IMPROVING PROJECT PERFORMANCE BY INTEGRATING CPM SCHEDULE & EARNED VALUE ANALYSIS

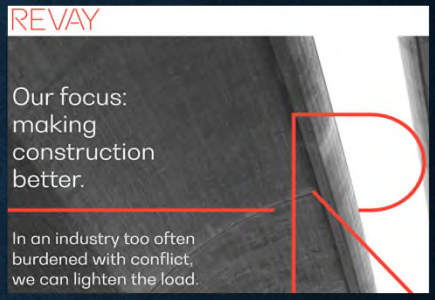
New Causal Analytics connecting Time and the Resources Inputs which Determine Time

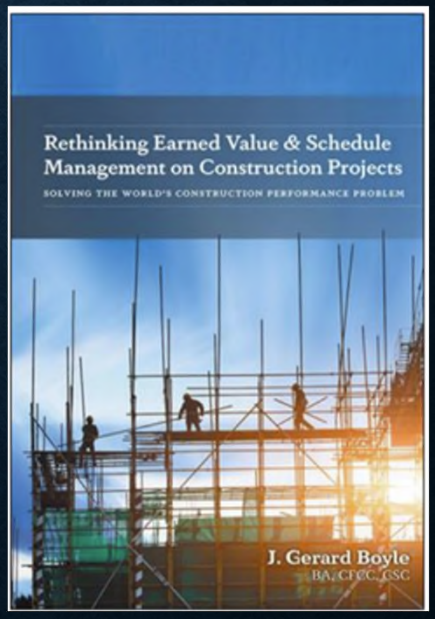
by J. Gerard Boyle

Delivered to the U.S. Government Accountability Office on August 14, 2023

WHO AM I?

- Over 40 years in ***Construction***: ***building; infrastructure; industrial; institutional; commercial; roads; tunnelling; airports, residential …***
- ***Former Contractor***; now ***Consultant (20+ yrs.) Revay***
- Expert: Project Management ***(GSC);*** CPM & Earned Value Performance Analysis; Risk; Forensic Analysis (***CFCC***); Contract Delivery; Dispute Res.
- ***Published author***: Book on EVM/CPM, articles (AACE, Law Journals, etc.), regularly present to industry and academia
- ***Successfully applied these analytics on major construction projects and programs***





THE CONSTRUCTION INDUSTRY IS FAILING & PERFORMANCE ANALYSIS IS PART OF THE PROBLEM

McKinsey report (2016)?

- *"**Productivity** below other industries*
- *Projects regularly **over budget and time targets***
- ***Reinvention** required: **Integrated, Advanced Performance analysis** and KPIs*
- New analytics should serve as a source of **performance *"truth"***

Requires a root causal understanding

PER THE GAO SCHEDULE ASSESSMENT GUIDE, AN INTEGRATED & RELIABLE SCHEDULE IS THE FUNDAMENTAL PERFORMANCE ANALYSIS TOOL

- Integrated CPM schedules difficult to obtain – some have given up on trying!
- It is worth the effort and commitment, and how can it be done?
- If obtained, are existing analytics adequate?

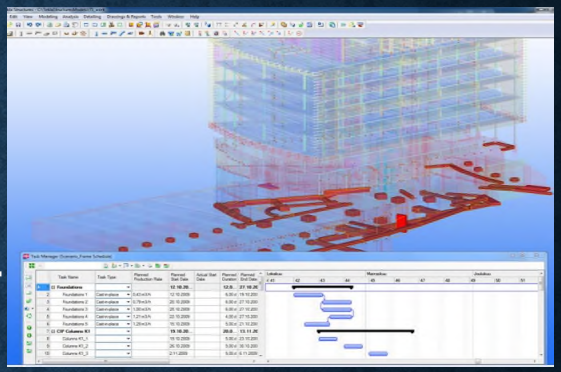
THE INTEGRATED MASTER SCHEDULE

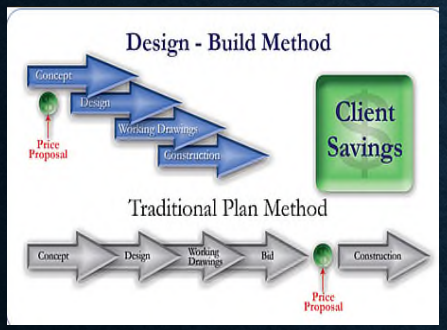
As a document that integrates the planned work, the resources necessary to accomplish that work, and the associated budget, the IMS should be the focal point of program management. In this guide, an IMS constitutes a program schedule that includes the entire required scope of effort, including the effort necessary from all government, contractor, and other key parties for a program's successful execution from start to finish.[1]

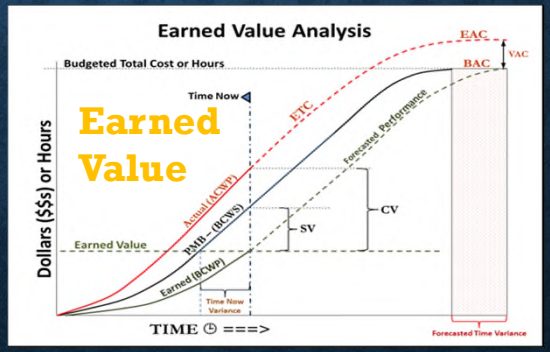
WHY ARE ALL OF THESE CONSTRUCTION INDUSTRY "SOLUTIONS" FAILING?

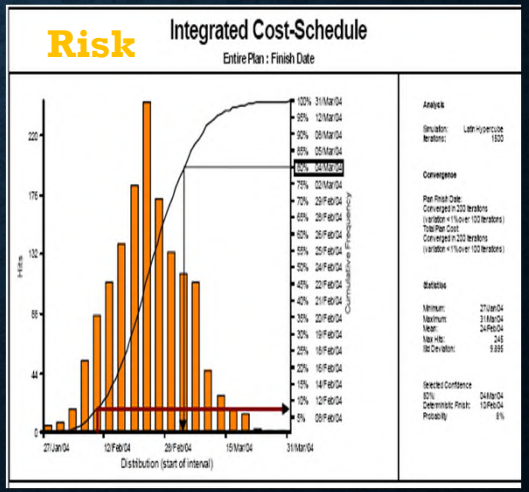
Technology:

- **CPM**
- **BIM**
- **4D Scheduling**
- **OCPM**







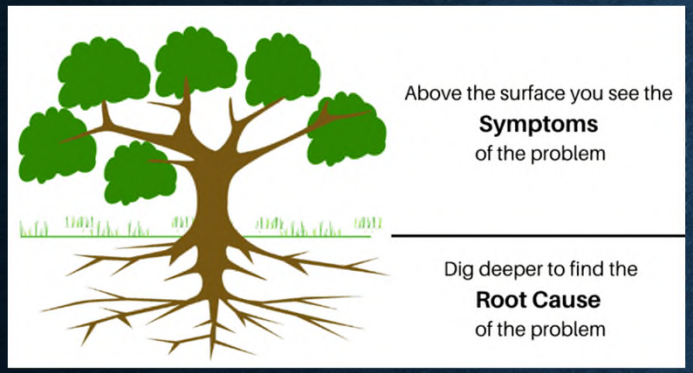


NEW ANALYTICS CAUSALLY INTEGRATE PERFORMANCE ANALYSIS

- *"Reinvention required: Integrated, Advanced Performance Analysis"*

Meet the McKinsey challenge

(1) The Problem – Symptoms, not Root Causes (output-based)



(2) The Solution – Root Causal Input Analytics

Integrated Cost & Time Formulas

OUTPUT | CAUSAL INPUTS

$$\underset{(Time)}{Duration} = \frac{Quantity}{Productivity \times Resources}$$

EVM

$$\underset{(Progress)}{SPI} = \underset{(Productivity)}{CPI} \times \underset{(Resource\ Supply)}{RPI}$$

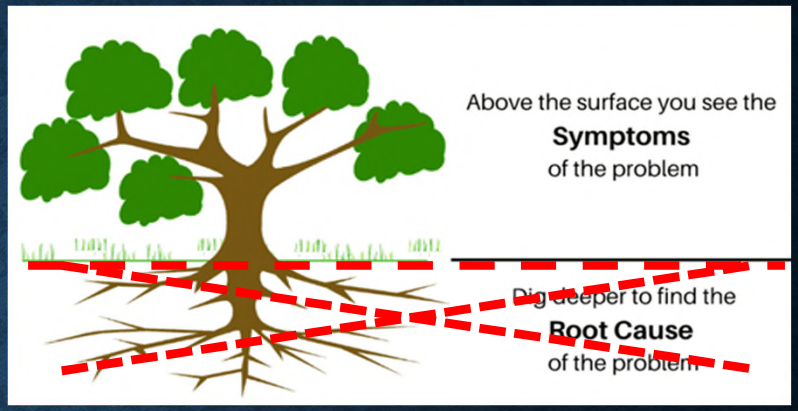
$$SV = CV + RV$$

MAP: ESCAPING PERFORMANCE FAILURE

(3) A Success Story

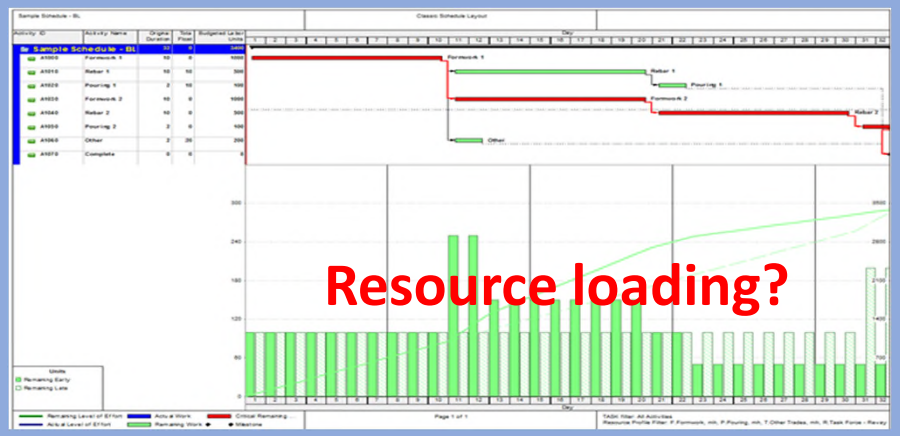
- On Budget: Contract Changes less than 2%!!!
- Construction On Time!!!!
- No claims!!!

Part 1



1. THE PROBLEM

Failed Promise and Shortcomings of CPM, Earned Value, Risk, and Contract Delivery

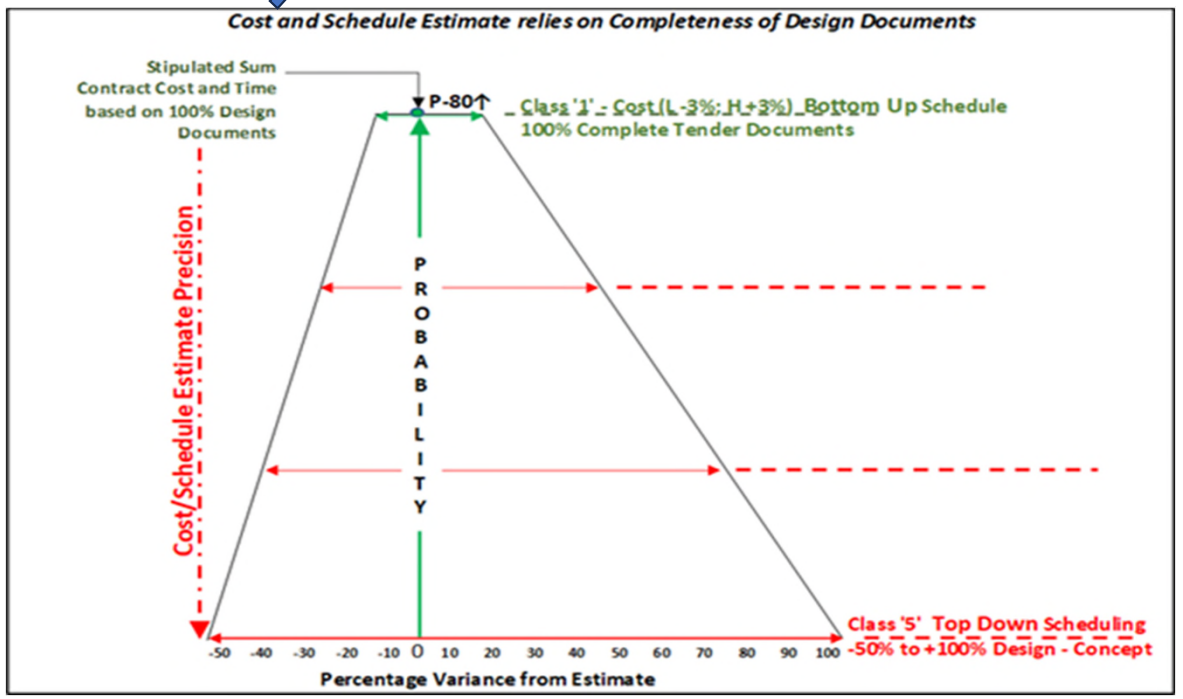


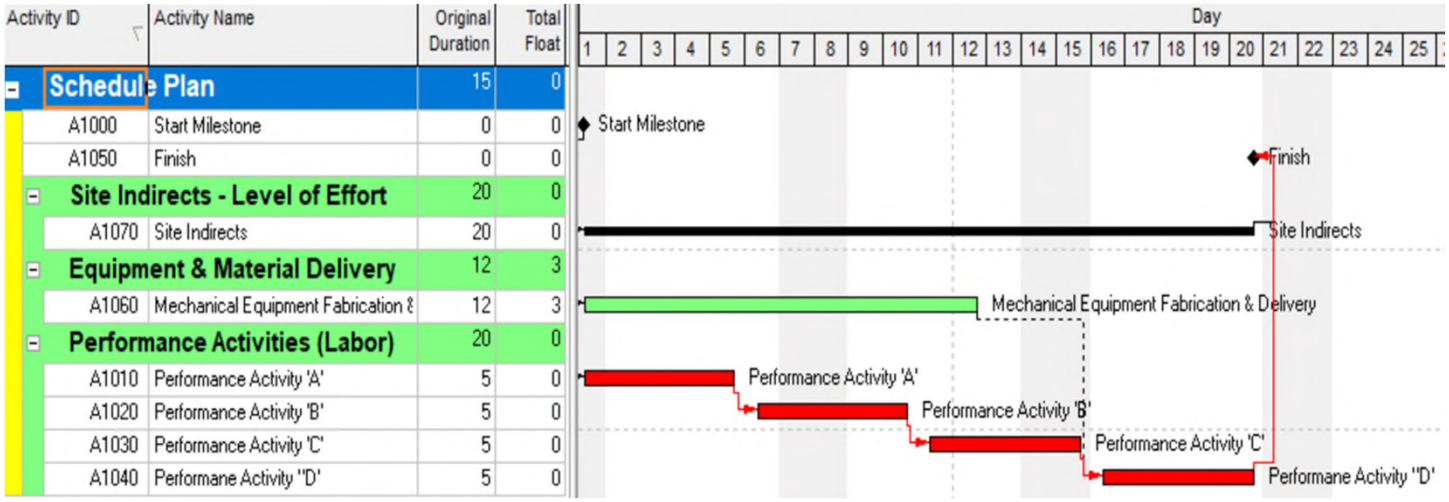
1.1 The Failed Promise of CPM Scheduling

No Resources = No Root Causal Understanding

Best Practice, Integrated Execution Schedule is the Optimal, most reliable Model?

Integrated, fully resource loaded, bottom up, Level 1





Activity ID	Activity Name	Original Duration	Total Float
Schedule Plan		15	0
A1000	Start Milestone	0	0
A1050	Finish	0	0
Site Indirects - Level of Effort		20	0
A1070	Site Indirects	20	0
Equipment & Material Delivery		12	3
A1060	Mechanical Equipment Fabrication &	12	3
Performance Activities (Labor)		20	0
A1010	Performance Activity 'A'	5	0
A1020	Performance Activity 'B'	5	0
A1030	Performance Activity 'C'	5	0
A1040	Performane Activity "D'	5	0

- ***Performance Activities get the work done.*** Mainly labour (but also equipment and machines performing work)
- Performance Activities are the controllable factor which determine time.

