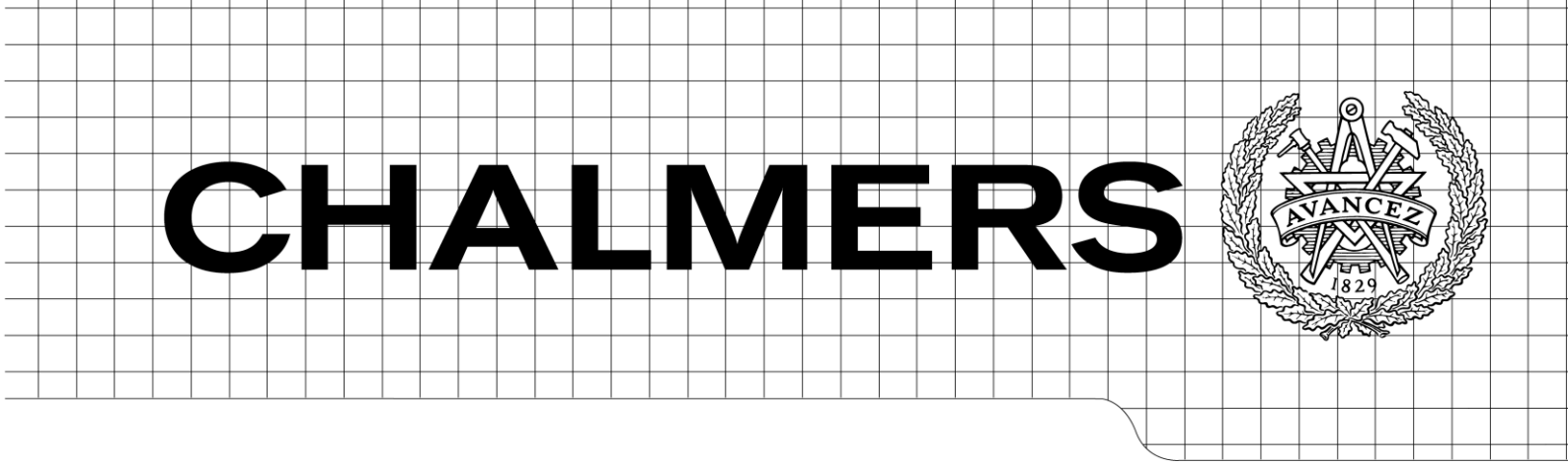

Safety Analysis and Model Transforming in EAST-ADL

Master of Science Thesis in Software Engineering

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Abstract

As architecture modeling becomes the trend in automotive industry, problems are raised regarding the gaining complexity in system design and safety analysis. The current safety analysis requires large amount of manual work and the result is usually unstable.

This study follows design research methodology and four artifacts are designed, implemented and evaluated. The outcomes of this research improves the current safety analysis working process by automating the model transformation and controlling version consistency between dependent model aspects. Besides, it also provides the possibility to apply safety analysis in an early stage of the development to reduce the amount of later modifications.

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Chapter 1 Introduction

With the growing number of integrated functions in automotive systems, one of the main tasks is to solve the contradiction between the increasing complexity of the system and the demands on accuracy and efficiency in system development. In order to cope with this problem, it is getting more and more popular to use suitable levels of abstraction for representing the system architecture. Various kinds of models and the corresponding analysis approaches are introduced to handle different situations. Among these, safety analysis together with system architecture models, which are crucial for measuring the vehicle's quality and safety in automotive industry, are chosen to be the topic in this study.

Currently, plenty of tools and approaches are targeting to support safety analysis by transforming between models according to the reviewed literature. However, challenges remain in maintaining consistency among safety requirements and analysis results, which means the final architecture design may not satisfy the corresponding safety requirements because of the unavoidable modifications in evolutions. Besides, how to guarantee the overall quality with a limited effort in time and cost is another issue worthy of discussion.

In this research, the researcher focuses on resolving those problems mentioned above by providing corresponding solutions together with relevant EAST-ADL artifacts. EAST-ADL is an Architecture Description Language (ADL) for automotive embedded systems (EAST-ADL specification). The overall goal of this study is providing automation and visualization support for current safety working flow. The error modeling is a concept in EAST-ADL which reflects the safety aspect from a system perspective. The research outcomes are evaluated by system engineers and safety engineers in order to collect feedback and improve the current and future solutions.

1.1 Problem statement and Research Questions

In order to apply the safety analysis to an architecture model, four steps are typically appropriate to conduct in automotive industry. First is defining an error propagation model from the architecture model, the error propagation model indicates the possible failures and how the failures are propagated in the architecture design. Fault tree analysis is the second step. Based on the information provided in the error propagation model, fault tree analysis provides a better understanding of how the system can fail. By taking the result from fault tree analysis into consideration, the third step is to find out how to reduce the risk of failures in the architecture model and modifying the architecture model is the fourth step. Those four steps are iteratively applied to eliminate the failure risks.

However, problems exist in those working procedures, most of the work are done manually and redundancy occurs when different teams are working for the same goal. Besides, inconsistency among system architecture model and error model occurs as they evolve. After the modifications are made on either architecture or error model side, there is no efficient way in the system to detect and control these changes with corresponding model on the other side.

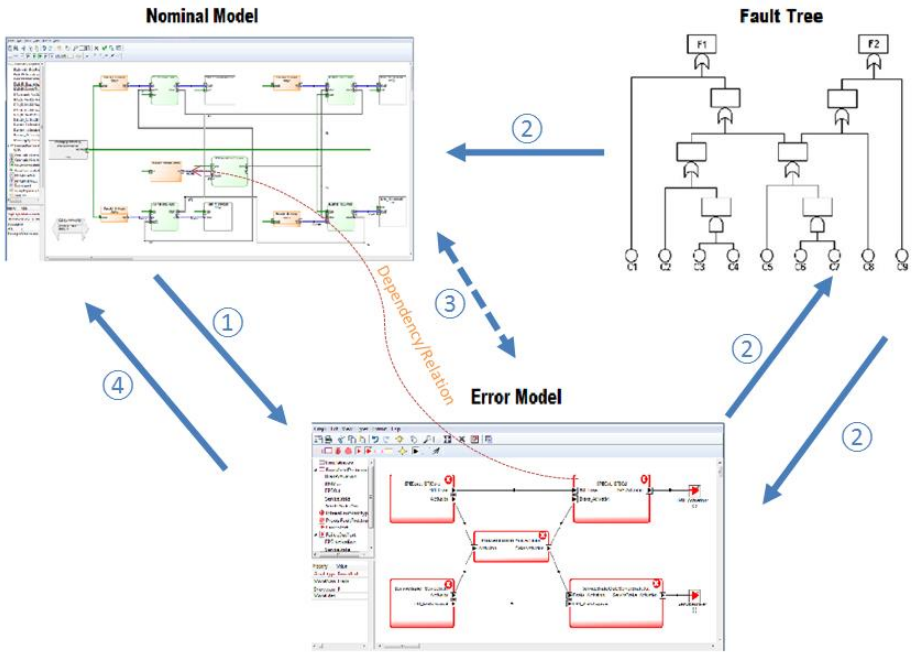


Fig 1.1 Safety Analysis working process

In order to cope with the problems explained above, five research questions are raised in order to provide a more efficient environment for safety analysis in EAST-ADL. Fig 1.1 illustrates the four procedures as mentioned above. The dependency between nominal and error model is illustrated as a tracing line. The numbers in this figure address the steps in working process and also corresponds to the section of research questions.

1.1.1 Defining

The first step, defining, is to create the error propagation model from the architecture nominal model, as shown by ① in the figure above. Decisions are needed to make which or what level of components is going to be used for generation. This is the first and most important step since only an accurate error model guarantees the quality for later steps. Alternatives exist while defining the error propagation model from the nominal model. Currently, manual work is required in order to determine which or what level error components are going to be generated. The problem comes to how to achieve an automated error propagation model generation which is not only adequate enough in capturing the error factors from nominal model but also flexible to be modified. So the first research questions is raised as ***RQ1****: How to efficiently define an error propagation model from the nominal model?*

Depending on the usage of error model, it has different structure from its nominal model. There are several routine manual refactoring on error model side, for example, collapsing the

connections and ports which have the same source element and destination element. Some algorithms are needed to be defined in order to reduce the manual work of refactoring. The second research question is defining process is revealed as ***RQ2****: How to reduce the manual work in refactoring the model?*

1.1.2 Analyzing

The second step is the analysis process. In this step, the fault propagation data in the error model is synthesized and analyzed into fault tree. The analysis tool automatically generates the corresponding fault tree once the error logic is defined. There are several analysis tools available in fault tree analysis area, such as AltaRica, HiP-HOPS, Rodelica. In this research, we need to decide which tool is the most efficient for EAST-ADL Fault Tree Analysis and create the corresponding analysis algorithm for EATOP. In order to provide a more efficient environment for fault tree analysis in EATOP, an implementation is needed to integrate EATOP with the fault tree analysis tool. So the third research question is: ***RQ3****: How to apply Fault Tree Analysis on EAST-ADL error model and relate the generated Fault Tree result with both error model and nominal model in EATOP?*

1.1.3 Understanding

As shown by ③ in Fig 1.1, this step is for evaluating and validating relations between the generated models after the previous two steps. In order to have a better understanding, a certain method of visualization between models is needed. The goal of this step is to help the user to understand how the error model is related with the corresponding architecture nominal model. The visualization should be able to reduce the manual work in the current status and provide a general view of corresponding models. For this reason, the fourth research question is revealed as ***RQ4****: How to visualize the error propagation model together with nominal model and fault tree?*

1.1.4 Evolving

After the models are evaluated, evolution is unavoidable. This step is about the modifications happening after the initial model generating stage, adjusting and improving the models in order to fit the constraints and fulfill the safety requirements. As shown in 1.1, the consistency between nominal model and error model are checked in this step.

Error modeling is the bridge between nominal models and fault tree analysis. Since the fault tree is generated directly from the error model, the consistency problem between fault tree and nominal model is transferred as the consistency between error model and nominal model. The handling of components inconsistency is quite important in automotive structure development area. So in this step, the research question is raised as ***RQ5****: How to ensure consistency between nominal architecture models and error models?*

1.2 Overview

The contribution of this study has been made in Electrical and Embedded System department at AB Volvo Group Trucks Technology, Advanced Technology and Research. Two supervisors from both industry and academic sides and a certain amount of safety engineers in this department were involved.

In this study, we designed and implemented several features based on EATOP. EATOP is an eclipse based EAST-ADL platform. The aims of those features are solving the research questions revealed in the previous section. For the questions in step ① defining, a one to one mapping pattern is designed to define the corresponding error model from architecture model. And the mapping design is implemented into EATOP plugin which is able to automatically generate error model elements out of existing function model elements. The final outcomes in first step reduce the manual work in error model defining. For fault tree analysis in the step ②, HiP-HOPS is integrated into EATOP and several fault tree analysis results are annotated in EATOP model. The graphic support for step ③ understanding in this research focuses on visualizing the relations between error modeling and architecture modeling since the relation visualization is the main topic in research question 4. For the inconsistency problem in step ④, a version control feature is developed to help the user manage and synchronize the changes from version perspective. In order to prove the design and implementation of each feature solving the research questions and achieving their goals, an evaluation is executed among system engineers and safety engineers from different departments in Volvo Group Trucks Technology. Even the whole thesis is carried out in one single company, it still produces the academic value to improve the common safety analysis procedures in automotive area and the result of this research is able to generalize to automotive industry.

This thesis report starts with a general introduction of the research background in chapter 2, which provides more detailed information about EAST-ADL function modeling along with error modeling and several concepts in safety analysis. Further elaboration and the solutions for each research question are presented from Chapter 5 to Chapter 8 respectively. Design use cases are demonstrated in each chapter and the final result screenshot are depicted in Appendix. Chapter 9 specifies how the evaluation data is collected in this study together with the collected data analysis. Chapter 10 draws a final conclusion with the outlines of future work.

Chapter 2 Background

This research is mainly based on EAST-ADL, an Architecture Description Language for automotive embedded system. A description about EAST-ADL is provided in the first section followed by a detailed explanation of two modeling concepts. EATOP and the tooling environment are summarized in section 2.3 and it is followed with a description about Fault Tree Analysis. The related work is elaborated in the end of this chapter.

2.1 EAST-ADL

EAST-ADL is an Architecture Description Language (ADL) to model functional-, system-, software-, and hardware-architecture in the automotive domain (eclipse EATOP, 2013). It is initially defined in the European ITEA EAST-EEA project and maintained by EAST-ADL Association. The main role of EAST-ADL is to provide a sufficient detail for design, analysis, documentation and synthesis in automotive electronic system modeling, it provides various levels of concerns for organizing and representing the automotive system.

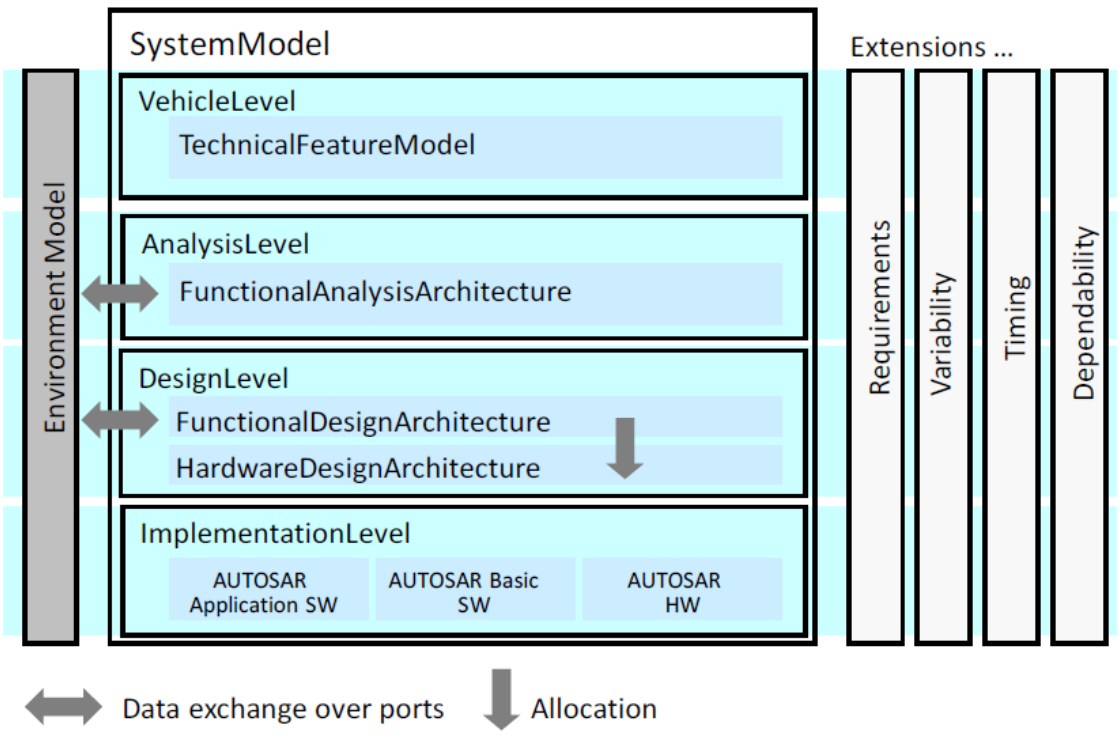


Fig 2.1 EAST-ADL 2.1.12 Abstraction Representation

As shown in Fig 2.1, the functionality of the vehicle in EAST-ADL 2.1.12 is described at four levels of abstractions, which are Vehicle Level, Analysis Level, Design Level and Implementation Level. Among those four levels, only implementation does not have its own structure, all the elements are represented by AUTOSAR since AUTOSAR focuses more on software architecture and execution platform while EAST-ADL is used for features, functional architecture and topology. The intent of Vehicle level is to state what the vehicle should do, it contains the modeling elements which represent the intended functionality. Analysis level provides an abstract functional architecture while Design level has the detailed functional definition. The right hand side of Fig 2.1 illustrates the extensions in EAST-ADL, which include structural constructs, behavioral constructs, variability, requirements, timing, dependability and so on. Those extensions reference the core elements with all abstraction levels. More detailed information about structural constructs and dependability will be elaborated in next section.

2.2 EAST-ADL Modeling Concept and Fault Tree Analysis

As discussed above, the modeling concepts of EAST-ADL, or so called EAST-ADL extensions, cover various areas from requirements modeling to timing modeling. In this section, we will provide more details with an example model about function modeling and safety modeling.

2.2.1 Function Modeling

Function Modeling is performed in the Functional Analysis Architecture and Function Design Architecture, which are also the root components in Analysis Level as FAA and in Function Level as FDA. The Allocation of Function Design Architecture is represented in corresponding Hardware Design Architecture. The concept provided in function modeling is the functions interact with each other through their function ports and connectors. Each of the function is modeled by function prototypes and they can be typed by a function type. And a function type is where contains ports, connectors and other function elements. The general structure is illustrated in Fig 2.2 and the class diagram of function modeling is shown in Appendix B.1.

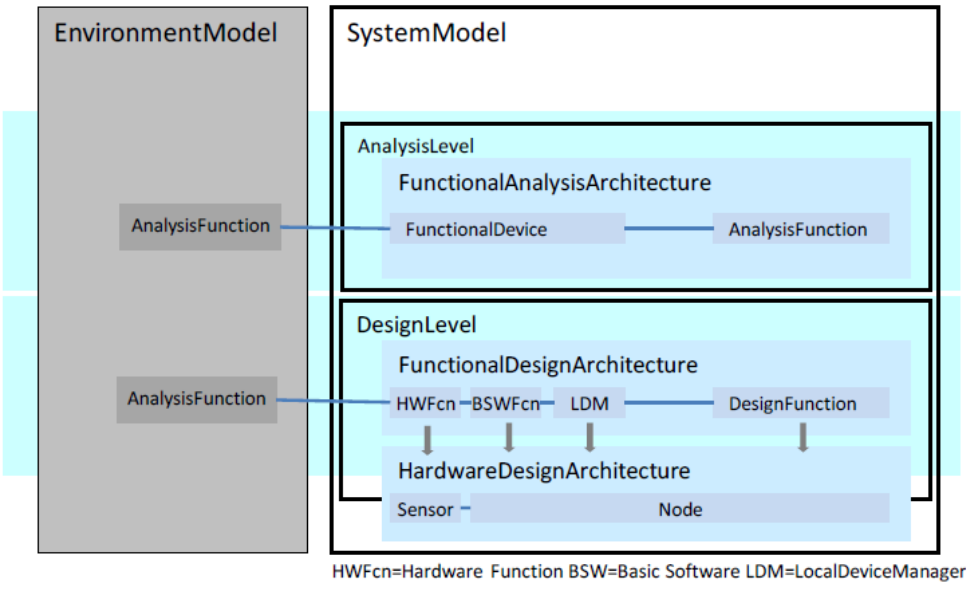


Fig 2.2 EAST-ADL 2.1.12 Function Modeling on Analysis Level and Design Level

As a standard example of EAST-ADL, “Brake_By_Wire_4Wheel” contains function modeling elements on both analysis level and design level. Those two levels are separated into two packages called “AnalysisLevelElements” and “DesignLevelElements”. As illustrated in Fig 2.3(a), the analysis function elements like AnalysisFunctionType(ABS_T, BatteryObserver..), FunctionalDevice(BatteryDoDSensor, BatteryVoltageSensor..) are directly located under the AnalysisLevelElements package. AnalysisFunctionType is used to model the functional structure on AnalysisLevel and the FunctionalDevice is the interface between the electronic architecture and the environment (EAST-ADL specification 2.1.12). While the DesignLevelElements are divided into function modeling and hardware modeling. “FCN” contains the function design architecture elements like DesignFunctionType(ABS_T, BBW_FDA..), used to model the functional structure on DesignLevel. And HardwareFunctionType (HW_Brake_T, HW_Encoder_T..) types DesignFuhnctionPrototypes (EAST-ADL specification 2.1.12). “HW” package, which means Hardware Modeling contains the elements to model physical entities of the embedded electrical/electronic system. The example DesignLevel elements are shown in Fig 2.3(b).

