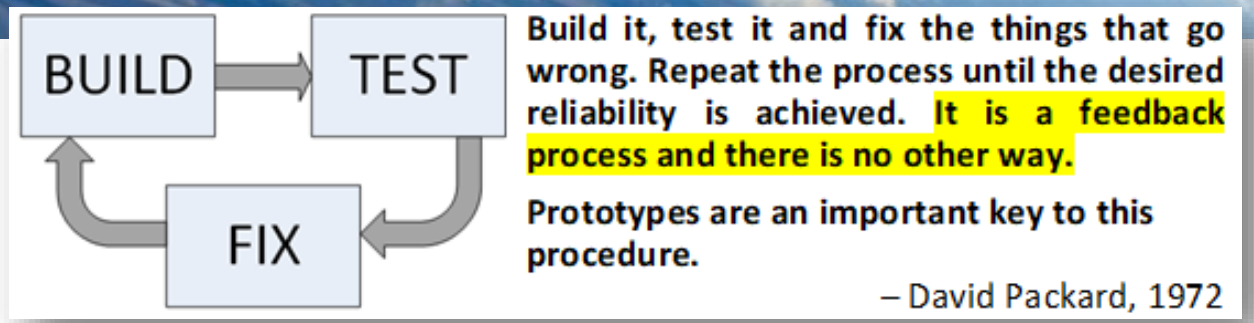
Achieving Predictable Delivery with Credible Modeling, Simulation, and Analysis (CMSA)



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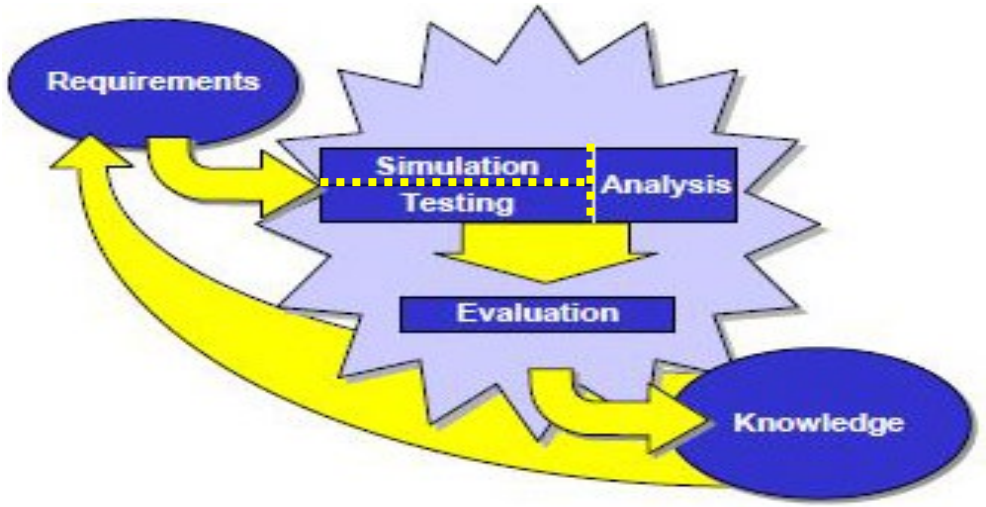
Side Effects of Simulation Based Acquisition (SBA)



Source: *Simulation, Test, and Evaluation Process (STEP) Guidelines*, Director, Operational Test and Evaluation, and Director, Test, Systems Engineering and Evaluation, 4 Dec 1997.

Results of decades of replacing field tests with running "cheaper" modeling and simulation (M&S)

- A reduced amount of simuland data is available for validating/calibrating M&S for products & processes
- Difficulty arises in assuring that M&S is credible for its intended use
- High risk of mis-using M&S to satisfy Digital Engineering and Model-Based Systems Engineering directives

→ **Given limited data from field and factory tests, the M&S credibility issue persists**