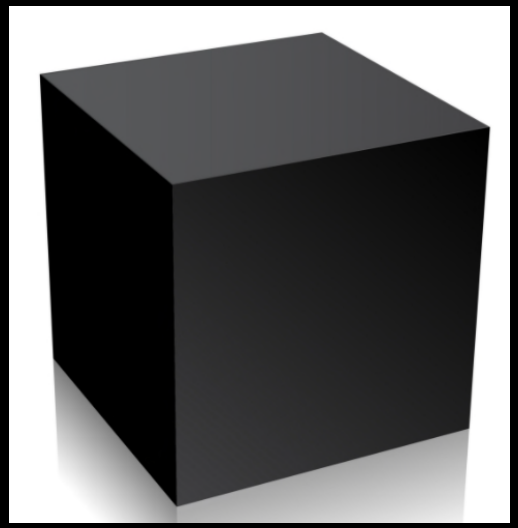
Performance Activities:
"Control the hours and control the project"

SCHEDULE PROBLEM PERSISTS

- *"What is described as a CPM schedule these days **isn't one at all**."*
- *"Widespread abuses of powerful software to produce **badly flawed or deliberately deceptive schedules** that look good but lack mathematical coherence or common sense … **Result is confusion, delayed projects and lawsuits**."*
- [***Critics Can't find the Logic in Many of Today's CPM Schedules* – interview with R. Farris, James O'Brien, Fred Plotnick, Jon Wickwire, et. al …**]** 20+ years ago.

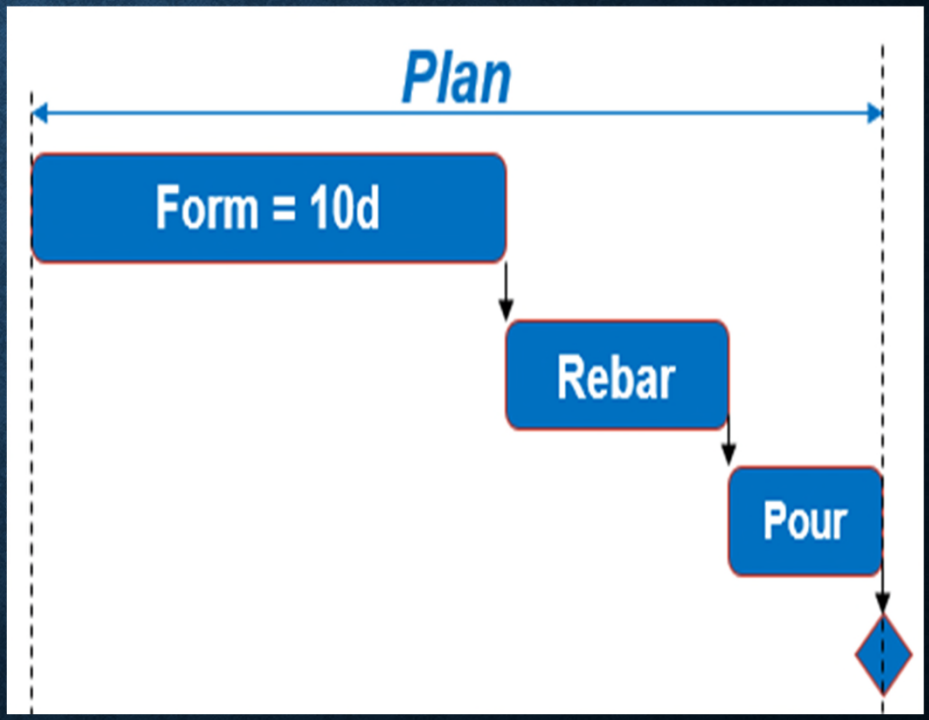
A Schedule without Resources **is a performance "Black Box"**

- Accepting a schedule without resources is like buying a car without knowing what's under the hood. Take it on faith?
- ***Resource information is required to understand the plan, analyze performance to-date, and reliably forecast the future.***
- Resource information provides ***root causal, deterministic*** explanation for performance, delays and disruptions.



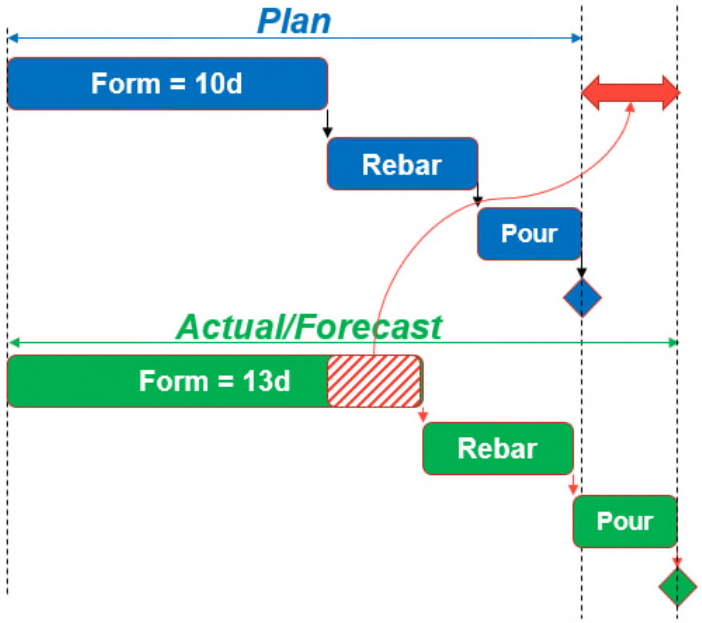
ACTIVITY DURATION IS A TIME OUTPUT. WHAT IS THE CAUSAL INPUT BASIS?

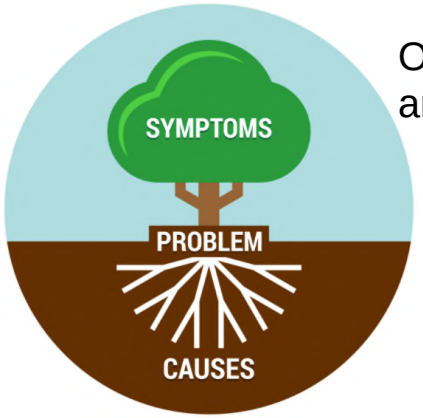
- **How much** forming is being done in **10 days**?
- How much must be done **each day**?
- What **labour resources are** required in order to perform the required work in 10 days?
- How efficient must labour be?



What is the Root Cause of Duration?

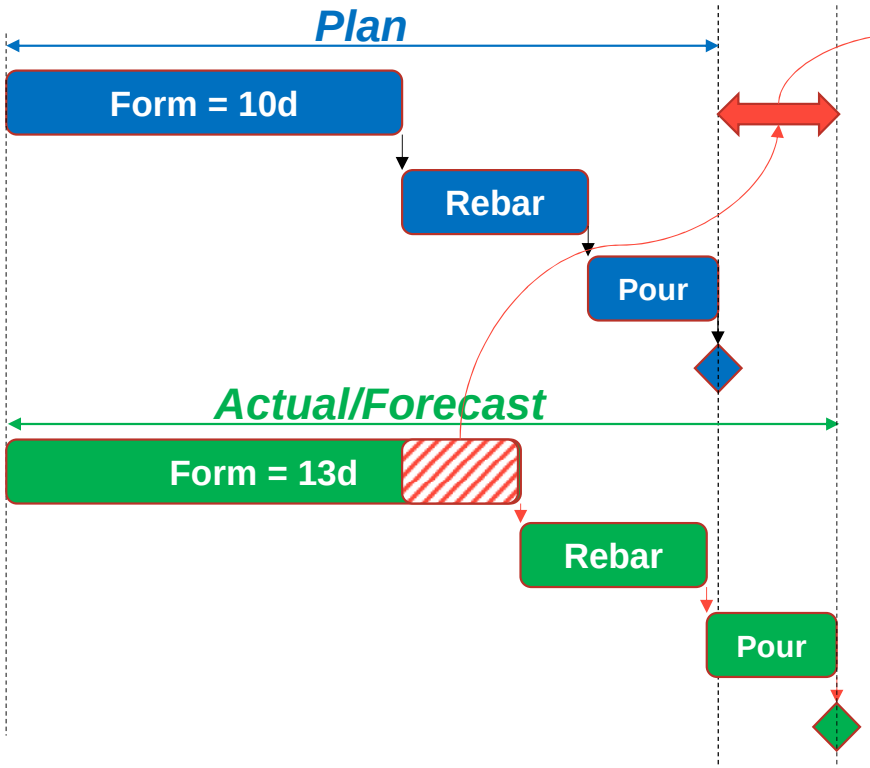
- Causation is: "*something that brings about an effect or a result*"
- Root causes are the **essential** cause
- If root causes are not known, **guesses** about causation may be **very wrong**?





Only "***Symptoms***" are analyzed.

Did embedded conduit change “cause” this delay?



What “caused” the delay?

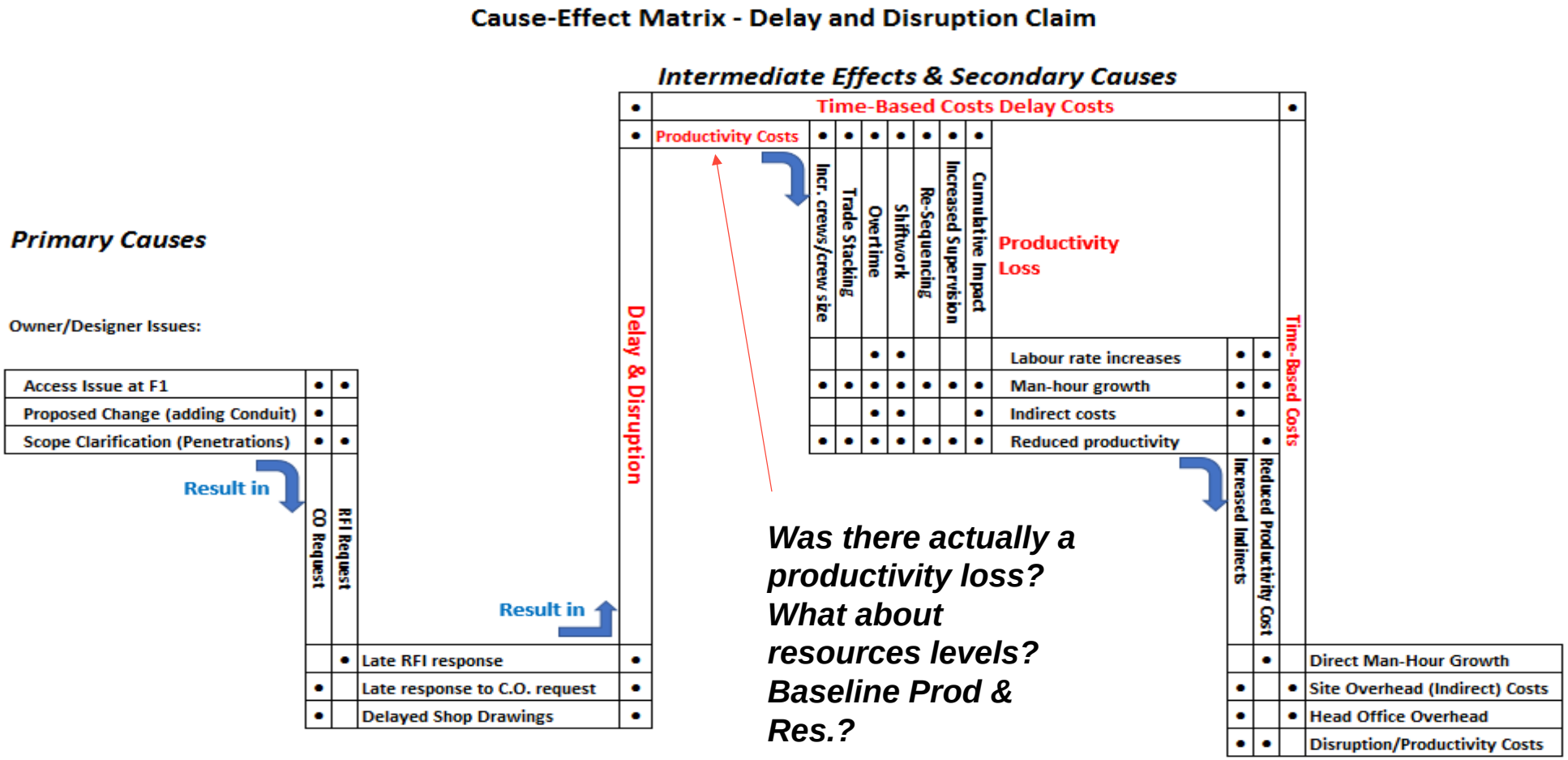
“Cause-Effect Matrix”

Primary Causes

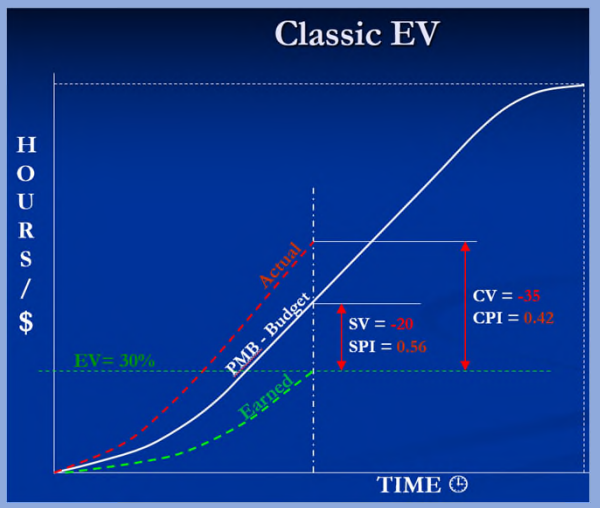
Owner/Designer Issues:

	CO Request	RFI Request		Delay & Disruption
Access Issue at F1	•	•		
Proposed Change (adding Conduit)	•			
Scope Clarification (Penetrations)	•	•		
Result in			Result in	
		•	Late RFI response	•
	•		Late response to C.O. request	•
	•		Changes to Scope	•

Classic Output-Based Cause-Effect Analysis: Root Causes?



1.2 Earned Value Shortcomings



EVM CORE PRINCIPLE #1: PLANNING & CONTROL THROUGH COST & SCHEDULE INTEGRATION

- **Project planning & control benefits strongly by …**
- **Integrating Schedule and Cost**
  - *"provide **strong benefits for program enterprise planning and control."***
  - *"**effectively integrate** the work scope of a program with the **schedule and cost** elements for **optimum program planning and control**."*
  - *The **primary purpose** of the system is to **support integrated program management**."* [SAE International]

CORE PRINCIPLE # 2 – ROOT CAUSAL ANALYSIS

- ***Proactive management***:
  - ***Early risk identification, corrective action, replanning***
  - ***Requires root causes to be effective***
- The root cause is the core issue—the ***highest-level cause***—that sets in motion the ***entire cause-and-effect reaction*** that ultimately ***leads to the problem***(s). [American Society for Quality]

EVM ABANDONS PMB OBJECTIVE: DOESN'T REQUIRE CPM SCHEDULING?!

- *"While* [**CPM**] ***quite capable**, the application of basic **earned value management techniques** does **not require the use of any particular scheduling methods**.* *[EIA-748]*

Core Principle is Integration of Schedule and Cost! No schedule required?

EV THEORY MISTAKES: ROOT CAUSE OF LABOUR DURATION NOT UNDERSTOOD

- "*Any **added resources** will …*
  - *have a **permanent negative** impact on **cost efficiency** and …*
  - *produce **no positive critical path schedule results**.*"

Seriously bad advice for PMs!!!