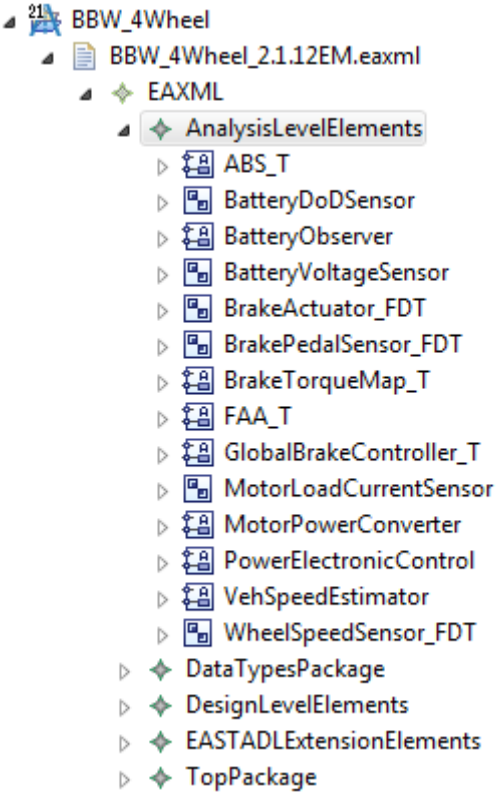


Fig 2.3(a) Analysis Level Elements in BBW

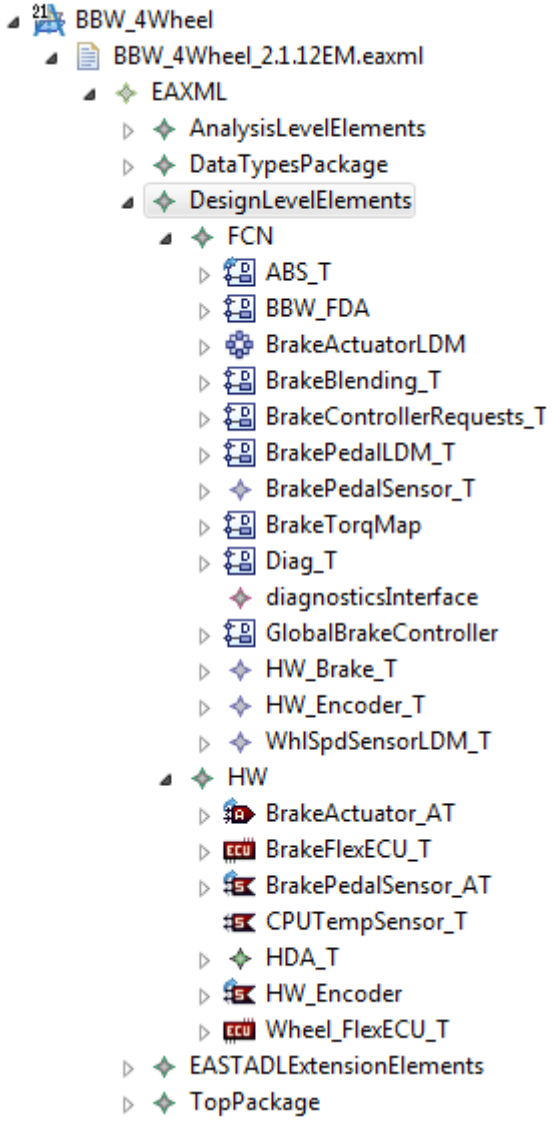


Fig 2.3(b) Design Level Elements in BBW

Fig 2.3 EAST-ADL Brake-By-Wire Example of Function Modeling

2.2.2 Error Modeling

EAST-ADL error modeling provides the concerns with faults, errors and failures throughout an architecture design process. It provides the support for safety engineering by representing possible incorrect behaviors of a system in its operation. (e.g., component errors and their propagations.) In this case, the abnormal behaviors of architectural elements as well as their instantiations in a particular product context can be captured and they are captured in one error modeling element called "Error Behavior". An incoming flaw or an internal flaw represents a fault for the component which may or may not result in a component failure. While an outgoing flaw which is propagated from the component results a failure. (EAST-ADL Domain Model Specification, V2.1.12).

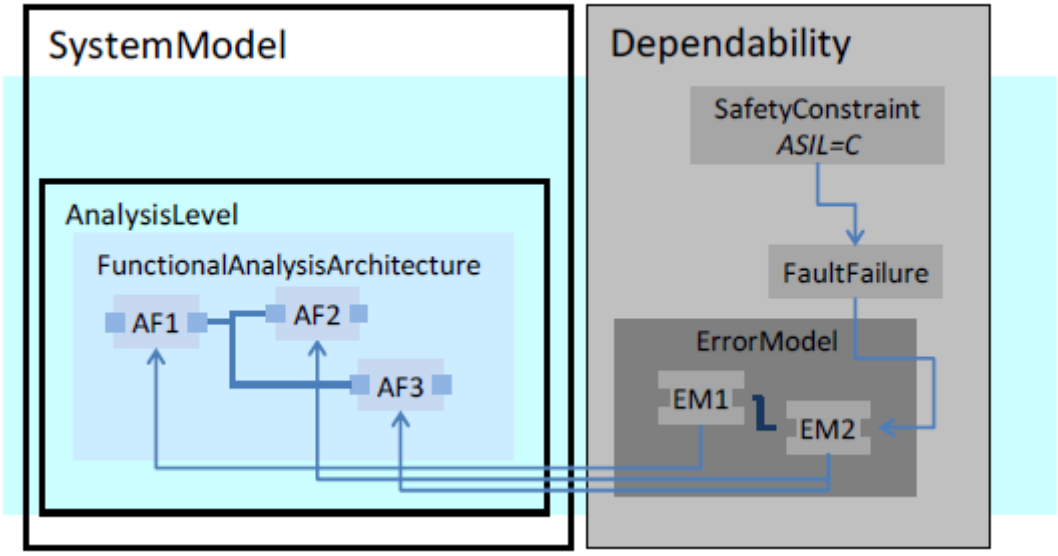


Fig 2.4 EAST-ADL 2.1.12 Error Modeling

Figure 2.4 illustrates the relations between error model and function analysis model. Error Modeling is regarded as a separate view from nominal architecture. The related error models present traces to the nominal architecture and the hazard together with error relation between the components. As presented in Fig 2.4, EM1 in Dependability side under ErrorModel represents the failure logic of AF1 in SystemModel side under AnalysisLevel and EM2 represnets both AF2 and AF3 in the system model, which means the tracing from error model to system model could be a one to one element mapping or one to many mapping according to the different situations. Besides providing the FaultFailure logic, error model elements also represent the ASIL level of its corresponding system model. More information about basic concept of failures is presented in section 2.2.3. The ASIL level is an automotive safety integrity level which expresses the required levels of safety in one system. Each hazardous event is assigned an ASIL to each required error model element, which means the criticality of this hazard. As shown above, EM2 is assigned the ASIL as level C. In general, Error modeling concept in EAST-ADL is a language construct for associating the annotations of error descriptions to the target system entities for maintaining the traceability (Chen, et al. 2013) and it is also the base of safety analysis which is elaborated in section 2.2.3.

Taking the Brake-By-Wire model as an example, Fig 2.5 carries out more detailed information of how error modeling elements behave in a system. The Dependability package of a system contains all the related elements which represent the system's ability to ensure service failures are at a level of frequency and severity that is acceptable and Error Modeling

is one of them. Inside DependabilityPackage, there are three ErrorModelTypes, one FaultFailure and one SafetyConstraint. A FaultFailure element represents a certain fault or failure on its refered anomal and a SafetyConstraint element represents the qualitative integrity constraints on a fault or failure. Since both FaultFailure and SafetyConstraint are belonging to SafetyConstraints concept in EAST-ADL and it is not the focus of this study, we'll not going into detail of this concept, but more information can be found in EAST-ADL Domain Model Specification, V2.1.12. As an ErrorModelType, "BrakeTorqueCalc_EM" represents the internal faults and fault propagations of the nominal element that it targets. This target is the dependency between function modeling and error modeling mentioned above. "BrakeTorqueCalc_EM" contains two FaultFailurePorts which is used for propagating the fault or failure; one InternalFaultPrototype called "InternalFault" represents the internal conditions that can cause failures of its target element when it's activated. And one Error Behavior which is called "BrakeTorqueFailureLogic" which contains the element's failure logic. The failure logic describes how the failure propagates inside this element.

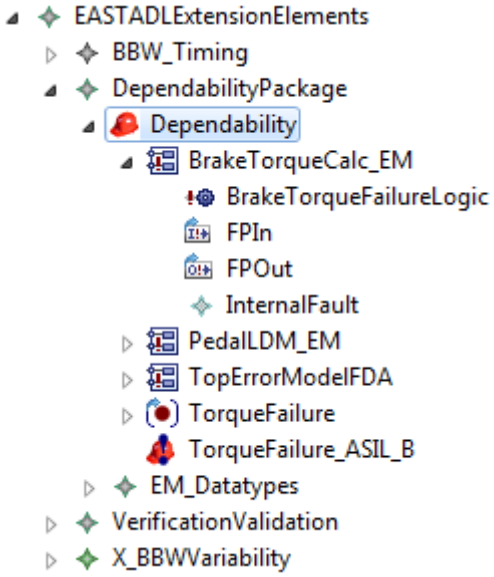


Fig 2.5 Error Modeling in BBW

2.2.3 Fault Tree Analysis

Before the Fault Tree Analysis is explained, we would like to discuss about the relations between fault, error and failure. As illustrated in Fig 2.6 (Avizienis et al. 2004, p.21), an error is activated from a fault and a fault is the initial cause of a failure. Failure occurs when an error is propagated to a service, this propagation causes a deviation of the service delivery from correct service (Avizienis et al. 2004). Error propagation is defined as an error successfully transforms into other errors by Avizienis et al. An error propagates from one component to another causes a failure.

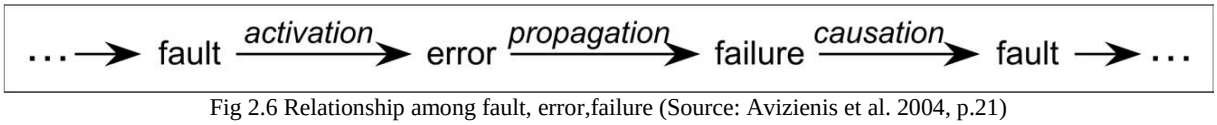


Fig 2.6 Relationship among fault, error,failure (Source: Avizienis et al. 2004, p.21)

Fault Tree Analysis is a systematic method of system analysis. It is a top down approach, which is used to analyze the system failure probability and resolve the causes of a system failure. This method is used to establish how the system can fail and identify the best ways to

reduce the risks in safety engineering area. Fault tree, as one outcome of the Fault Tree Analysis, is deductive models which deduce causes of the event backwardly, it's conducted to show the possible causes and relationships which result in the top event. Besides the fault tree, the fault tree analysis also provides an analysis result based on the created fault tree. The analysis result contains a list of information behind the Fault Tree. Cutsets, for example, is one analysis result which illustrates the elements that must occur to cause the top event happen. Depending on different Fault Tree Analysis Algorithms, the analysis result also present the prioritization of the events leading to the top event or the optimized resources to avoid the top event.

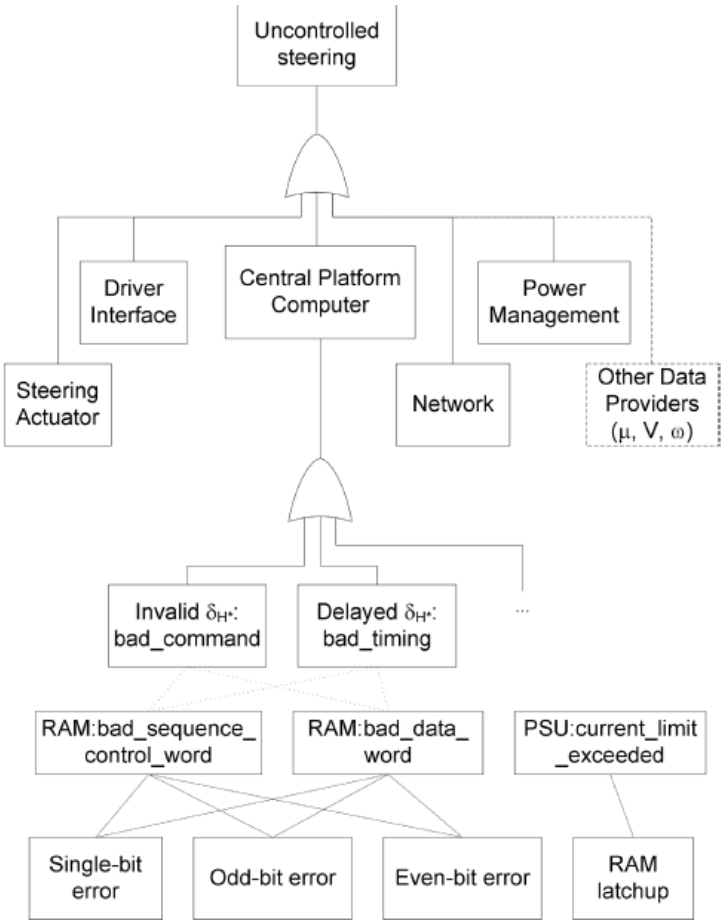


Fig 2.7 Example Fault Tree (source: Rupanov et al. 2012, p.7)

Fig 2.7 (Rupanov et al. 2012, p.7) depicts one example Fault Tree of steer-by-wire system. In this example, the final failure "Uncontrolled steering" is caused by either the failure in steering actuator, driver interface, central platform computer, network, power management or other data providers. Among them the central platform computer failure is reasoned to bad command, bad timing and so on. The fault tree provides a graphical tree view of failure analysis which makes the result easy to understand.

2.3 EATOP

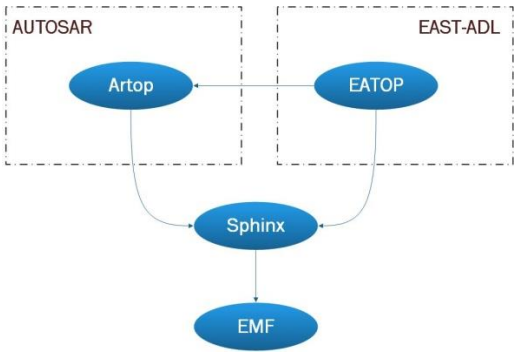


Fig 2.8 EATOP tooling environment

EATOP is an Eclipse-based implementation of EAST-ADL. It is an open source project under the Eclipse Modeling project. As illustrated in Fig 2.8, EATOP is based on Sphinx modeling tool platform and closely aligned with Artop. Artop is an AUTOSAR Tool Platform. One main feature of EATOP is providing one Eclipse-based tool platform implementation for the important versions and revisions of EAST-ADL. As an open source project, EATOP's goal is reconciling and consolidating these different implementations and enhancing the functionality supporting of EAST-ADL. EATOP could be installed in general Eclipse IDE as an external tool or as one standalone software. When the EATOP perspective is open in Eclipse IDE, it is available to create EAST-ADL project under EAST-ADL explorer and create multiple EAST-ADL files under one EAST-ADL project.

2.4 HiP-HOPS

HiP-HOPS (Hierarchically Performed Hazard Origin & Propagation Studies) is a safety analysis tool. It is recognized as a state-of-the-art technique in the area of dependability analysis. The safety analysis tools play the part of a valuable aid in ensuring that the system designs meet their safety goals. Among these tools, HiP-HOPS takes place on the actual architectural model of the system with some annotations of the failure logic. It contains fast algorithms of Fault Tree analysis and Failure Models and Effects Analyses (FMEAs). The basis of the analysis in HiP-HOPS can be provided by architectural models which is described in single or multiple perspectives. The model file can be saved and re-used for different models and contexts (Papadopoulos, et al., 2011).

Chapter 3 Related Work

Several areas are covered in this thesis, which are automotive modeling language, safety analysis process and development, Fault Tree Analysis and error propagation together with change propagation. In each area, several latest academic articles are studied as related work in this thesis. The related works play the role of navigator to lead the academic direction of this research.

Cuenot, et al proposed a basic safety procedure as shown in Fig 3.1. This safety analysis process concept is raised in "Safe Automotive soFtware architecture" (SAFE) project and it is applicable for both AUTOSAR and EAST-ADL modeling language. This working procedure is used as a base in this research and several improvements are provided in this research.

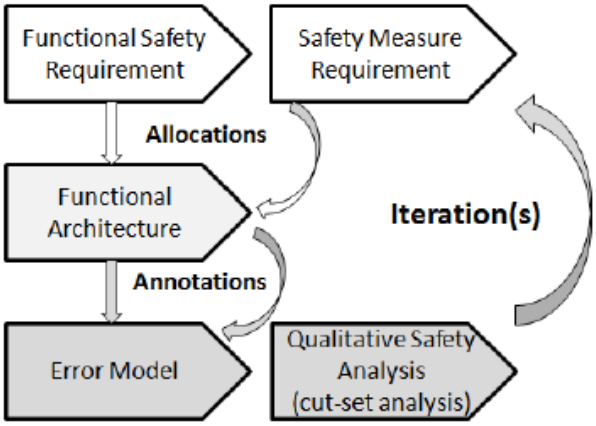


Fig 3.1 Safety analysis process overview for functional safety concept (Cuenot, et al., 2013)

The automotive industry are using several modeling languages. Besides EAST-ADL, the AUTOSAR (AUTomotive Open System ARchitecture) standardized architecture is used for describing software component implementation and integration together with ECU configuration (Cuenot, et al., 2013). Delivered in 2012, AUTOSAR 4.0 contains a well-defined set of safety mechanisms responsible for error detection and error handling. AUTOSAR does not, however, support modeling and analysis of error propagation. Since the EAST-ADL safety support are applicable to both AUTOSAR and EAST-ADL, we focus on the latter.

The need of creating connections between architecture model and fault tree analysis addressed in third research is still a valid and common question in safety analysis area. Grunske and Han provide a comparison between existing safety evaluation methods and AADL's error annex from modeling support, process support and tool support three perspectives (Grunske and Han, 2008). The pros and cons of applying HiP-HOPS Fault Tree Analysis is also addressed in comparison. Even this paper focuses on presenting the strength of AADL's error annex, it

is still a valid guide and reference in terms of applying HiP-HOPS on the EAST-ADL error propagation model. There are several well-developed fault tree analysis tools in automotive area, while the demand from the user is having an early safety analysis for current working models, but no tool support is available for an early safety analysis without having a whole meaningful set of error propagation models. The challenge addressed in this research is to efficiently apply Fault Tree Analysis to early safety analysis. One solution and algorithm is provided in *Systems Modeling with EAST-ADL for Fault Tree Analysis through HiP-HOPS*(Chen, et al., 2013) by applying HiP-HOPS Fault Tree Analysis to EAST-ADL error models. It proved the possibility of having Fault Tree Analysis in EAST-ADL safety analysis. But the solution is lacking of tool support. The use of HiP-HOPS is also presented in *Engineering failure analysis and design optimisation with HiP-HOPS* (Papadopoulos, et al., 2011). This research proposed one solution to integrated HiP-HOPS Fault Tree Analysis into the research tool EATOP. This integrating makes it possible to apply safety analysis in an early stage of a design. In addition, the quality of the analyzed result is one most important factor for fault tree analysis. Since HiP-HOPS analysis highly depends on the structure and semantic meanings provided in error logic, it is important to form the error logic in a sufficient way. Several strategies are provided by Giese and Tichy (Giese and Tichy. 2006) in terms of optimizing the configuration for a component based error logic. Inspired from their proposal, one component based error logic is also addressed in this research.

By providing several scenarios of architecture changes and the effects to fault tree analysis, Getir, et al. provides a sufficient algorithm to automatically analyze several specific types of model evolution with fault tree analysis (Getir, et al., 2013). Malik and Hassan (2008) provide several common change propagation heuristics in their paper and effort have also been put in adapting the common changes to a general circumstance. Not only the common changes have been investigated, the unpredictable changes are also defined by Salay et al(2013). They introduced the uncertainty change propagation concept and defined algorithms for computing those propagations by several use cases. Even more and more types of modifications are captured and analyzed under those articles, it is still not enough to address all the evolution possibilities in one research and needless to say a tool supporting to monitor those changes. Instead of increasing the amount of model evolution types to be automatic analyzed, this paper provide a solution to monitor all possible evolutions by version control. By performing this solution, any change is able to be monitored and the user is able to define their own strategy to cope with model evolution.

