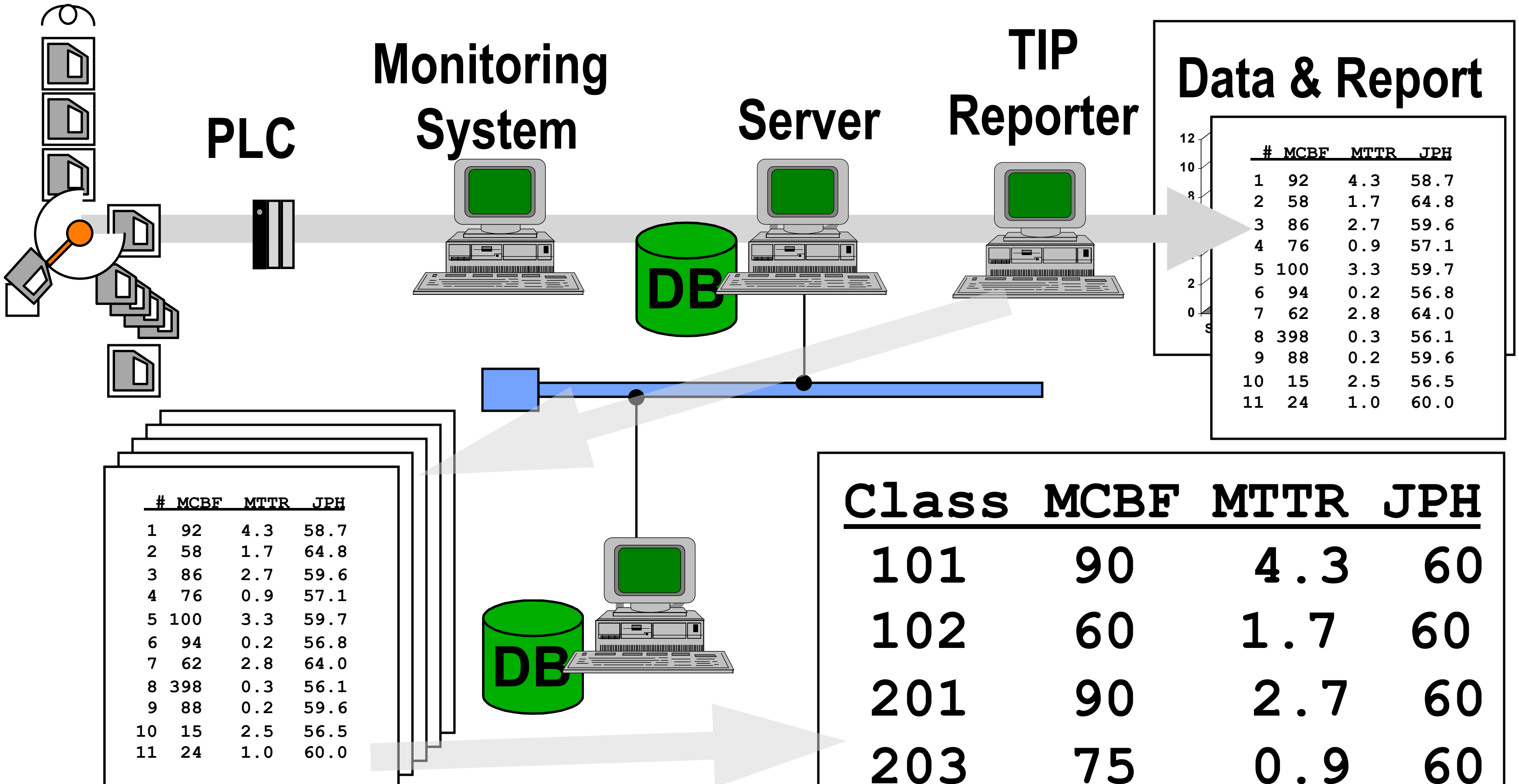
Simulation Dat

Sta.	Speed	Do ne		
1	60	5%	3%	1%
2	65	6%		
3	70	5%		
4	65	5%		

I can justify it, because **we're** going to perform better at **our** plant. We have better training, better PM, and all of our children are above average!


Design
Production
Identify
Portfolio, Centers
Evaluate "Pull"
Collect Data
Phase 0 Database
DATA
Plant Floor Monitoring
MODELS
Analysis
C-MORE Simulation
C-MORE Simulation
Plan/Select
Review Meetings
Team Meetings
Current Problems
Implement
Designers
Plant Personnel
Evaluate
New Layout
Track Throughput
Protect Throughput