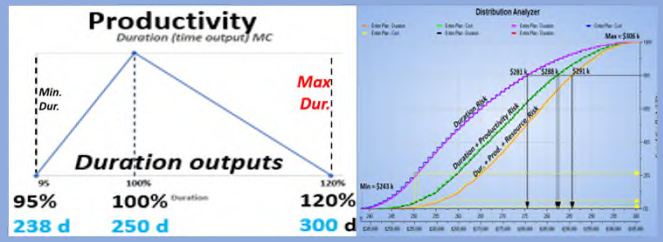
Duration = 10 days

Duration = 10 days

More workers = lower productivity & no time benefit

SUMMARY OF EV PROBLEMS

- **Not integrated** with CPM
- **Defers** schedule analysis to CPM
- **Misunderstands root, deterministic cause** of labour activity duration
- **Cost-centric** – considers CV,/CPI paramount; SV,/SPI limited utility
- No **Resource Variance**?
- Assumes **no causal connection** between PMB performance & EV metrics
- Assumes **CV not connected to SV**



1.3 Integrated CPM Monte Carlo Risk Analysis - Shortcomings

BACKGROUND: RE-THINKING RISK ANALYSIS

- RP 41R-08 Shortcomings of "*range estimating*" *Understanding Estimate Ranging,* reassessment in 2008
- Failure to explicitly quantify "***risk drivers***" meant that ***analysis not risk-driven***
- ***Cost and schedule*** impact ***not integrated***
- Failed to recognize industry "***progression*** *towards … **big data*** **[megadata]**, *machine learning, and **artificial intelligence***".

POST 2008 - PURPOSE OF RISK ANALYSIS

- **CONTINGENCY**: Determine the amount of ***cost & schedule contingency*** needed to provide ***a degree of confidence*** in both targets
- **FORECASTING**: "*Estimate the **probability** of finishing on/before the **schedule date** and on/under the **cost estimate**.*".
- PERFORMANCE BENEFIT:
  - ***Early warning*** of ***schedule risks,***
  - ***Proactive management***
  - ***Risk Mitigation/Avoidance***
- **ROOT CAUSES**: Identify "***root***" causal risks (using "Risk Drivers")

Risk Labour Loading: Hours not loaded

ID	Description	Remaining Duration
0030	Construction	250

2023: Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul

General | Dates | Constraints | Links | Resources | Costs | Risk and Uncertainty | User Fields | Suspend and Resume

			Units				Cost
Unit of Measure	Loading	Units/period	Remaining	Budget	Earned	Actual	Remaining
$/day	Normal	1,020	255,000	255,000	0	0	$255,000

- No labor hours
- $1 dollar of budget assumed to = 1 hour of labor

One Resource Unit:	Res. Unit:	Resource Loading:	Task Duration:	Units per period ("Burn Rate"):	Remaining Resources:	Cost Per Unit:	Cost of Resource:
'A'		'B'	'C'	'D' = 'E' ÷ 'C'	'E' = 'C' X 'D'	'F'	'G' = 'E' X 'F'
Labour $ unit	dollar	Normal	250	1,020.00	255,000	$ 1.00	$ 255,000

$$\textbf{Daily (Burn) Labor Rate} = \frac{\textbf{Budget Dollars (\$)}}{\textbf{Duration (d)}} = \frac{\$255,000}{250} = \$1,020 \textbf{ per day}$$

NASA JCL supports no labour hour loading

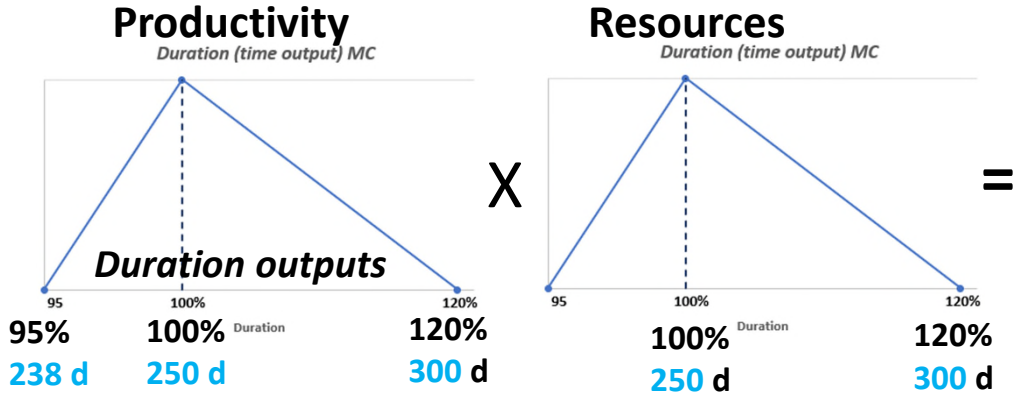
- "*For a Joint Cost & Schedule Confidence Level* (JCL), **cost loading** a schedule is sufficient and a ***resource loaded schedule is not required***."
- "*Intent of JCL policy is **not to recreate** the **lower level management** responsibility of … **managing resources** (labor, etc.) but to instead **model macro tendencies** …*"
- Basis for "***confidence***" when ***labor resources*** not considered?

> *"Because resources directly relate to an **activity's duration**, assigning resources such as **labor** to activities **ensures duration will be realistic & rational**."*
> [**GAO – Best Practice 3**: Assigning Resources to all activities]

Output-Based Tri. Distribution: Max/Min Errors?

CPM Algorithm models different duration (output) values

Output



- ***Are the maximum (& minimum) limits chosen by the analyst deterministically correct?***

If Prod + Res 20% lower, does the duration = 300 days?

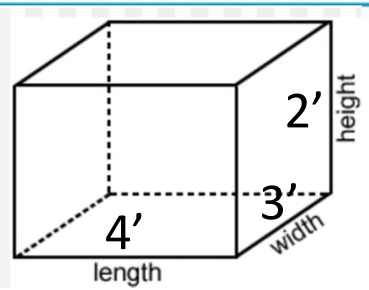
MC Output Error in Maximum calculation

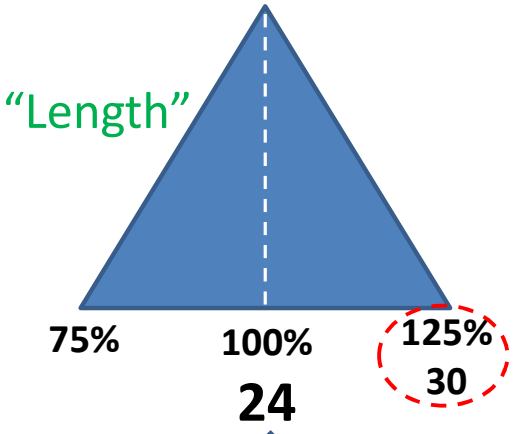
INTERNATIONAL

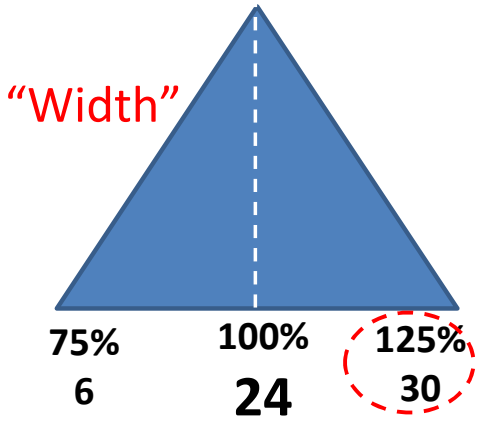
$$Deterministic\ Volume = L \times W \times H = \underbrace{4' \times 3' \times 2'}_{Add\ 25\%} = 24\ c.f.$$

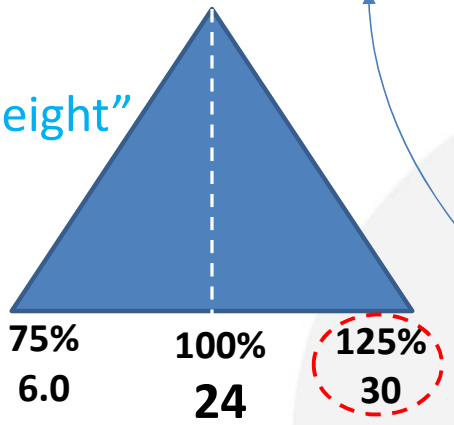
Algorithm

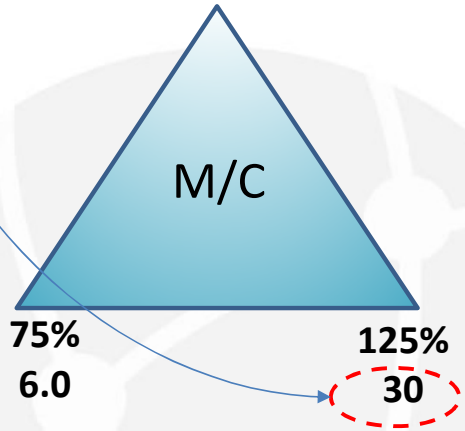
$$Det.Max.Volume = 5' \times 3.75' \times 2.5' = 47\ c.f.$$











Vol. instead of Length

- *No **MC algorithm** for **input** dimensions.*
- *Instead models the **output** - volume (24 c.f.)*

Max = 125% x 24 = 30 c.f.

SUMMARY OF RISK PROBLEMS

- **Not integrated** with CPM although PMB is the objective
- **Uses Summary Level schedule instead of Class 1 Execution Schedule**
- **Asserts that labour activity duration is determined by time**
- **Labour hours not loaded**
- Risk Software algorithm is **output based**. Does not permit modelling of the root causal inputs which **determine labour activity duration**

1.4 Failure of Alternative Contract Delivery Methods

P3 Risk Transfer Assumptions?

Public private partnerships under increasing attack in the UK

August 19th, 2011 · Keith Reynolds · 2 Comments · Privatization, P3s & public services, Transparency & accountability

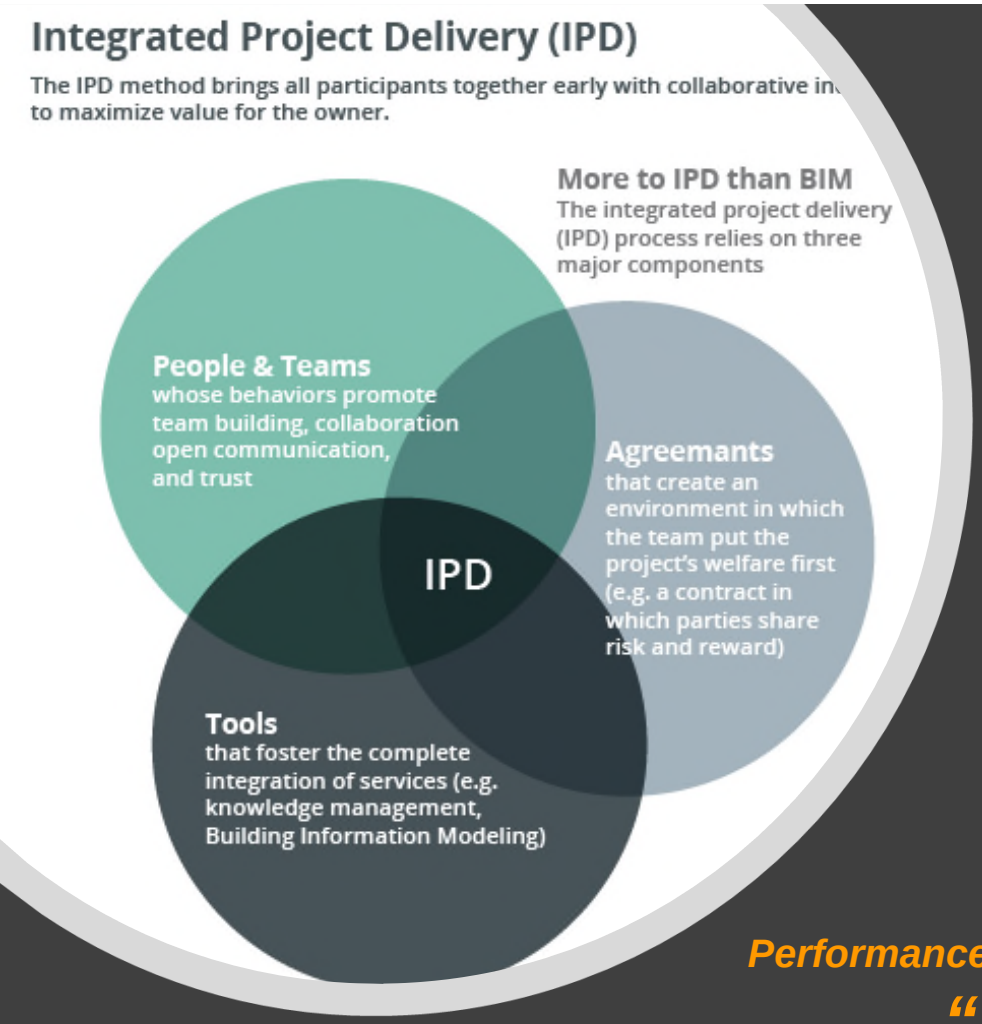
- *"[In P3's] the **private sector** assumes a **major share** of the **risks** in terms of financing and **construction** and ensuring **effective performance** … from **design and planning**, **through execution** … to long-term maintenance."*

THE NATIONAL Council For Public-Private Partnerships
PARTNERSHIPS FOR PROGRESS

Figure 3: Typical Risk Transfer Scenario Under PPP Arrangements[45]

	Responsibility for Risk		Transferred?
	Public/DBB	PPP	
Development Risks			
Performance	Public	Private	X
Interface	Public	Private	X
Design Risks			
Scope	Public	Shared	X
Errors and Omissions	Public	Private	X
Interference/Coordination	Public	Private	X
Life Cycle	Public	Private	X
Construction Risks			
Performance	Private	Private	
Schedule	Public	Private	X
Cost Overruns	Public	Private	X
Changes in Scope	Public	Public	
Force Majeure	Shared	Shared	
Financing Risks			
Schedule Slippage Additions	Public	Private	X
Interest Rate Risk	Public	Private	X

If performance is not analyzed, risk transfer assumptions break down!



Integrated Project Delivery – Improved performance without accountability?

- *IPD is built on **collaboration**, which in turn is built on **trust**. … mutual respect and trust … **tolerance**."*
- *"**No individual accountability for poor performance** … because all have a stake in success (Risk Pool)."*

Performance must be objectively and independently evaluated!

