Using SysML to Support Software FMEA

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Agenda

- Motivation
- Prior Work
- Approach
  - *Requirement Discovery*
  - *Integrating Use Cases and SW FMEA*
  - *Applying SysML to Specification Conformance*
- Future Work

Motivation

- Recent NASA Fault Management workshops indicate that application of SW FMEA to flight software has been limited
  - *FMEA generally applied to HW components*
  - *Little formalization in tying FMEAs with software architectural support*
  - *Dependency analysts and software developers use different technologies*
- Understanding the effects of software resources and design choices to mitigate certain off-nominal conditions is essential.
  - *Message corruption*
  - *Queue overflow*
  - *Device malfunction on software behavior*
- Prior research suggests that SysML and UML can help close the gap between design development and dependability analysis
- Some techniques and approaches are presented

Some Prior Work

- Leangsukun , et. al 2003
  - *Assuming that dysfunctional behavior is known, capture it using UML models*
  - *Defined new UML stereotypes to describe dysfunctional behavior*
  - *Requires high quality UML representations to enable analysis*

- Guiochet, et. al 2004
  - *Applied UML in medical robotics domain to do risk analysis*
  - *Assessed functional behavior only*

Prior Work (cont'd)

- David, et. al 2008
  - *Goal was to close gap between early conceptual design engineers and dependability analysts*
  - *Found that dependability estimation was not always well mastered*
  - *Wanted to automatically deduce dysfunctional behavior from conceptual design model (UML)*
  - *Analyzed sequence diagrams of conceptual UML models*
    - Auto-generated FMEA entries for every message sender (e.g. cause) /receiver (e.g. effect)
    - Failure modes characterized as partial function, no function, intermittent function, unintended function
    - Generated too many inputs that needed user intervention
  - *Later work for automated FMEA synthesis used a SysML model to integrate a component database to characterize the failure modes*

Prior Work Lessons

- Using UML/SysML for reliability analysis is appropriate
- Prior work has focused on functional component behavior
  - *Can lead to simplified view of present/absent component behavior vs degradable service provided by software design*
- Automated FMEA synthesis without model context understanding can generate large amounts of data requiring manual intervention
- A dysfunctional dictionary of component failure information can help focus component failure analysis
- Work on addressing software design choices is still needed