Data for Future Designs



Multiple Plants

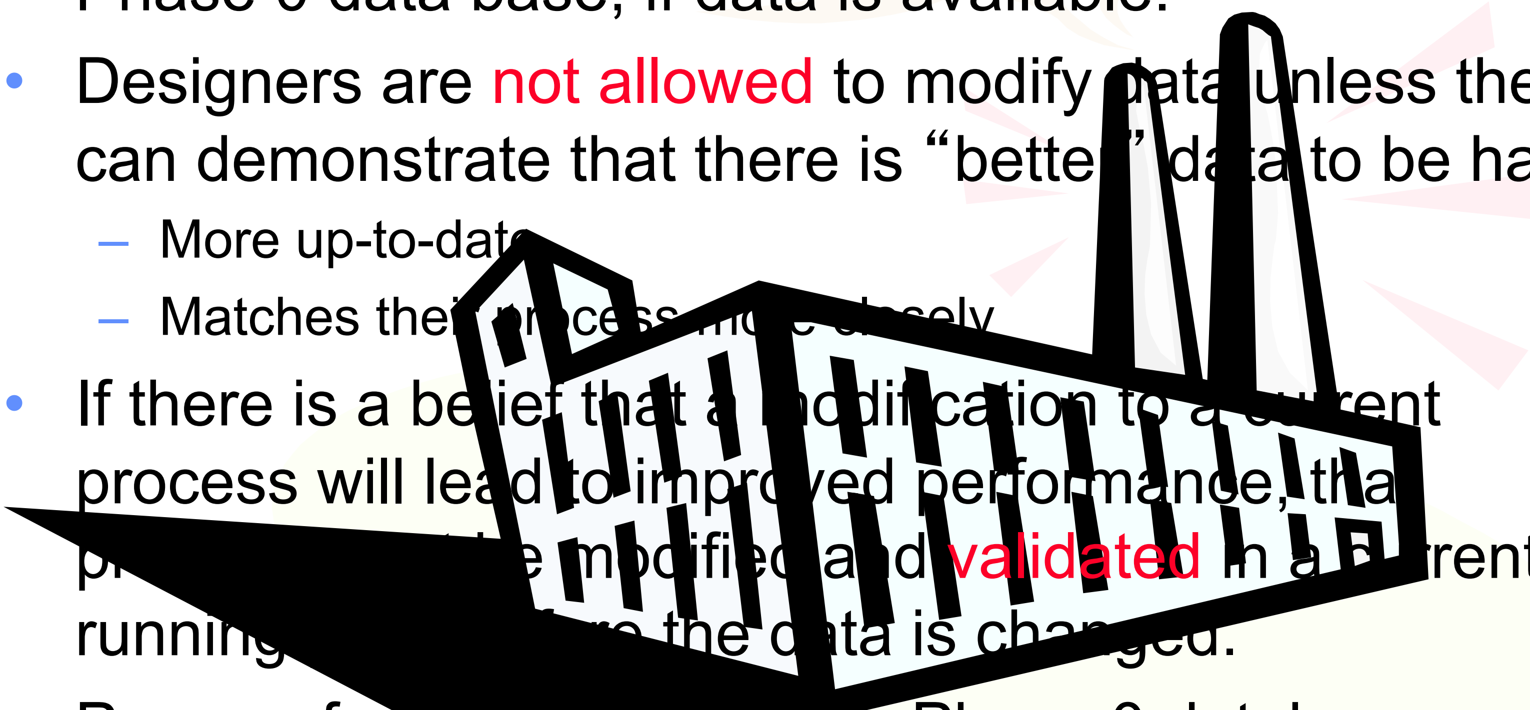
Class	MCBF	MTTR	JPH
101	90	4.3	60
102	60	1.7	60
201	90	2.7	60
203	75	0.9	60

Phase 0 Database

GM

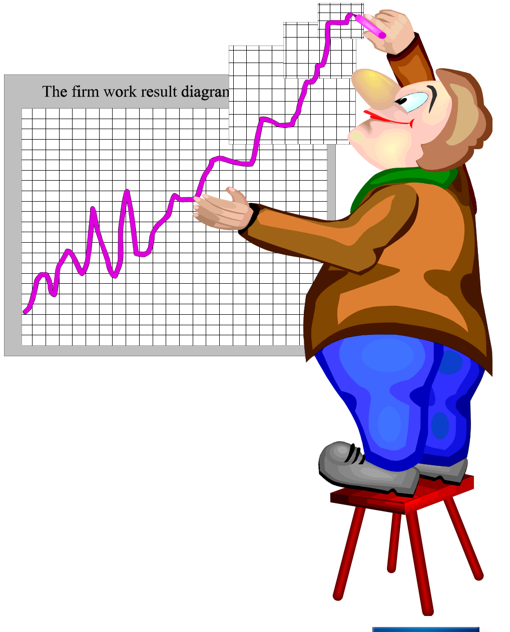
Results

- All simulations for GM NA Car & Truck plants use the Phase 0 data base, if data is available.
- Designers are not allowed to modify data unless they can demonstrate that there is “better” data to be had.
  - More up-to-date
  - Matches their process more closely
- If there is a belief that a modification to a current process will lead to improved performance, that pr[illegible]e modified and validated in a current running [illegible] before the data is changed.
- Poor performers are noted in Phase 0 database and taken to Engineering for redesign.



Results

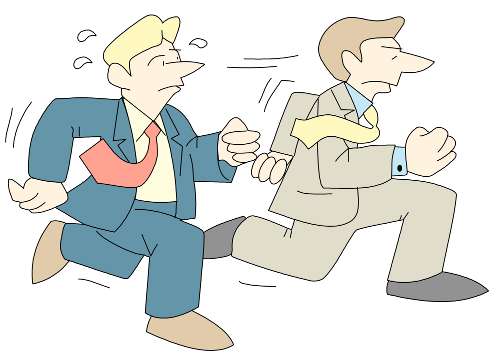
- Our latest GMT800 truck plant designs have performed much better, and have not required the massive injections of investment required in the past to improve throughput.
- These plants accelerated up their throughput curves more quickly than past plants.
- Loss of net profit from not being able to supply these highly profitable trucks was avoided.

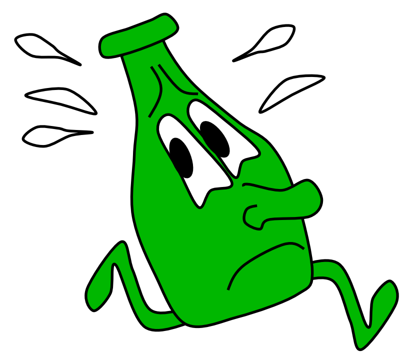


Relentless Pursuit of the Constraint

- Designs were performing better, but the design process still appeared to be in chaos.
- So, were started to pursue the constraint into the policy & measurement world....