"Trust but Verify"

No Transparency about performance means lower productivity and increased cost

- '***Many players*** *in the industry benefit from* ***today's market failures****, earning a substantial share of revenue and profits from change orders and claims, and reducing exposure to competition* ***in an opaque market****.'* [McKinsey Report]

MCKINSEY GLOBAL INSTITUTE

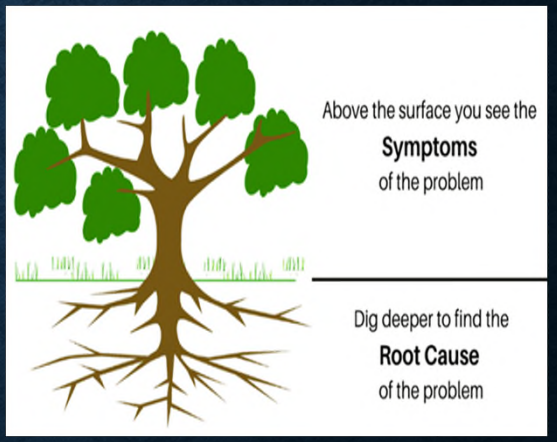
REINVENTING CONSTRUCTION: A ROUTE TO HIGHER PRODUCTIVITY

Industry dynamics

- Construction is opaque and highly fragmented

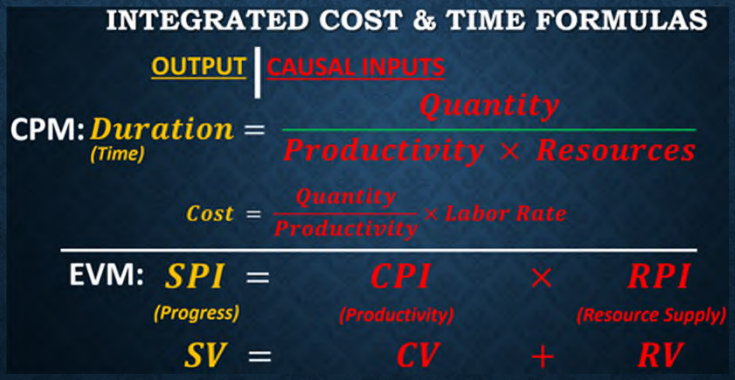
THE PROBLEM COMMON TO ALL FAILED FIXES: ROOT CAUSES UNEXAMINED

- Analysis is **Output-based** – **symptoms** above the surface - **because schedules are not resource loaded**
- The **Root Causes of duration** require knowledge of the **performance inputs** – **productivity** and the **labour resources** - which **determine duration**.
- Without **causal under**standing, there is not performance **transparency,** and therefore responsible parties cannot be held **accountable** and expeditious corrective action is not taken



Part 2

2. THE SOLUTION: NEW INTEGRATED ROOT CAUSAL ANALYTICS



A map through the Solution

PART 2

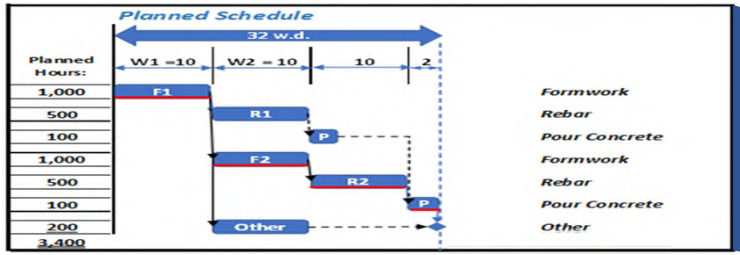
$$Causal\ Duration = \frac{Quantity}{Productivity \times Resources}$$

2.1 New Causal Duration & Cost Formulas

$$RV = Actual - Planned$$

$$EV_{Causal}: SPI = CPI \times RPI$$

2.2 New EVM Metrics connect Time to Causal inputs



2.3 Integrated EVM/CPM Causal Analysis

2.1 NEW CAUSAL DURATION & COST FORMULAS

$$Causal\ Duration = \frac{Quantity}{Productivity \times Resources}$$

$$(Labor)Cost = \frac{Quantity}{Productivity} \times \$Labor\ Rate$$

What Causes the Duration of a labor activity?

Output Based Duration

- What is the causal, deterministic basis for output?

$$Activity\ Duration = \frac{Quantity}{\textbf{Daily Output}} = \frac{10{,}000\ (s.f.)}{\textbf{1,000}\ (s.f.)} = 10\ days$$

Input Based (Causal) Duration

- Productivity and the Rate of Resource Supply determine labor time duration per following formula:

$$\textbf{Activity Duration} = \frac{Quantity}{Productivity \times Resource\ Supply} = \frac{10{,}000\ \cancel{s.f.}}{10\ \frac{\cancel{s.f.}}{\cancel{hrs.}} \times 100\ \frac{\cancel{hrs.}}{day}} = 10\ days$$

(Causal Input Formula)

Output = 1,000 sf./d

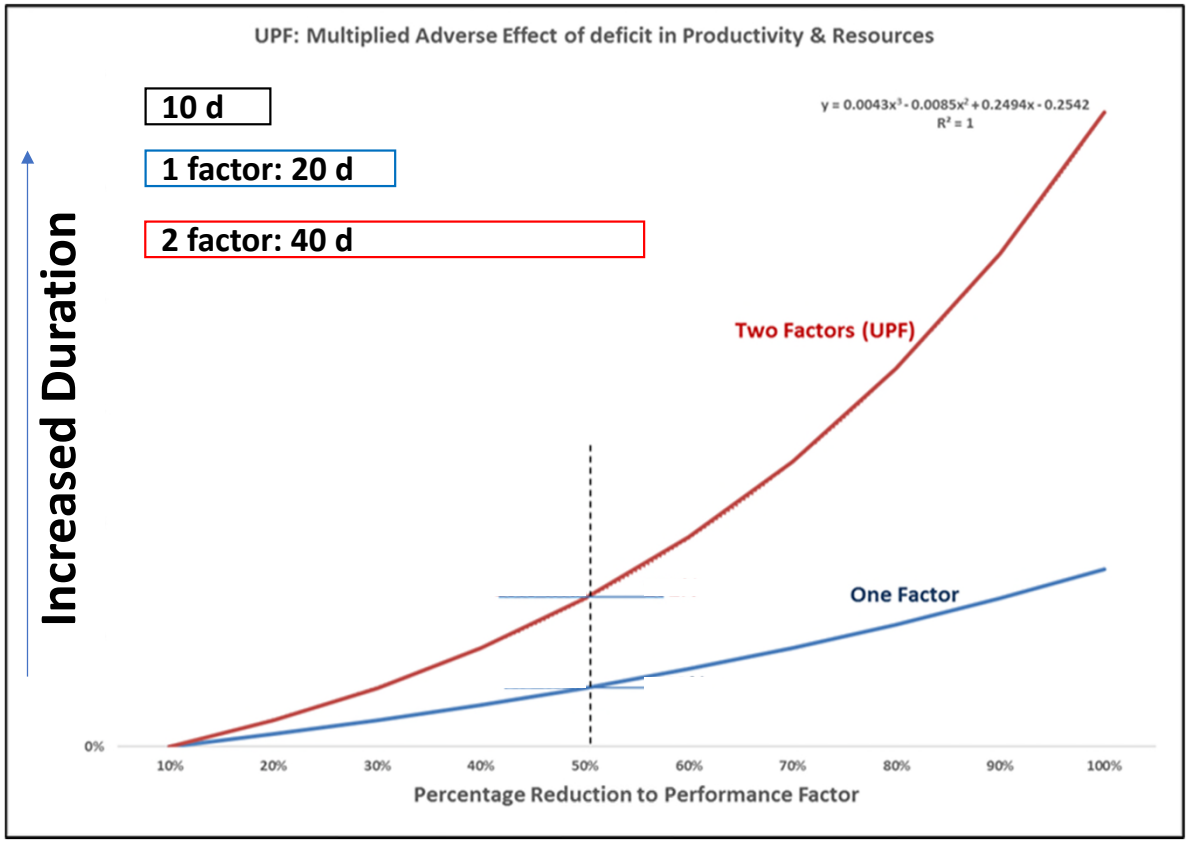
MATRIX OF DURATION OUTCOMES

$$Activity\ Duration = \frac{Quantity}{Productivity \times Resource\ Supply}$$

- Activity duration varies as productivity & res. vary
- If ***productivity < plan*** and ***resources = plan***, ***duration increases (red-coloured cells)***
- ***Prod. < plan*** and ***Res. < plan***, ***worst case*** duration increase (red)
- Negative and positive prod and res could ***offset and have no duration effect*** (depends on magnitude) [white cells]

ACTIVITY DURATION: EFFECT OF VARIANCE FROM PLANNED RESOURCE OR PRODUCTIVITY TARGETS per CAUSAL FORMULA				
		PRODUCTIVITY		
		Below Plan	*Per Plan*	*Above Plan*
RESOURCES	*Below Plan*	Longer Duration (worst case)	Longer duration	Longer, Shorter or No change
	Per Plan	Longer Duration	Planned duration	Shorter Duration
	Above Plan	Longer, Shorter or No change	Shorter Duration	Shorter Duration (best case)

Duration effect of Productivity & Resource Deficits



$$Duration = \frac{10,000\ s.f.}{5\frac{s.f.}{hr.} \times 50\frac{hr.}{day}} = 40d$$

Both factors 50% below plan: Exponential growth

$$Duration = \frac{10,000\ s.f.}{5\frac{s.f.}{hr.} \times 100\frac{hr.}{day}} = 20d$$

1 factor 50% below plan Linear growth

Correcting Risk Theory: Productivity determines labour cost; not time

Output Cost formula

$$\boldsymbol{Cost}(\$) = \boldsymbol{Duration}(\boldsymbol{d}) \times (\boldsymbol{Burn\ Rate})\boldsymbol{RRS}\frac{\boldsymbol{hrs.}}{\boldsymbol{d}} \times \boldsymbol{Labour\ Rate}\frac{\$}{\boldsymbol{hr.}}$$

Causal Duration Formula

$$(\boldsymbol{Burn\ Rate})\boldsymbol{RRS}\left(\frac{\boldsymbol{Hrs.}}{\boldsymbol{d}}\right) = \frac{\boldsymbol{Quantity}(\boldsymbol{s.f.})}{\boldsymbol{Duration}(\boldsymbol{d}) \times \boldsymbol{Productivity}\left(\frac{\boldsymbol{s.f.}}{\boldsymbol{hr.}}\right)}$$

$$\boldsymbol{Cost}(\$) = \cancel{\boldsymbol{Duration}(\boldsymbol{d})} \times \frac{\boldsymbol{Quantity}\ \cancel{(\boldsymbol{s.f.})}}{\cancel{\boldsymbol{Duration}\ (\boldsymbol{d})} \times \boldsymbol{Productivity}\left(\frac{\cancel{\boldsymbol{s.f.}}}{\cancel{\boldsymbol{hr.}}}\right)} \times \boldsymbol{Labour\ Rate}\left(\frac{\$}{\boldsymbol{hr.}}\right)$$

$$Cost(\$) = \frac{Quantity\ (s.f.)}{Productivity\left(\frac{s.f}{hr.}\right)} \times Labour\ Rate\ \left(\frac{\$}{hr.}\right)$$

Correcting EVM cost assumptions

Per EVM …

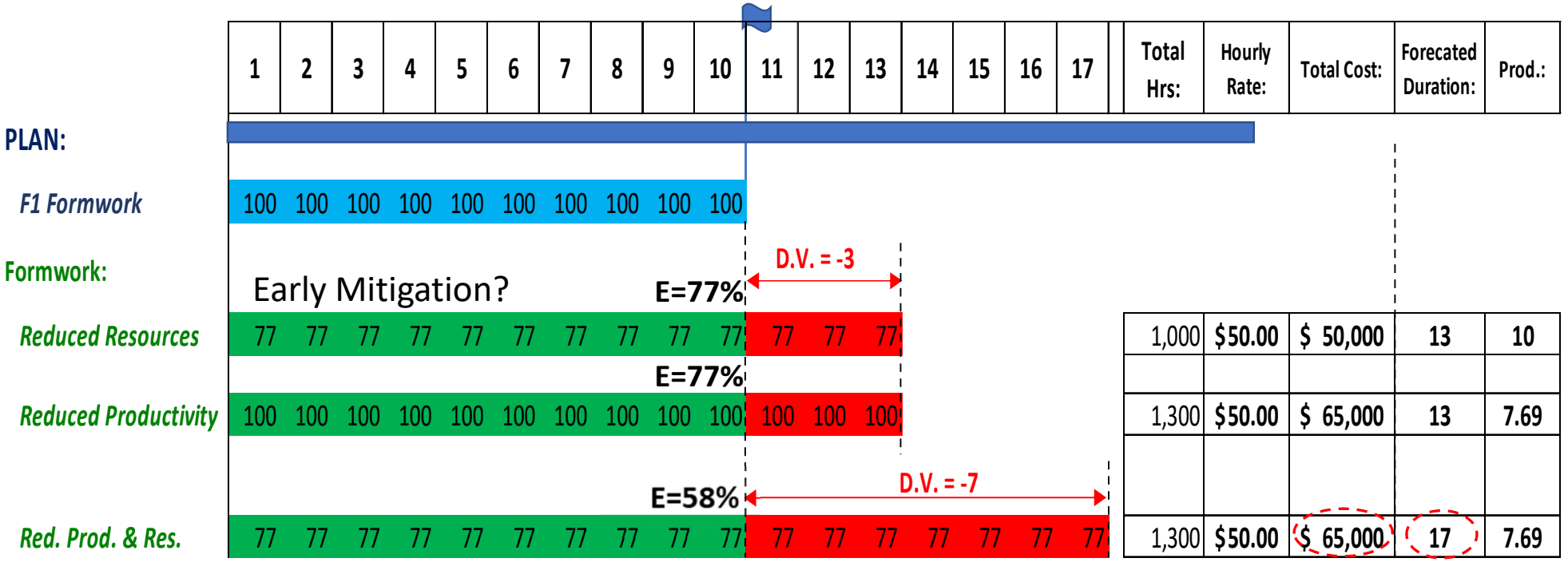
- If CPI is *0.50* "*work will **likely …***
  - ***take twice as long*** *to finish, and*
  - ***probably cost more*** *due to* ***extended duration***."

- "*Any **added resources** will have a **permanent negative** impact on **cost efficiency** and will produce **no positive critical path schedule results***."

- ***Productivity alone*** does ***not determine duration***
- ***Time*** does ***not determine cost***

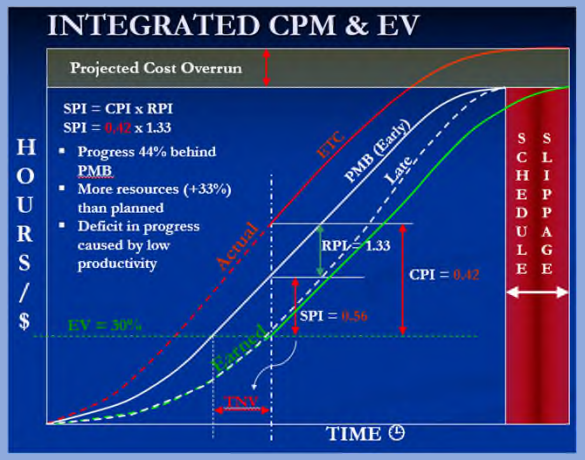
- Productivity ***not necessarily*** impacted by ***level of resources***.
- Adding resources should ***not be assumed*** to have ***no schedule benefit***

Forecasting Duration & Cost with new formulas



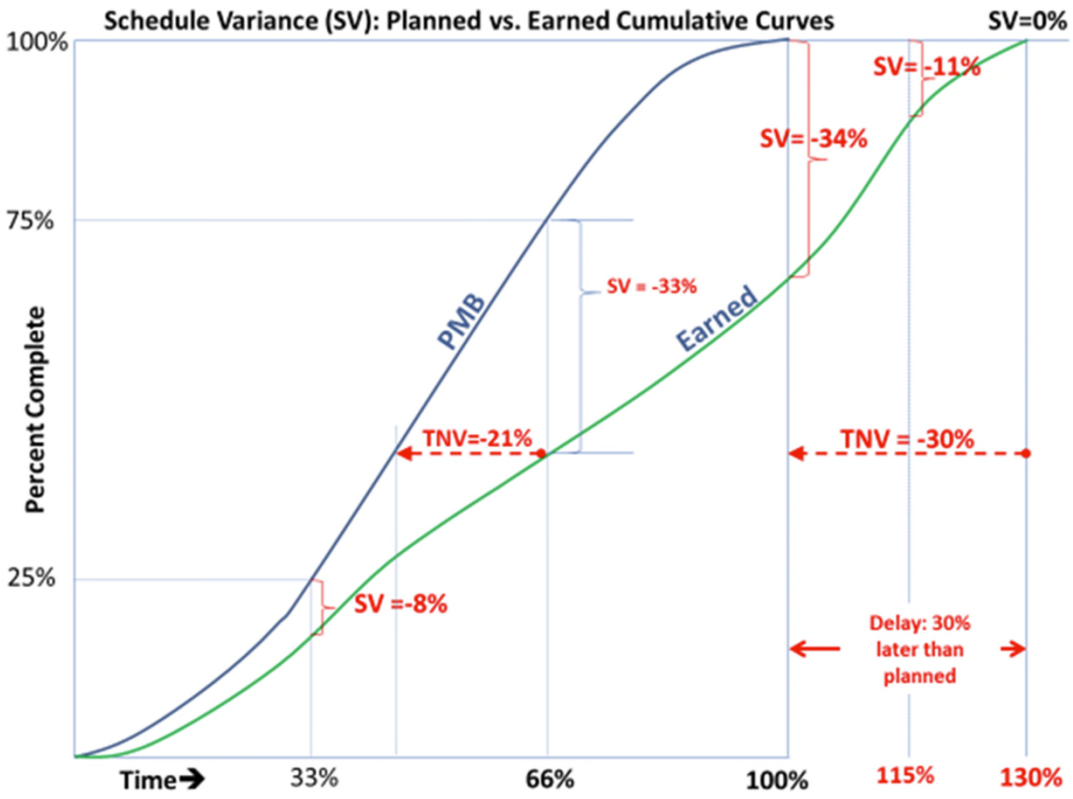
$$Cost = \frac{10,000\ \cancel{s.f.}}{7.69\ \frac{s.f.}{\cancel{hrs.}}} \times \$50\ per\ hr. = \$65,000$$

$$Activity\ Duration = \frac{10,000\ \cancel{s.f.}}{7.69\ \frac{\cancel{s.f.}}{\cancel{hrs.}} \times 77\ \frac{\cancel{hrs.}}{day}} = 17\ days$$