Chapter 4 Research Methodology

According to the fact that this research aims at improving the safety analysis working process, action research and design research are taken into consideration since both of them could be used to address an improvement in information systems. Design research is a constitution of finding problem, design and development in information technology area. It is sometimes called as "Improvement Research", which means the improving performance plays an important part in design research. Action research is a fundamentally change-oriented approach and it focuses on practical problems with theoretical relevance (Cole, et al., 2005). As specified by the name, action research applies changes through action. Even if both research methods aim at improvement, there are dissimilarities among them. Action research emanates from social science while design research emanates from engineering science. Design research demands innovation and novel technology and it aims for cutting-edge technology, where action research goes more for normal design practice and it demands rather safe solutions based on robust technology(Goldkuhl, 2013). Being related to an FFI (Strategic Vehicle Research and Innovation) project, this research applies more innovation and cutting-edge technology than existing robust technology. Besides, new artifacts are designed and implemented in this research rather than improving by observing action. Due to the reasons above, design research is selected to be conducted in this thesis work.

The research process in this study is listed in Table 4.1. It is based on the design science research model given by Vaishnavi and Kuechler (Vaishnavi and Kuechler, 2004). Step 1 is defining a problem. All the data for defining problems in this research are collected by industry supervisor among the experts working in system architecture and safety analysis area in Volvo Group Trucks Technology. By considering the probability of the problems to be solved and the priority of importance of each problem, five research questions are revealed. After the questions are defined, step 2 designing is performed. A design process is divided into implementing a design and modifying a design as shown in table 4.1. The critical elements defined in each research question are reflected in the design. For example, the critical elements of first research question "How to efficiently define an error propagation model from the nominal model?" are "efficiently define" and bridging two modeling concepts. In order to reflect those two aspects in the design, a sufficient mapping strategy is designed to bridge different modeling elements. The time performance is also taken into consideration when defining the algorithm in order to fulfill the demands of "efficiency". More elaboration for this research question is presented in Chapter 5. Besides, several modifications are applied in order to finalize a design. When an initial design is released, an investigation is needed to prove the feasibility of the design and this investigation is executed by researcher. Whenever problems found in the investigated design, a discussion is arranged among supervisors and researcher to decide whether to modify the design and if yes, how to modify it. When a design is approved and available to develop, the research comes to step 4, the development stage which is listed as "Developing the design" in the table. The modification of design which is

step 3, also occurs during the development process in order to secure that the implementation meets the user's expectation. For example, when designing the solution for the first research question "How to efficiently define an error propagation model from the nominal model?" different kinds of function ports are not taken into account until the problem revealed during development phase, so the design is modified during development. The boundary between design and development in this research is the design draws a concept of solution for each problem while the development implements the designed solution to artifact. In the phase of developing the design, agile method is applied and each sprint lasts three weeks. The planning and retrospective in each week is performed among the author and the supervisor in Volvo. A final retrospective for each sprint is organized every three weeks among both supervisors and the author.

Table 4.1 Guidelines of this research method process (Adapt Vaishnavi and Kuechler, 2004)

Research Method Framework
1. Defining a problem
• Analyze the collected data
• Define a problem from the analyzed result
2. Implementing a design
• Identify the critical elements of the design
• Characterize how each design will be addressed in the implementation
3. Modifying the design
• If any part of the design does not work, modify the design
• Clarify the reason of modification
4. Developing the design
• Implement the design
• Address the critical elements in the design
5. Modifying the development
• If any part of the development does not work, modify the development
• Review the design
• If any part of the development does not fit the design, modify the development
6. Measuring the outcome
• Evaluate the outcome of the development
• Analyze the result of the evaluation
7. Reporting the result
• Report the design and the development
• Report the result of the evaluation

The evaluation process is conducted to measure the research outcome and it is listed as step 6 in table 4.1. Two evaluation stages are performed in the half-way and the end of the thesis project respectively. System engineers are involved in the first evaluation while the safety engineers participated in the second evaluation. Before the evaluation process, each design and development are repeated till a reasonable outcome is completed and approved by the supervisor. The feedbacks and valuable input are collected from both evaluations stages for drawing the final conclusion. The detailed evaluation methodology is reported in Chapter 9. Beside the formal evaluation, retrospective is performed in the end of each iteration in developing process. The main task of retrospective is to report what have been done during this iteration and what research question has been solved. If new question has been addressed, what efforts could be done in the future. The last step is step 7, it is applied as reporting the

result. A report which presents the design, development and evaluation in this research is the outcome of this step.

Chapter 5 Defining and Reorganizing Error Model

In this chapter, the research questions “How to efficiently define an error propagation model from the nominal model?” and “How to reduce the manual work in refactoring the model?” will be addressed. As shown in Fig 5.0, both questions are revealed in defining process as number ① and the red arrow. The solution in defining process automates the generation and refactoring of error model from nominal model.

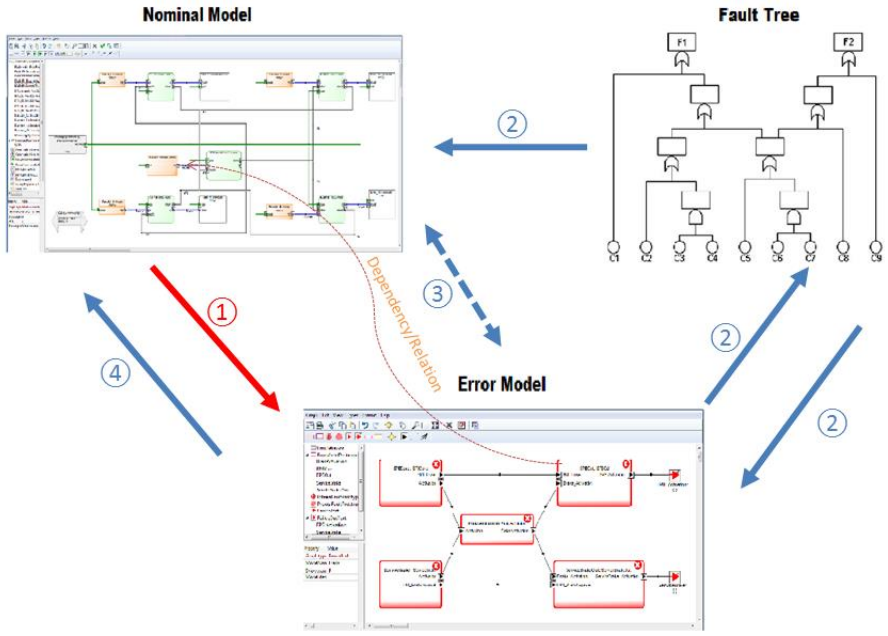


Fig 5.0 Safety analysis process – defining

In order to provide a better understanding of the nominal model concept before addressing the solutions for each research question, an example EAST-ADL model is presented in section 5.1. It locates the nominal modeling in a whole picture of EAST-ADL and explains some specific elements mostly used in nominal models through the BrakeByWire example. Sections 5.2 and 5.3 explain the solution of defining error propagation model and reorganizing error model questions respectively. Each of the section starts with a concept description which briefly explains why and how the solution is applied to this specific question. More detailed information of how the solution is addressed is presented by different example use cases. Section 5.2.2 gives an example use case through BrakeByWire model of

how the error models are generated and section 5.3.2 provides the examples for error model reorganization. A one to one model mapping is designed and developed during error model generation and this is presented in section 5.2.3. The alternatives and decisions that have been made during resolving the research question is discussed in the end of each section.

By showing explicit considerations of safety concerns throughout an architecture design process (Blom, et al.,2013), the functional safety modeling mitigates the risks in the long run. Error propagation modeling, as one part of safety modeling and an extension of the nominal architecture model, will be demonstrated in this section. A one to one mapping pattern between EAST-ADL nominal model and error propagation model will be provided. An EATOP based plug-in is implemented according to this pattern in order to automatically generate an error propagation model. After the user selection, this error propagation auto-generation plug-in is able to create all the error model elements together with error behavior under a suitable container and set all the corresponding targets and instance references according to EAST-ADL2.1.12. In order to enhance the user experience and reduce the manual work, collapsing error model elements and navigating targets are implemented as additional features in this error propagation plug-in. The result screenshots of both error model generation and error model re-organization are shown in *Appendix A.*

5.1 EAST-ADL Example Model Structure Description

The figure below illustrates the structure of top level packages defined in EAST- ADL 2.1.12. All elements, such as requirement, behavior, function type etc., are classified into the sub-packages inside "EAST-ADL" package as shown in *Fig 5.1*.

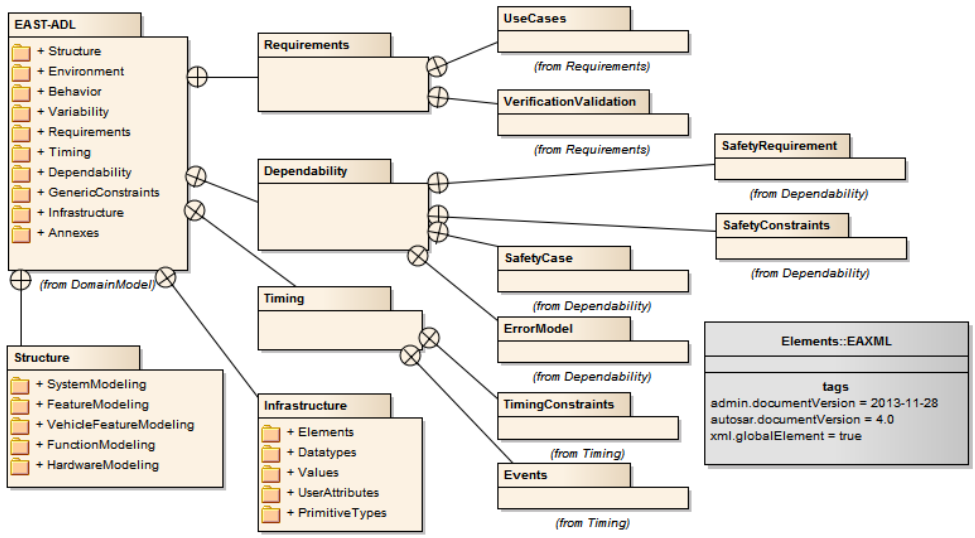


Fig 5.1 Packages in the EAST-ADL domain model

The top container for each instance is called "EAXML", the XML-based exchange format for EAST-ADL, supported e.g. by EATOP. In order to allow information exchange between organizations and tools of design artifacts, this language specification describes how to capture the needed information for relevant analysis and synthesis but does not define how the analysis or synthesis should be done (EAST-ADL specification 2.1.12). Before we start with the example, several element concepts in EAST-ADL needed to be declared. All the

explanations are collected from EAST-ADL specification 2.1.12 and each of the element can also refer to Fig B.1 in Appendix B.

Function modeling:
"The function modeling is performed in the FunctionalAnalysisArchitecture (in the AnalysisLevel) and the FunctionalDesignArchitecture (in the DesignLevel). The main modeling concept applied here is functional component modeling:Functions interact with one another via ports that are connected by connectors owned by the composing function. Occurrences of functions are modeled by typed prototypes in the composing function. These occurrences are typed by types."(EAST-ADL specification 2.1.12)

Function Type
"The Function Model Type includes DesignFunctionType and AnalysisFunctionType. It may interact with other Functions through their FunctionPorts. Furthermore, a FunctionType may be decomposed into the contained parts that are FunctionPrototypes. This allows the functionalities provided by the parent Function to be broken up hierarchically into sub-functionalities." (EAST-ADL specification 2.1.12)

Function Prototype
"The FunctionPrototype contains DesignFunctionPrototype and AnalysisFunctionPrototype. It represents references to the occurrence of the FunctionType that types it when it acts as a part. The FunctionPrototype is typed by a FunctionType. So the FunctionPrototype represents an occurrence of the FunctionType that types it." (EAST-ADL specification 2.1.12)

Function Port
*"Function Port contains FunctionFlowPort, FunctionPowerPort and FunctionClientServerPort. FunctionFlowPorts are single buffer overwrite and non-consumable.They can be connected if their FunctionPort signatures match. Each FunctionFlowPort has a direction of "IN" or "OUT" or "IN/OUT". The FunctionPowerPort is a FunctionPort for denoting the physical interactions between environment and sensing/actuation functions. The FunctionPowerPort conserves physical variables in a dynamic process. The FunctionClientServerPort is a FunctionPort for client-server interaction. A number of FunctionClientServerPorts of clientServerType "client" can be connected to one FunctionClientServerPort of clientServerType "server"." (EAST-ADL specification 2.1.12)*The meta-model of Function Port is also shown in Fig B.3.

Function Connector
"Function Connector represents the connections between Function Ports. It could connect between FunctionPrototypes and between FunctionPrototype and its located FunctionType. The latter connection is called the delegation connection." (EAST-ADL specification 2.1.12)
The meta-model of Function Connector is also shown in Fig B.2.

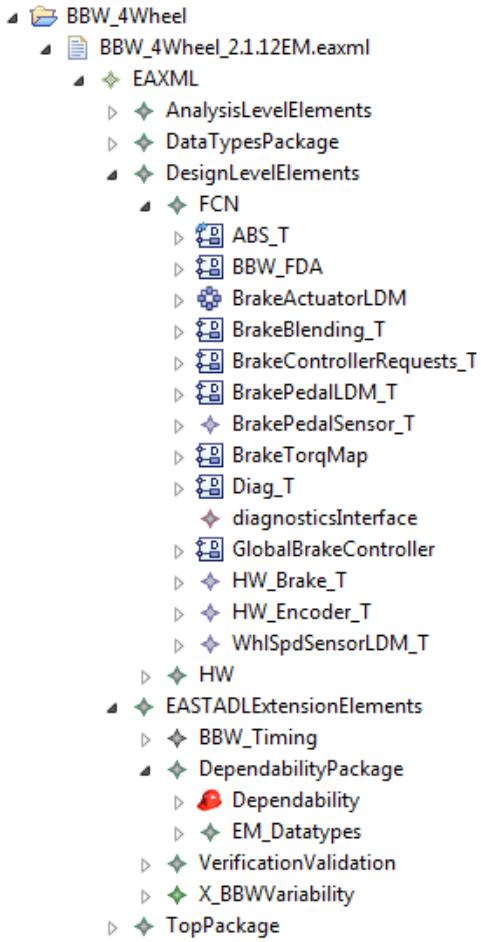


Fig 5.2 BBW_4Wheel General TreeView

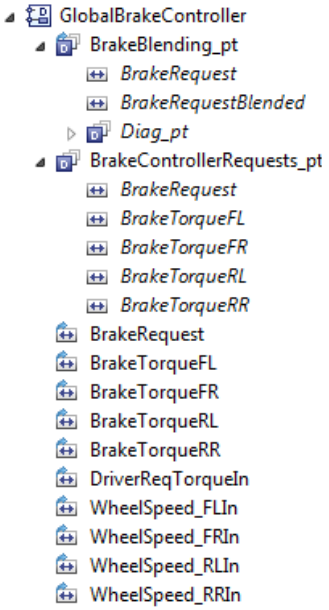


Fig 5.3 GlobalBrakeController DesignFunctionType TreeView

In this chapter, we take the BrakeByWire_4Wheel.eaxml as the example model. This model is a factious Brake-By-Wire system represented in EAST-ADL. As depicted in Fig 5.2, different model elements are divided into different packages. The function modeling or the so called nominal modeling are located in AnalysisLevelElements as analysis function model elements and in DesignLevelElements as design function model elements. The focus of this chapter is the design function model elements sit in FCN package. According to the structure of each function element under FCN package, we select the GlobalBrakeController DesignFunctionType to be the example model in this chapter since it contains sufficient elements for explaining the error model generating and reorganizing concepts.

The tree view of The DesignFunctionType GlobalBrakeController is shown in Fig 5.3. It contains two DesignFunctionPrototypes and several function ports. Among them, the DesignFunctionPrototype BrakeBlending_pt has a type of BrakeBlending_T and BrakeControllerRequests_pt has a type which is called BrakeControllerRequests_T in package FCN. A prototype inherits all the sub-elements of its type. In this case, BakeBlending_pt inherits the function ports BrakeRequest and BrakeRequestBlended from BrakeBlending_T together with the DesignFunctionPrototype Diag_pt is a DesignFunctionPrototype typed by Diag_T inside BrakeBlending_pt. Another FunctionPrototype BrakeControllerRequests_pt contains several function ports, which are BrakeRequest, BrakeTorqueFL/FR and BrakeTorqueRL/RR. The whole structure can also been seen in the graphical view in Fig 5.4. Besides the inner structure of GlobalBrakeController, Fig 5.4 also captures the structure of its prototypes

(DesignFunctionType BrakeBlending_T, DesignFunctionType BrakeControllerRequests_T) and their sub-prototypes (Diag_T). The container are the FunctionTypes while the contained boxes are the FunctionPrototypes. As explained in the tree view, the dependencies exist from BrakeBlending_pt to BrakeBlending_T and from BrakeControllerRequests_pt to BrakeControllerRequests_T. Besides, inside BrakeBlending_T, the Diag_pt is typed by Diag_T.

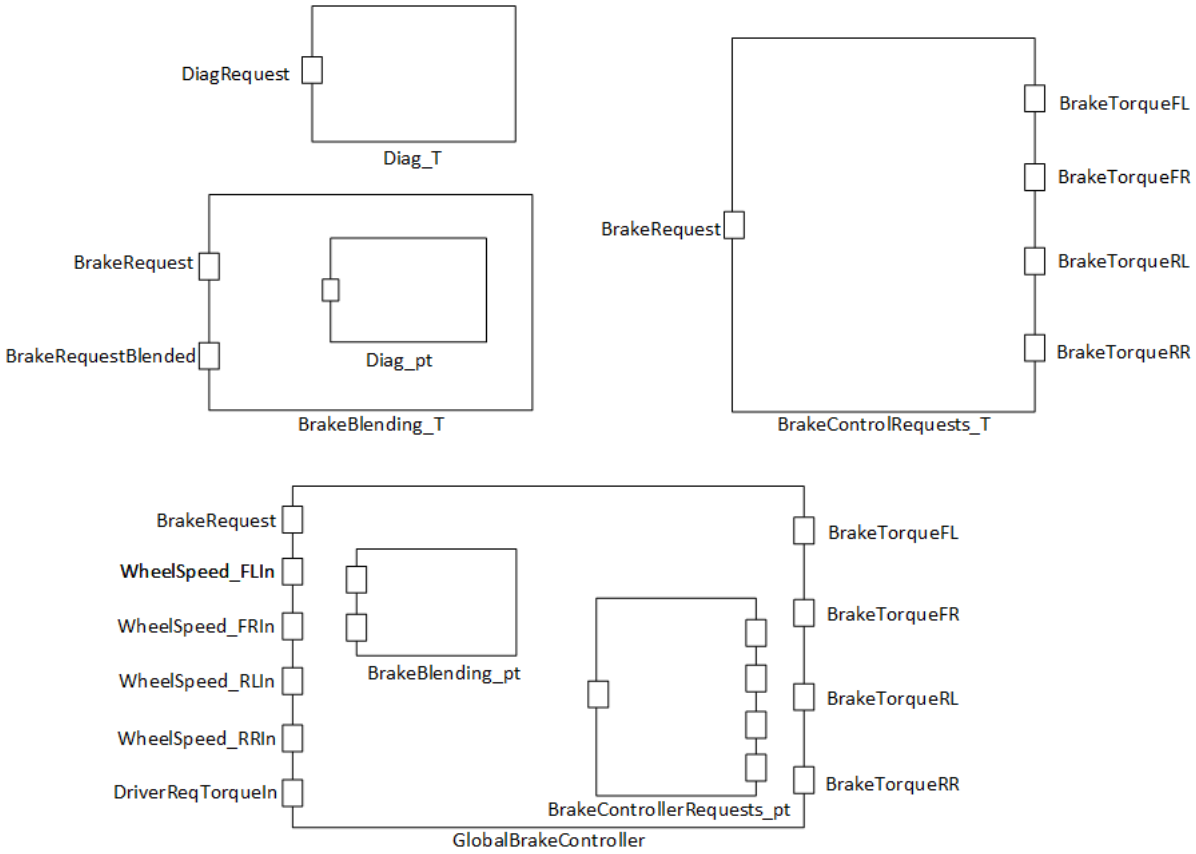


Fig 5.4 GlobalBrakeController DesignFunctionType Structure

All the function InPorts are located on the left side of each component and the OutPorts are on the right side. Normally, OutPort is the source for a connector while InPort is the destination. A connector is used to bridge components and support the signal transition. According to the structure of FunctionType GlobalBrakeController, there are no connectors defined. Except the port "DiagRequest" located in FunctionType Diag_T, the rest are all FunctionFlowPort, which means there is only signal in or out from this port. While the "DiagRequest" is a ClientServerPort, the signal could go two directions through this port. As a ClientPort, the DiagRequest could send the request to a ServerPort and receive the response from that ServerPort. More detailed information is elaborated in section 5.2.3 one to one mapping.