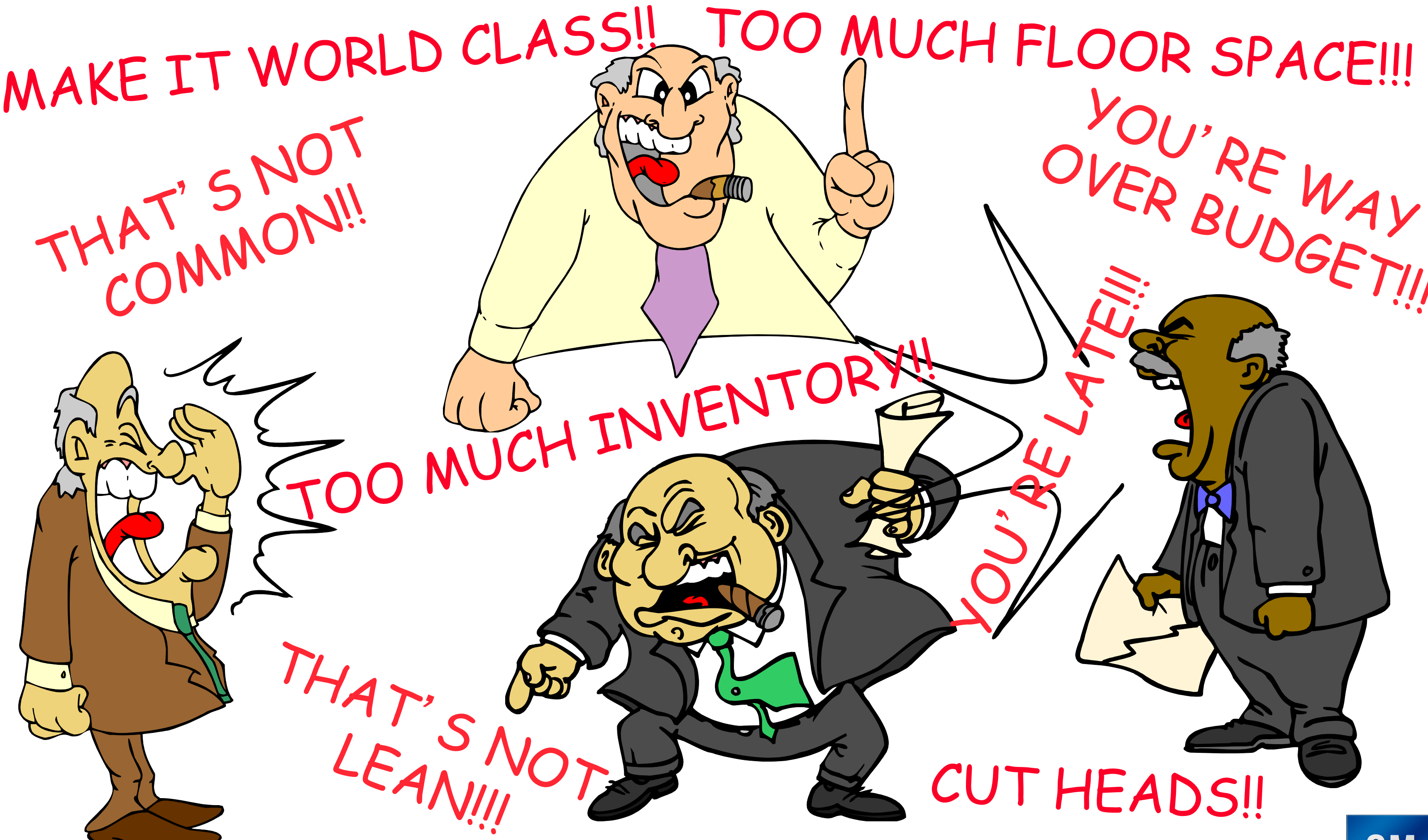
Manufacturing Engineering ←



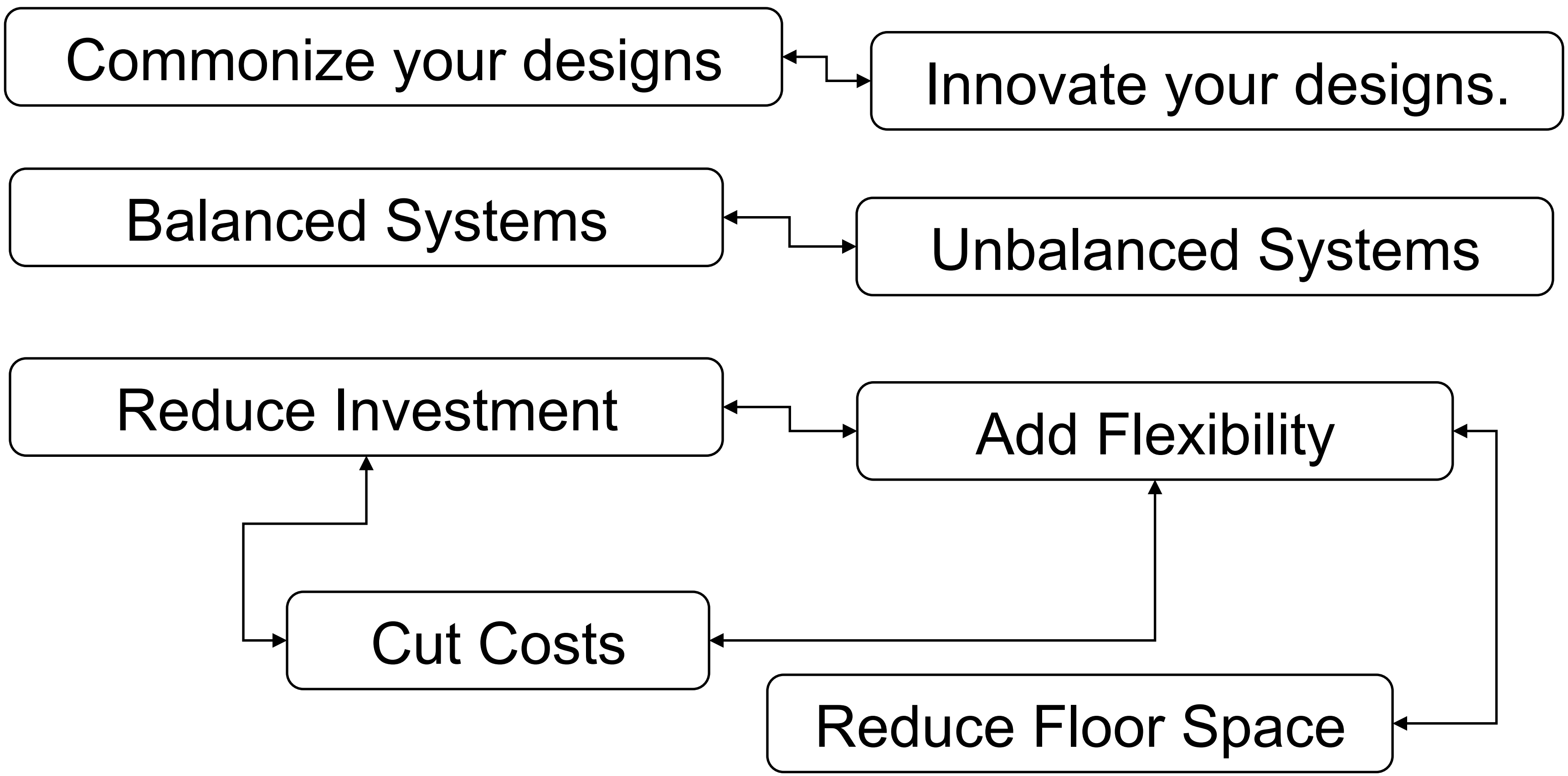


Manufacturing Management →

Typical Design Review Meeting



A Few Conflicts...



Conflict Results

- The inability to resolve these conflicts in design strategies leads to our Undesirable Effects:
  - Finger Pointing
  - Poor Teamwork
  - Wasted meeting time
  - Distrust between groups
  - Divergent efforts
  - Silos
  - Empire building
  - We know how to do this, they don't.
  - etc.

Can Find a Better Way?

- Can TOC concepts help us find a better way - determine a best, overall design?
- Can we determine an overall optimization measure, once our necessary conditions have been met?
- Can we teach the organization how to use it?

TOC & Manufacturing Design

What to Change?

- TOC helped us to determine that the local optimization paradigm was a root cause. Each part of the organization was trying to hit their local, "stretch" targets, hoping that would improve the bottom line.

What to Change to?

- Take a global optimization approach.
- Use RONA & Net Profit as measures for global optimization.

GM

Design Cloud

Improve the performance of GM’s manufacturing systems.

Improve every element that goes into the manufacturing system.

Put our efforts into optimizing every aspect of the system.

Improve only those elements that improve the overall system.

Put our efforts into optimizing the system as a whole.

Developing Solutions

- How are we going to obtain the needed consensus and active collaboration to implement this solution?

- Obviously, we have to play a game!
  - Go to groups in manufacturing design who are in crisis.
  - Have them verbalize their current situation.
  - Convince them their current efforts will not change the situation.
  - Demonstrate a better method.
  - Apply to their design.

Design Game

- Ask the question, “What are GM’s obstacles to successfully designing manufacturing systems?”
- As in the TOC class, we take their list of obstacles and then eliminate them.
- Give them a scenario with perfectly accurate data, clear expectations, with perfect employees, no product problems, etc.