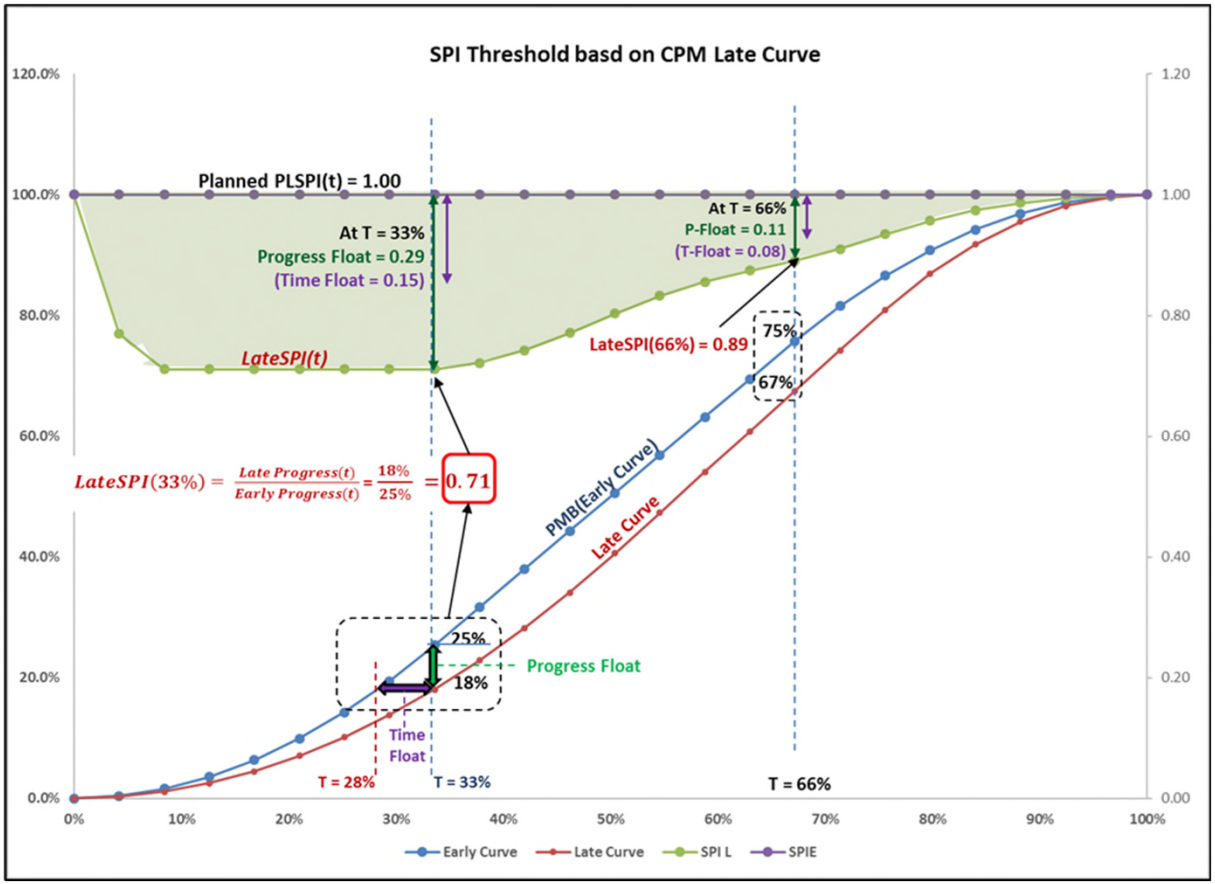
2.2 New Earned Value Formulas & Metrics

SV/SPI **Primary Metrics** because PMB is Objective



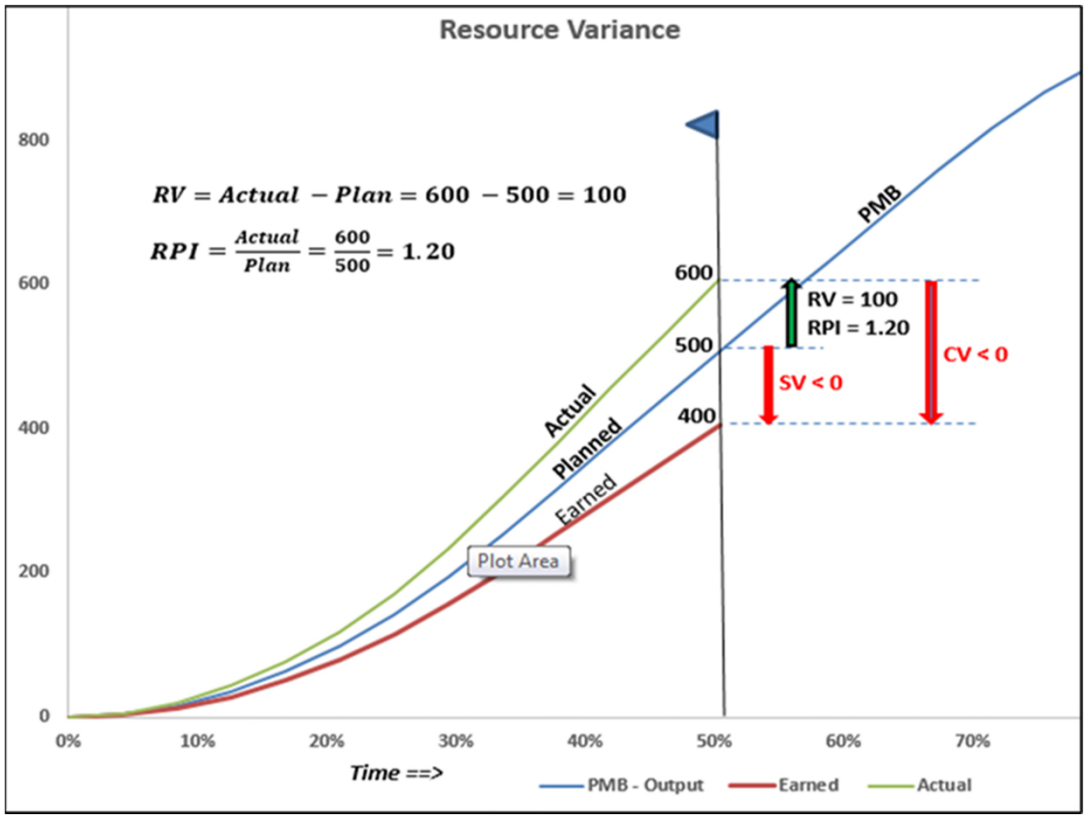
- Recall EVM: "*SPI* ***not recommended after 80%*** *of the work*" because ***ultimately equals 1.0"***
- If a deficit in project progress there is deficit in time ***vs. (PMB) THE PERFORMANCE OBJECTIVE!!***
- ***Root cause of negative SV/SPI, which translates to time variance, is always productivity (CV/CPI) and/or resources (RV/RPI)***

CPM Late Curve is SV Threshold



- CPM ***Late Curve***: all activities start on late date. Likely critical after.
- **Late curve** is ***SV(PMB) threshold!***
- Threshold @ 33% of time: **SPI = 0.71**
- Any ***float consumption increases time risk*** (path convergence)

Resource Variance: the Missing Metric



- *Resource Variance* (RV) = **Actual hours – Planned hours**
- *Resource Performance Index* (RPI) = **Actual ÷ Planned hrs**.

NEW CAUSAL EVM FORMULAS

$$© \; CV + RV = (Earned - Actual) + (Actual - Planned) = Earned - Planned$$

$$Schedule\ Variance\ (SV) = Earned - Planned,$$

Output Variance $SV = CV + RV$ Variance in Causal Inputs

$$©\; CPI \times RPI = \frac{Earned\ Value}{Actual\ Value} \times \frac{Actual\ Value}{Planned\ Value} = \frac{Earned}{Planned}$$

$$Schedule\ Performance\ Index\ (SPI) = \frac{Earned}{Planned}$$

Output $SPI = CPI \times RPI$ Variance in Causal Inputs

INTEGRATED COST & TIME FORMULAS

OUTPUT | **CAUSAL INPUTS**

CPM: $\underset{\textit{(Time)}}{Duration} = \dfrac{Quantity}{Productivity \times Resources}$

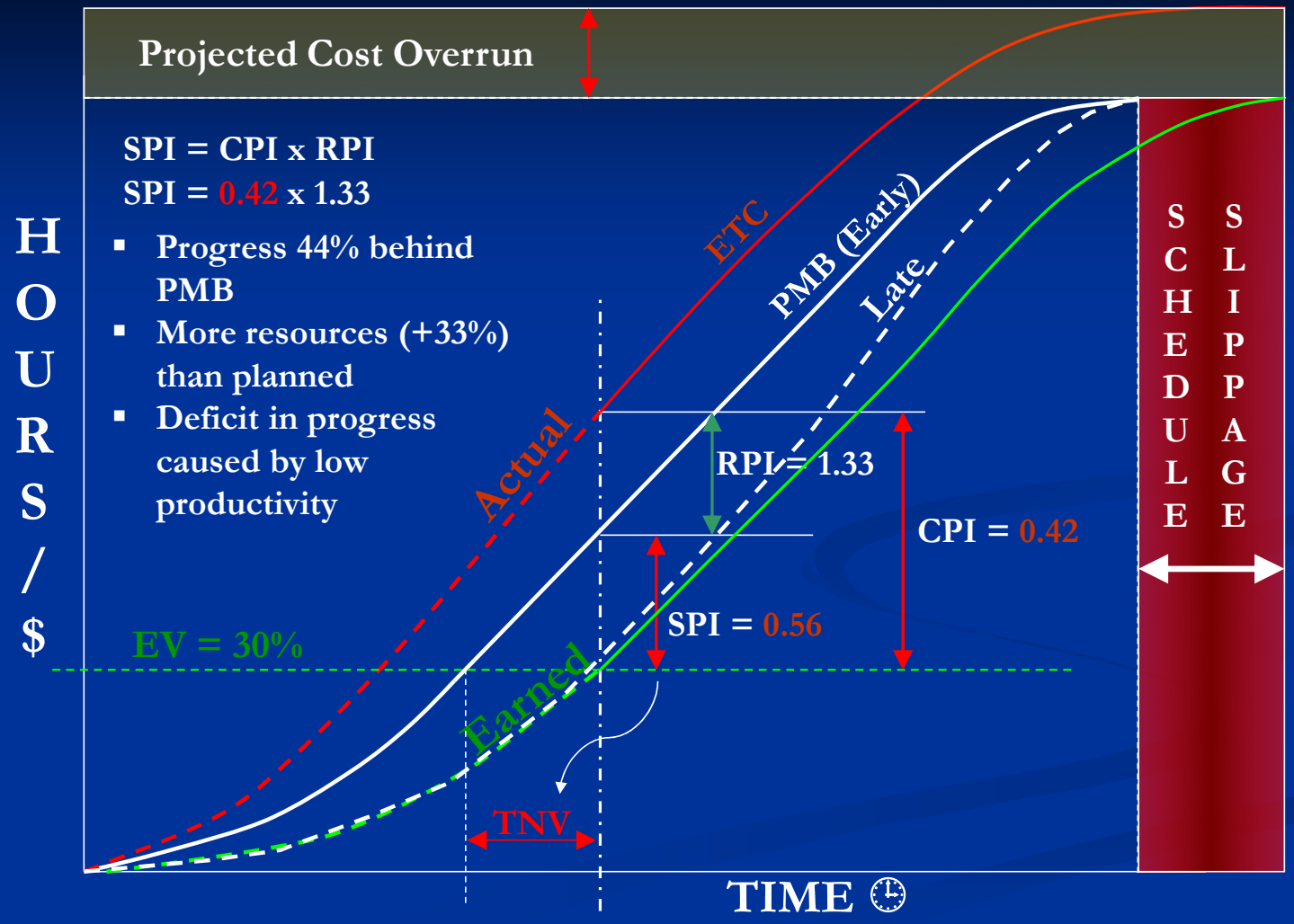
$$Cost = \frac{Quantity}{Productivity} \times Labor\ Rate$$

EVM: $SPI = CPI \times RPI$

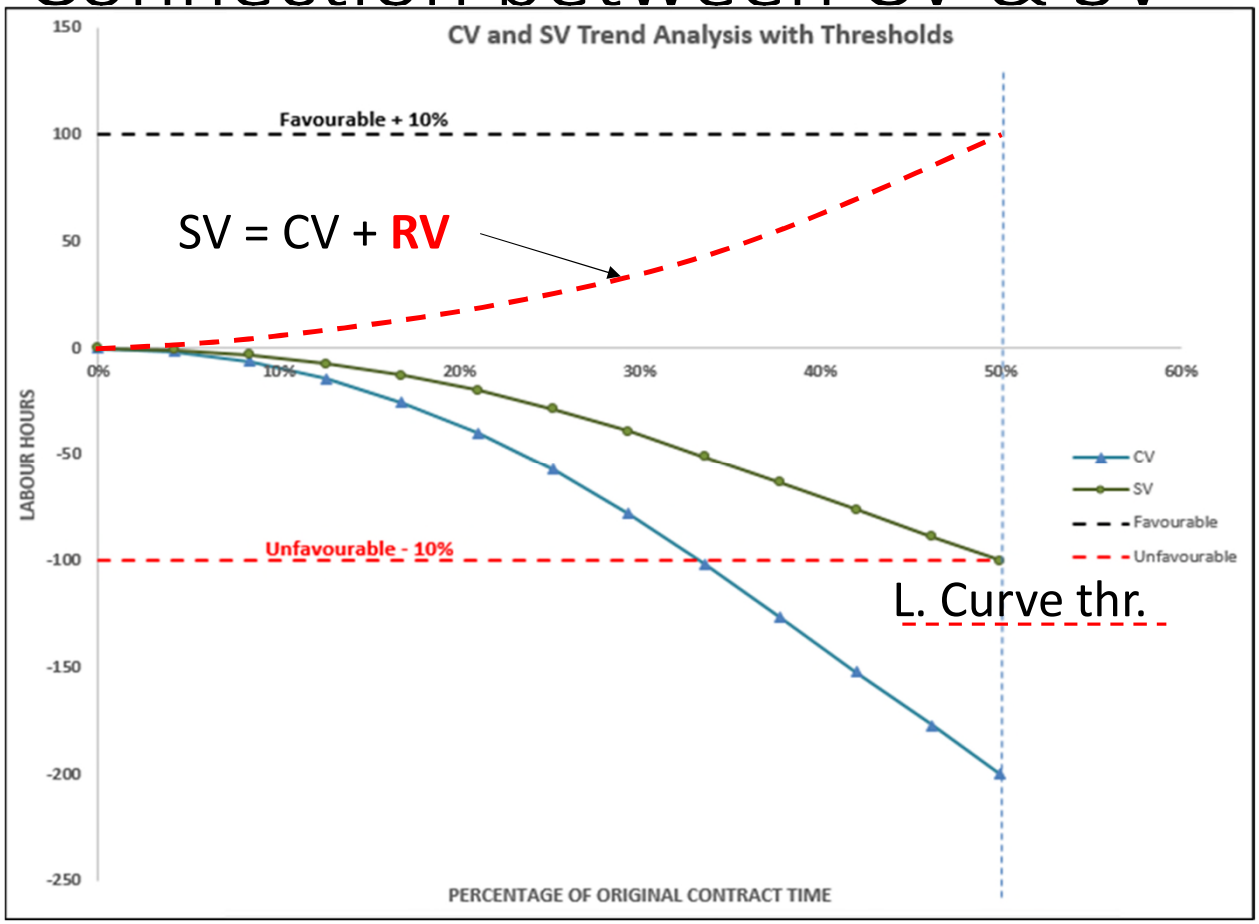
(Progress) *(Productivity)* *(Resource Supply)*