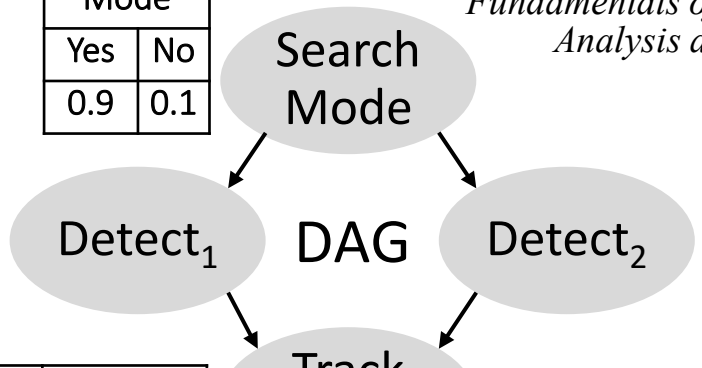
Credible Modeling, Simulation, & Analysis (CMSA) is needed for successful SBA

A Performance Bayes Net (notional example from our 2014 CASD paper)

A unique joint probability distribution model consists of

- ✓ directed acyclic graph (DAG)
- ✓ populated conditional probability tables (CPTs) →

Simplified version of Ball's example in *The Fundamentals of Aircraft Combat Survivability Analysis and Design* (2nd ed., 2003)



Search Mode	Yes	No
	0.9	0.1

Search Mode	Detect$_1$	
	Yes	No
Yes	0.6	0.4
No	0	1

Search Mode	Detect$_2$	
	Yes	No
Yes	0.9	0.1
No	0	1

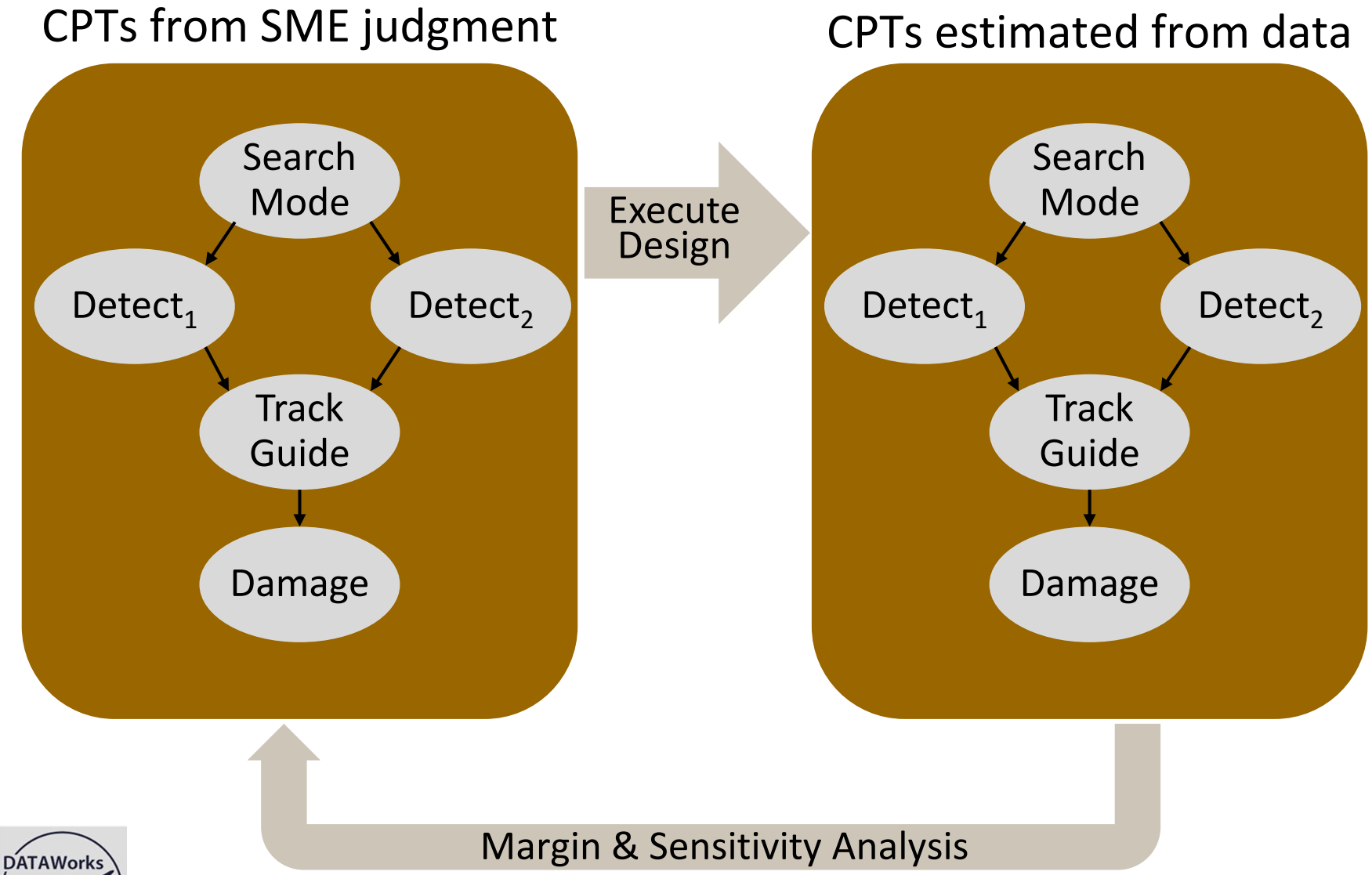
Det$_1$	Det$_2$	Track Guide	
		Yes	No
Yes	Yes	0.9	0.1
Yes	No	0.4	0.6
No	Yes	0.2	0.8
No	No	0	1