BrakeTorqueFR [FunctionFlowPort]

Advanced

Property	Value
Category	
Direction	OUT
Name	
Short Name	BrakeTorqueFR
Type	AA_TorqueType [/DataTypesPackage/AA_TorqueType]
Uuid	80f07acd-bba6-463f-8bde-4d3c2388a039

Fig 5.5 BrakeTorqueFR FunctionPort

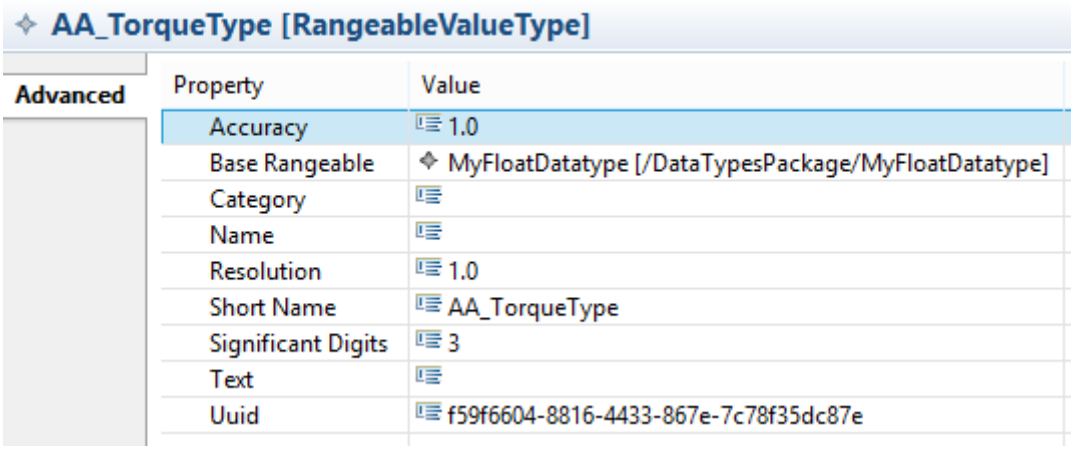


Fig 5.6 AA_TorqueType DataType

Since each of the ports is responsible for supporting the signal transition and different data are contained in different signals. There is an attribute called "Type" for each FunctionPort pointing out what data can be carried through this port. As illustrated in Fig 5.5, the AA_TorqueType is defined to be the type of FunctionFlowPort BrakeTorqueFR which is an OutPort of FunctionType GlobalBrakeController. The AA_TorqueType is defined as a Rangeable Value Type as seen in Fig 5.6. We are not going into detail of each data type since it's not highly related to the problems we are going to solve. More detailed information of data type can be found in EAST-ADL 2.1.12 specification.

5.2 Error Model Auto-generation

5.2.1 Concept Description

Error modeling and function modeling are defined as separated concepts in EAST-ADL. The generated error model elements reflect the structure of selected function elements in error modeling concept. And they are used for analyzing the error propagation in the architecture design and preparing for later Fault Tree Analysis. In order to provide a sufficient error propagation model for later usage and integration, a reasonable mapping pattern is defined between function modeling and error modeling in this section and an example use case of error model generation are demonstrated in the next section. According to the mapping pattern, the existing function model elements are analyzed and transferred into corresponding error model elements. As a separated concept from function modeling, the concept of error modeling elements are presented as follow and the meta-model of each element can also be found in Appendix B.

Error Modeling

"The EAST-ADL error modeling provides support for safety engineering by representing possible incorrect behaviors of a system in its operation (e.g., component errors and their propagations). The purpose of the error models is to represent information relating to the anomalies of a nominal model element." (EAST-ADL specification 2.1.12)

Error Model Type

"An ErrorModelType represents the internal faults and fault propagations of the nominal element that it targets. Typically the target is a system/subsystem, a function, a software component, or a hardware device." (EAST-ADL specification 2.1.12)

Error Model Prototype
"The ErrorModelPrototype is used to define hierarchical error models allowing additional detail or structure to be described in the error model of a particular target. An ErrorModelPrototype represents an occurrence of the ErrorModelType that types it." (EAST-ADL specification 2.1.12)

Fault-Failure Port
"Fault-Failure Port could be divided into FaultInPort and FailureOutPort according to the error propagation direction. The FaultInPort represents a propagation point for faults that propagate to the containing ErrorModelType. The FailureOutPort represents a propagation point for failures that propagate out from the containing ErrorModelType." (EAST-ADL specification 2.1.12)

Fault-Failure Propagation Link
"The FaultFailurePropagationLink represents the links for the propagations of faults/failures across system elements. In particular, it defines that one error model provides the faults/failures that another error model receives. A fault/failure link can only be applied to compatible ports, either for fault/failure delegation within an error model or for fault/failure transmission across two error models." (EAST-ADL specification 2.1.12)

Internal FaultPrototype
"The InternalFault represents the particular internal conditions of the target component/system that are of particular concern for its fault/failure definition. The system anomaly represented by an InternalFault, which when activated, can cause errors and failures of the target element." (EAST-ADL specification 2.1.12)

Error Behavior
"ErrorBehavior represents the descriptions of failure logics or semantics that the target element identified by the ErrorModelType exhibits. Typically the target is a system, a function, a software component, or a hardware device. Each ErrorBehavior description relates the occurrences of internal faults and incoming external faults to failures. The faults and failures that the errorBehavior propagates to and from the target element are declared through the ports of the error model. ErrorBehavior defines the error propagation logic of its containing ErrorModelType." (EAST-ADL specification 2.1.12)

5.2.2 Example Use Case
In previous working procedure, defining the system error model manually is usually tedious and error-prone. The use case below will explain how the automatic error model generation works and how it is related with nominal model.

GlobalBrakeController ErrorModelGeneration
When "CreateErrorModel" function is triggered by FunctionType GlobalBrakeController, the following error modeling elements in Fig 5.7 are generated.

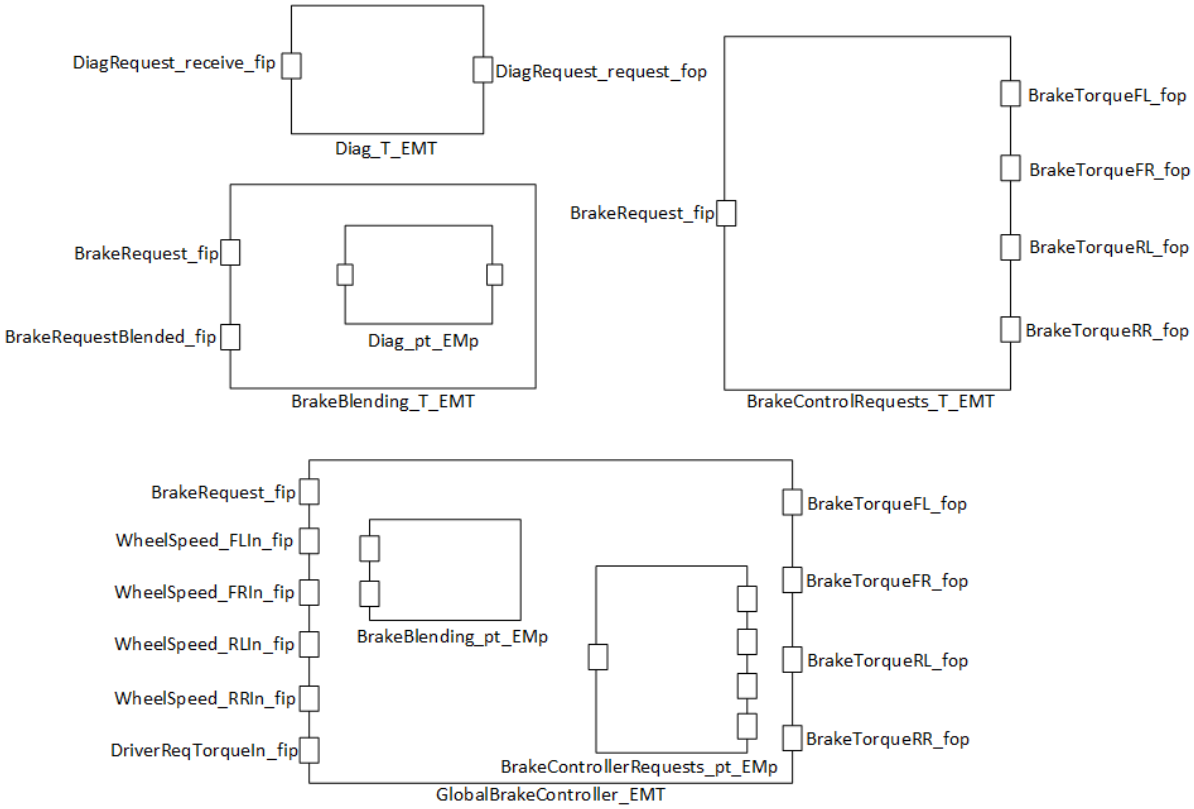


Fig 5.7 Generated GlobalBrakeController ErrorModel Structure

Four ErrorModelTypes and three ErrorModelPrototypes target to the corresponding functional model. The target dependency is shown as an attribute in ErrorModel as illustrated in Fig 5.8.

GlobalBrakeController_EMT [ErrorModelType]

Advanced

Property	Value
Category	
Hw Target	
Name	
Short Name	GlobalBrakeController_EMT
Target	GlobalBrakeController [/DesignLevelElements/FCN/GlobalBrakeController]
Text	
Uuid	b7c2db33-c405-42ac-be77-67de79fc1206-1411805753400

Fig 5.8 ErrorModelType GlobalBrakeController_EMT Attributes

By parsing all the subelements under the selected "GlobalBrakeController", the generator generates all the corresponding error model elements, relations and dependencies under "GlobalBrakeController_EMT". Whenever a new FunctionType is detected to be the type of the selected or contained FunctionPrototype, the whole procedure is executed recursively until no more type dependencies exists. In this example, after detecting two prototypes inside the selected GlobalBrakeController, the plugin starts to generate the All the generated ErrorModelTypes are located flatted under Dependability element called "Dependability#" inside packages "EASTADLExtensionElements/DependabilityPackage" under the root EAXML. If this path does not exist in the required root element, the function would create one in order to keep the location of Error Modeling consistent. The symbol "#" is a replace of a number, which means the times of *CreateErrorModel* function has been triggered in one Eclipse runtime instance.

All FaultInPorts generated from the FunctionFlowPorts which have the Direction as “IN”, and when the Direction equals “Out”, it is realized as FailureOutPort in error propagation model. As specified in EAST-ADL 2.1.12 ErrorModel class diagram in Appendix B, each FaultFailurePort and FaultFailurePropagation has its instanceReference relation to the targeted functionPort, which is another way of showing dependency. For the datatype each port carries, the corresponding ErrorType is generated under the "Dependability#". As shown in Fig 5.9, Instead of mimicking the datatype of the ports, the ErrorType is an enumeration with values failure and non-failure. This corresponds to the property of FaultFailurePort as explained before, each FaultFailurePort represents whether a failure going through the port or not. In this case, when a failure goes out from a FailureOutPort, its ErrorType is simply set as “Failure”. And if no failure is going out, a “NonFailure” is applied in this FaultFailurePort element.

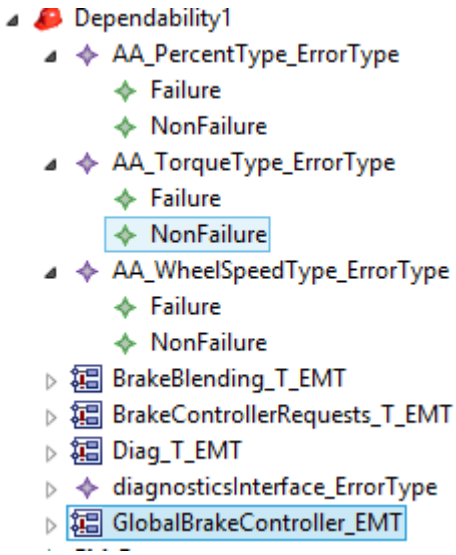


Fig 5.9 ErrorType of GlobalBrakeController_EMT Generation

Comparing the structures between the function modeling in Figure 5.4 and the generated error modeling in Fig 5.7, we can tell that this generation follows a one to one mapping pattern. All error model elements can be easily tracing back to function model elements through the dependency attribute which is named as “target” in error model elements. This use case provides a general view of what are generated by applying error model auto generation and why it is generated in this pattern will be explained in next one to one mapping section. How these elements are generated are elaborated in Algorithm section.

5.2.3 One to One Mapping

The Error Model Generation performs one to one mapping between function modeling and error modeling, the section below provides more detailed information of how the one to one mapping pattern is designed and the corresponding algorithm in error model generation.

One to One Mapping Pattern Design

The error model generator plug-in, as an output for the first research question, defines a one to one mapping pattern from function modeling to error modeling. By comparing the structures and connections between function modeling and error modeling, the mapping rule is designed for error model generating. The detailed mapping definition is shown in *Table 5.1*. Table 5.1 provides a defined one to one mapping pattern from nominal model to error propagation

model along with the naming rule. Each element in “Error Model” column targets to the corresponding element in “Nominal Model” column. The naming rule is also applied in error model generator Plug-in, which auto-generates the error model element with the given name.

Table 5.1 One to one Mapping Rule

Nominal Model	**Error Model**	**Error Model Naming Rule**
Package	Dependability	Dependability_#
FunctionType	Error Model Type	FunctionType_EMT
FunctionPrototype	Error Model Prototype	FunctionPrototype_EMp
FunctionConnector	FaultFailurePropagationLink	FunctionConnector_ffpl
FunctionConnectorPort(In)	FaultFailurePropagationLink_ toPort	N/A
FunctionConnectorPort(Out)	FaultFailurePropagationLink_ fromPort	N/A
FunctionFlowPort(In)	Fault in port	FunctionFlowPort_fip
FunctionFlowPort(Out)	Failure out port	FunctionFlowPort_fop
DataType(Type of Port)	Enumeration	DataType_ErrorType
N/A	EnumerationLiteral(child)	Failure
N/A	EnumerationLiteral(child)	NonFailure
N/A	ErrorBehavior	ErrorModelType_ ErrorBehavior

As depicted in Fig 5.1 EAST-ADL Domain model, the FunctionModeling is located in “Structure” concept from Domain Model while the ErrorModel is from “Dependability”. So for each nominal model in the same package, the corresponding error model belongs to the same Dependability element. The reason of having error model locating inside Dependability element is depending on the structure in EAST-ADL 2.1.12. As shown in Fig 5.1, the Structure concept which contain the function modeling is under EAST-ADL package while the error modeling is under Dependability Package.

The mapping rules of FunctionType, FunctionPrototype, together with FunctionFlowPort have been explained in the previous use case. Each matching rule are following the definition and structure of each elements. The FunctionType in function modeling has the same position as ErrorModelType in error modeling and it is a target of an ErrorModelType. The same reason applied to FunctionPrototype to ErrorModelPrototype and FunctionPort to FaultFailurePort. In each FunctionPort, DataType is included as the type of the port. In error model, each of the FaultFailurePort contains an Enumeration type acting as the DataType and

the Enumeration type has two child which means failure and nonfailure for each FaultFailurePort and the reason of this matching is elaborated in 5.2.2 example use case.

The FunctionConnector is used for supporting the signal transmitting between ports and the FunctionConnectorPort helps the FunctionConnectors bridge different FunctionPorts. Each FunctionConnectorPort points to a FunctionPort and FunctionConnector, which means this FunctionConnector connects this FunctionPort. Each valid FunctionConnector has to have two FunctionConnectorPorts in order to bridge the connection. But each FunctionPort could be pointed by more than one FunctionConnectorPort which means each port is able to carry more than one kind of signal. Since the connector in error model has the responsibility to connect between ports, when bringing this function connector to Error Models, the FunctionConnector is realized to be FaultFailurePropagationLink and the FunctionConnectorPort with IN direction is performed as FaultFailurePropagationLink_toPort while the OUT direction is FaultFailurePropagationLink_fromPort.

When all the structure of the error model has been set, one ErrorBehavior would be generated for each ErrorModelType, this ErrorBehavior does not have any mapping element from the Nominal model, it is used for describing the error logic and behaviors in error model. The logic included in the ErrorBehavior are applied in Fault Tree Analysis in Chapter 6 and more detailed information about the syntax of the error logic is explained in section 5.2.5 the Alternatives and Decisions.

5.2.4 Alternatives and Decisions

In order to meet user's needs and keep the system efficient at the same time, several alternatives have been taken into consideration during design stage. In this section, those decisions and alternatives will be discussed and explained.

Different Realization of different function ports

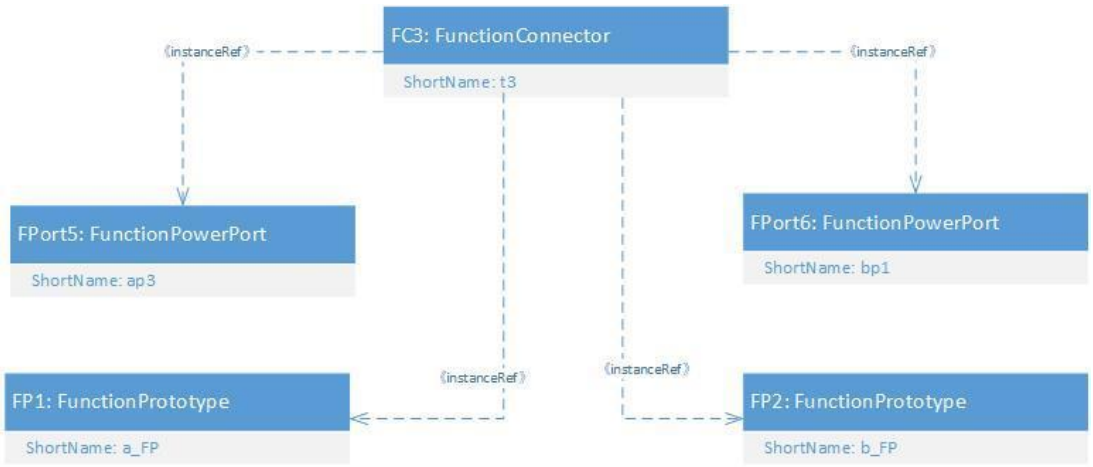
In EAST-ADL2.1.12, there are three kinds of function ports belong to the function modeling, which are FunctionFlowPort, FunctionPowerPort and FunctionClientServerPort. FunctionFlowPort, as a symbol of data transmission, is typed by EADatatype. The transformation of flowPort between function modeling and error modeling has been depicted in use case 1 and in table 5.1. FunctionFlowPort has a direction which indicates the containing function either requires or provides the data. Whereas, for both FunctionPowerPort and FunctionClientServerPort, the power transmission and require-response transmission are bidirectional. The previous unidirectional one to one error model mapping does not support this anymore. For this reason, we decided to have a two to one mapping for only FunctionPowerPort and FunctionClientServerPort along with their connectors. The FunctionPowerPort is a FunctionPort for denoting the physical interactions between environment and sensing/actuation functions. As shown in table 5.2, it has two direction called "across" and "through". The through FunctionPowerPort is responsible for sending out the power signal and across FunctionPowerport is able to receive the signal. According to this one direction property, we define the mapping from through FunctionPowerPort to FailureOutPort and from across FunctionPowerPort to FaultInPort. The FunctionClientServerPorts perform the signal sending in two directions. A FunctionClientPort is responsible for sending the request and receive the response from FunctionServerPort while the FunctionServerPort is responsible for receiving the request from FunctionClientPort and send back the response. So there are one FaultInPort and one FailureOutPort matching with

either FunctionClientPort or FunctionServerPort. The example ClientServerPort generation object diagram is illustrated in Fig 5.10.