$$SV = CV + RV$$

INTEGRATED CPM & EV



Connection between CV & SV



- Calculate RV
- Late Curve threshold

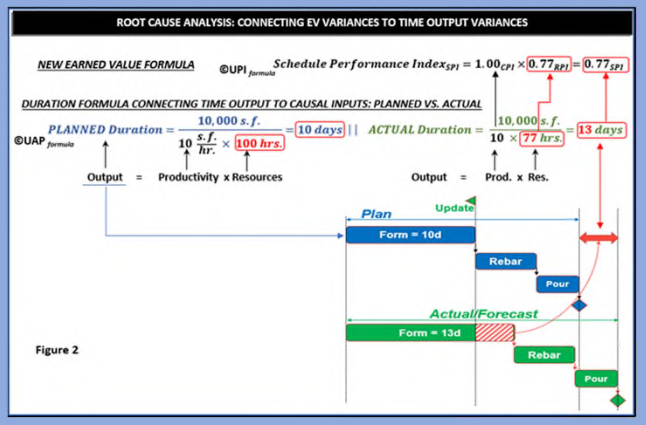
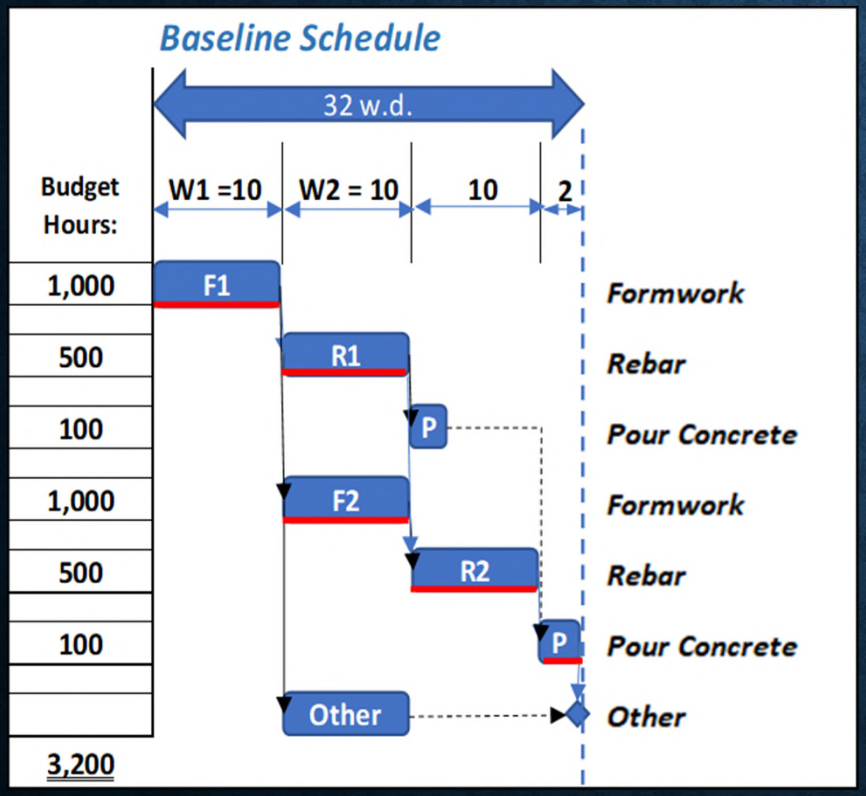


Figure 2

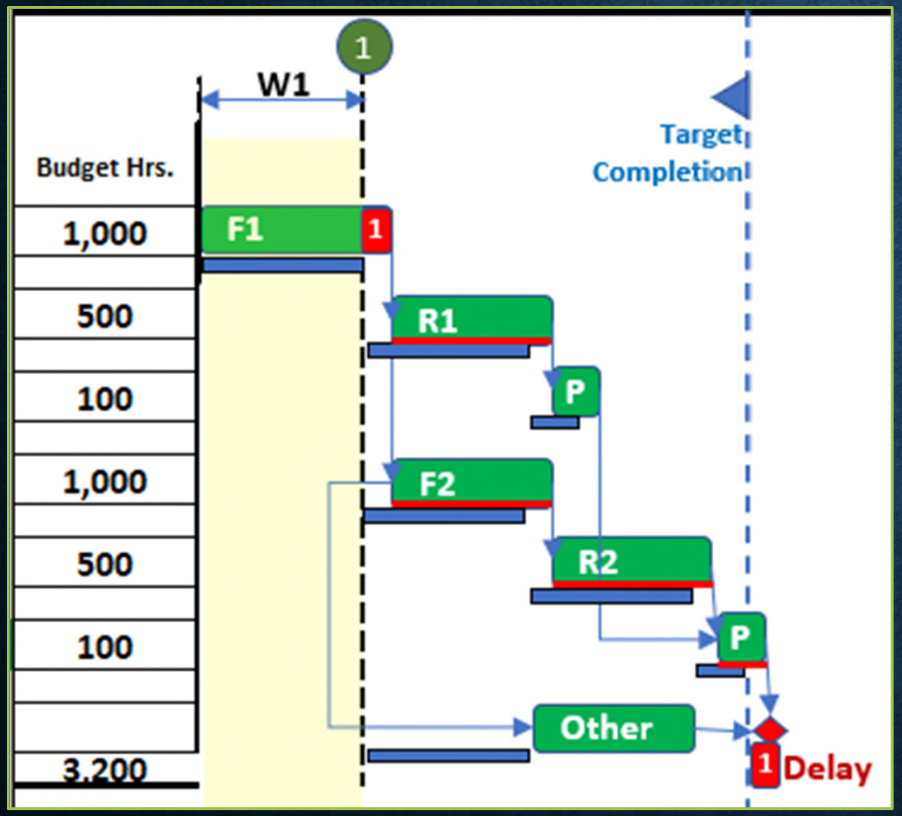
2.3 Integrated CPM & EVM Causal Analysis

CPM "WINDOWS" ANALYSIS USING NEW INTEGRATED ANALYTICS



- Schedule duration = 32d
- 10-day updates ("Windows" of time)
- Baseline loaded with labor hours.

WINDOWS ANALYSIS: FIRST UPDATE



- Formwork ***not completed*** per plan
- Contractor ***forecasts 1 day*** to complete
- ***Unexamined forecast***?

DURATION FORMULA FORECASTED LONGER DURATION

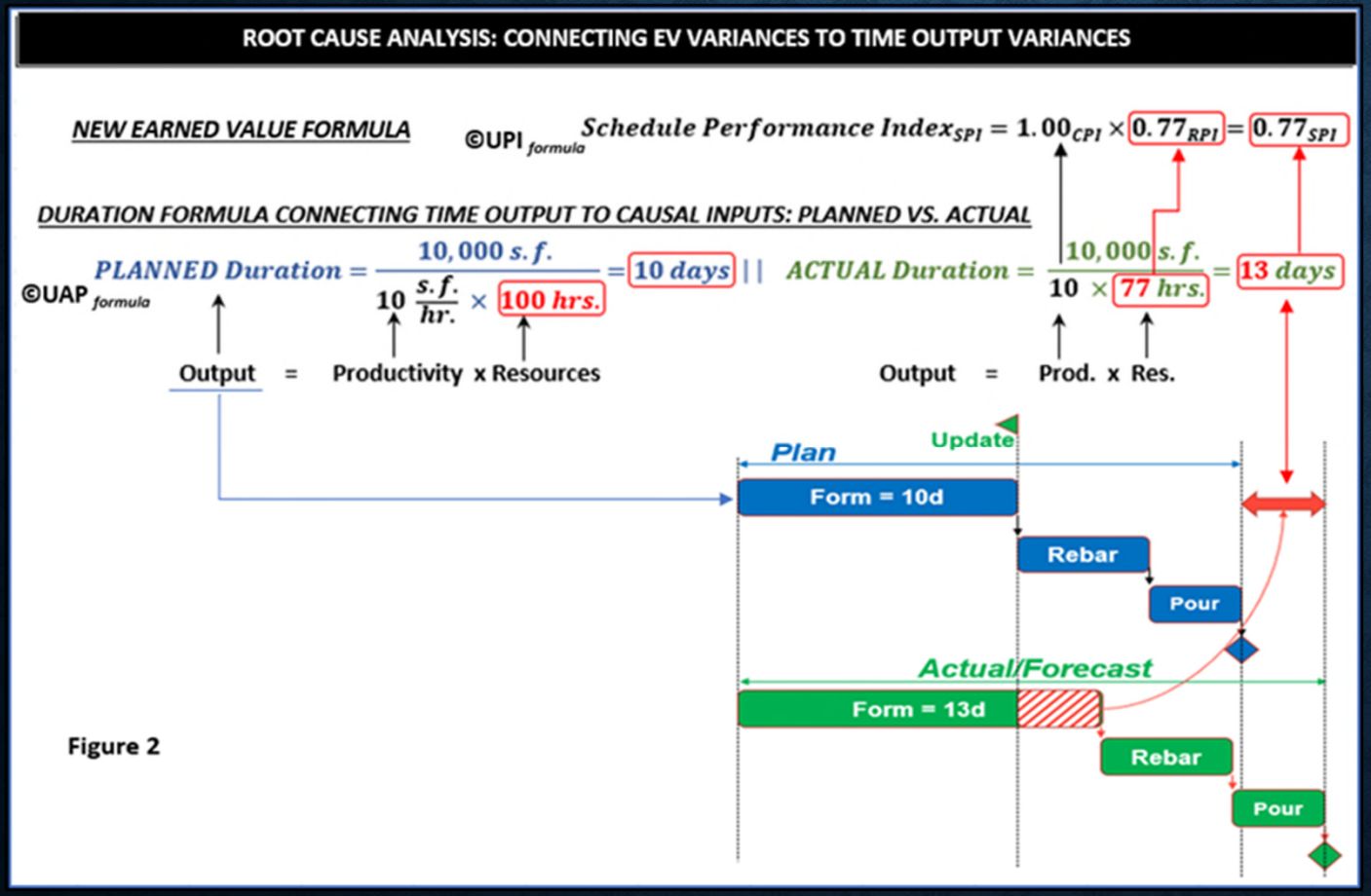
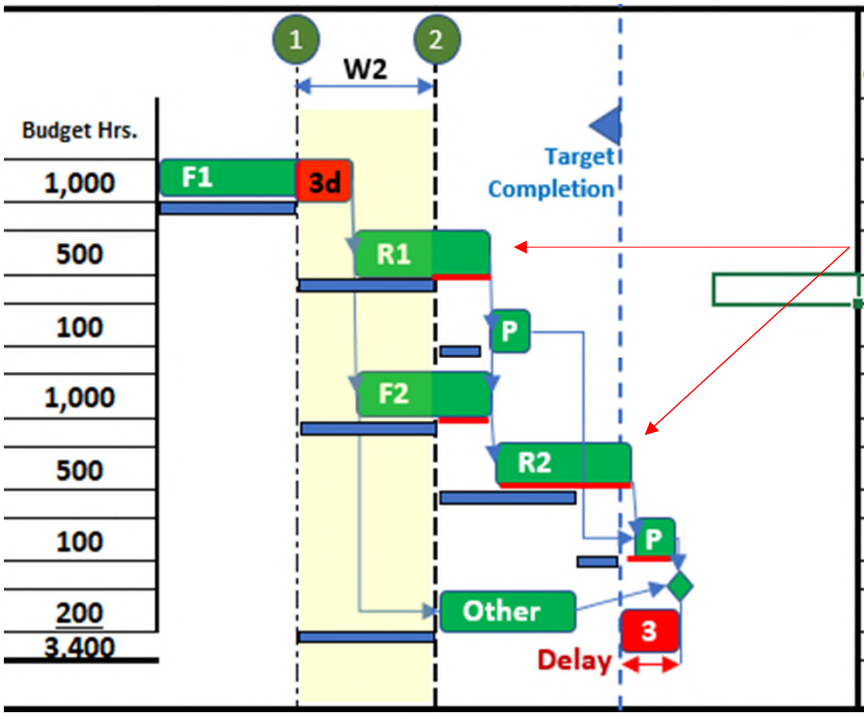


Figure 2

- RPI 0.77 - **23% fewer hours than planned** to date.
- **Productivity as per plan**
- Causal Duration formula forecasts 3-day delay, which ultimately occurs due to no mitigation

Window 2: No mitigation & Rebar Risk!!



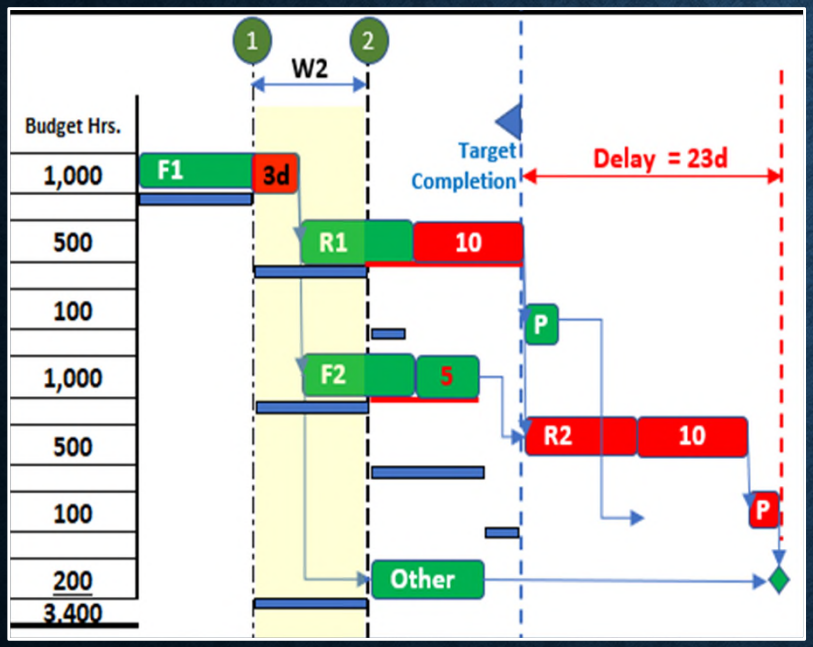
%age Complete:	Earned Hours:	Actual Hours:	Planned Hours:	SV = CV + RV			SPI = CPI x RPI		
				SV	CV	RV	SPI	CPI	RPI
100%	1,000	1,000	1,000	0	0	0	1.00	1.00	1.00
50%	250	300	500	-250	-50	-200	0.50	0.83	0.60
	0	0	0						
50%	500	520	1,000	-500	-20	-480	0.50	0.96	0.52
	0	0	0						
	0	0	0						
	0	0	0						
51%	*1,750*	*1,820*	*2,500*	*-750*	*-70*	*-680*	*0.70*	*0.96*	*0.73*