Track Guide	Damage		
	None	Disable	Kill
Yes	0.1	0.2	0.7
No	1	0	0

Building/using Bayes Nets based on CMSA for multiple product performance analyses led to

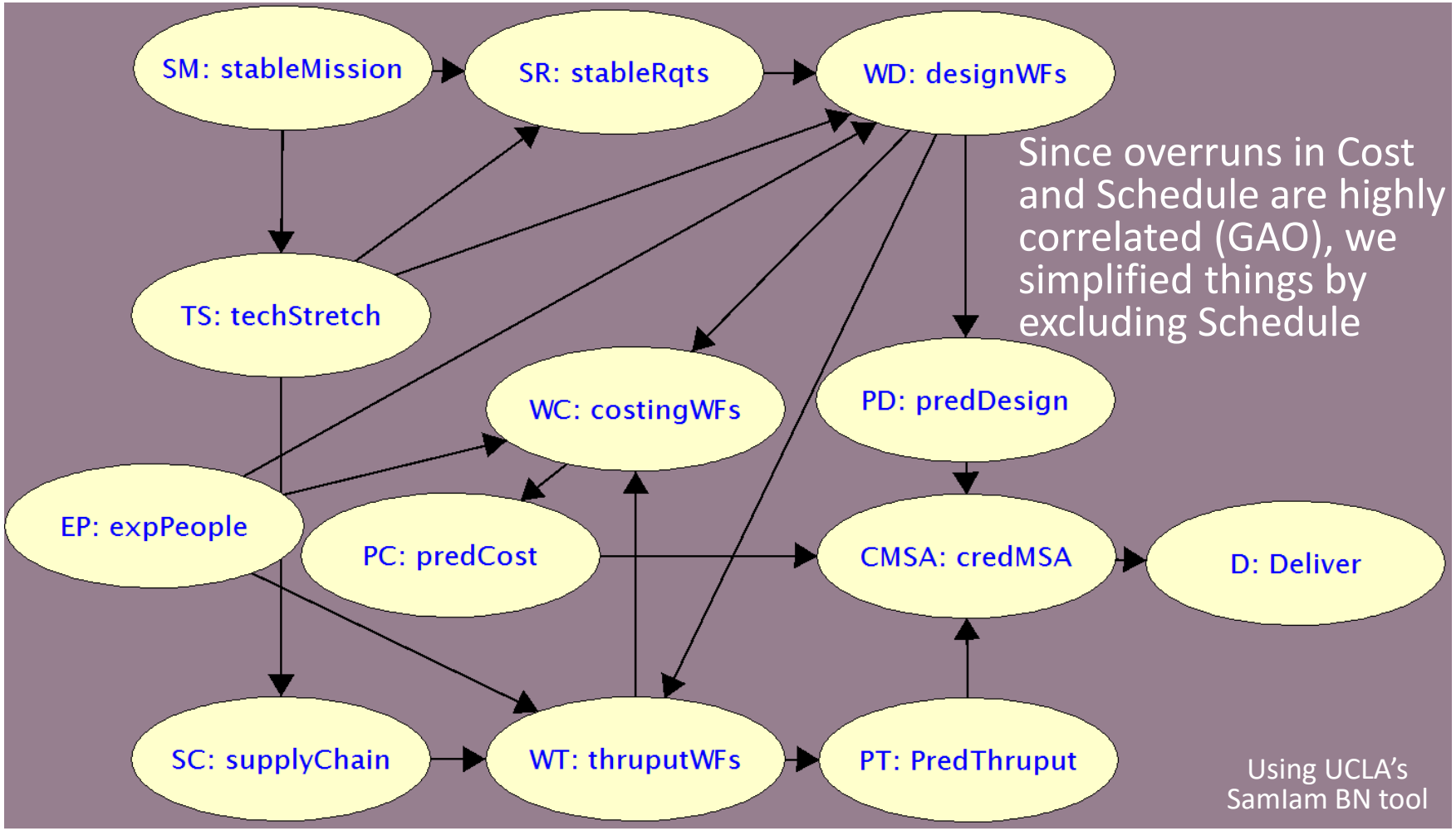
- using SME judgment + M&S data to build/analyze ***Predictability Bayes Nets*** (PBNs)
- using the Language of Probability to analyze & improve products and processes