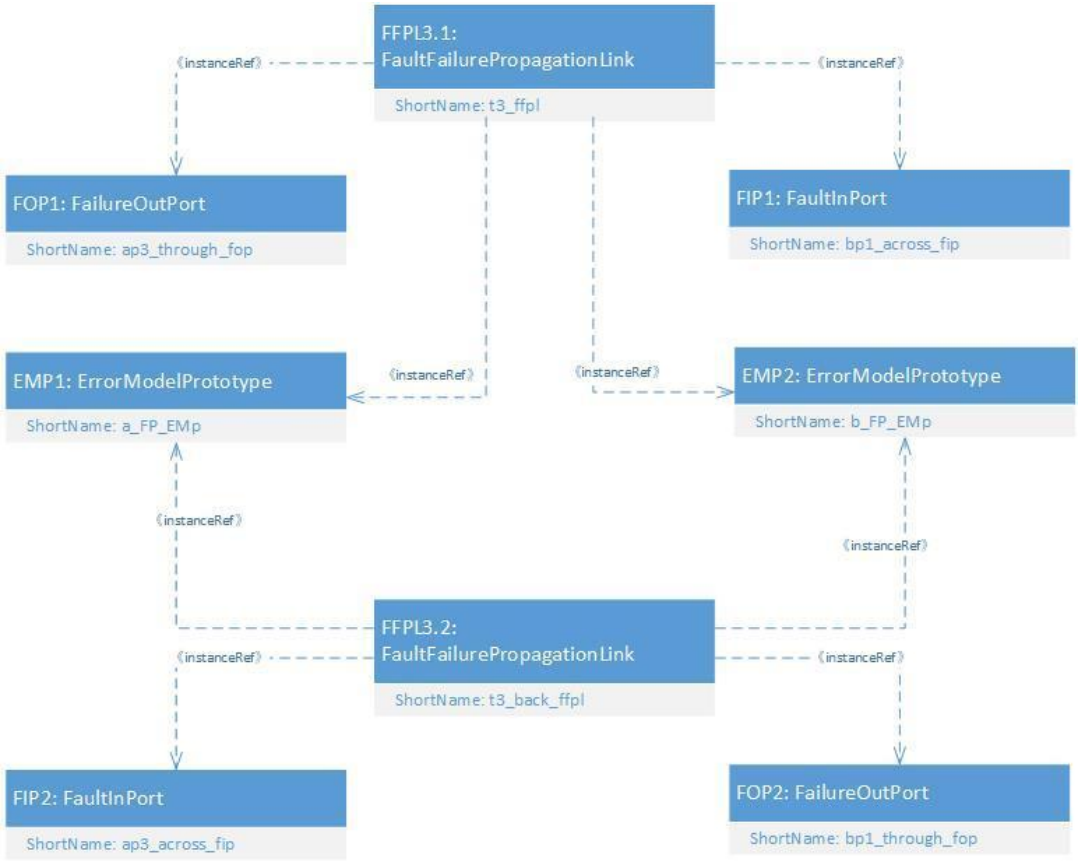
Table 5.2 FunctionClientServerPort and FunctionPowerPort mapping

Nominal Model	Error Model	Error Model Naming Rule
FunctionClientServerPort (Client)	FaultInPort	FCP_receive_fip
FunctionClientServerPort (Client)	FailureOutPort	FCP_request_fop
FunctionClientServerPort (Sever)	FaultInPort	FSP_receive_fip
FunctionClientServerPort (Sever)	FailureOutPort	FSP_response_fop
FunctionPowerPort(across)	FaultInPort	FAP_across_fip
FunctionPowerPort(across)	FailureOutPort	FAP_through_fop
FunctionPowerPort(through)	FaultInPort	FTP_across_fip
FunctionPowerPort(through)	FailureOutPort	FTP_through_fop

To make the mapping concept easier to understand, the object diagram below illustrates how a FunctionConnector together with two FunctionPowerPorts are defined and generated in Error Model. This FunctionPowerPort concept is also applicable for FunctionClientServerPort. Fig 5.10(a) illustrates a scenario of one FunctionConnector "t3" connects two FunctionPowerPorts which are "ap3" in FunctionPrototype "a_FP" and "bp1" in FunctionPrototype "b_FP".



(a) FunctionModeling(FunctionPowerPort)



(b) Error Modeling(FunctionPowerPort)

Fig 5.10 FunctionPowerPort Transformation

While Fig 5.10(b) is the generated Error Model elements, one FunctionConnector "t3" in function model is realized as "t3_ffpl" and "t3_back_ffpl" two FaultFailurePropagationLinks. For each power port, one FailureOutPort with suffix "_through_fop" and one FaultInPort with suffix "_across_fip" are generated and are connected by the corresponding FaultFailurePropagationLink. This design in the end makes it easier to point out the error and its direction in order to address the failure.

Error Behavior

In order to check whether the safety requirements are met or not, EAST-ADL error modeling supports safety analysis by providing detailed information about the failure behavior. Error behavior, which plays this specification role, captures what output failures of the target architecture component are caused by what faults of this component (Blom, et al., 2013). In this error model auto-generation design, one error behavior is added in each ErrorModelType when system generates a one to one mapping pattern. As a way of showing error propagation, an ErrorBehavior is only generated when the corresponding FunctionType has at least one OutPort and one InPort. And for each ErrorBehavior, only FaultInPorts and FailureOutPorts are captured in failure logic description. No internal failure will be presented since the automatically generated failure logic is provided as a base, not all error model elements contain internal failure. For this reason, user has to modify the error logic manually when an internal failure is needed. Each equation indicates if any failure comes in from the Failure-inport, it is propagated as a Failure to the outPort. If an internal failure is detected, all the

Failure-outports are effected and the internal failure is propagated to other Function element which has connection with the outPort contains a failure. Since HiP-HOPS is chosen to be the safety analysis tool, according to the HiP-HOPS error logic structure rule, the failure error behavior description has the following syntax and/or semantics and the reason of choosing HiP-HOPS will be explained in Chapter 5. The reason of providing "OR" instead of "AND" between each potential failure is that the safety analysis is used to capture a worst case scenario which causes a failure. "OR" expresses that any possible event's occurance leads to a failure. All the possibilities are considered in the error logic as the input of fault tree analysis. In the syntax below, each outport propagates the failure from each of the inport. In this case, the presented error element has N outports and M inports.

Failure-outport1= Failure-inport1 OR Failure-inport2 OR … Failure-inportm;
Failure-outport2= Failure-inport1 OR Failure-inport2 OR … Failure-inportm;
… OR …
Failure-outportn= Failure-inport1 OR Failure-inport2 OR … Failure-inportm;

Constraints

Several constraints are applied when generating an error model. Those constraints are classified into severe and non-severe. Any severe violation will stop the system from execution while the non-severe violation is a warning which may lead to further problems but system is still available for execution. When a user's request violates the severe constraint, an error message will pop up describing the constraint and the user has to redo the request. When a non-severe violation has been detected, the system will throw the warning message in error log which can be seen by opening "Problem" view in EATOP and keep executing the request. The table below lists all events which violate the constraints in Error Model Generating. The constraints in Error Model Generating are all applied for detecting whether there is a warning exists in the demanding function model. These three non-severe constraints are not regarded as errors in the model. For example, a FunctionPrototype is a meaningless prototype when it has no type to be inherited. And a FunctionConnector needs two ConnectorPorts to be connected between function types and prototypes, otherwise, it becomes a single connector without connections. Besides, each FunctionConnectorPort points to a FunctionPort which the connector connected with, if it has no functionPort, the connector will not be able to find its source or destination. Those are the potential faults in function modeling, but it doesn't effect to generate the error model by one to one mapping. At this point, each of them is defined as a non-severe constraints which need to be modified after the request has been executed by the system.

Table 5.2 Constraints in Error Model Auto Generating

Request	Description	Severity
Generating	A FunctionrPototype has no type	non-severe
Generating	A FunctionConnector has no FunctionConnectorPort	non-severe
Generating	A FunctionConnectorPort has no FunctionPort	non-severe

5.3 Error Model Reorganization

5.3.1 Concept Description

The reason of having the error model reorganization is the one to one mapping pattern is not specific or customized enough for real work. Besides, most projects are rather big, it is time consuming to deploy changes by hand. Error Model Reorganization aims at reducing the manual modifications among error model elements, the frequently manually routine modifications are be done by machine.

Since at the error propagation perspective, engineers will not care about the original ports, only whether there is a failure propagated from the element or not. In addition, the complete structure inherited from function modeling is also overwhelmed when it comes to error propagation analysis. Based on these facts, we decided to design and implement the collapsing feature based on error model prototypes and error model FaultFailurePorts.

5.3.2 Example Use Case

Collapsing ErrorModelPrototypes

The collapsing ErrorModelPrototype function is only applicable for selecting more than one ErrorModelPrototypes under the same container (Usually the container is ErrorModelType). Otherwise, it is regarded as illegal modification. In order to hide the lower level ErrorModelPrototypes which does not affect the failure result, system will bring them to a new ErrorModelType which only contains the selected ErrorModelPrototypes, create a new ErrorModelPrototype under where the previous ErrorModelPrototypes sit in and typed it by the newly created ErrorModelType with modified connections. In order to make this understandable, we assume ErrorModelPrototype BrakeControllerRequest_pt_EMp and BrakeBlending_pt_EMp under “GlobalBrakeController_EMT” shown in Fig 5.7 are selected to be collapsed. The result model is illustrated in Fig 5.11.

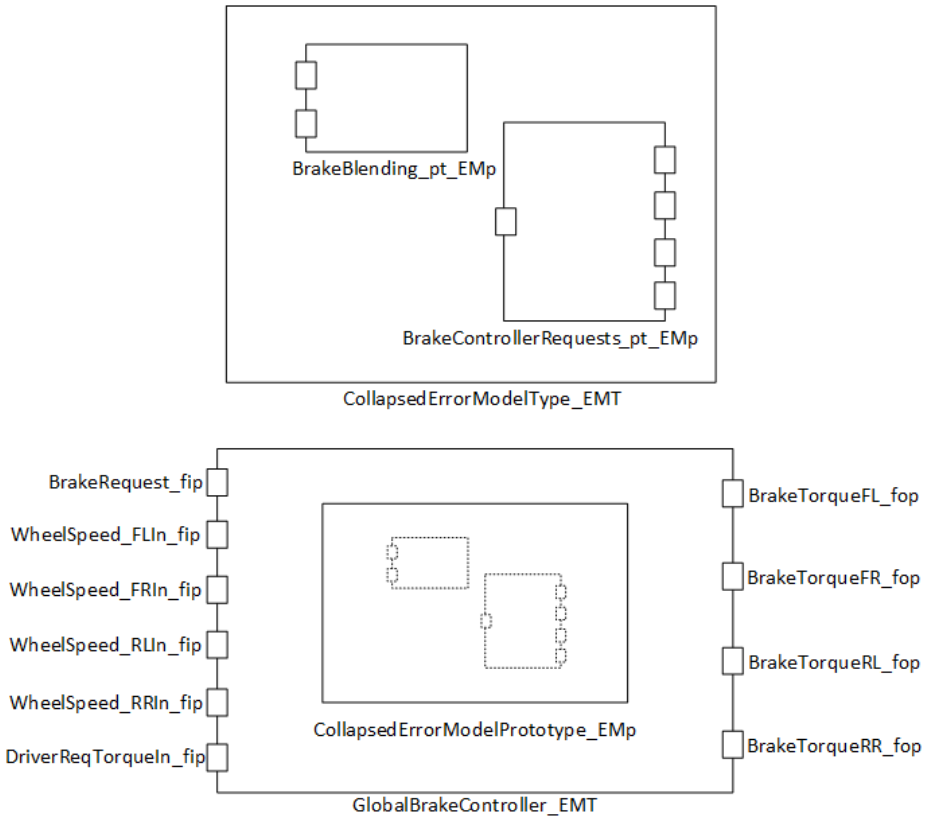
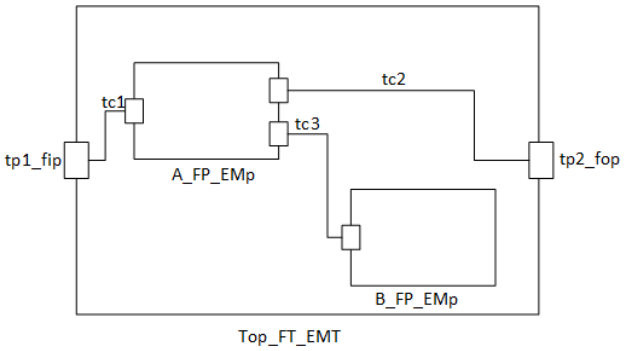
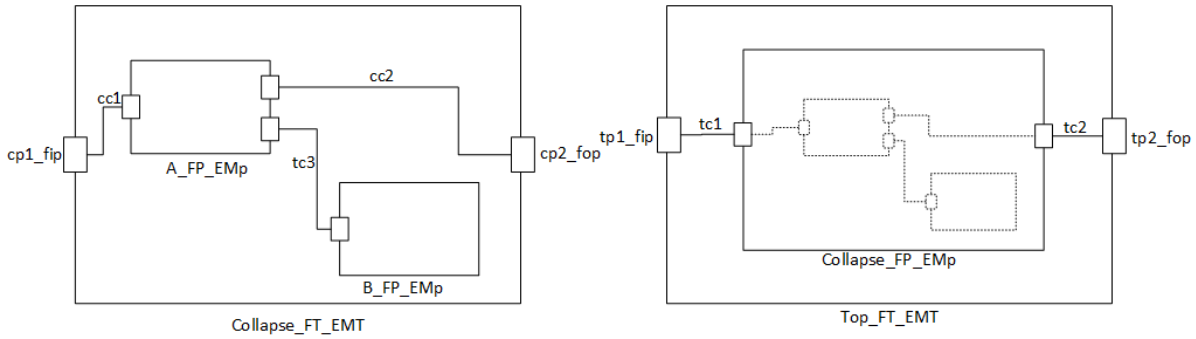


Fig 5.11 Prototype Collapsed BlobalBrakeController_EMT Structure

A new ErrorModelType CollapsedErrorModelType_EMT is generated which contains the selected ErrorModelPrototypes. Besides, a new ErrorModelPrototype called CollapsedErrorModelPrototype_EMp takes the place of previous two elements. The dashed boxes represent the previous structure in GlobalBrakeController. And the CollapsedErrorModelPrototype_EMp is typed by CollapsedErrorModelType_EMT. Since there is no connectors exist between the error elements, no external port is generated for the ErrorModelType. Fig 5.12 captures another use case when the selected prototypes are connected with each other.



(a) Top_FT_EMT ErrorModelType Structure



(b) Prototype Collapsed Top_FT_EMT ErrorModelType Structure
Fig 5.12 Top_FT_EMT Structure Diagram

The original Top_FT_EMT ErrorModelType shown in Fig 5.12(a) has two ErrorModelPrototypes and three FaultFailurePropagationLinks connect those three elements. In Fig 5.12(b), two new FaultFailurePropagationLinks are created in "Collapse_FT_EMT" to connect from new created ErrorModelType to the extracted ErrorModelPrototypes. Cc1 is created to connect between cp1_fip and the inport of A_FP_EMp and cc2 connects one of the outport of A_FP_EMp with cp2_fop. Tc3 has been remained since this is regarded as an internal connector among the selected ErrorModelPrototypes. This change will be useful when the lower level elements are needed to be ignored when analyze the failure, so whether the failure happens in "a_FP_EMp" or "b_FP_EMp" is only seen as a failure in "Collapse_FP_EMp".

Collapsing FaultFailurePorts

In function modeling, different signals and data are transmitted through different ports, while in error modeling, whether there is a fault goes in or a failure come out is the only factor will be concerned.

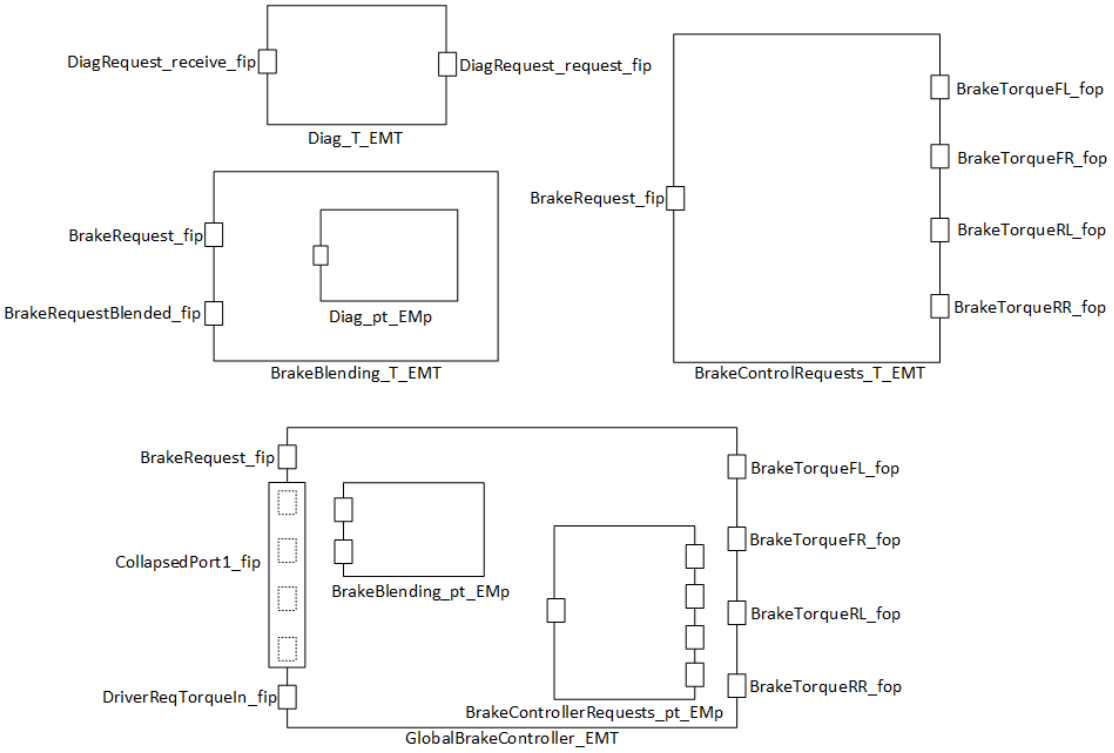


Fig 5.13 Port Collapsed FlobalBrakeController_EMT Structure

For the same purpose as Collapsing ErrorModelPrototypes, Collapsing FaultFailurePorts combined more than one ports into one and reset all their instanceReferences. The collapsing ports function is only available for either FaultInPorts or FailureOutPorts which sit in the same container. In the example model, we assume all the WheelSpeed_fip Inports can be regarded as one for the error propagation perspective. Fig 5.13 depicts the result error modeling when FaultInPorts WheelSpeed_FLIn_fip, WheelSpeed_FRIn_fip, WheelSpeed_RLIn_fip and WheelSpeed_RRIn_fip are selected to be collapsed. One FaultInPort called "collapsedPort1_fip" is created and it has the same ErrorType as the collapsed Ports. Since those WheelSpeed ports are removed from their ErrorModelType, if there are connectors connecting with those ports, they will be adjust to connect the newly created CollapsedPort1_fip instead.

5.3.3 Alternatives and Decisions

The alternatives and decisions have been made in error model reorganization will be presented in this section.

Constraints

Several constraints are applied when Collapsing ErrorModelPrototypes and FaultFailurePorts. Similar as section 5.2.5, those constraints are divided into severe and non-severe. Table 5.3 lists all events which violate the constraints.

Table 5.3 Constraints in Collapsing ErrorModel Elements

Request	Description	Severity
Collapsing ErrorModelPrototypes	The collapsed ErrorModelPrototypes sit in different ErrorModelTypes	severe
Collapsing ErrorModel FaultFailurePorts	The collapsed FaultFailurePorts sit in different ErrorModelTypes	severe
Collapsing ErrorModel FaultFailurePorts	The collapsed ports include both FaultInPort and FailureOutPort	severe

For example, it is not allowed to collapsing two ErrorModelPrototypes are located in different ErrorModelTypes since the collapsing should not change the model structure. The same rule is applicable for collapsing ErrorModel FaultFailurePorts. Besides, the FaultInPort and FailureOutPort should not be collapsed since it also changes the Error Model structure and the data or signal between those ports might be missing from collapsing. Those rules are strict when collapsing. An error message pops up when those situations have been requested. The system will not execute those commands till the user changes his request.

5.4 Algorithm

This section focuses on explaining how the features described in this chapter are implemented. The critical functions for each feature are presented in pseudocode for easy understanding.