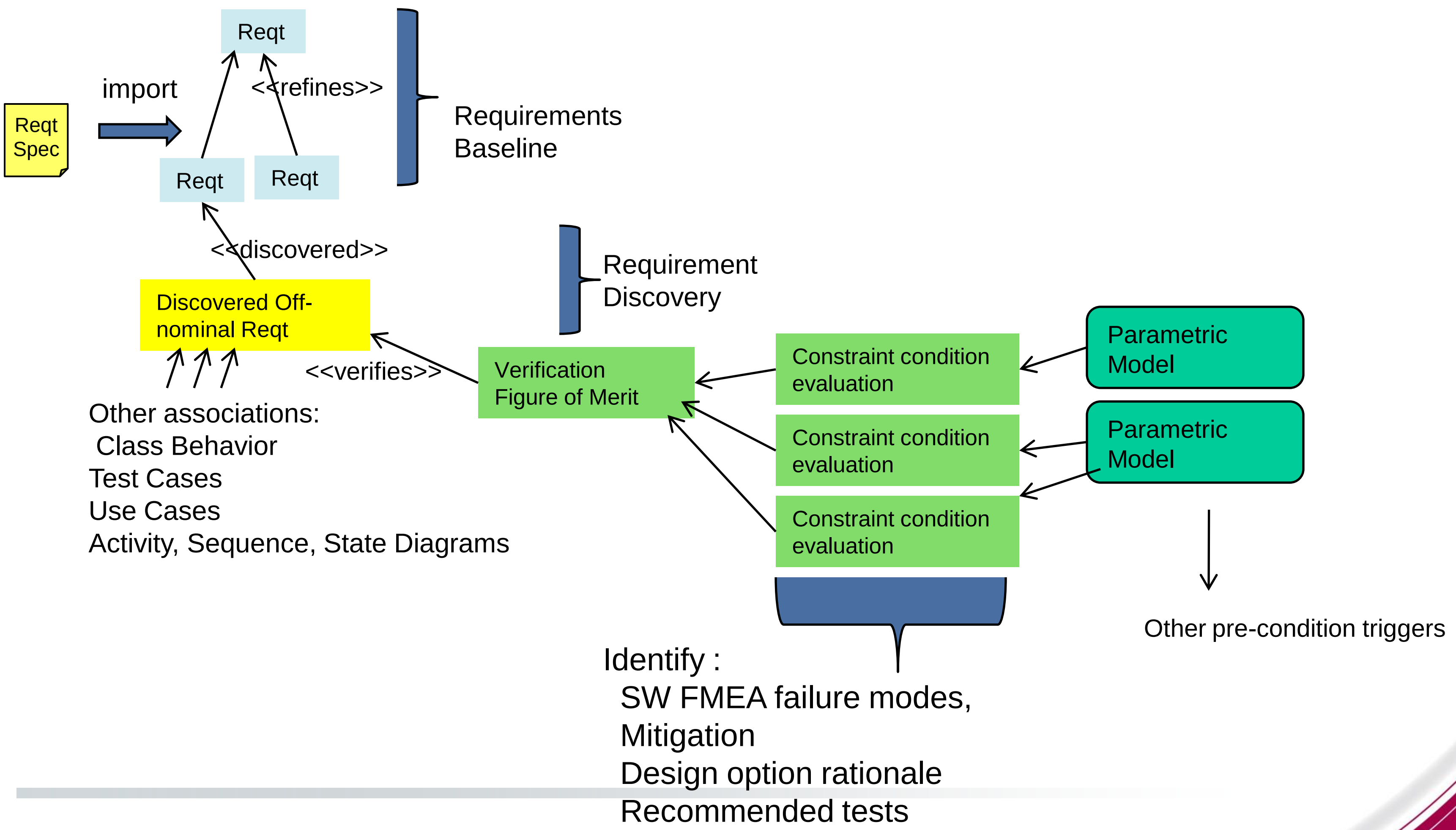
Challenges

- High quality UML/SysML models are not always available
  - *In agile-base development requirements and design evolve throughout the lifecycle*
  - *Design-code alignment studies of flight software show that faithful UML representations may only capture 40% to 60% of the implementation*
  - *Basing automated analysis on incomplete information could be misleading*
- FMEA knowledge has generally been HW component based
  - *Component FMEA data not discussed in terms of use case scenario*
- Promote software design that recognizes design choices that can impact behavior and provides effective off-nominal options when needed

Approach

- Realize UML models (and SW FMEA insights) evolve over lifecycle
- Approach application of SysML as part of risk mitigation effort
  - ***Perform requirement, concern, and goal discovery using classic SysML***
  - ***Consider integration of use cases and SW FMEA***
  - ***Leverage SysML framework to conduct specification conformance (e.g. functional failure analysis)***
- Extend UML model with SysML model annotations
  - *Use stereotype extensions to characterize expected requirements, derived constraints, off-nominal conditions for test and their status*
  - *Apply stereotype annotations as part of peer-review discovery, legacy FMEA insight*
  - *Define figures of merit (assessment indicators) to evaluate constraint compliance, specification/test, FMEA conformance and completeness*
  - *Even recommendations not accepted can be evaluated in a context*
- Develop/use automated tools to perform analysis
  - *Not all data needs to be embedded in SysML*
  - *Back end analysis can be tied into SysML parametric models*

Requirement Discovery Management



Integrating Use Cases and SW FMEA

- Use cases and SW FMEA generally viewed separately
  - *Use cases describe functional behavioral requirements— as nominal, alternate, exception/error courses of action*
  - *SW FMEA describes failure modes of software resources and mitigation of those failures*
  - *Scope of SW FMEA is broader than functional requirements as design choices may affect operations, non-functional behavior*
- Advantages:
  - *Integration provides problem context and would clarify its mitigation approaches*
  - *Provides a functional framework in which classes of failure modes could be addressed (e.g. failure of pre-condition/post-conditions are failure mode detections)*
- Challenges:
  - *Step granularity and crosscutting concerns affect scalability, manageability*
  - *Automated support needed for efficiency*

Use case-SW FMEA Integration

- Approach:
  - *Formalize use case steps via parameterization of pre-conditions, post-conditions and actions*
  - *Extend the use case schema to identify failure modes and their mitigation*
  - *Incorporate Requirement Discovery approach*
  - *Modularize use case processes (e.g. log function checks)*
  - *Autocorrelate legacy FMEA database with use case data*
  - *Operationalize non-functional requirements via benchmark tests*
  - *Include design assumptions*
  - *Link to other UML/SysML artifact references to manage granularity*
    - E.g. Specification references, UML/SysML diagrams, specialized stereotypes such as goals
  - *Develop automated analysis tools to check for consistency*

Use Case – SW FMEA integration

- Example uses a table representation here for conciseness.