Design Game Scenario

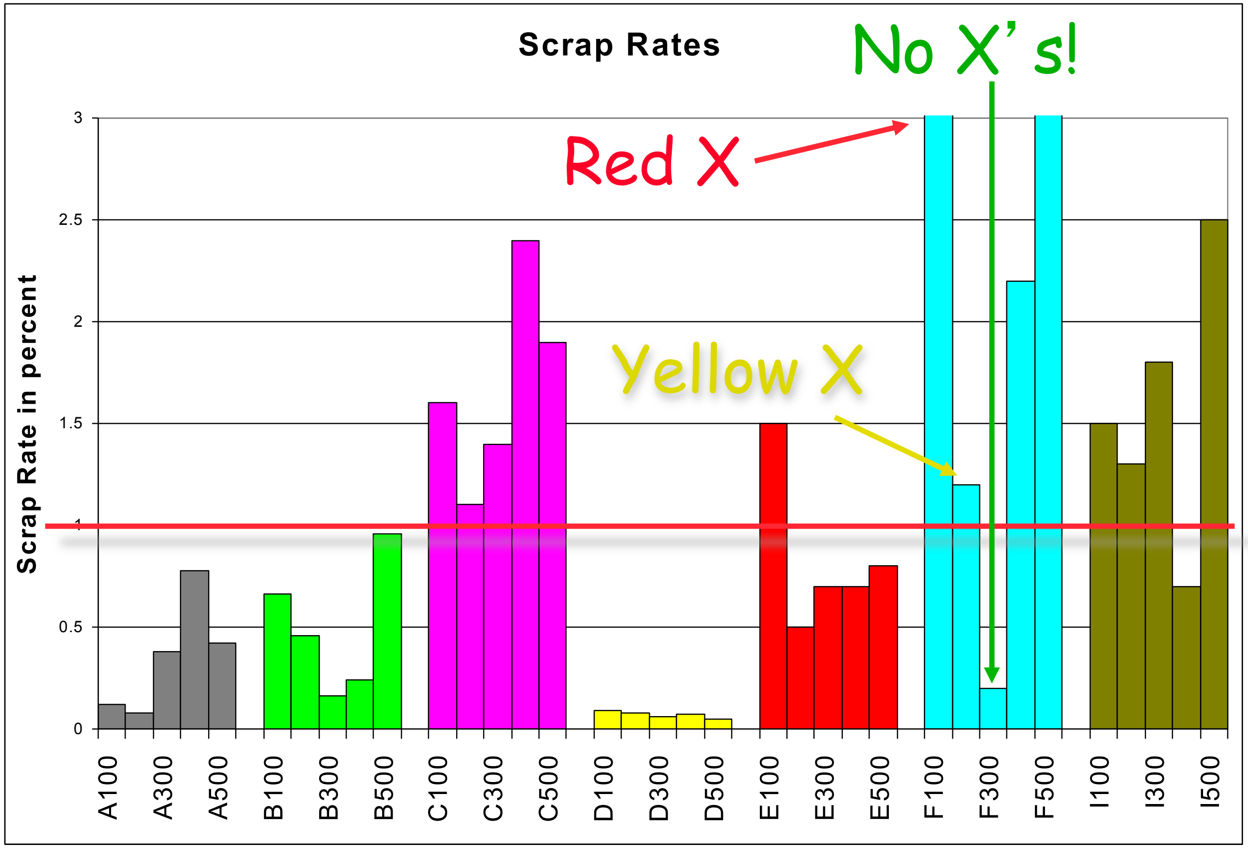
Problem

- Design the optimal manufacturing line. It should be "world class" in every measure.
- There are 7 station types plus a conveyor. There are five possible choices for each station type and the conveyor.
- Add buffer as required.

Mandates

- Meet the budget!
- Serial Lines are Synchronous and allow for better quality!!!
- Create your own targets based on actual data.
- Since you create the above targets you should have no trouble meeting them.
- Move the company towards World Class in every measure!!
- Minimize Buffers & Inventories - NVA
- Keep Operating Expense Low.
- Keep downtime to a minimum!!
- Keep Scrap to a minimum!
- Don't create waste by overspeeding machines.

Setting World Class Targets



Players set their own targets, and get Yellow or Red "X's" for each machine that is "Close" (Yellow)or "Way Over" (Red).

Target setting strengthens the local optimization paradigm.

Setting Targets

- Players set targets for Scrap, Investment, Operating Expense, Overspeed, Stand Alone Availability (S.A.A.), and Inventory (Buffer).
- They must meet their budget requirements, which is a "stretch" target.
- It all must fit into the space allowed. For this example, the system is land-locked, so adding more floor space is not an option.

Decisions, Decisions

Model	Sec/Unit	Units/ Proc	Cycl. Tm	Spd(jph)	MCBF	MTTR	Scrap(%)
A100	0.65	88	57.05	63.1	1476	8	0.12
A200	0.69	88	61.02	59	2205	24	0.08
A300	0.70	88	61.64	58.4	720	18	0.38
A400	0.66	88	57.69	62.4	348	34	0.39
A500	0.72	88	63.16	57	560	11	0.42

Model	I(1000's)	OE(1000's)	S.A.A.	S.A.T.(jph)	Cost/job*	Sq Feet
A100	802	2	0.994	62.67	1.11	5625
A200	582	9	0.989	58.33	1.76	10000
A300	487	17	0.976	56.80	2.67	7500
A400	344	18	0.908	56.42	2.64	12500
A500	192	16	0.982	55.72	2.23	15625

One "Best" Design?

- Given that there are 5 choices for 8 types of processes, there are 390,625 different design possibilities, before buffering is even considered.
- Adding buffers makes the number of solutions boundless.
- And, of course, you have to reach a "stretch" budget target.
- The design must fit into the space allowed.