5.4.1 Error Model Auto-generation

The ErrorModel Auto-Generation allows user to selected more than one FunctionType elements and it generates all the corresponding error elements for the selected function

elements and generates the related function elements recursively. The pseudocode below shows the general algorithm of the main function in ErrorModel Generation.

```
1. Get selected function elements as SelectedFunctionTypes
2. For each SelectedFunctionType in SelectedFunctionTypes
      1. Create ErrorModelType
      2. Get DataTypes of FunctionPorts
      3. Generate Corresponding ErrorTypes for each DataType
      4. For each FunctionPort in FunctionPorts
            1. If FunctinFlowPort; Generate corresponding FaultFailurePorts
               according to one to one mapping pattern
            2. If FunctionPowerPort; Generate corresponding FaultFailurePorts
               according to one to one mapping pattern
            3. If FunctionClientServerPort; Generate corresponding
               FaultFailurePorts according to one to one mapping pattern
      5. Refer ErrorType to corresponding FaultFailurePorts
      6. Get FunctionConnectors in SelectedFunctionType
      7. For each FunctionConnector in FunctionConnectors
            1. Create Corresponding FaultFailurePropogationLink
            2. Add FaultFailurePropagation_fromPort and
               FaultFailurePropagation_toPort
      8. Get FunctionPrototypes in SelectedFunctionType
      9. For each FunctionPrototype in FunctionPrototypes
            1. Generate ErrorModelPrototype
            2. Get FunctionType typed by FunctionPrototype
            3. Check the existence of FunctionType's corresponding
               ErrorModelType
                  1. If Exist
                        1. Continue
                  2. Else
                        1. Call 2.1, SelectedFunctionType = FunctionType

      10. Generate ErrorBehaviour according to the ErrorModelType's structure
```

The system goes through all the selected function elements and generate corresponding error model elements. Whenever a new FunctionType is detected to be related, the system will set the new FunctionType as the new function element parameter for next recursion.

5.4.2 Error Model Reorganization

For Error Model Reorganization, we will explain both the algorithms in feature collapsing error model prototypes and collapsing error model ports. The pseudocode below shows the general algorithm of the main function in Collpasing ErrorModelPrototypes.

```
1. If selected ErrorModelPrototypes all belong to the same container
2. Yes;
      1. Create CollapsedErrorModelType
      2. Create CollapsedErrorModelPrototype
      3. Type CollapsedErrorModelPrototype by CollapsedErrorModelType
      4. For each SelectedErrorModelPrototype in SelectedErrorModelPrototypes
            1. Get FaultFailurePropagationLinks of
               SelectedErrorModelPrototype
            2. For each FaultFailurePropagationLink in
               FaultFailurePropagationLinks
                  1. Get the ConnectedErrorModelPrototype in the other
                     direction of the FaultFailurePropagationLink
```

```
                    2. Check whether the connectedErrorModelPrototype is in
                       SelectedErrorModelPrototypes
                          1. Yes; innerLinks.add(FaultFailurePropagationLink)
                          2. No; outerLinks.add(FaultFailurePropagationLink)
             3. Get FaultFailurePorts of SelectedErrorModelProtype,
                fromPorts.add(FaultFailure_fromPort),
                toPorts.add(FaultFailure_toPort)
             4. Create a copy of SelectedErrorModelProtoype in
                CollapsedErrorModelType
       5. For each outerLink in outerLinks
             1. Get fromPort and toPort of OuterLink
             2. If fromPort is in fromPorts
                   1. Yes, innerFromPorts.add(fromPort)
                   2. Else, outerFromPorts.add(fromPort)
             3. If toPort is in toPorts
                   1. Yes, innerToPorts.add(toPort)
                   2. Else, outerToPorts.add(toPort)
       6. Add outerFromPorts to CollapsedErrorModelType as
          FaultFailurePort_from
       7. Add outerToPorts to CollapsedErrorModelType as FaultFailurePort_to
       8. Create DelegationFaultFailurePropagationLink_from to connect
          FaultFailurePort_from with corresponding outerFromPort
       9. Create DelegationFaultFailurePropagationLink_to to connect
          FaultFailurePort_to with corresponding outerToPort
       10. Link outerLinks to corresponding FaultFailurePort_from and
          FaultFailurePort_to
3. Else;
       1. Stop program from executing
       2. Send Error Message to Interface
```

The main procedure in collapsing ErrorModelPrototypes is find the external links which are not connected with the selected ErrorModelPrototypes on both sides. Because when those ErrorModelPrototypes are collapsed to a higher level, the external links need to link to the newly generate ErrorModelType. So the critical part is adding the correct ports on the Collapsed ErrorModelType and link them with the previous external links.

The collapsing ports and prototypes have similar algorithm while the prototypes takes a few more steps than collapsing ports. The pseudocode below shows the general algorithm of the main function in Collpasing ErrorModelPorts.

```
1. If selected ErrorModelPorts all belong to the same container
2. Yes;
       1. If the selected ErrorModelPorts are all FaultInPorts
             1. Create new FaultInPort under the same container
             2. For each selected FaultInPort
                   1. Add the target reference to the newly created
                      FaultInPort
                   2. Adjust the connectors which connected to this port to
                      the newly created FaultInPort
             3. Provide a short name and UUID to the newly created FaultInPort
       2. If the selected ErrorModelPorts are all FailureOutPorts
             1. Create new FailureOutPort under the same container
             2. For each selected FailureOutPort
                   1. Add the target reference to the newly created
                      FailureOutPort
                   2. Adjust the connectors which connected to this port to
                      the newly created FailureOutPort
```

```
            3. Provide a short name and UUID to the newly created
               FailureOutPort
      3. Else;
            1. Stop program from executing
            2. Send the Error Message of the selected ports have different
               directions(Both FaultInPort and FailureOutPort exist)
3. Else;
      1. Stop program from executing
      2. Send Error Message
```

5.5 Summary

In this chapter, a one to one mapping concept between nominal and error model is proposed and addressed. The feature is designed and implemented to be efficiently defining error model elements out of nominal model elements, which is related with RQ1 *How to efficiently define an error propagation model from architecture model.* In addition, RQ2 *How to reduce the manual work in refactoring the model* is also addressed in this chapter. In order to reduce the manual work in refactoring error model elements, two model collapsing strategies is designed and implemented. From function perspective, both artifacts automate model transformation and error model generation connects the different aspects from system architecture to safety architecture. From performance perspective, error model generation's time performance become weak when handling a large system model. And besides collapsing as one type of refactoring, there are more types of manually routine refactoring are under investigation.

Chapter 6 HiP-HOPS Fault Tree Analysis in EATOP

As the third research question addressed, there is a need to apply the Fault Tree Analysis on EAST-ADL error models and relate the generated Fault Tree result with both the error model and the nominal model. As explained in chapter 2, fault tree analysis is used to analyze the system failure probability and resolve the causes of a system failure. To get an automatically analyzed system failure is also the final goal of generating error model out of function model. There are currently several tools supporting fault tree analysis, but none of them are directly available for EAST-ADL models. So the first challenge is looking for a suitable tool to get EAST-ADL models supported in a short time. When EAST-ADL model is parsed by one of the Fault Tree Analysis solution tools, the rest of the work is to connect the generated Fault Tree with the error model and nominal model in EATOP. Among all existing Fault Tree Analysis solutions, HiP-HOPS is selected as the Fault Tree Analysis tool to be integrated in this research. Since the HiP-HOPS error logic is supported in EATOP Error Behavior element as described in section 6.2.4 and the tool itself is handy and easy to be downloaded and integrated. Besides, the support from the founder of HiP-HOPS in this research is also a great help. In all, we believe HiP-HOPS is most suitable tool for this project. Section 6.1 presents the different goals for solving this problem since several unstable factors exist in this research. Section 6.2 provides the design and solution for each goal revealed in section 6.1 together with their final result.

6.1 Different Levels of Goals

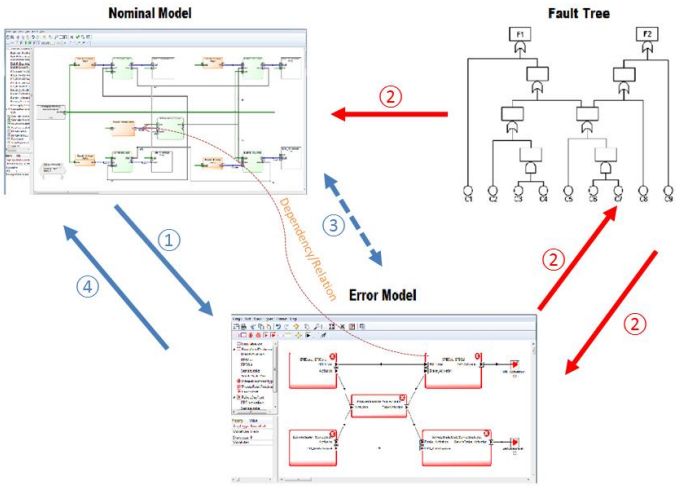


Fig 6.1 Safety Analysis process –Fault Tree Analysis

Fault Tree Analysis analyses the failure logic in the EAST-ADL error model, the final goal of this feature is connecting error model and Fault Tree as shown in the figure below. Besides, it requires an easy and efficient way to present the result after analyzing, in order to trace back to the error model and even the nominal model. Since this feature requires outsourced work, the completion time becomes hard to measure. According to this, we planned to have different levels of goal to achieve in the end.

1. *Supporting Fault Tree Analysis of EAST-ADL*
2. *Easily Generating Fault Tree in EATOP*
3. *Relate the generated result with EAST-ADL model*

The first and lowest level is getting HiP-HOPS support Fault Tree Analysis of EAST-ADL model. Currently, HiP-HOPS is available for e.g. Simulink models. So we contacted Professor Yiannis Papadopoulos in University of Hull, who is also one of the founder of HiP-HOPS. They provide a solution for making HiP-HOPS support EAST-ADL model language. When the first level goal is achieved, we say that a primitive connection between EAST-ADL and Fault Tree Analysis is built but the usability at this level is rather low since user has to manually provide the input file and required information to HiP-HOPS. In addition, the generated result can only be viewed through a web browser by opening the generated html file. So the second level of goal is easily generating Fault Tree in EATOP. What we expect to have at this level is user easily selecting the system (ErrorModelType in EAST-ADL) and generating the corresponding Fault Tree and other related results. Instead of going through a bunch of steps, user could easily get the result by clicking one button in EATOP platform. The highest level goal is relating the generated result with EAST-ADL model. To make the connection not only one way from EAST-ADL to Fault Tree but also trace back from Fault Tree to EAST-ADL model, some visual connection is shown in the error model by parsing the result. This function not only enhances the functionality of this feature, but also increases the usability of the whole connection and provide an easier working basis for the safety engineers. Before getting into details, several terms used in Fault Tree Analysis should be introduced.

Fault Tree
As the Fault Tree Analysis explained in section 2.5, Fault Tree is one main output generated from Fault Tree Analysis. Each fault tree is composed by different symbols, which represents the event, gate and transfer and one example fault tree is captured in Fig 2.7.

CutSet
Analysis result which illustrates the set of events which must occur to cause the top event to happen. This is also addressed in section 2.4.

ASIL Level
The ASIL level is an automotive safety integrity level which expresses the required levels of safety in one system. Each hazardous event is assigned an ASIL, and failure in the error model corresponding to this event are given the same ASIL.

6.2 Design and Result

In this section, the design and outcomes are demonstrated corresponding to each level of goal. For easy understanding, the same model will be used as the example for all three goals. Since a meaningful model is required for Fault Tree Analysis, a new model called

"EMSimple_2FT.eaxml" including internal failures are introduced and explained in later paragraph.

6.2.1 Error Model for Fault Tree Analysis

Since the relation between function model and error model has been explained in Chapter 5, we omit the corresponding function model description here to avoid redundancy. Besides, the new Error Model is illustrated in both model diagram and object diagram.

As shown in the figure 6.2, ErrorModelType "s1" is the top element which contains the failure and fault information and it has two FailureOutPorts, which are "SystemFailure" and "SystemFailure2". Four ErrorModelPrototypes are part of s1. They are typed by three ErrorModelTypes respectively and this will be illustrated in later object diagram. Among those four prototypes, three of them contain internal fault. Since "Pfrontlefts11" and "Pfrontrights11" are typed by the same ErrorModelType, they both contain the internal fault called "s11InternalFault" and prototype "PInputs" has "InputBE" as its internal fault. There are two paths among "PInputs" and "Pcombiner". One of them starts from "FL" out port of "PInputs", passes through "Pfrontlefts11" and ends up in "FL" in port of "PCombiner". The other one goes through the right line. In ErrorModelPrototype "PCombiner", the FailureOutPort "CombinedFailure" combines the failures from "FL" and "FR" and separates them into "SystemFailure" and "SystemFailure2" by FaultFailurePropagationLink "Out" and "Out2".

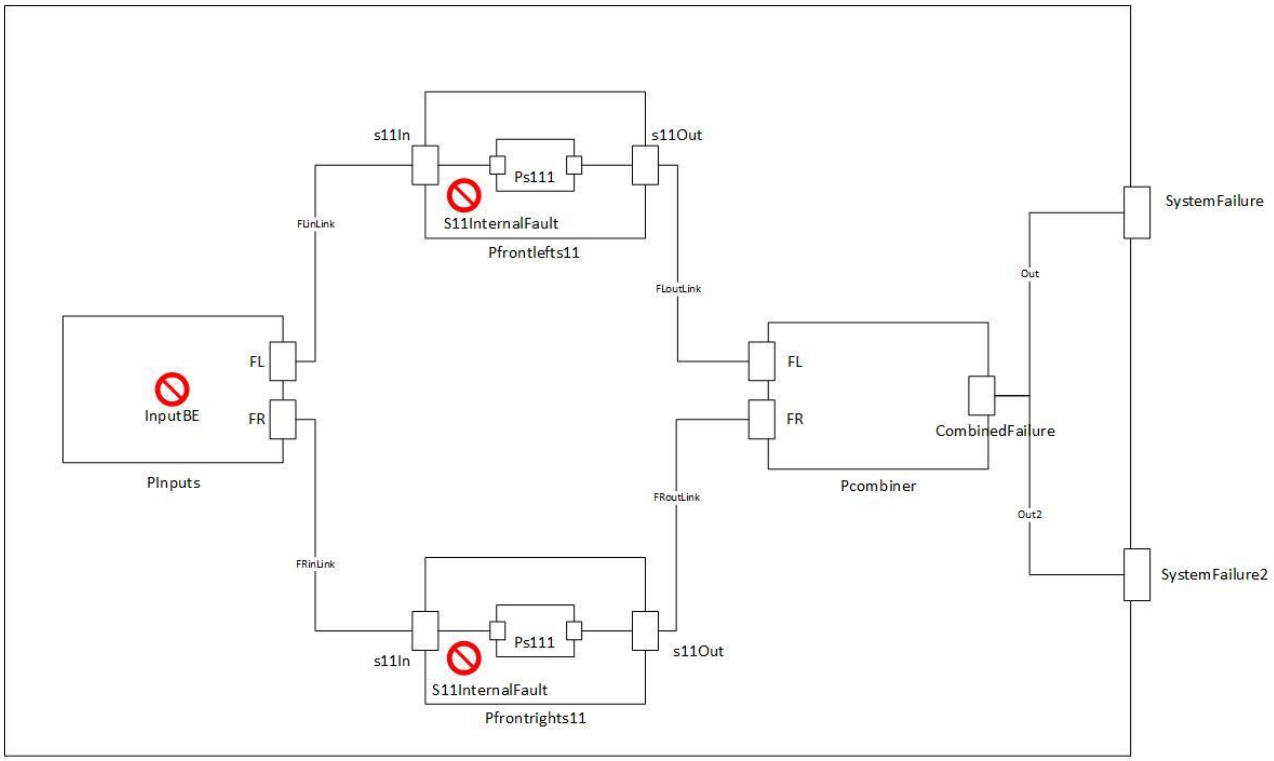


Fig 6.2 Error Model Diagram of "s1"

Fig 6.3 Detailed Diagram of Elements and relations in ErrorModel

To make the model information more straightforward, the diagrams have been separated into one general which contains the model elements of "s1" no lower than ErrorModelPrototype in Fig 6.4, and the other provides the detailed information between those ErrorModelPrototypes and their typed ErrorModelType in Fig 6.3. From the object diagram 6.4, we can easily tell

that ErrorModelType "s1" has four ErrorModelPrototypes and six FaultFailurePropagationLink. Besides, "SystemFailure" and "SystemFailure2" are the ports belong to s1.

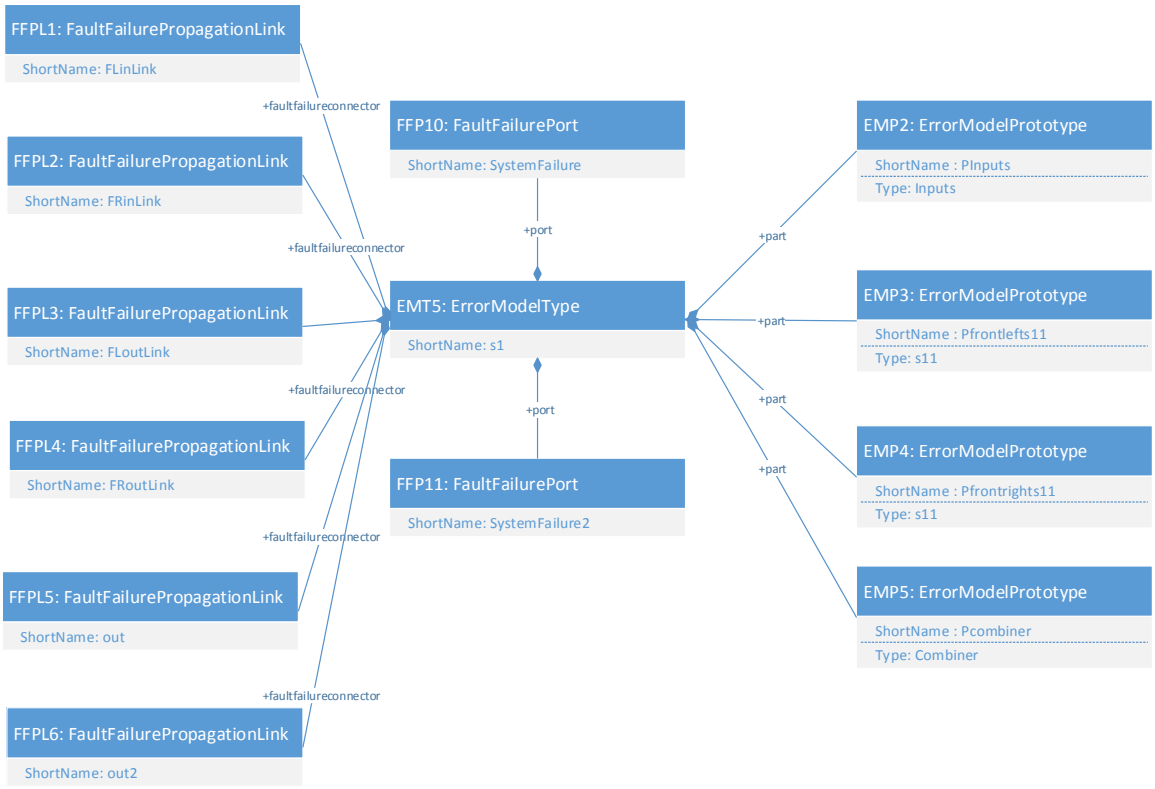


Fig 6.4 Detailed Diagram of Elements and relations for ErrorModelType "s1"

All the relations between ErrorModelType and ErrorModelPrototype in "EMSimple_2FT.eaxml" are illustrated as above Fig 6.3 and Fig 6.4. For better understanding, ErrorModelType, ErrorModelPrototype and their ErrorBehavior are listed in the left column. The elements in the middle column are mostly FaultFailurePorts and the right side elements are the FaultFailurePropagationLink connect different ports. The InternalFaultPrototype are shown in the middle column which are numbered as "IFP1" and "IFP2" which belong to ErrorModelType "Inputs" and "s11" respectively. One part is not explained in the model diagram is ErrorModelType "s11" contains one ErrorModelPrototype "Ps111" which is typed by "s111".

6.2.2 Generating Fault Tree in EATOP

Goal 1 - Supporting Fault Tree Analysis of EAST-ADL

The work of parsing eaxml file in EATOP to hipxml was handed out on 22 of April and it is done on June 12th. Septavera Sharvia, a phD in Computer Science and a researcher at University of Hull, provided on important element. She has completed a feature of translating an eaxml file to hipxml by giving the directory of the source eaxml and the short name of the selected top system. The provided "EAXML2HIPXML.jar" which is added in dependency to a java class. The corresponding hipxml will be generated in the same directory as "filePath". In order to parse the generated hipxml, the HiP-HOPS tool is needed. It can be downloaded from its official website at: http://www.hip-hops.eu/index.php/downloads. There is commercial version for analyzing bigger models, while in this research we choose the evaluation version which has a limitation of 20 components. In order to create Fault Tree by

using HiP-HOPS analysis, the generated file should be located in a folder called "HiP-HOPS_FailureEditor". After the xml file is moved to the right folder, HiP-HOPS is available to parse it by running in the command line. The input parameter should be "hipop filename.xml outputtype=XML".