Req ID	UC Module Name	UC Step	PreConditions/ Failue Mode Detection	Description	Action	Text	Requirement Type	Nominal PostConditions	Parent Req't ID(s)	Verification Event	Verification Method [A, D, T, I]	Verification Ref	Resources	Comments	SW FMEA ID		sponse/ igation	Mission Effect	Assumption	Other Refs
Req_ATT-10	AttitudeRequest	1	Guard[ATTITUDE__REQUEST=FALSE]; ALT[Req_Att-10-1]		[ref:ADD[ATT_SPEC,ADD_Req-8, ADD_Req-9]; CALL[UC:ItemCheck("attitude request command",ATT_STATEVAL-1)	Upon receipt of an Attitude Request command , the FSW shall verify that the attitude request is normalized, to within +/-(ATT_STATEVAL-1).	Functional	If (UC:ItemCheckVal) then Assert[ATTITUDE_REQUEST_NORMALIZED=TRUE];ALT[Req_ATT-10-2]	Req_ATT-2	FQT-Phase1	T	TBD_TestProcedureRef	Commandbuffer, Attitude Determination		ATT-10_FAIL-1, ATT-10_FAIL2					[ref:Attitude Request Sequence Diagram]
Req_ATT-10-1	AttitudeRequest	1.01	Upon entry: ATTITUDE_REQUEST=TRUE	Invalid Attitude Request due to request in progress		The FSW determines there is Attitude Request already in progress	Discovered	Increment[IGNORED_CMD_COUNT]	Req_ATT-10	FQT-Phase1			Commandbuffer, Attitude Determin		ATT-10_FAIL-1	low	Command will need to be resent		Attitude request is never part of a synchronized block commandset	[ref:Attitude Request Sequence Diagram]
Req_ATT-10-2	AttitudeRequest	1.02	(ATTITUDE_REQUEST=FALSE) & UC:ItemCheckVAL=FALSE	Request cannot be normalized	CALL[LogService(ATT", "ATT Request cannot be normalized")]	The FSW determines the Attitude Request cannot be normalized	Discovered		Req_ATT-10	FQT-Phase1		ed	Determination		ATT-10_FAIL-2	mod	Down stream processing willl use stale data until request is corrected	Diagnose based on ground logs.Low if correction received with ATT_UNSTABLE_TIME sec	Attitude request is never part of a synchronized block commandset	[ref:Attitude Request Sequence Diagram]
																				[ref:Attitude Request Sequence Diagram]
Req_LOG-10	LogService(stg,msg)	10	Guard[LogBuf<LogBufMAX];ALT[UC:LogService_fail("Log buffer overflow")]	This Use case performs the logging service for component <stg> with message <msg>		The FSW will log message <msg> for the identified component <stg>		Assert[LOG_SERVICE_COMPLETE=TRUE];Print[<msg>]; LogBUF++	Req_LOG-1	Unit Test			LogBuffer							[ref: Log Service Activity Diagram]
		20				end[LogService]														[ref: Log Service Activity Diagram]
Req_LOG-20	LogService_fail(msg)	10	LogBuf>=LogBuffMAX	This Use case processess a log service failure		The FSW will request a system reset upon a log service failure		Assert[LOG_SERVICE_COMPLETE=False]; Assert[SYSTEM_RESET_NEEDED=True]	Req_LOG-1	FQT-Phase1			LogBuffer		LOG-20_FAIL-1	high		Mission Disrupted		[ref: Log Service Activity Diagram]
		20				end[LogService_fail]														

Not all discovered requirements may survive in agile development. This mitigation affects operations. Using a message queue design could obviate this