“Twin” PBNs: Probability Guideposts and Estimates (same DAG)



Using CMSA best practices, we are extending PBNs beyond Product Performance to include Cost and Factory Throughput predictions

An Enterprise-level PBN links CMSA to Mission, People, Workflows (WFs)



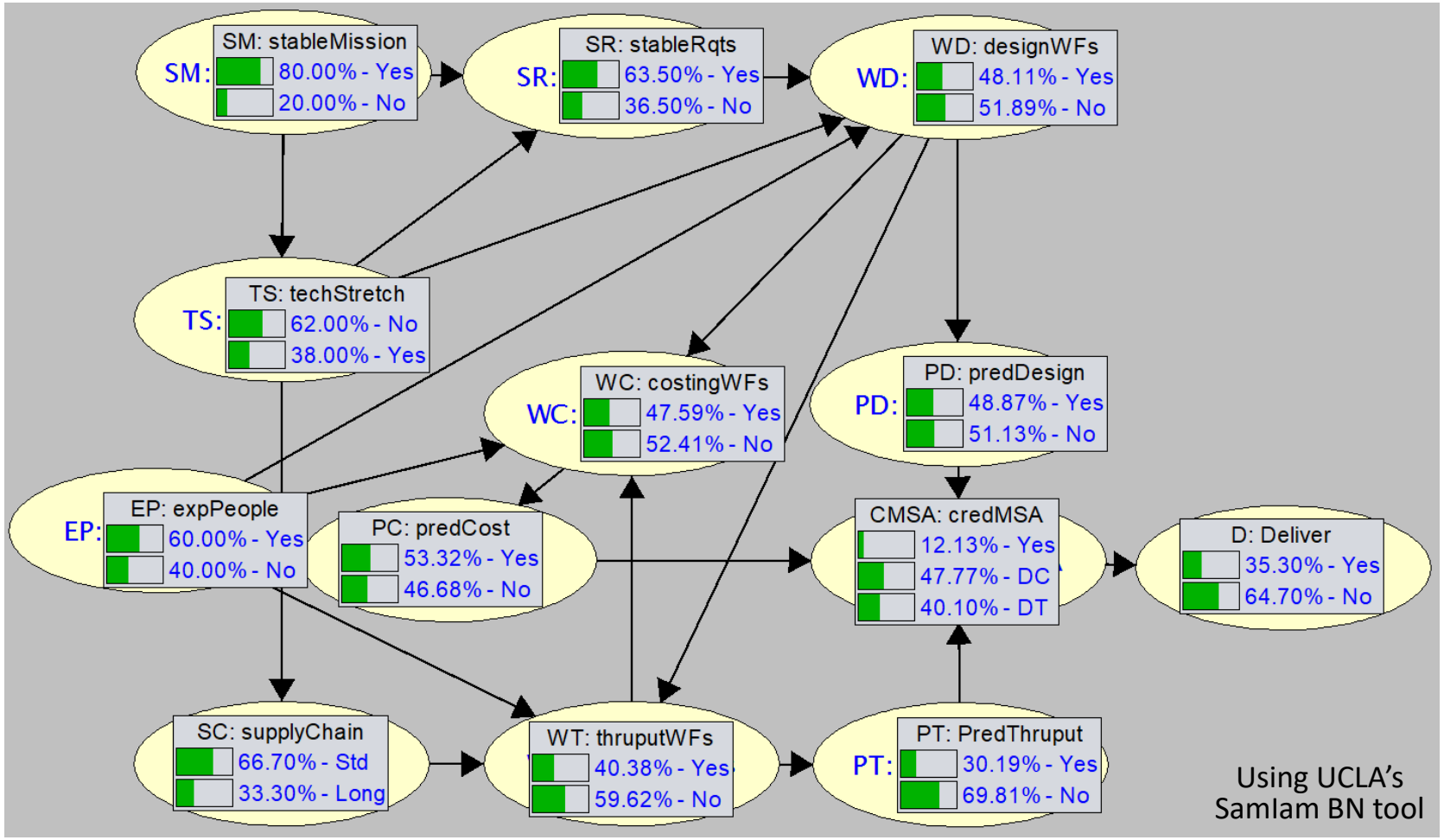
- This PBN models enterprise's population of programs' ability to deliver products:

