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Digital Engineering Effectiveness for Cyber-Physical Systems

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Document Markings

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Problem Statement

Digital Engineering (DE) has the potential to improve project outcomes (e.g., reduction of acquisition risk for cost and schedule) for cyber-physical systems (CPS) by enabling defect detection to "shift left".

"Shifting left" is enabled by developing new methods (e.g., model-based analysis) that discover important defects/issues earlier in the product lifecycle.

The benefits of DE have been clearly demonstrated in other domains (e.g., nuclear power system design). However, recent studies highlight the challenges of both implementing DE and measuring the DE process for CPSs.

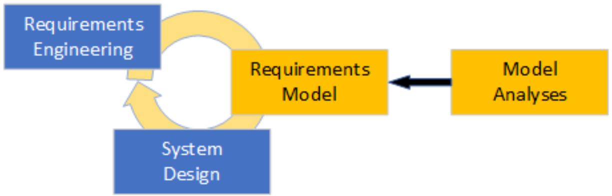
There is no guarantee that applying DE methods early in the development lifecycle for CPSs and software will result in the improved likelihood of attaining stakeholders' goals.

We review research on Digital Engineering for Cyber-Physical Systems and recommend how to evaluate DE methods

Digital Engineering Examples

The landscape is littered with successful examples of how digital methods have improved legacy engineering practices:

- 1950s-60s: NASA Mariner program
- Paper → 2D CAD → 3D CAD
- Model-based analysis for mechanical engineering, electrical engineering, thermal
- Virtualization for maintenance

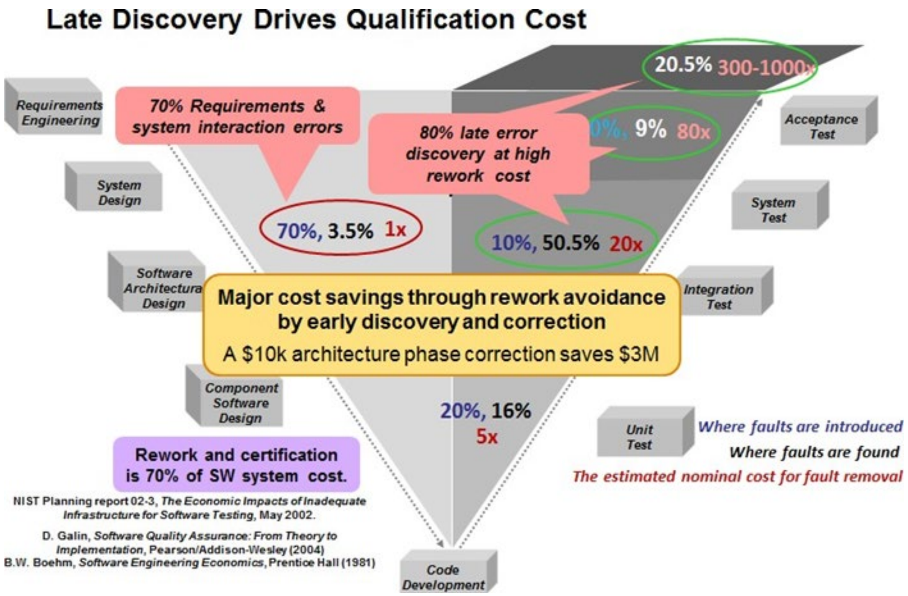


How do the DE practices improve legacy engineering practices??

- Early detection of defects and/or issues
- Feedback using the results of the model-based analyses to mature the design improves the quality of the design

Late Discovery of Defects/Issues Costs More

Gap Between Defect Origin and Discovery



(Feiler, Goodenough, Gurfinkel, Weinstock, & Wrage, 2013)

When DE is applied effectively we should see a significant impact on when we find defects within the lifecycle

Lifecycle Phase	Injection %	Legacy Discovery %	DE Discovery %
Requirements	70	3.5	80
System Design			
Software Architecture			
Component Software Design			
Code Development	20	16	15
Unit Test	10	50.5	3
Integration Test			
Acceptance Test		9	2
Post-Acceptance Test		20	0

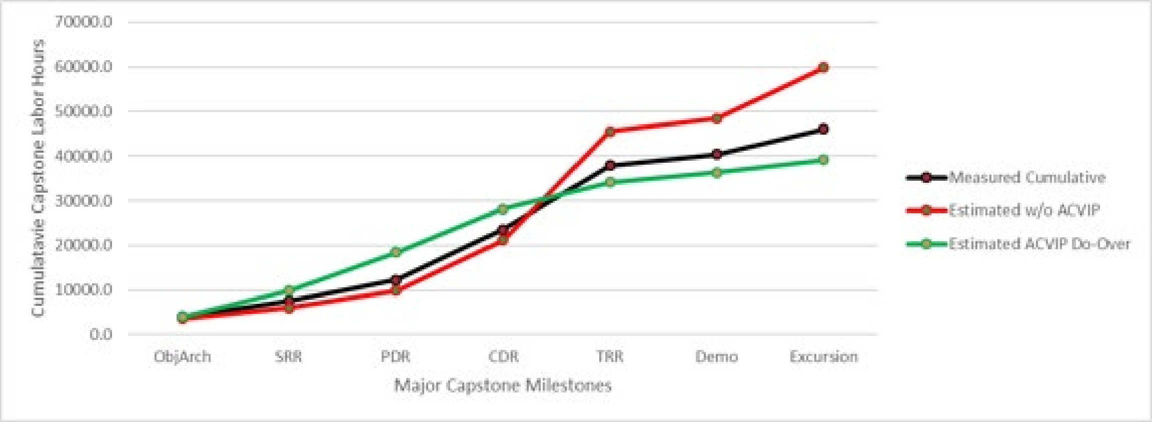
Data from Army FVL JMR MSAD – Capstone

The Joint Multi-Role (JMR) Mission System Architecture Demonstration (MSAD) provided an environment to assess the effect of DE on an embedded computing system for a cyber-physical system