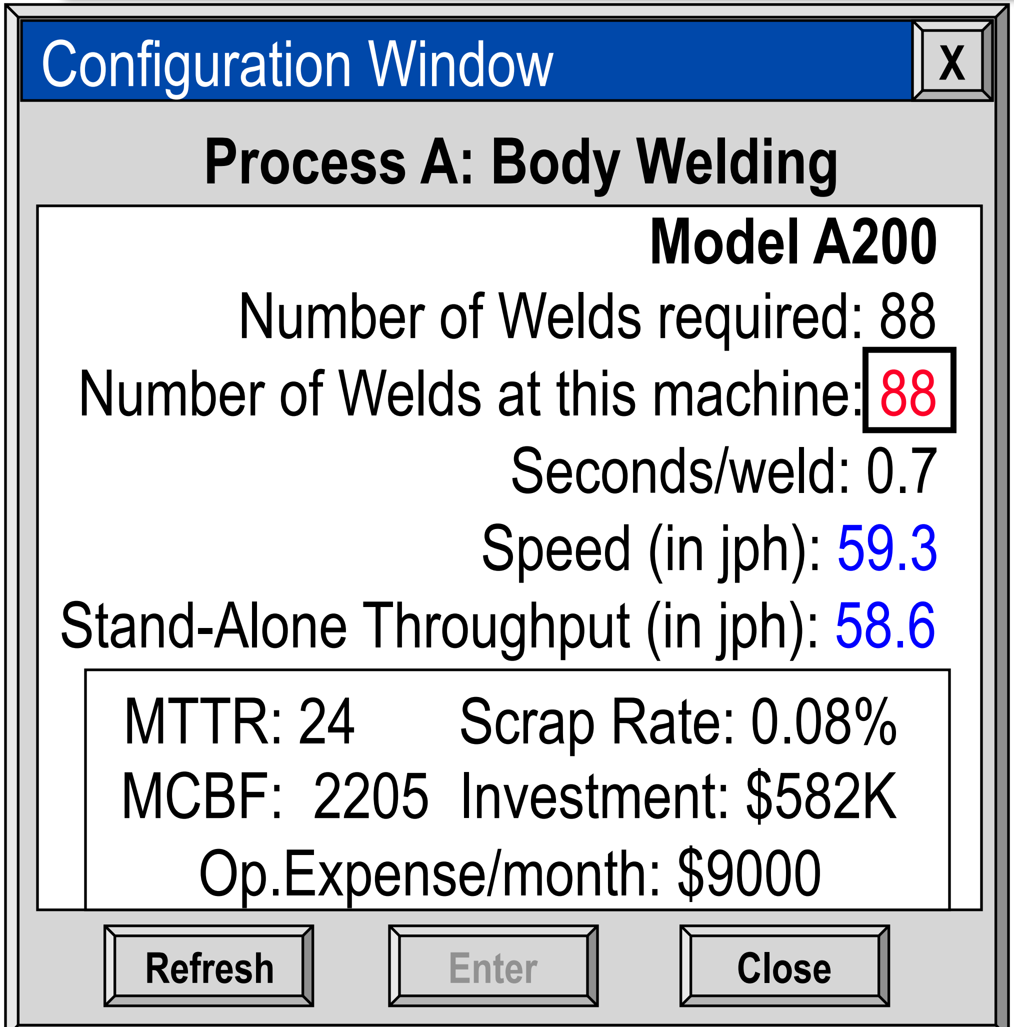
Typical Selections

Targets Worksheet

Total Cost $ 5,812 =>94% Over Budget!

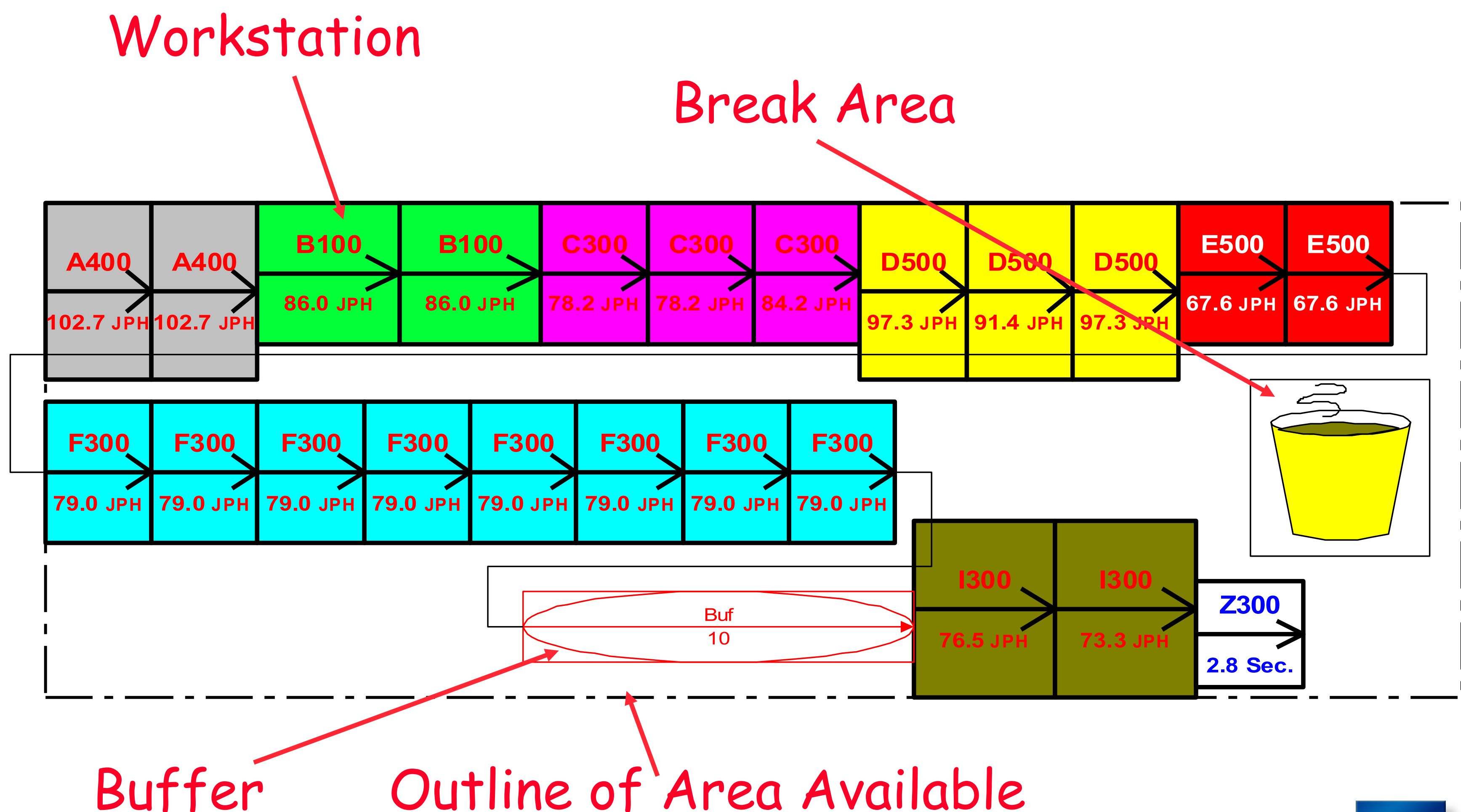
Series: (Enter the number of machines in the appropriate col.)	100	200	300	400	500	**Fault Count (By Row)**		
Process A: Spot Welds				2				XXXXX
Process B: Part Welds	2						XXX	XX
Process C: Drilling			3				XXXX	XXX
Process D: Bolting					3			X
Process E: Sealing		2					XXXXX	XX
Process F: Painting			8				X	
Process I: Inspection			2				XXX	XXXX
Process Z: Conveyor			1					X
PROCESS VIOLATIONS:							16	18
Buffers					Total==>	10	1	0
Grand Total Violations							17	18

Data



Data entry screen for workstations. Work can be distributed among each station so that each one is balanced. Thus, you can assign 44 welds to this A200 process, and 44 welds to the next A200 process.