$$D \stackrel{def}{=} Cost \wedge Throughput \wedge designIntent$$

- The Query: What is the marginal probability of successful product delivery?
- Evidence of a given program's performance affects all of the probability estimates in this enterprise-level PBN

Building a PBN prioritizes data relevance for closing the loop on specific queries

PBN's Prior Marginal Probabilities (given notional CPTs shown in paper)

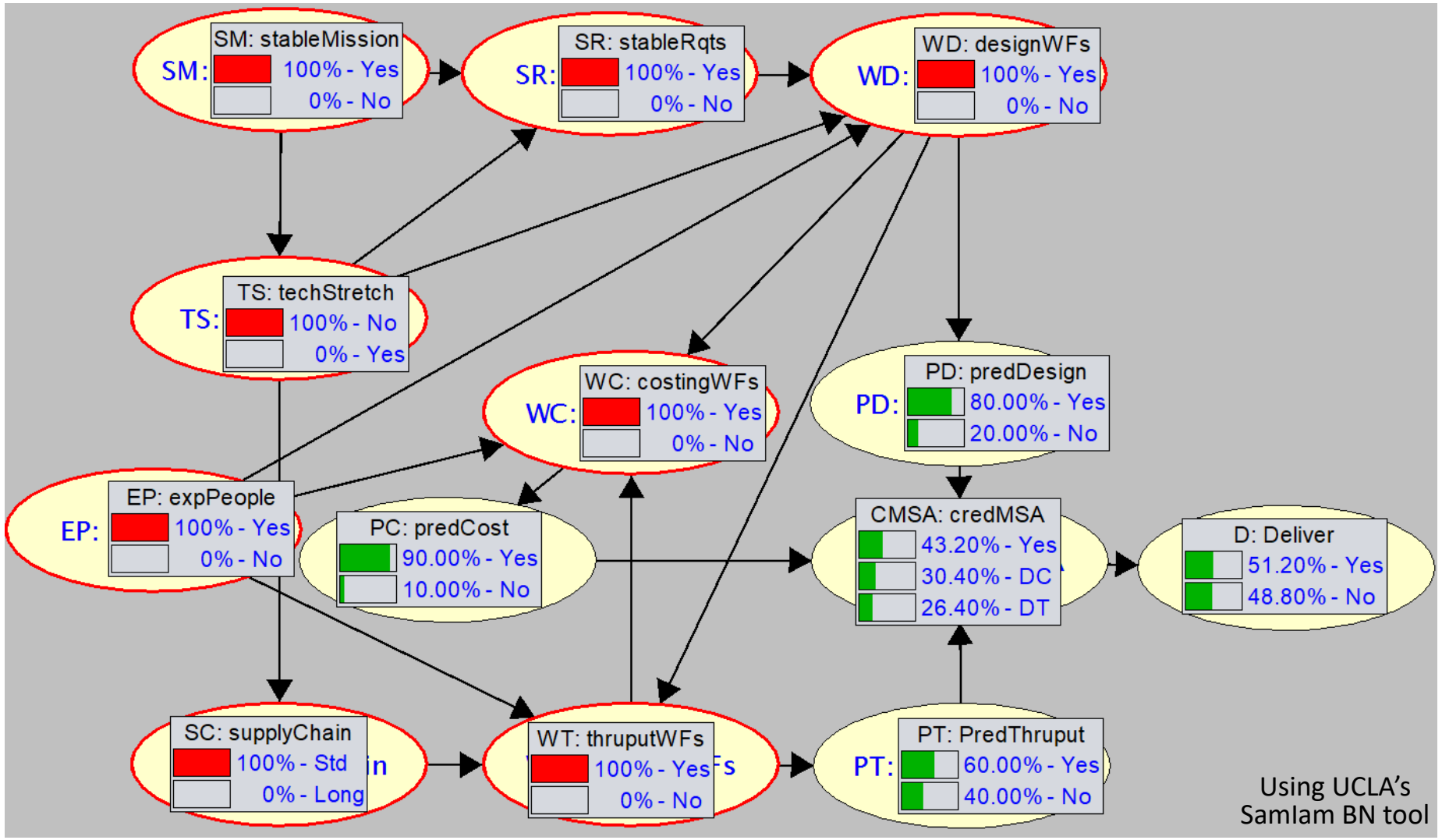


These marginals answer queries regarding the enterprise's population of programs <u>before</u> re-computing them given data from a specific program

$\leftarrow \Pr(Deliver = Yes) \approx 0.35$

The next 2 slides represent <u>individual</u> program queries within a population of programs

Posterior Marginals – “best case Deliver” prediction



- Red bars deductively propagate “forward probabilities” for a notional program
- Green bars indicate probabilities of achieving (or not) what M&S predicted