When a full analysis is complete, the result Fault Tree and the corresponding fault tree analysis information is carried in an html file which is opened in a web browser. The final fault trees of the example error model presented in section 6.2.1 are shown as follow.

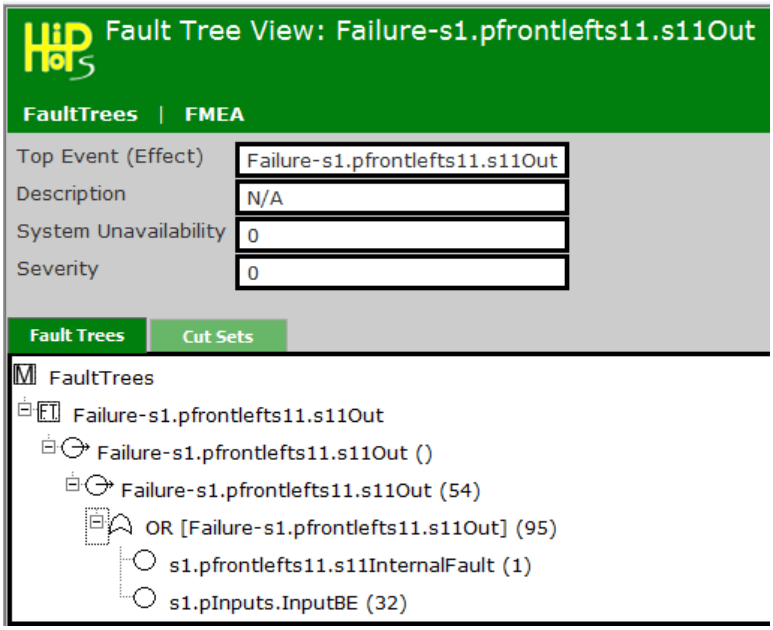


Fig 6.5(a) FaultTree Result of Failure-s1.pfrontlefts11.s11Out

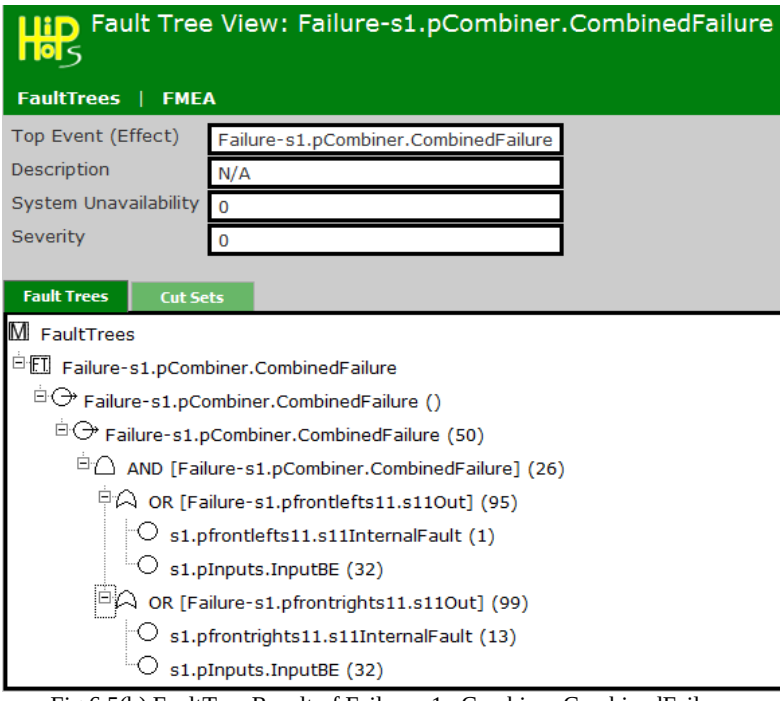


Fig 6.5(b) FaultTree Result of Failure-s1.pCombiner.CombinedFailure

Fig 6.5 FaultTree Result

The result Fault Trees showing that there are two possible paths conduct the final failure in element "s1". We will not discuss more about how the Fault Trees are generated and why it's generated in this way since our research work is improving the usability of EATOP and

makes the Fault Tree Analysis available for EAST-ADL model. So from the description above we draw a conclusion that the first goal is achieved and HiP-HOPS is available for analyzing EAST-ADL models.

Goal 2 - Easily Generating Fault Tree in EATOP

Taking the work of the first goal as a basis, the second goal is to improve the ease of use when making Fault Tree Analysis in EATOP. It is designed to automating the manual work of the previous section and let the user be able to see the result as shown in Fig 6.5 by clicking one button in EATOP. Instead of passing the eaxml file path and the element name which is going to be analyzed, the user could easily select the element and choose "HiP-HOPS - Fault Tree Analysis". The result screenshot is presented in Fig 6.6.

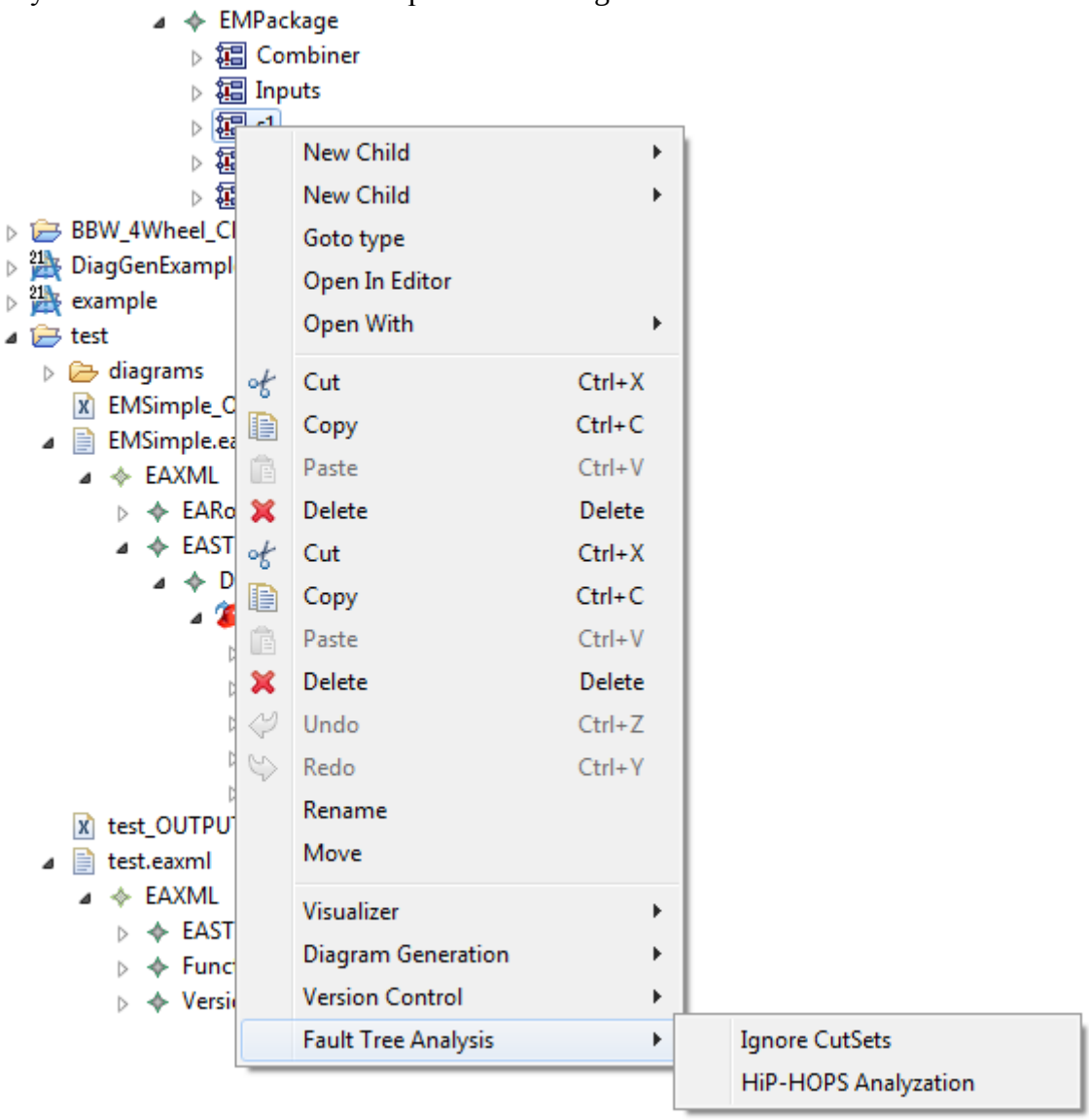


Fig 6.6 Select element for Fault Tree Analysis

The same example as previous section, the ErrorModelType "s1" is selected to be analyzed. By clicking the Fault Tree Analysis option, user gets the result view as shown in Fig 6.5 in EATOP instead.

6.2.3 Relate Fault Tree with EAST-ADL

Goal 3- Relate the generated result with EAST-ADL model

In the end, we would like to have a feature not only to generate the Fault Tree from EAST-ADL model, but to trace back from the analyzed result to the error elements. The first challenge is what to relate. Since the result image is generated as html file, it is hard to relate it with EATOP elements by clicking in the image. But the analyzed result also contains one xml file which keeps the information of all the CutSets. CutSet here is the element which must occur to cause the top event happen. It can be seen as a pre-condition of the top element failure. This is useful information to show on the EAST-ADL tree view to guide the user find the possible faults. So for this relating part, we selected to show the cutset information in the "Error Log" view in EATOP. Besides, the elements which are defined as cutsets are marked in the tree view, if this marked error model element has a function target which is introduced in 6.2, the targeted function elements are also be marked in the end.

In the previous example, the cutsets include the internal fault "InputBE" in prototype "pInputs" and the internal fault "s11InternalFault" in prototypes "pfrontlefts11" and "pfrontrights11". It is depicted in the browser as the figure below.

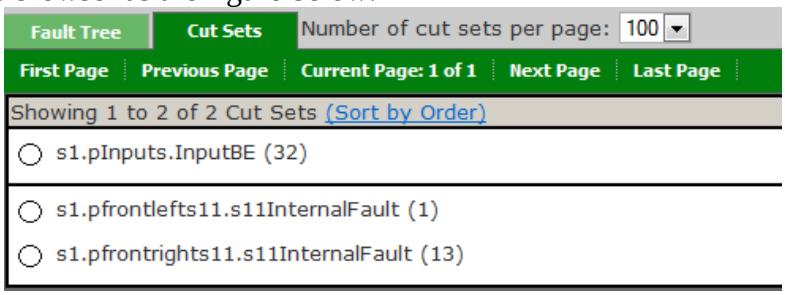


Fig 6.7 CutSets in Browser View

There are possibilities that overlapping exists in different sets of cutset. As shown in Fig 6.8, there are two sets of CutSets when s1 is selected as the top event, which are s1.pInputs.InputBE and s1.pfrontlefts11.s11InterFault as one stream and s1.pInputs.InputBE, pfrontlefts11.s11InternalFault and s1.pfrontrights11.s11InternalFault as another stream. This means either the failure exists in InputBE, s11InternalFault cause the final failure in s1. In addition, the message in Fig 6.8 also shows that the s11InternalFault can be either in pfrontlefts11 or pfrontrights11.

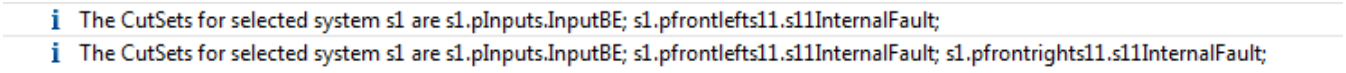


Fig 6.8 CutSets information

The left hand side of Fig 6.9 is the initial tree view of EMSimple_2FT.eaxml before running the Fault Tree Analysis. On the right hand side, the elements analyzed as CutSet are decorated with a red dot on the top right of each icon. In the tree view, all the elements are decorated no matter which cutset it is from. But by selecting the decorated element, user is able to read the information of which cutset it belongs to from the attribute view. The function modeling in Fig 6.10 illustrates the relation from Fault Tree Analysis to nominal model, not only the error model elements are marked as cut sets, the error model elements targeted function model elements are also marked to be related with CutSets.

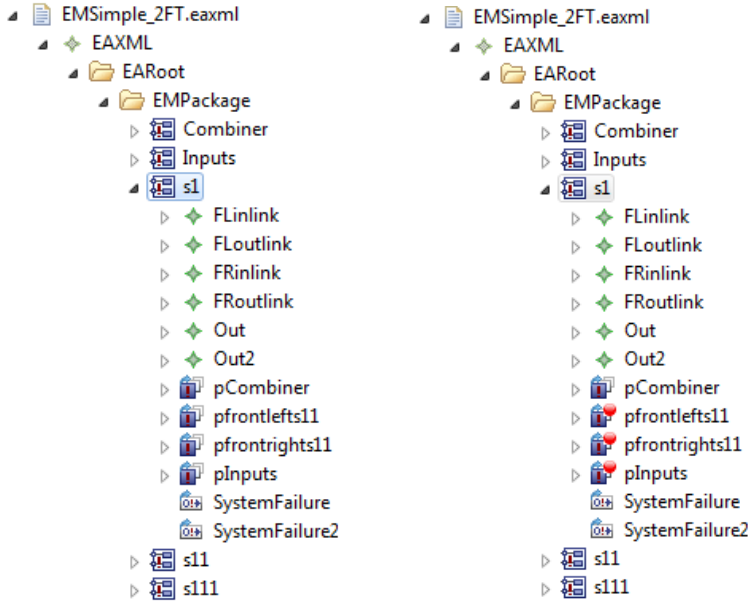


Fig 6.9 CutSets Marking

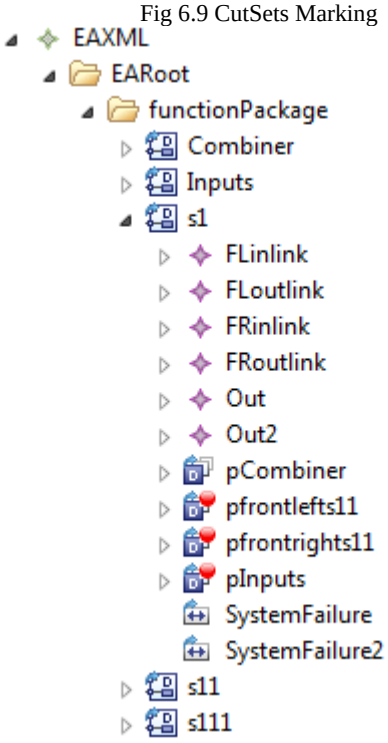


Fig 6.10 CutSets Marking on Function Element

Not only marking the CutSets, a feature is also implemented to remove the marks when they are not needed any more. It is called “Ignore CutSets” shown in Fig 6.6. By running this feature, all the cutset decorations which belong to the selected element and its target element will be erased.

6.3 Summary

In this chapter, a design and implementation of integrating HiP-HOPS Fault Tree Analysis into EATOP is addressed and this is related with RQ3: *How to apply Fault Tree Analysis on EAST-ADL error model and relate the generated Fault Tree result with the model*. The

feature is able for user to apply Fault Tree Analysis to EAST-ADL error model in EATOP and it also supports applying Fault Tree Analysis at an early age of a system design which reduce the failures in later design. Besides, it also reflects the analysis result into the model view which enhance the usability of Fault Tree Analysis. Automating Fault Tree Analysis for EAST-ADL is a fair effort. By using a third party commercial artifact (HiP-HOPS), existing tooling can be used, although extra installation needs to be purchased for industrial use.

Chapter 7 Graphical Support in EATOP

In this chapter, we will focus on providing a valid solution for the research question about visualization, which is about visualizing the error propagation model together with nominal model. As shown in fig 7.0. Visualization between error model and nominal model improves the readability of the error model structure. A user could check out the relation between the error model and its targeted nominal model through a graphical view instead of going through the tree view to find out the targeting information. It increases the efficiency of the safety analysis effort and reduces the manual work in understanding.

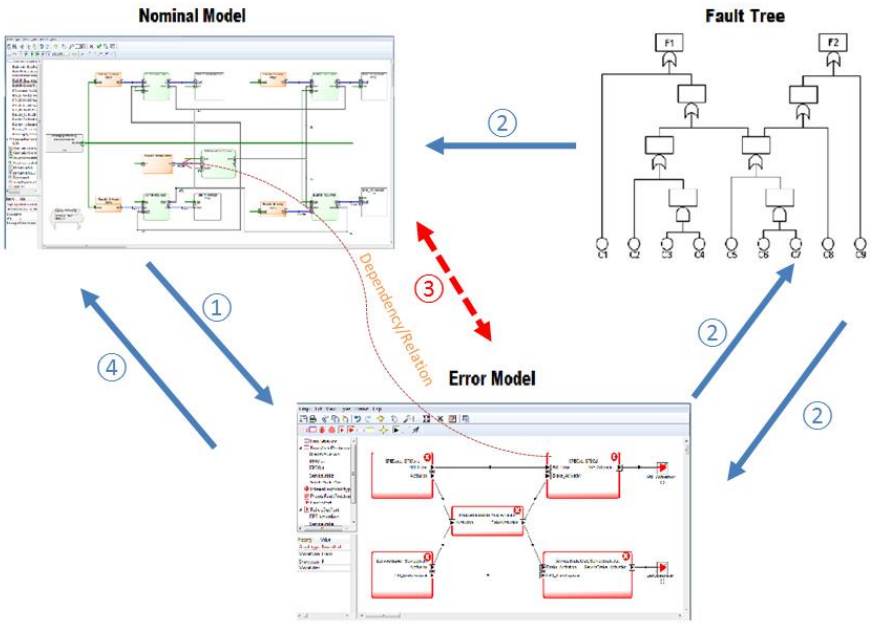


Fig 7.0 Safety Analysis Process - Understanding

7.1 Investigations in model visualization

The goal of this task is to visualize the dependency from error propagation model to nominal model by using an existing diagram editor. The dependency here means the target attribute in error model element which points to its targeted nominal model element as elaborated in

Chapter 5. Some investigation is needed in order to find a proper graphical tool to be integrated to solve the research question in a limited time.

7.1.1 Integrate Continental Graphical Editor

The first option is the graphical editor developed by Continental ("conti-"). This graphical editor supports different concepts of EAST-ADL in EATOP by dragging and dropping the model element from EATOP navigation tree to the diagram panel.

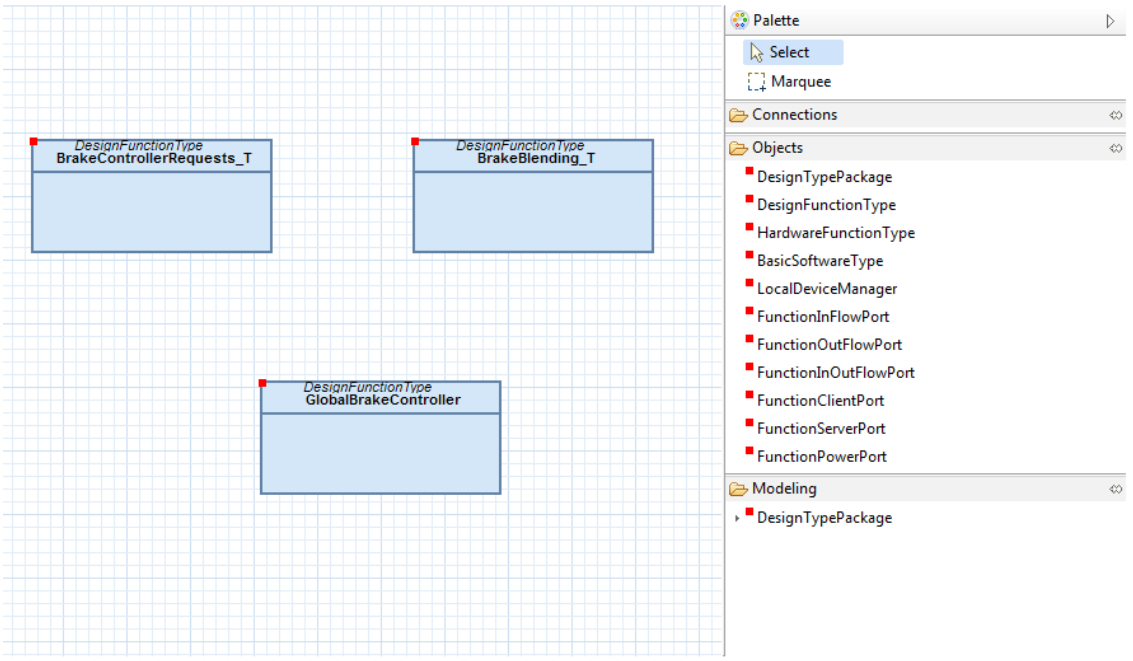


Fig 7.1 example view in continental graphical editor

As shown in Fig 7.1, a lower level hierarchy in the diagram panel is reached by double click the container. There are restrictions for what elements can be dragged into what level's diagram. For example, the diagram above is a DesignPackage Level which contains three DesignFunctionTypes. When user double click "GlobalBrakeController", a blank page is opened which is available for having DesignFunctionPrototype level elements to be contained. One disadvantage of this editor is that user may destroy the element structure by dragging the wrong prorotypes elements to another type. Not only by dragging the elements to the diagram panel, it also allows user to create new elements from Palette on the right hand side. As shown in Fig 7.1, there are eleven objects and one modeling element is available to be drawn on this level of diagram. As issue with editor is that it only supports EAST-ADL 2.1.10 and an older EATOP version. Another more recent version of of conti-graphical editor aims to support EAST-ADL 2.1.11, but is is still buggy. Right now, there is no graphical editor available in EATOP which supports EAST-ADL 2.1.12. In order to integrate the conti-graphical editor with the feature for visualizing the dependency, we need to adapt the editor to EAST-ADL 2.1.12 with EATOP 0.5.0. The amount of work to adapt the conti-graphical editor to a new version is beyond this research. So we decided to skip this approach.