Raytheon, a JMR MSAD Capstone Performer, provided this Chart as part of their Capstone Lessons Learned Briefings (Raytheon and General Electric Aviation, 2020)

Note that:

- Increase in effort early in lifecycle (because more effort is being done earlier)
- Leads to overall reduction in effort (because we find the issues earlier)



Measuring Digital Engineering Effectiveness

Effective use of Digital Engineering is more about culture than it is about ROI. We can observe what happens, but not why it happens:

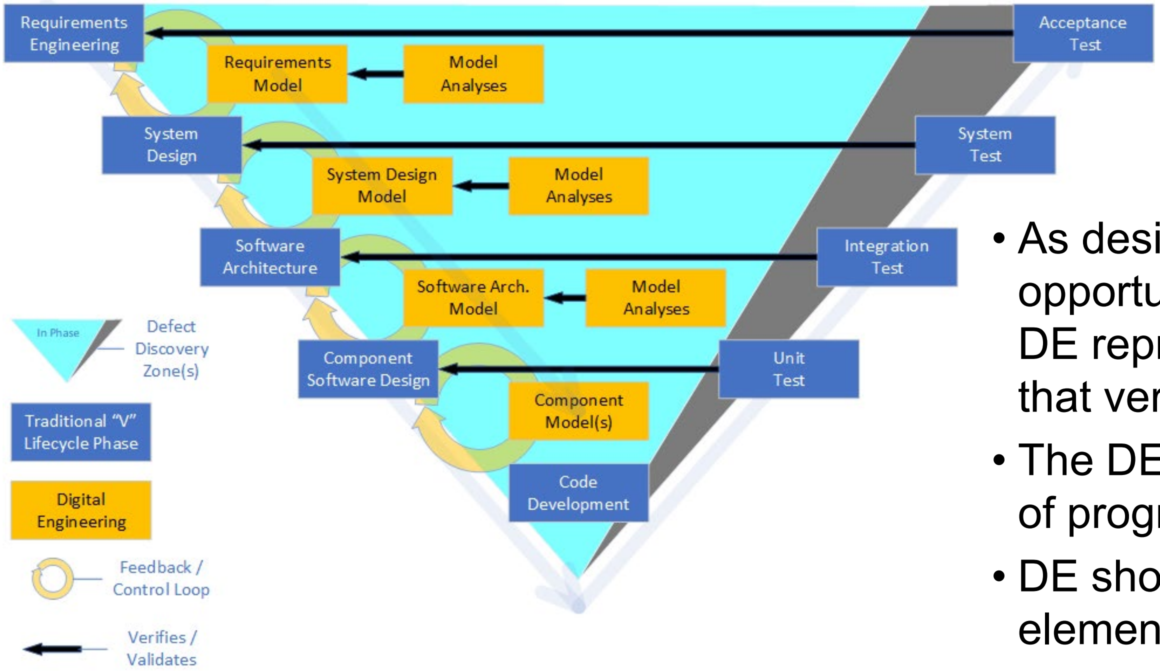
- What are the DE artifacts used for? Early assessment of design choices? V&V?
- What is actually modeled? Computing resources? Does the modeling process evolve with the design, i.e., from black boxes to white boxes?
- When a defect escapes detection, does the developer try to understand how it could have been found with their DE environment?

Measuring what we are accustomed to measuring (e.g., effort, schedule, quality) might not be effective

- Can the fidelity of the modeling effort be based only on the hours spent on modeling?
- We could measure model attributes (e.g., Has the model been reviewed?). Can this be used as an indicator of system quality at this point in the life cycle?
- Do you base the measure of quality on the number of defects found? Many organizations do not even count defects until after a “baseline” has occurred.

Effective use of DE will result in higher quality with less overall effort, but we must resist using self-fulfilling measures

Our Version of the "V" for Incorporating DE Practices



We believe that the DE system representation can mature, in a similar way to the physical system

- As design decisions are made, there is opportunity to improve the fidelity of the DE representation(s), and the analyses that verify and validate the approach
- The DE effort should be justified as part of program-wide risk mitigation
- DE should be focused on the system elements that pose the most challenges

All Cyber-Physical Systems have problems during system integration that can be mitigated with DE tools and methods

Conclusions

DE is a major change for CPS development

Don't focus exclusively on quantitative measures. They can be skewed by a myriad of factors that are out of direct control. Instead, increase the usage of qualitative measures and be mindful that your measures do not become targets.

Identify the practices that distinguish an organization that is just "checking the DE boxes" from one that is building the DE culture into its development approach. These distinguishing practices include the following:

- Budgetary tolerance for up-front costs (i.e., a learning curve) when adopting DE methodology.
- Culture change will be necessary. There are proven methods for overcoming cultural resistance that should be considered as part of the planning for DE.
- Identify separate measures that show whether DE is being used (e.g., tighter feedback loops) from whether it is effective (higher product quality and avoiding cost and schedule overruns).
- Learn how to apply DE practices for maximum effect. Some problems may not be appropriate, some may not warrant the additional effort. Although initially the organization should err on the side of over-modeling, feedback control should indicate whether or not the effort is adding value.