$$F1\ Rebar\ Duration\ Plan = \frac{12\ t.}{0.024 \times 50} = 10d$$

$$F1\ Rebar\ Duration\ Forcast = \frac{12}{0.019 \times 43} = 20\ d$$

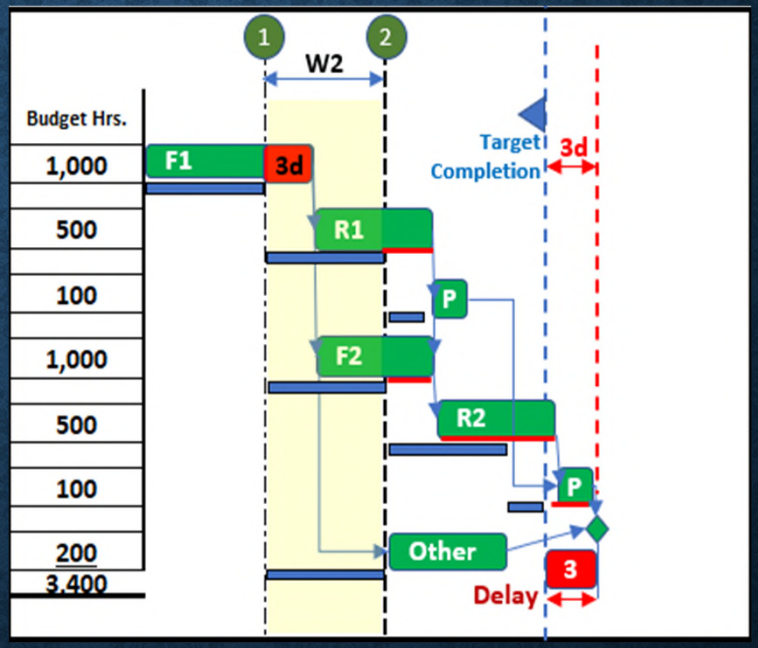
ROOT CAUSAL ANALYSIS VS. CONTRACTOR OUTPUT SCHEDULE

Durations Per Causal Formula



Forecast adjusted based on Current Productivity and Rate of Resource supply

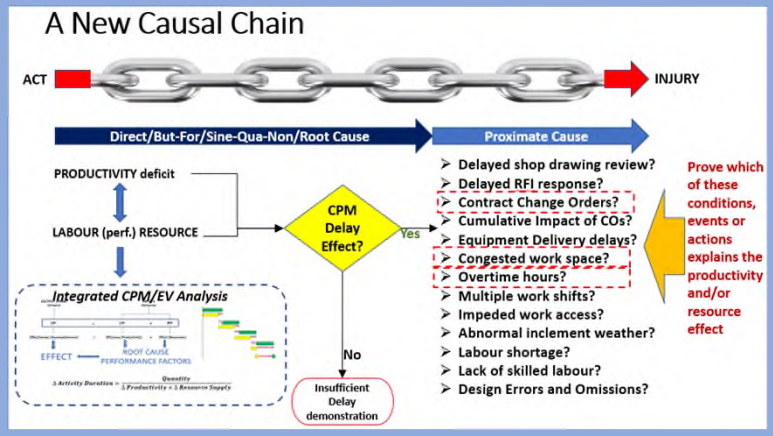
Contractor Forecast



Assumes baseline remaining duration.

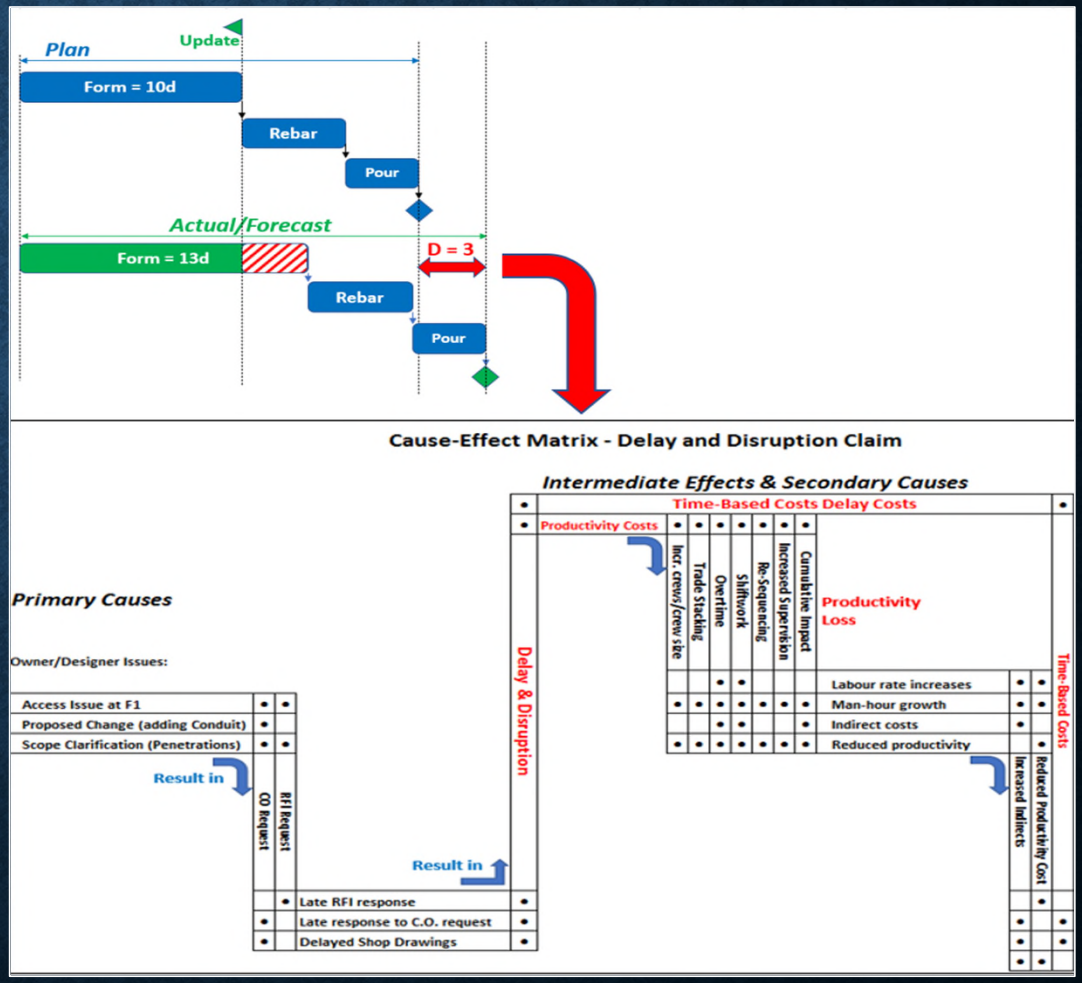
- **Unless performance improves, delay will be 23 days instead of 3**
- **Use casually-based early warning to mitigate!!!**

2.4 Rethinking Root Causation with the New Analytics

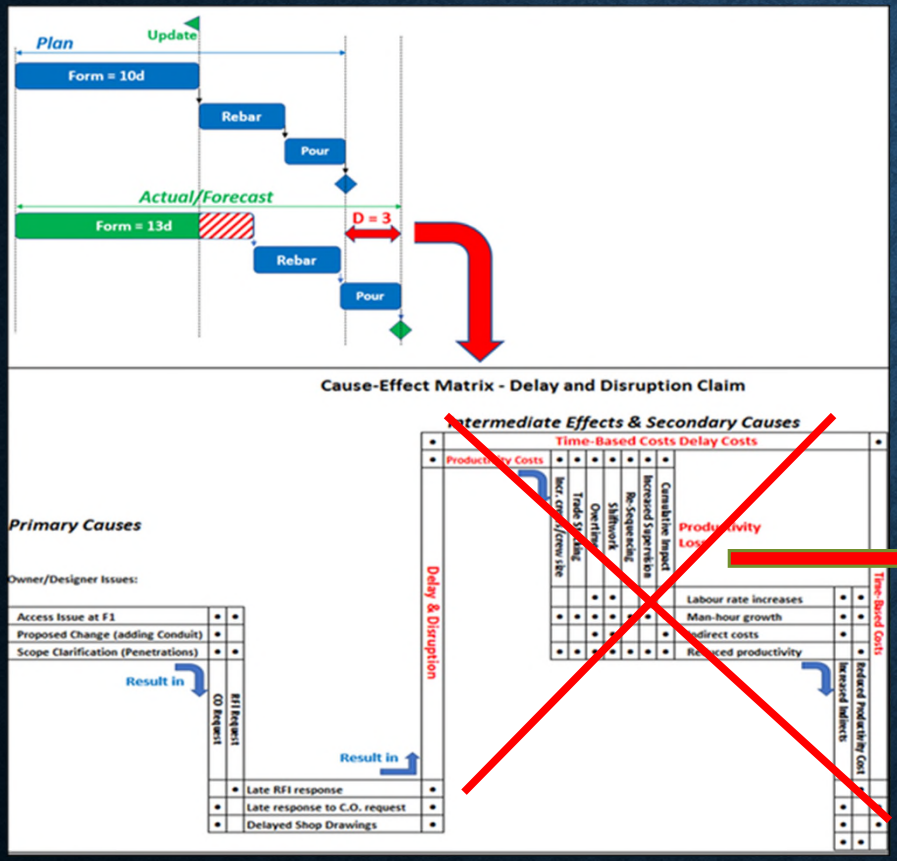


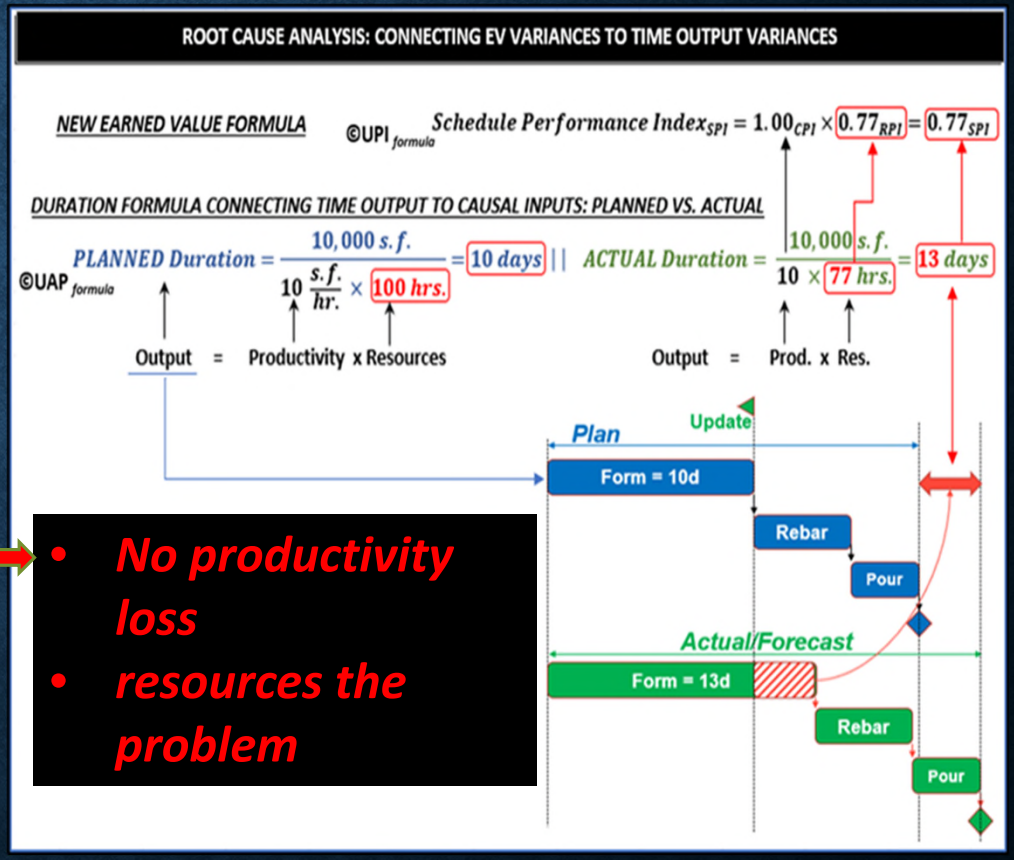
OUTPUT ANALYSIS IS "*HE SAID, SHE SAID*"

- ***Contractor says …***
  - **low productivity** due to COs, delayed respond to RFIs … stacking, O.T.
  - **Increased labor** added cost and **lowered productivity** more
- ***Owner says …***
- Productivity problem, if it exists, is **contractor-caused** the problem



WILD GOOSE CHASE – COMPLICATED & FRUITLESS





- *No productivity loss*
- *resources the problem*

DIRECT AND PROXIMATE CAUSES

- ***Direct*** Cause:
  - ***Root Causal***: act or agency which ***produces the effect***
  - Meets ***but-for test***. ***Sine qua non***: without which not.
  - For ***labor activity***, either or both *productivity and resources*
  - ***Deterministic, direct*** **cause of delay**
- ***Proximate*** cause: (CO's, delay RFIs, shop drawings, weather etc.)
  - Anything that impacts productivity and resources
  - ***Potentially*** the cause of below-plan productivity or resources
  - Can exist ***without having an impact*** on duration
  - Must be Proven on the ***basis of balance-of-probabilities***.
  - ***Not deterministic***

A New Causal Chain

Direct/But-For/Sine-Qua-Non/Root Cause → **Proximate Cause**

PRODUCTIVITY deficit ⇕ **LABOUR (perf.) RESOURCE**

CPM Delay Effect?

Yes

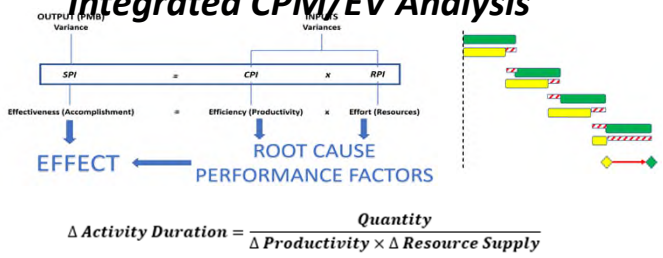
- Delayed shop drawing review?
- Delayed RFI response?
- Contract Change Orders?
- Cumulative Impact of COs?
- Equipment Delivery delays?
- Congested work space?
- Overtime hours?
- Multiple work shifts?
- Impeded work access?
- Abnormal inclement weather?
- Labour shortage?
- Lack of skilled labour?
- Design Errors and Omissions?

Prove which of these conditions, events or actions explains the productivity and/or resource effect

No

Insufficient Delay demonstration

Integrated CPM/EV Analysis



$$\Delta\ Activity\ Duration = \frac{Quantity}{\Delta\ Productivity \times \Delta\ Resource\ Supply}$$

No by-passing Direct Causes

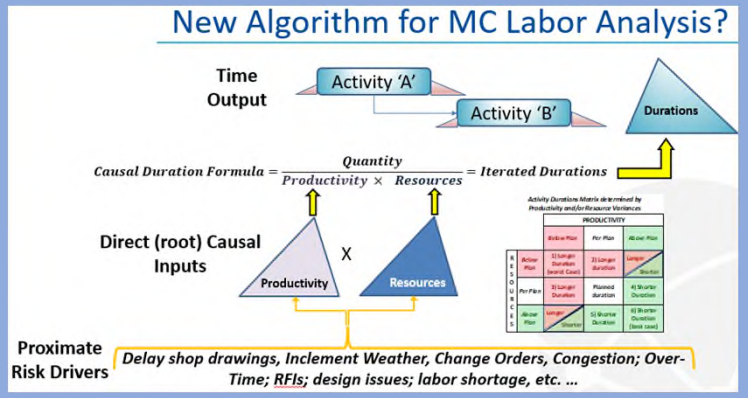
If duration Delay, then
Direct Cause is …

DETERMINISTIC DIRECT CAUSE

Productivity x Resources

Proximate Causes for one or both prod. & resources:

- Weather
- RFIs
- Changes
- Overtime
- Delayed Shop drawings
- Work stoppage
- other



2.5 Rethinking Integrated CPM/Risk Analysis

Rethinking Risk Drivers

TYPICAL RISK DRIVERS:

- Duration uncertainty
- Installation experience coordination issues
- **Shortage of labor resources**
- Design and fabrication issues
- Equipment suppliers too busy
- Schedule duration unrealistic
- **Productivity lower than planned**

ROOT CAUSAL RISK DRIVERS:

- Productivity
- Resources

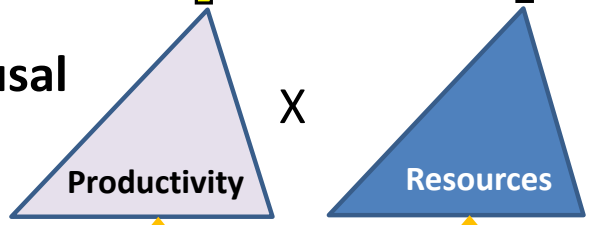
Proximate Causes

New Algorithm for MC Labor Analysis?