$$\leftarrow \Pr(Deliver = Yes|evidence) \approx 0.51$$

Inference example (diagnosis): Posterior Marginals

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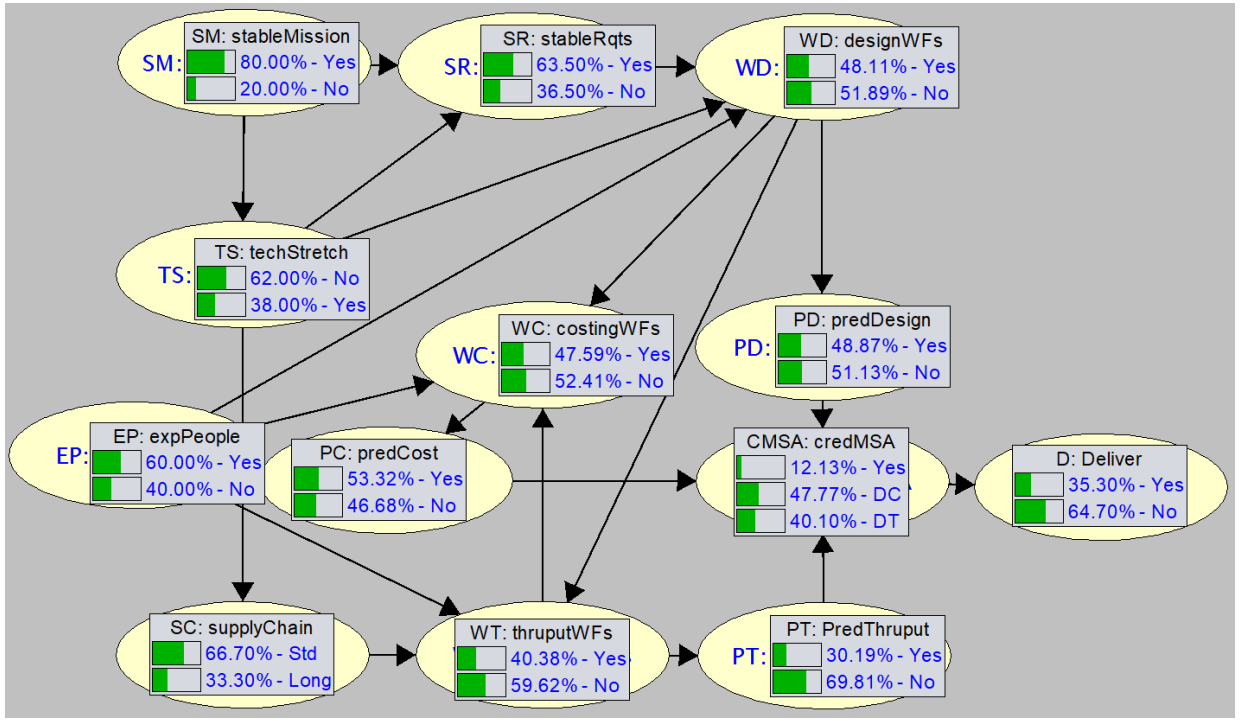
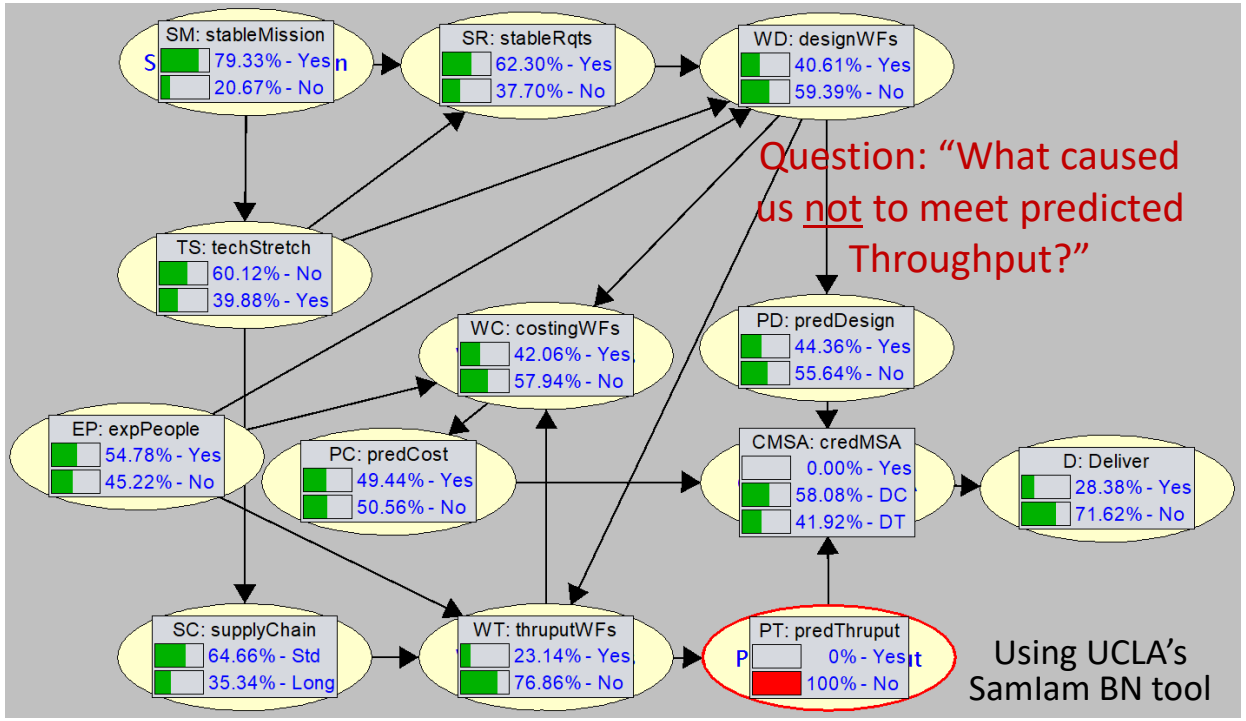
For reference, here are the population's prior marginals