These requirements capture off-nominal behavior and mitigation

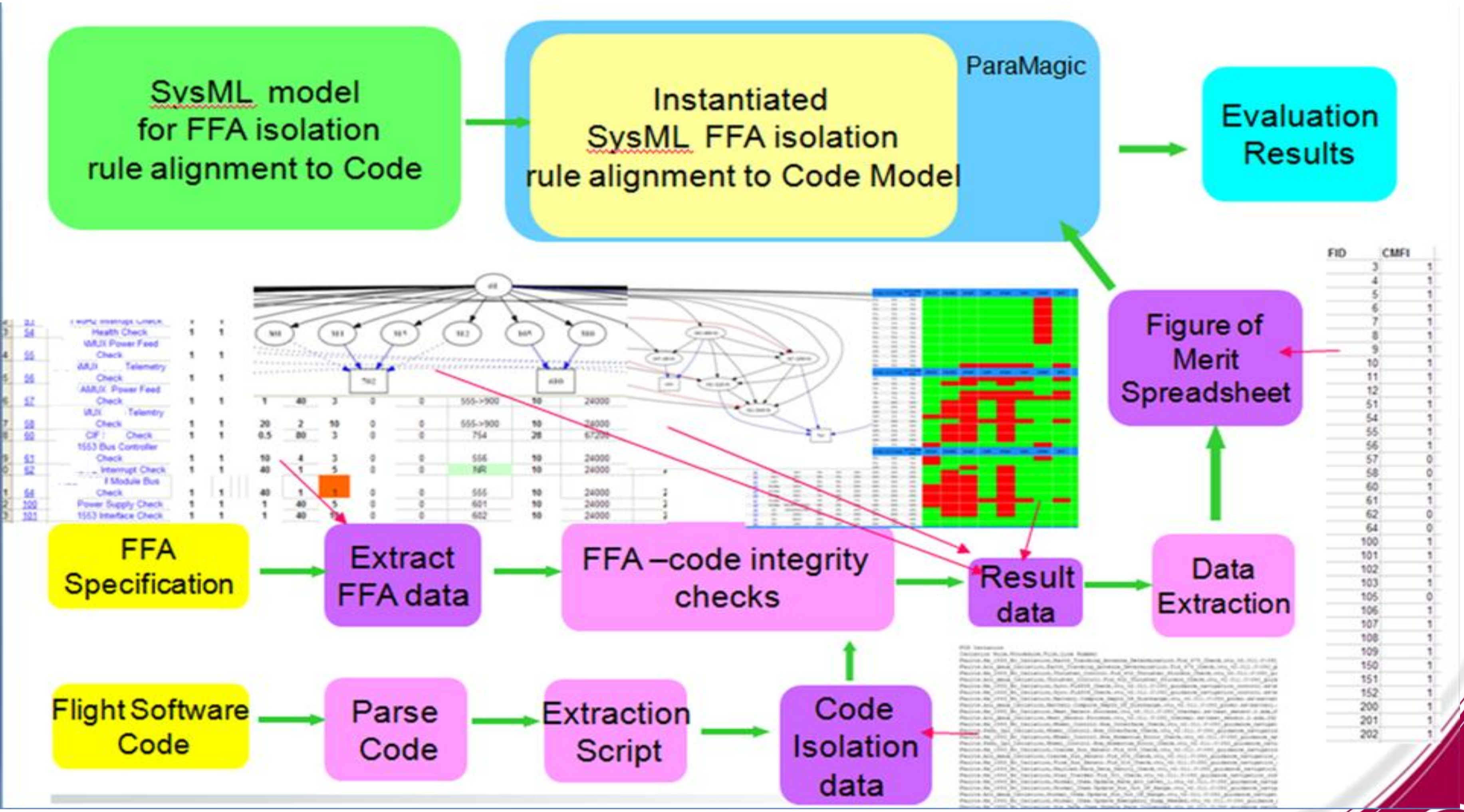
Resources and diagram links assist correlation with legacy FMEA data