Time Output

$$\textit{Causal Duration Formula} = \frac{\textit{Quantity}}{\textit{Productivity} \times \textit{Resources}} = \textit{Iterated Durations}$$

Direct (root) Causal Inputs



Activity Durations Matrix determined by Productivity and/or Resource Variances

RESOURCES	PRODUCTIVITY: Below Plan	PRODUCTIVITY: Per Plan	PRODUCTIVITY: Above Plan
Below Plan	1) Longer Duration (worst Case)	2) Longer duration	Longer / Shorter
Per Plan	3) Longer Duration	Planned duration	4) Shorter Duration
Above Plan	Longer / Shorter	5) Shorter Duration	6) Shorter Duration (best case)

Proximate Risk Drivers

Delay shop drawings, Inclement Weather, Change Orders, Congestion; Over-Time; RFIs; design issues; labor shortage, etc. …

Part 3

3. A PROJECT SUCCESS STORY IMPLEMENTING THE NEW CAUSAL ANALYTICS

HOW THE NEW, INTEGRATED ANALYTICS HELPED CONVINCE A CONTRACTOR TO …

- Follow its own Plan
- Abandon its delay claim
- Increase labour levels
- Finish on time and on budget

INTEGRATED COST & TIME FORMULAS

OUTPUT | CAUSAL INPUTS

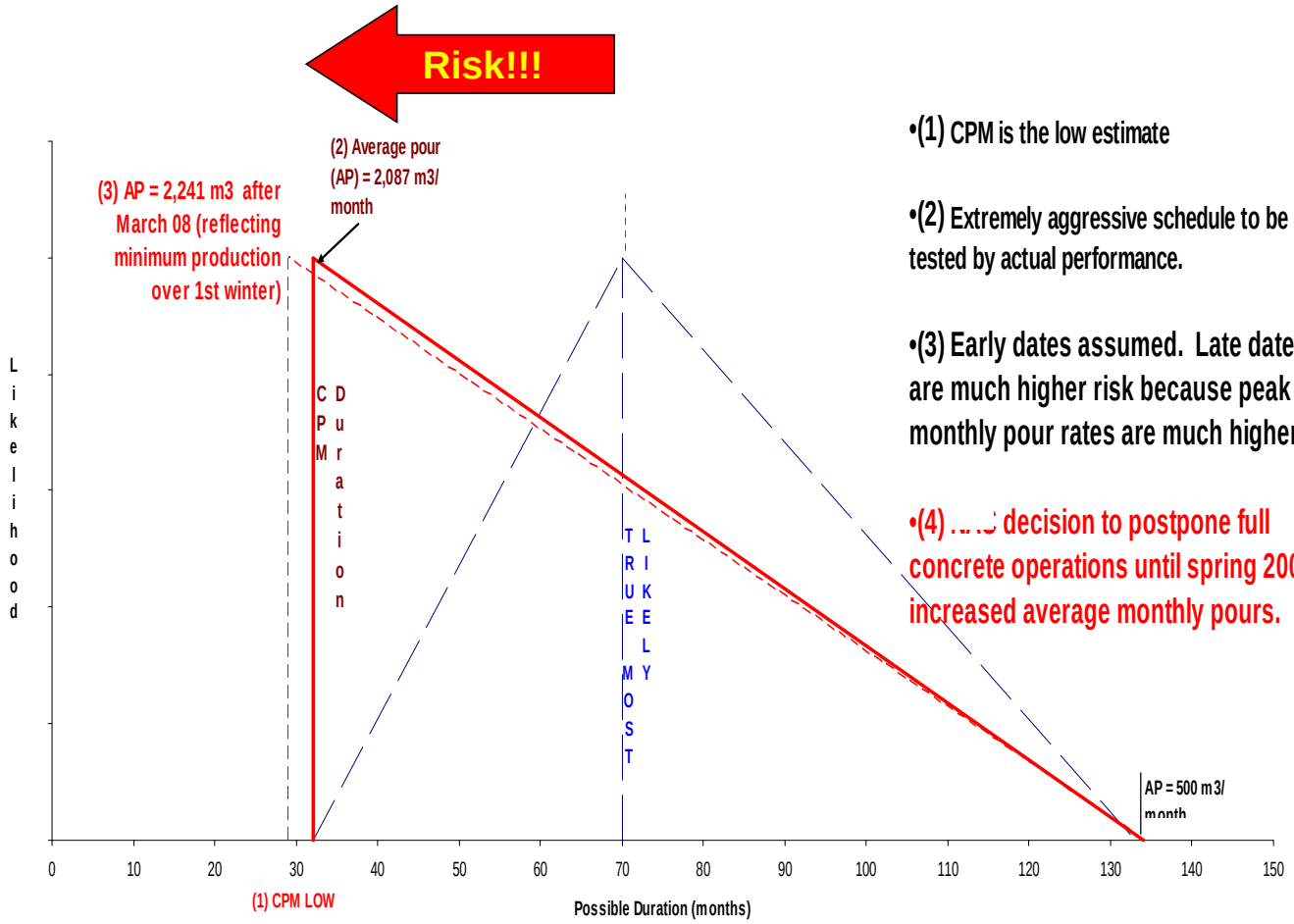
CPM: $Duration_{(Time)} = \frac{Quantity}{Productivity \times Resources}$

$Cost = \frac{Quantity}{Productivity} \times Labor\ Rate$

EVM: $SPI_{(Progress)} = CPI_{(Productivity)} \times RPI_{(Resource\ Supply)}$

$SV = CV + RV$

Pre-Construction Risk Assessment: Planned Duration not possible



•(1) CPM is the low estimate

•(2) Extremely aggressive schedule to be tested by actual performance.

•(3) Early dates assumed. Late dates are much higher risk because peak monthly pour rates are much higher.

•(4) [illegible] decision to postpone full concrete operations until spring 2008 increased average monthly pours.

PRE-TENDER CONSULTATIONS WITH CONTRACTORS

Design expedited to achieve start in September to allow advancement of slab work before winter.

ASSUMPTIONS:

- Full Productivity achieved within 3 – 4 weeks
- Concrete casting rates up to 3,000m^3/mnth.
- 600,000 – 700,000 manhrs. (150 men average & 200 peak).
- Slabs for first 3 trains completed in first 5-6 months.

LARGE D-B-B PROJECT: FULLY RESOURCE LOADED

All of this on D-B-B Projects!!!

	MATERIALS			LABOR		TOTAL BUDGET	
	Material Qty	Units	Material Budget	Planned Labor manhours	Planned Labor Budget		
PHASE 1			CAD 20,122,702	395,559	CAD 16,232,072	CAD	36,354,774
YWP			**CAD 667,554**	**17,085**	**CAD 672,384**	**CAD**	**1,339,938**
Skim Slab	2,546	m³	CAD 320,712	3,178	CAD 116,304	CAD	437,016
Concrete	1,080	m³					
Rebar	178	tonnes	CAD 219,564	2,928	CAD 146,376	CAD	365,940
Walls	60	m²	CAD 127,278	10,980	CAD 409,704	CAD	536,982
SOG	4,588	m²					
Round Columns	-	pcs					
Suspended Slabs	-	m²					
BRB			**CAD 181,518**	**3,465**	**CAD 143,895**	**CAD**	**325,412**
Skim Slab	13	m³	CAD 75,006	394	CAD 14,409	CAD	89,415
Concrete	437	m³					
Rebar	72	tonnes	CAD 88,097	1,175	CAD 58,731	CAD	146,828
Walls	56	m²	CAD 18,415	1,896	CAD 70,755	CAD	89,169
SOG	813	m²					
Round Columns	-	pcs					
Suspended Slabs	228	m²					
DFS			**CAD 3,177,613**	**61,392**	**CAD 2,533,224**	**CAD**	**5,710,838**
Skim Slab	1,065	m³	CAD 1,376,136	7,219	CAD 264,253	CAD	1,640,389
Concrete	7,214	m³					
Rebar	1,188	tonnes	CAD 1,463,760	19,517	CAD 975,842	CAD	2,439,602
Walls	11,924	m²	CAD 337,717	34,655	CAD 1,293,129	CAD	1,630,846
SOG	6,056	m²					
Round Columns	-	pcs					
Suspended Slabs	2,789	m²					
1PG			**CAD 1,049,801**	**20,413**	**CAD 840,005**	**CAD**	**1,889,806**
Skim Slab	444	m³					

LAGGING PROGRESS – TIME & CLAIMS RISK!

- Compliant R-L CPMs
- "***Riding the Late Curve***"
- Higher risk!
- Acceleration claim? ***Low productivity caused by owner?***
- -Waiting Game for owner delays

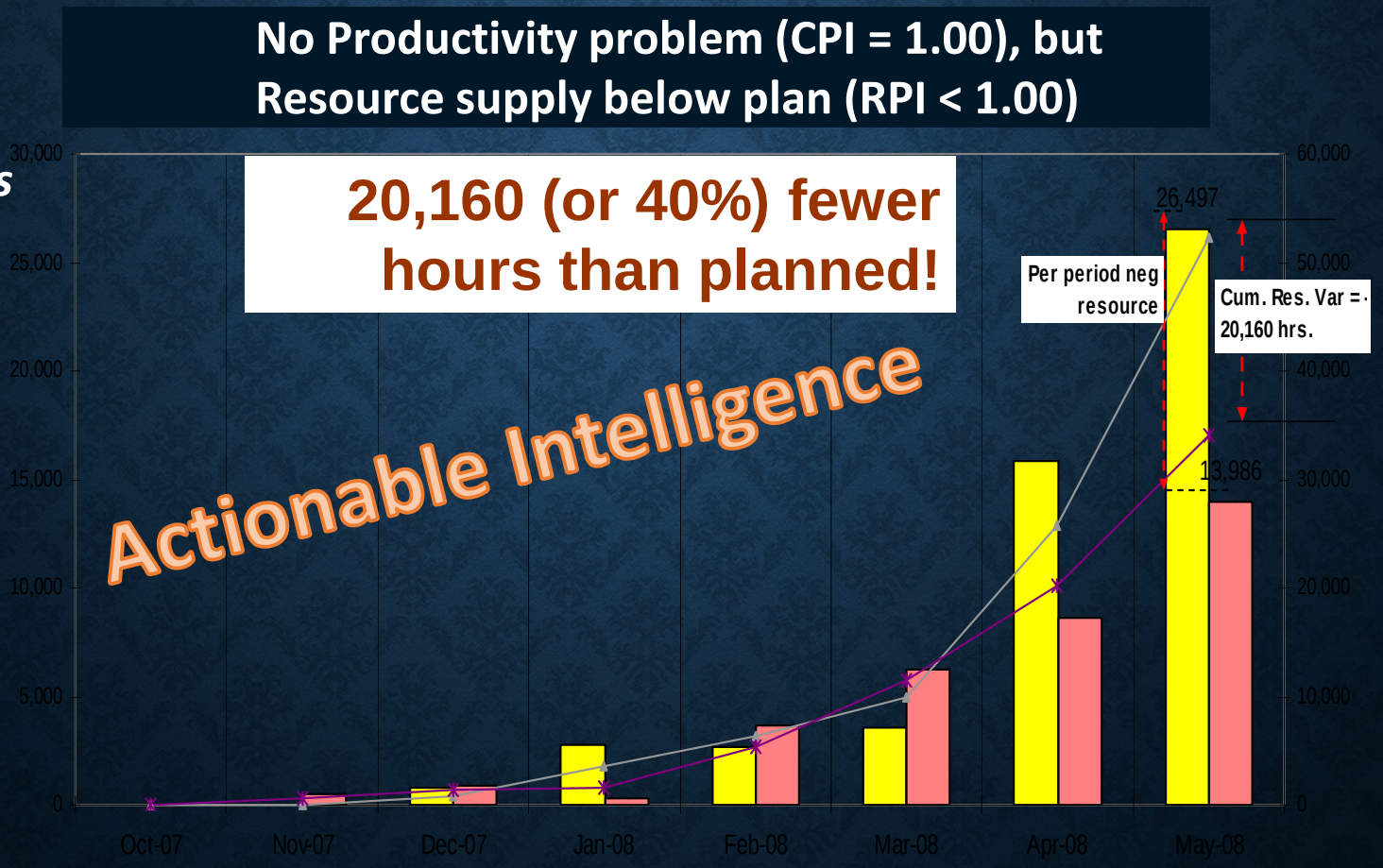
CAUSAL ANALYTICS REVEAL LOW LABOR SUPPLY IS THE PROBLEM

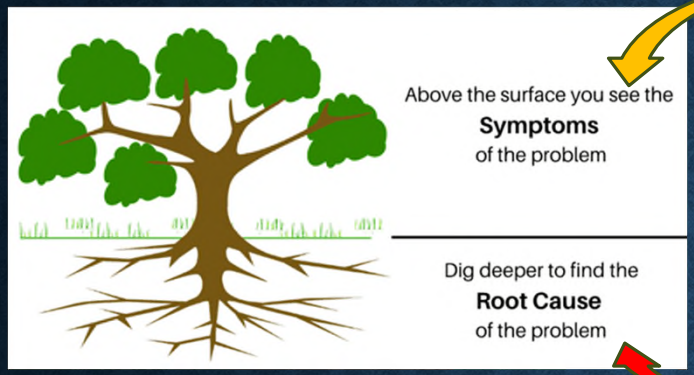
Success!!!!

-labor resources increased; no Prod. loss

-Finished on-time and on-budget!!!

-Contractor made money!





INTEGRATED COST & TIME FORMULAS

OUTPUT | CAUSAL INPUTS

CPM: $Duration_{(Time)} = \frac{Quantity}{Productivity \times Resources}$

$Cost = \frac{Quantity}{Productivity} \times Labor\ Rate$

EVM: $SPI_{(Progress)} = CPI_{(Productivity)} \times RPI_{(Resource\ Supply)}$

$SV = CV + RV$

4. CONCLUSION

New Causal Performance Analytics that reveal the Performance Truth & Dramatically improve Project Outcomes

CPM CAUSAL MODEL V. MEGADATA & OTHER "PANACEAS"

- *… there's a **new challenge** to **sound reasoning about causes and effects**. While awareness of the **need for a causal model** has grown …, many … would like to **skip the hard step of constructing … a causal model and rely solely on data***
- *"**Statistics alone** cannot tell **which is the cause and which is the effect**. … big data is profoundly dumb **about causes and effects**"*
- *if we are in possession of a **causal model**, we can often **predict the result of an intervention***

[Judea Pearl, The Book of Why – The New Science of Cause and Effect]

The Benefits of Prefabrication in Construction

Public-Private Partnerships (P3)

New Procurement Strategies - The Future of Procurement
Procurement Can Create Strategic Supplier Relationships for a Strong Competitive Advantage. EY Works With Businesses to Develop Resilient **Procurement** Strategies for Profitability. Supply Chain Solutions. Sourcing Strategy.

CONCLUSION

- ***Integrated, Class 1, fully resource loaded, CPM schedule* is *optimal causal performance analysis tool*. *New Analytics take advantage of this model.***
- ***Productivity and resources*** are **root causal performance factors** that **determine labour activity duration**
- New EVM and CPM formulas ***fully integrate*** performance analysis
- ***Enables causal-based early warning*** of off-trends - effective ***risk avoidance and mitigation*** possible.
- **Dramatically *improved* *project planning and control***
- Analytics compel ***rethinking of causation***
- Challenge of getting reliable integrated ***resource loaded schedules*** **must be met**.
- ***Buyers of construction*** can ***effect change***, but need encouragement