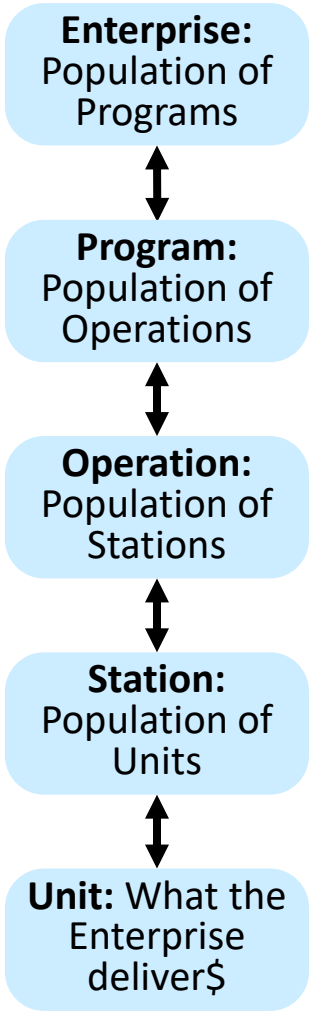


Effect on marginals given failure to meet Throughput



Unlike individuals interpreting & arguing over local statistical estimates, having a unified probability model enables transparent, collective inference across an entire network

Gaining experience at deeper levels with PBNs and CMSA



- The $\boldsymbol{Enterprise \leftrightarrow Program\ PBN}$ shown above is notional (SME judgment); it prioritizes data to be collected to estimate marginal Probability of Delivery
- We have built deeper-level PBNs (see paper) using data and SME judgment, e.g.,
  - $\boldsymbol{Program \leftrightarrow Operation\ PBN}$: To prioritize data needed before deciding whether to do a field recall, given a failing component's effect on probability of mission failure ← resulted in avoiding high replacement costs
  - $\boldsymbol{Operation \leftrightarrow Station\ PBN}$: To analyze impact of operable takt time on factory throughput, given rework & supply chain delays
  - $\boldsymbol{Station \leftrightarrow Unit\ PBN}$: To accelerate return of material to forward flow at a Production Test Station, given test failures and rework
- Increasing collective fluency in the Language of Probability is improving Predictability by "impedance matching" during multi-level communication

A current challenge: Achieving CMSA, not just for predicting product performance, but for all M&S, requires applying DoD's best-practice VV&A; see https://www.cto.mil/sea/vva_rpg/

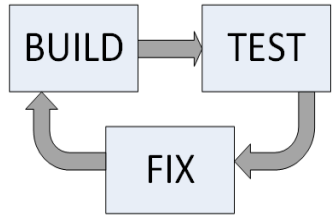
Summary and Conclusions

- When people within different levels of the enterprise communicate regarding technical product/process details, ambiguity often arises—especially when decision conditions are "gray" due to misusing imperfect data or out-of-date experience for unspoken agendas
- Stakeholders reduce this ambiguity as they learn & use the Language of Probability and CMSA; uncertainty is quantified prior to making a decision, which increases Predictability
- A Bayes Net is a substrate for capturing essential details to answer any probabilistic query, arising at any level, by integrating beliefs & imperfect data within a joint probability model
  - The same collaborative Bayes Net Protocol applies at any level (scalability):

    Queries → Event Nodes/States → Causal DAG → Computation of Answers to Queries

    Result: Minimizing delay in transparently "closing the loop"

  - We can see which data will (or will not) reduce uncertainty
  - Building/using Bayes Nets together gets easier with practice



Build it, test it and fix the things that go wrong. Repeat the process until the desired reliability is achieved. It is a feedback process and there is no other way.

Prototypes are an important key to this procedure.

– David Packard, 1972

Making the right decision at the right time becomes more likely