Recommended test

Discovered requirements not currently in baseline

This impact could force a redesign of Log Service

Applying SysML to Specification Conformance



Future Work

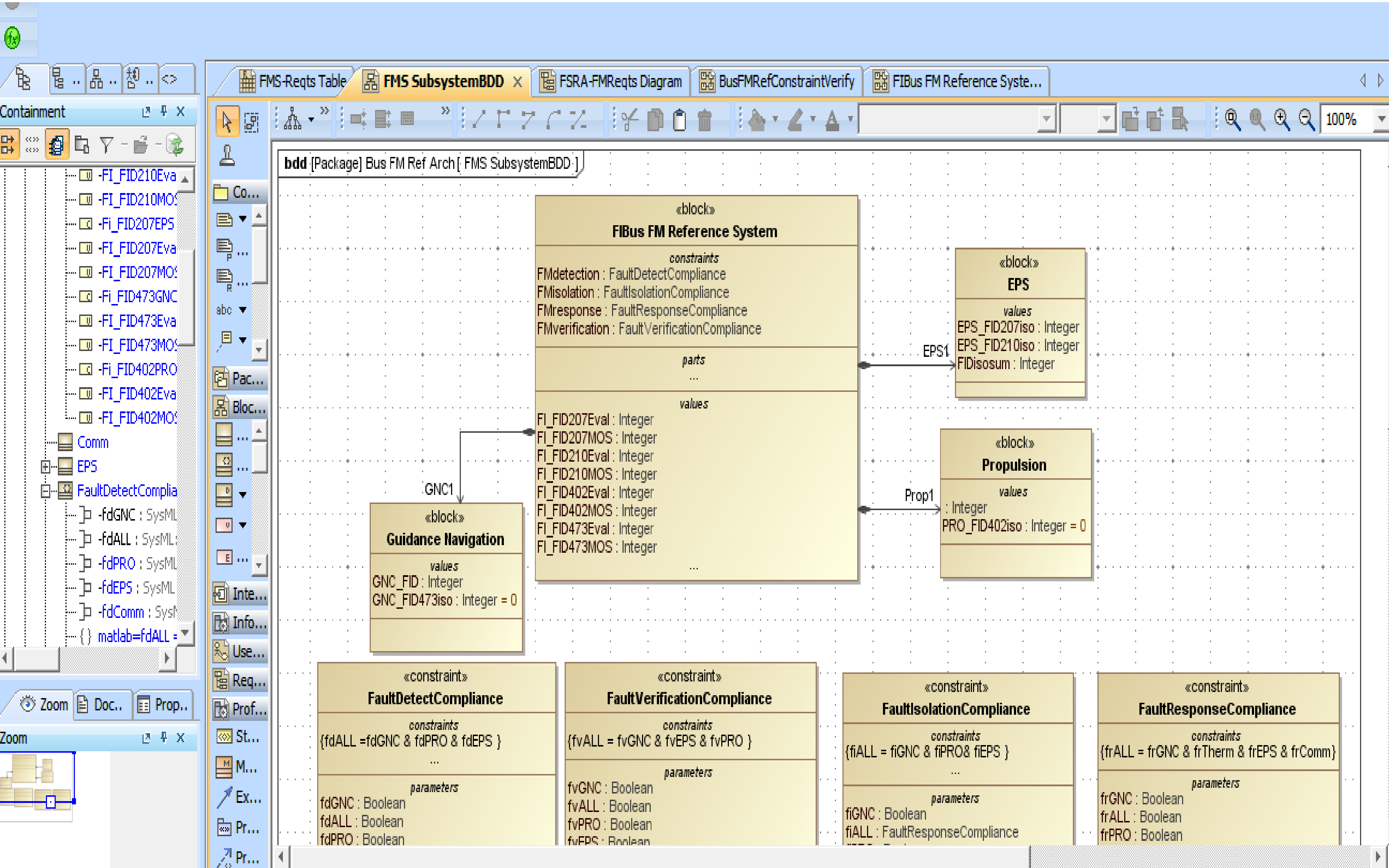
- As models evolve want to develop automated ways to apply model annotations
  - *Requires understanding model differences over time*
  - *UML/SysML supports model transformations*
  - *Looking at applying pattern analysis using Prolog*
- Strong desire to assess design choice impacts on mission accomplishment
  - *Formulate mission accomplishment levels with reward-based models using performability analysis*
  - *Assists in assessing different fault management strategy/goal options*
    - Adaptive goal-oriented fault tolerant systems
    - Graceful degradation
    - Multiple fault design robustness