Sample Design - 1st Run



Sample Results

Design Game Report

Target Throughput:	70 JPH
Actual Throughput:	49 JPH
Throughput Dollars:	$2,817 K
Operating Expense:	$2,077 K
Net Profit:	$ 743 K
Investment:	$5,546 K
RONA:	13.34%

Done

Our student got 49 JPH when s/he needed 70 JPH. It will take 7.5 years to payback our investment. Obviously, there is a lot of upside potential in Net Profit & RONA if we can increase throughput up to our demand rate.

(C-More is run in the background to generate Actual Throughput, which is always in JPH in GM.)

Design Game Report

Target Throughput (JPH) :	70
Unit Price :	$47.25
Material Cost per Unit :	$15.00
Actual Throughput (JPH) :	49
Hours/day worked :	7.2
Scrap Reworked :	45%
Annual Demand ($000) :	5,953
Annual Production ($000) :	4,166
Annual Throughput ($000) :	2,817
O.E./year ($000) :	2,077
Scrap Loss ($000) :	26
Net Profit ($000) :	740
Investment ($000) :	5,546
RONA :	**13.34%**

Done

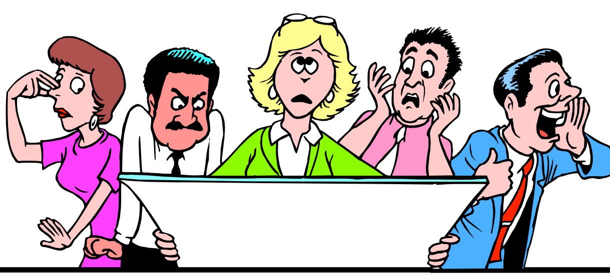
Design Game Report

Target Throughput:	70 JPH
Actual Throughput:	49 JPH
Throughput Dollars:	2,817 K
Operating Expense:	2,077 K
Net Profit:	743 K
Investment:	5,546 K
RONA:	13.34%

Done

End of 1st Run

- Using the traditional method of local optimization results in every team having a different design, and all falling well short of their throughput goals. Most "bleed red" and/or fail to fit into the required area, miss their budgets, and have too many red X's.
- What are the possibilities of consensus among the teams on the best design?
- Buffers are often the first thing "sacrificed."
- Leads to our list of Undesirables Effects listed earlier.



Second Run

- Remove all mandates and local measures - only use Net Profit & RONA for decision making.
- Use RONA at the workstation level to decide on each workstation.
- End up with only a few variations to test from an system level perspective. (Down from 390,625)
- Use C-More to add the optimal amount of buffer to maximize RONA.
- End up with one “best” design for making money.

Workstation RONA

	Number	Capacity	RONA
B100	2	87.5	28%
B200	3	72.1	42%
B300	4	81.8	16%
B400	2	96.0	20%
B500	4	70.5	25%

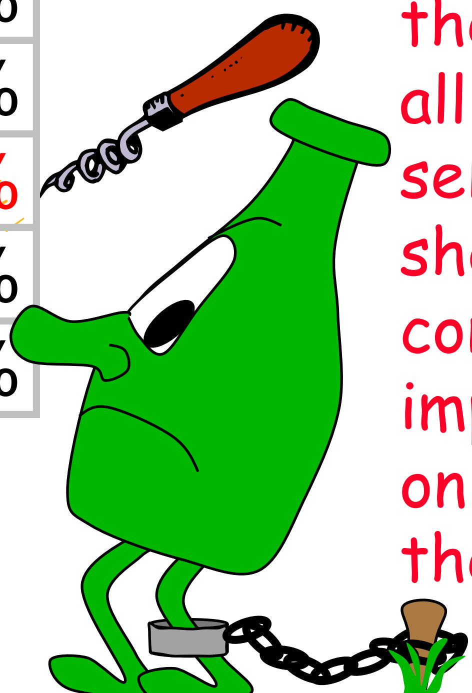
E100	3	100.4	0%
E200	2	79.8	17%
E300	2	72.6	16%
E400	2	75.2	4%
E500	2	67.3	-15%

RONA calculation made per workstation, based on number of machines required to make demand.

For workstation RONA's that are close, check both in system model.