References

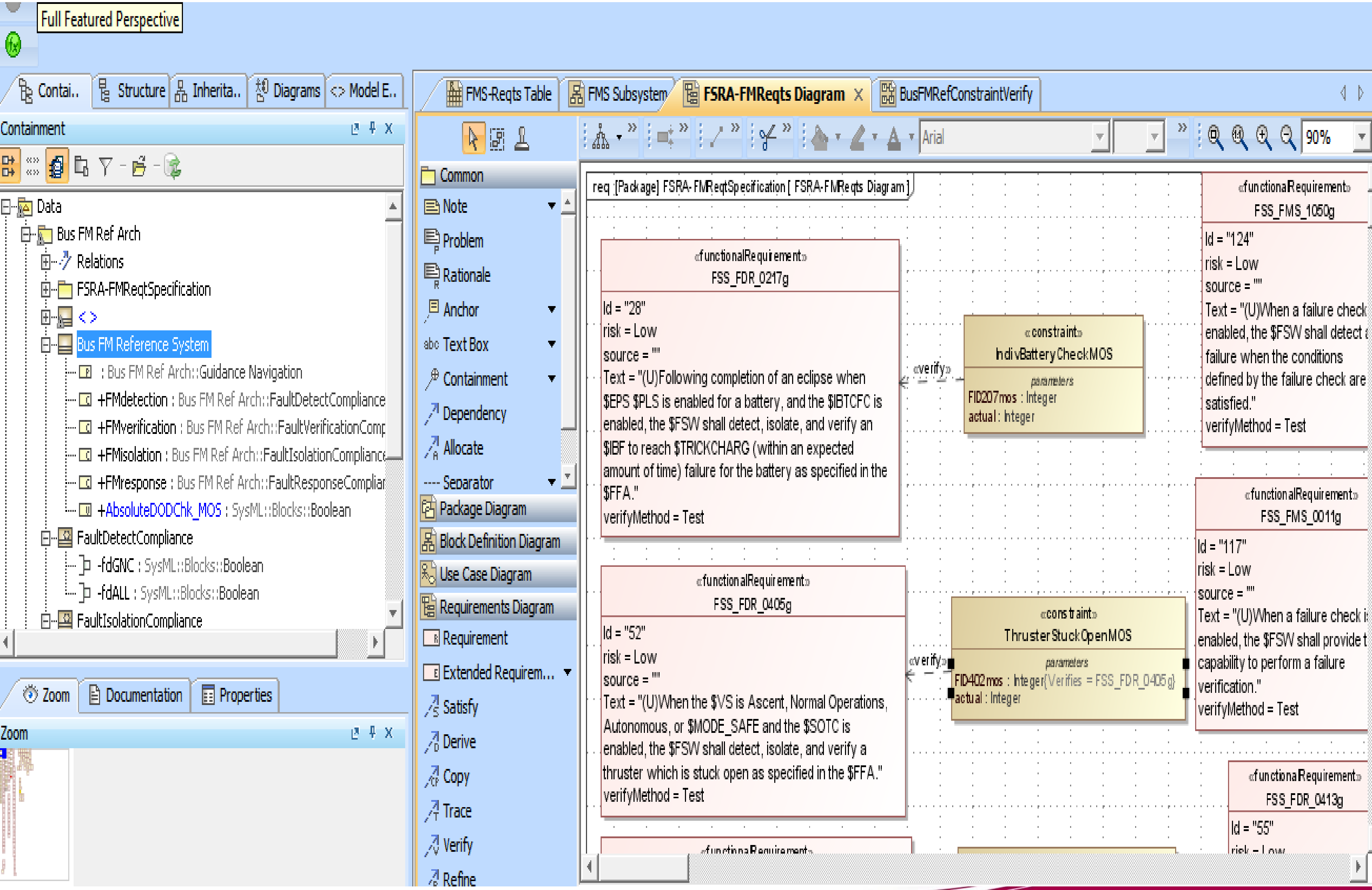
- David, Idasiak, and Kratz, “Towards a better interaction between design and dependability analysis: FMEA derived from UML/SysML models”, *ESREL 2008 and 17th SRA-EUROPE annual conference*, Valencia : Spain, 2008
- Guiochet, J. Motet, G. Baron, C. Boy, G. “Toward a human-centered UML for risk analysis.” In Jonhson, C.W. & Palanque, P. (eds), *IFIP World Computer Congress, Human Error, Safety and Systems Development; Proceedings. Intern.Symp. 2004, p177-191*
- Leangsukun, C. Song, H. Shen, L.. “Reliability modeling using UML.” *International Conference on Software Engineering Research and Practice*, Las Vegas, June 2003