Designed-In Constraint

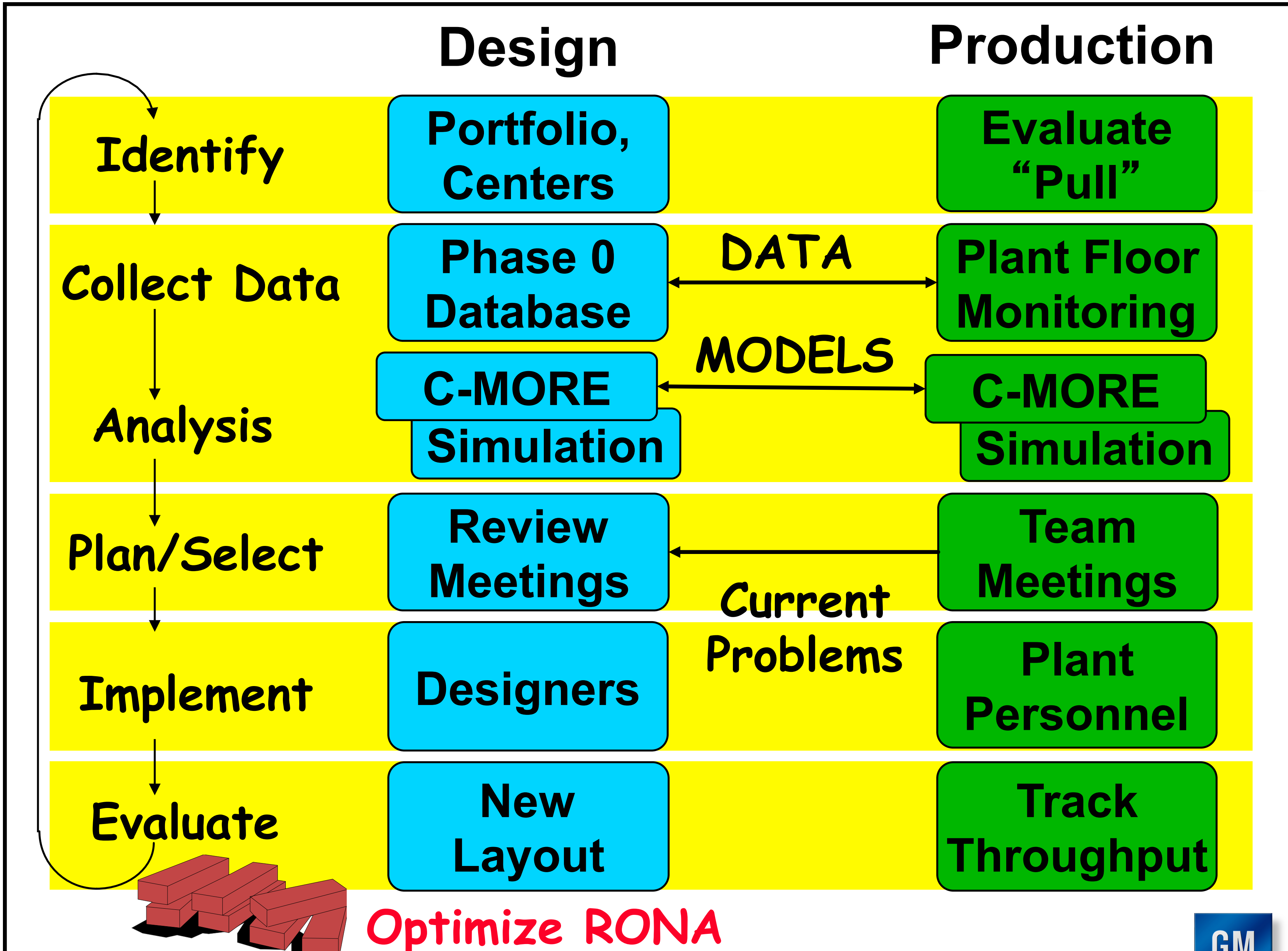
Sta.	RONA
A500	51%
B200	42%
C400	1819%
D500	82%
E200	17%
F500	47%
I300	1220%



The designed in constraint, from this perspective, is that workstation that has the lowest RONA of all the stations selected. This station should be the focus of continuous improvement activities on the design side of the house.

Results after 2nd Run

- One basic design that can be agreed upon by everyone in the room.
- Experimentation past this point is usually around uncertainty.
  - Demand, model mix
  - Downtime data
  - Buffer protection investment to cover uncertainty risk
- Basis for incremental change - will the change increase Net Profit or improve RONA?


Design
Production
Identify
Portfolio, Centers
Evaluate "Pull"
Collect Data
Phase 0 Database
DATA
Plant Floor Monitoring
MODELS
Analysis
C-MORE Simulation
C-MORE Simulation
Plan/Select
Review Meetings
Team Meetings
Current Problems
Implement
Designers
Plant Personnel
Evaluate
New Layout
Track Throughput
Optimize RONA

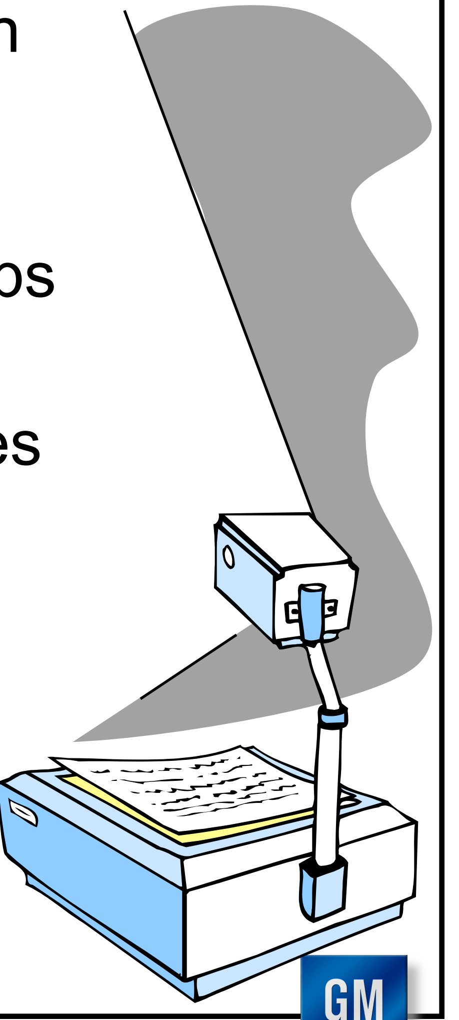
System Design using TOC in GM

- Design assembly lines to be unbalanced, and design in the constraint.
- Break up the system with buffers. Use C-More & the RONA equation to get the most "bang for the buck."
- Over protect the "designed in constraint" with buffers.
- Use RONA calculations to optimize design, perform trade-offs.
- Our basic rule of thumb is: *"There is no rule of thumb - you gotta do the math (analysis)."*

Factory after TOC implementation

Status within GM

- Class developed for training engineers on optimizing system design using RONA. Focus is on simulation engineers.
- Rolling out to manufacturing design groups in GM.
- Used for understanding impact of changes to current designs.



Summary

- Improving throughput in GM assembly plants has increased our Net Profits by over $2 billion.
- The data we collected from these plants help us design the next wave of plants. These new plants having higher throughput than the previous designs.

- The use of RONA in design is our next step to further improving our profitability.
- TOC is still primarily a “Production thing” in GM.