Backup

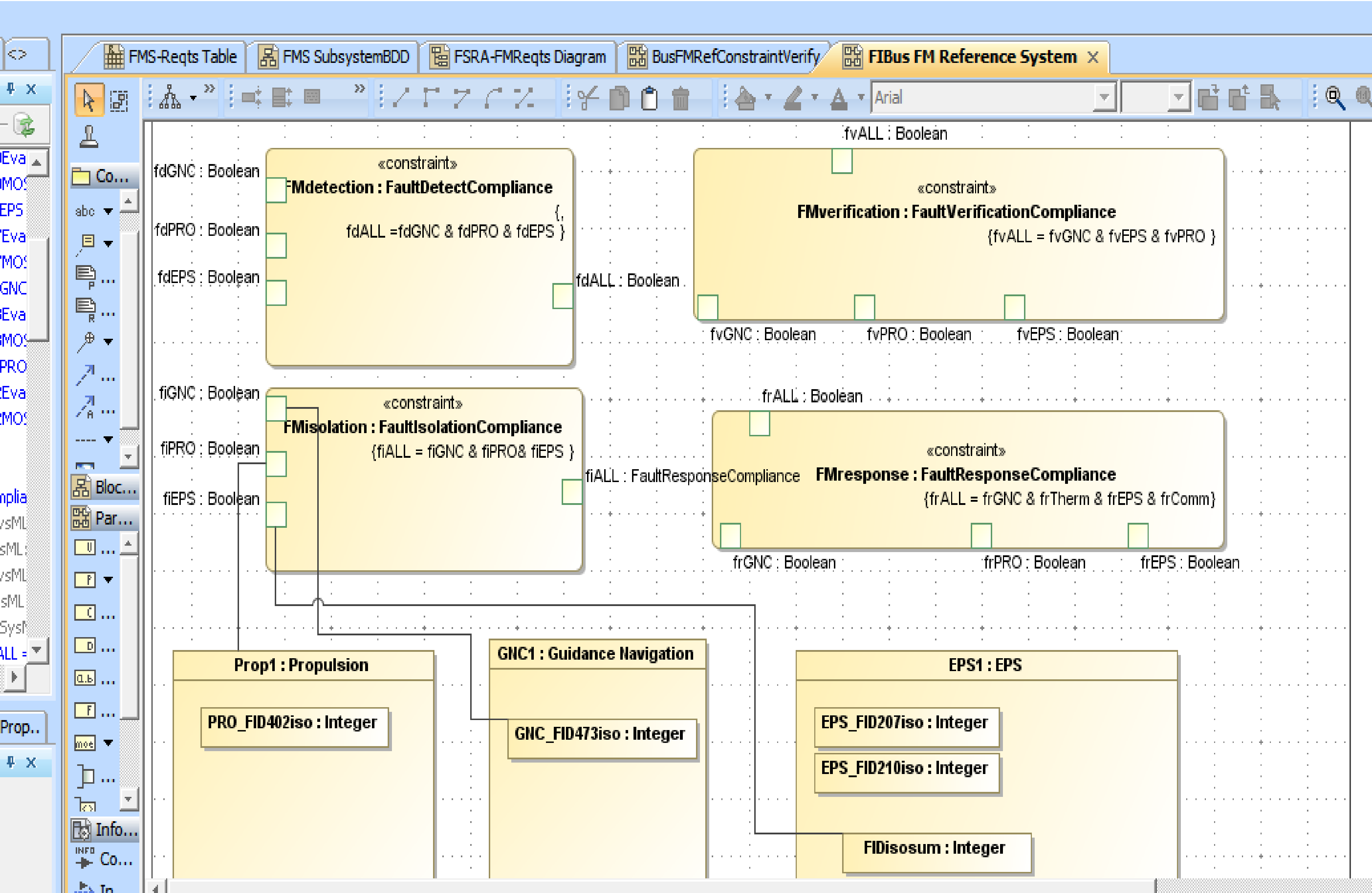
Fault Management Bus Reference Model



Requirements Constraint Management



Fault Management Isolation Map



Constraint Evaluation