7.1.2 Integrate Diagram Viewer

This approach requires the generation from EATOP model object to xml schema. The graphical xml generator will use visualizerdiagram schema. Visualizerdiagram is an EATOP specified diagram schema which is created by AB Volvo. A visualizer diagram reader plugin is required in order to visualize the xml file. The diagram viewer generates a read-only view

from its xml file and present the file in diagram editor in EATOP. As shown in Fig 7.2, the *.visualizerdiagram can be read in EATOP, but it does not allow the user to edit the diagram directly. Instead, if some changes is needed, user should go to the model element and after the modification is done, an update is needed for the the generated *.visualizerdiagram files.

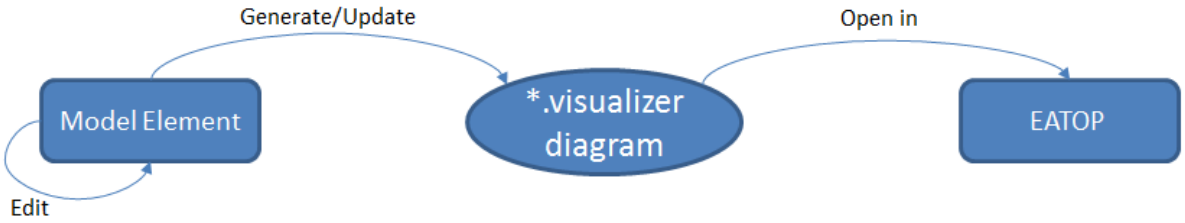


Fig 7.2 xml file generating

The EATOP internal diagram viewer is convenient to use and the appearance of the graph depends on how the algorithm handles complicated situations, for example, the element overlapping or huge amount of connectors.

7.2 Different views generated by Diagram generator

Different views which are generated by the diagram generator are presented in this section Identifiable element view, realizes a single box in the graph with its name for each of the selected element. It is applicable for any kind of EAST-ADL element. Error Model Type view & target and Error ModelPrototype view & target are shown when ErrorModelType element is selected in EATOP. And the diagram is generated according to the selected elements' structure. The later subsections will explain how and what elements are generated in different views respectively.

7.2.1 Identifiable Element

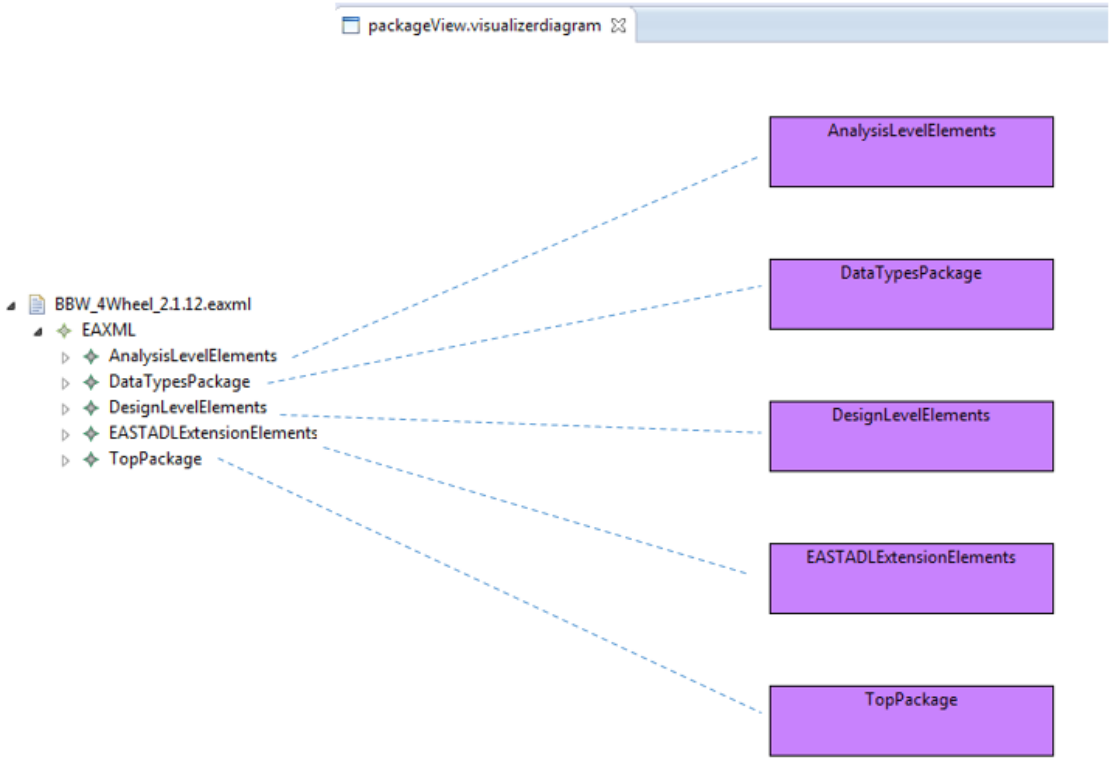


Fig 7.3 Identifiable View – Package View

The identifiable element in the superclass of most elements EAST-ADL and provides an identity attribute (UUID). Fig 7.3 is one example view of IdentifiableView in EATOP. The left hand side shows the model elements of the EAST-ADL explorer navigation while the right hand side is the generated diagram by selecting all the packages under EAXML which belongs to the file BBW_4Wheel_2.1.12.eaxml.

7.2.2 ErrorModelType and ErrorModelPrototype View

Instead of using the GlobalBrakeController in BrakeByWire example which is presented in Chapter 5 we are going to create a new example nominal model for presenting the graphical visualization in different views and in consistency checking in chapter 8. Different diagram views for the GlobalBrakeController model are provided in Appendix C-I and Appendix C-II, but the new example provides a simpler and more illustrative structure.

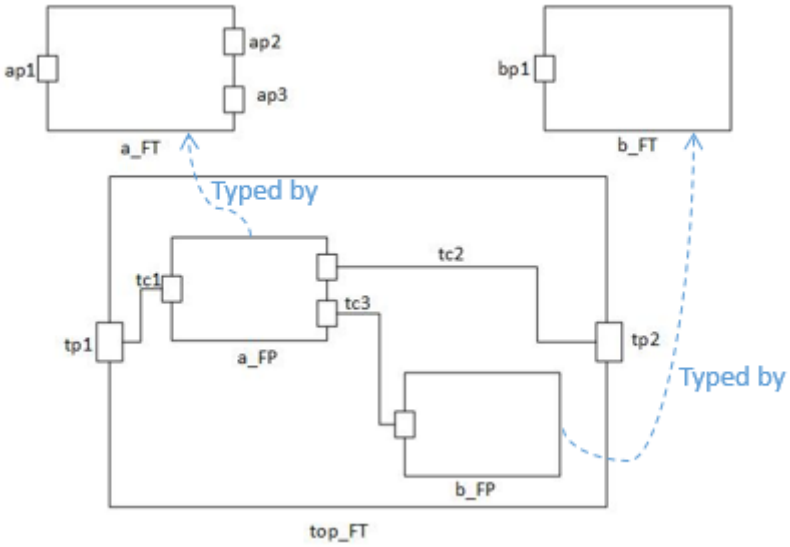


Fig 7.4 Structure of the Example Nominal Model

Fig7.4 presents the structure at Function Prototype level of the example nominal model. Three FunctionTypes are named as “A_FT”, “B_FT” and “Top_FT”. As a container, “Top_FT” contains two FunctionPrototypes and three FunctionConnectors. Among them, “tc1” and “tc2” are delegated connectors, which connect between higher level element and the lower ones. Each FunctionPrototype has its FunctionType. In this case, “A_FP” is typed by “A_FT” and “B_FP” is typed by “B_FT”. The typed FunctionPrototype will inherit all the subcomponents contained in its type.

By using the error model auto-generation artifact which is developed and explained in Chapter 5, we created an example error model depends on the example nominal model by selecting all three Function Types a_FT, b_FT and top_FT. The ErrorModelType view and ErrorModelPrototype view supported by diagram generator is presented in Fig 7.5 and Fig 7.6 respectively.

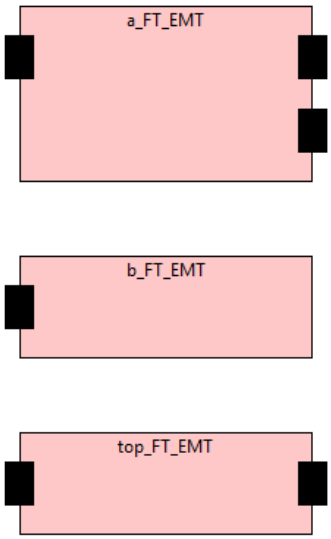


Fig 7.5 example error model – ErrorModelType view

The ErrorModelType view presents the structure of the selected ErrorModelTypes at a type level. In type level, only in ports and out ports are visible. The size of each ErrorModelType depends on the amount of ports it has. For easy viewing, all the types are shown in a vertical order and the space between two types are the same and predefined for each type, so there is no overlapping in different types and user could easily scroll up and down to view all the selected types in one diagram.

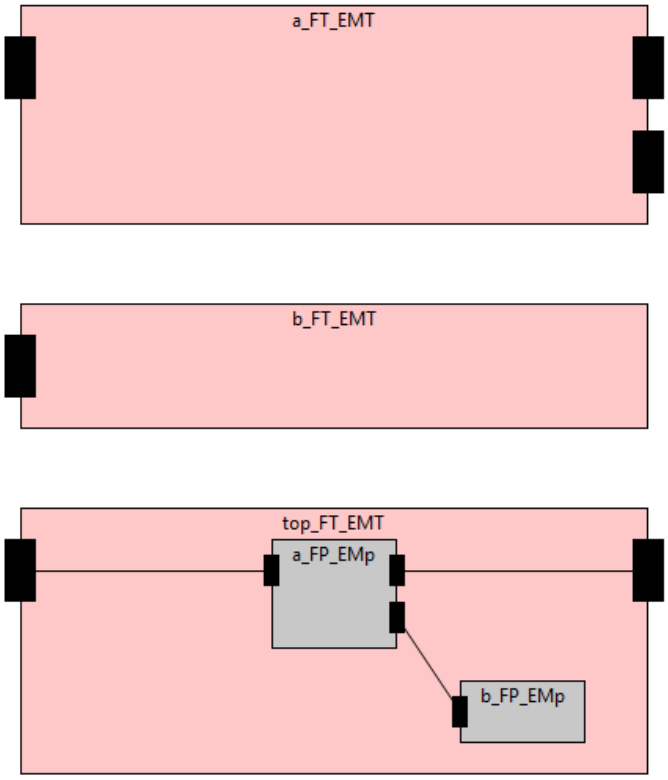


Fig 7.6 example error model – ErrorModelPrototype view

The ErrorModelPrototype view presents the ErrorModelPrototypes in the selected ErrorModelType. Fig 7.6 illustrates a prototype view when a_FT_EMT, b_FT_EMT and top_FT_EMT are selected to be presented. From the presentation in Fig 7.6, we can tell that

there is no prototype located in a_FT_EMT and b_FT_EMT and there are two ErrorModelPrototypes a_FP_EMp and b_FP_EMp in top_FT_EMT. They are connected with each other and their container with FaultFailurePropagationLink. As the error model showing in this section is generated by one to one generation elaborated in Chapter 5. The whole structure in nominal model has been kept in error model, so as we can see the structure of error model in Fig 7.6 is the same as the structure of nominal model in Fig 7.4. Besides, in order to provide a clear structure when it comes to a big model with quite a lot prototypes sit in one type, we designed and implemented a three-column algorithm when it comes to arranging the positions of each prototype in ErrorModelPrototype view. The three-column algorithm divided all the prototypes in one type into three area, which are left, middle and right. And locate them according to the connection and its own properties. More detailed information about this algorithm are elaborated in section 7.3 and *Appendix A – III*.

7.2.3 ErrorModelType and ErrorModelPrototype Target View

Introducing the dependency concept with tracing line between error modeling and nominal modeling is the main purpose to visualize the error model elements together with their targets. In EATOP, the target is presented as one attribute in each of the error model element. It means this error model element illustrates the error propagation of the targeted element. Normally, the targeted element is a nominal model element at the same level. For example, one ErrorModelType has a DesignFunctionType or an AnalysisFunctionType as a target. While one ErrorModelPrototype has a target as a DesignFunctionPrototype or an AnalysisFunctionPrototype. In this section, ErrorModelType and target view and ErrorModelPrototype and target view are presented with the same example model as elaborated in section 7.2.2.

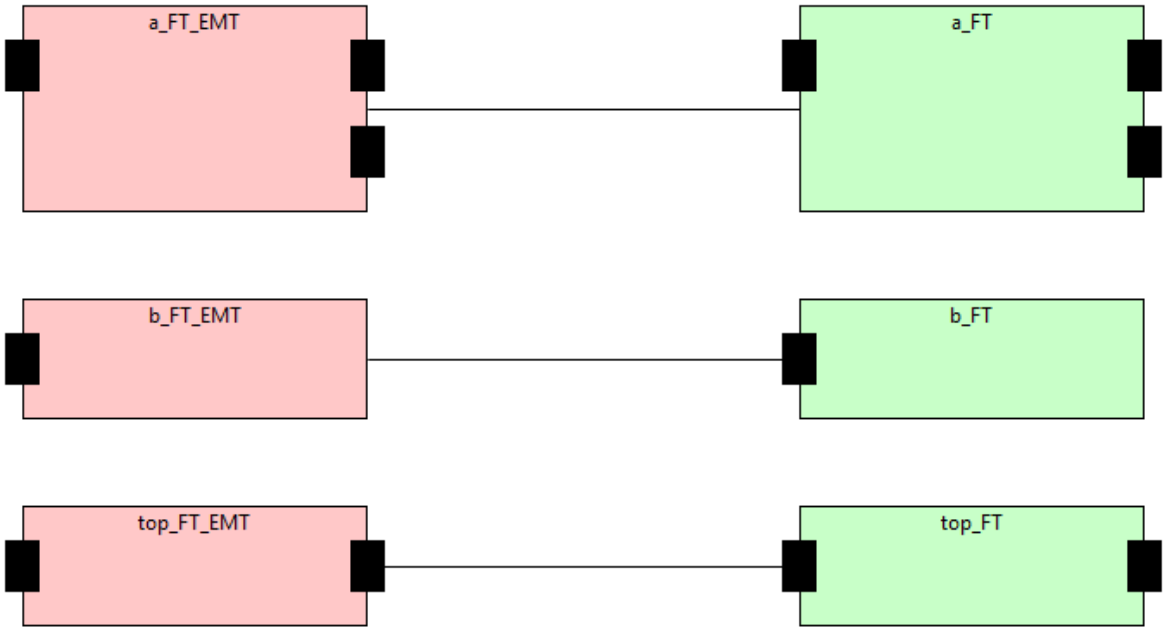


Fig 7.7 example error model – ErrorModelType with Target view

Fig 7.7 presents an example view at type level when a_FT_EMT, b_FT_EMT and top_FT_EMT are selected to be shown with their targets. The left hand side are the selected ErrorModelTypes and the right hand side are each of the selected ErrorModelType's target. The line between each ErrorModelType and it's target presents the tracing line. Not only the element which is targeted is shown in the diagram, but also it's structure. As illuatrated above,

a_FT_EMT's target a_FT has one in port and two out port while b_FT holds only one inport and top_FT has one inport and one outport. The targeted element have exactly the same structure as their ErrorModelTypes.

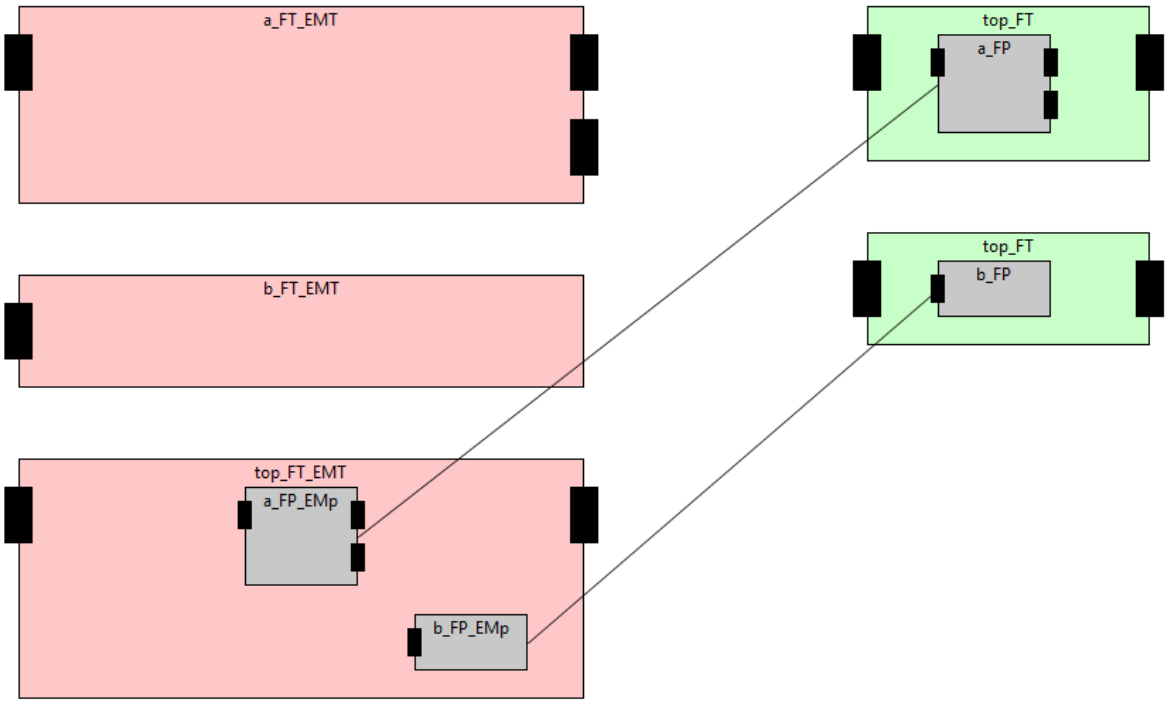


Fig 7.8 example error model – ErrorModelPrototype with Target view

Fig 7.8 is an example target view at ErrorModelPrototype level when a_FT_EMT, b_FT_EMT and top_FT_EMT is selected. Since no other line type is supported in this visualizerdiagram schema, in order to not mix the FaultFailureConnector with the tracing line, the connections in each ErrorModelType is not shown in target view. But the position of each prototype in error model side still applies ErrorModelPrototypes and the right hand side presents each ErrorModelPrototype's target. As shown above, a_FP_EMp's target is a_FP which belongs to the type called top_FT and b_FP_EMp has a target as b_FP which is also located in top_FT. The targeted type is repeatable since there could be more than one prototype targeted by the selected ErrorModelPrototypes are sitting in the same type which is also the case above. The reason of this design is that in ErrorModelPrototype's target view, each of the targeted element should be drawn by ErrorModelPrototype perspective, so the selected ErrorModelTypes which have no ErrorModelPrototype (a_FT_EMT,b_FT_EMT for example) is not necessarily to be presented in the targeted side. Allow the targeted type to be repeatable is also according to this concern.

7.3 Structure and Algorithm

The diagram generator plugin is structured in three parts. Diagram folder is responsible for generating XML file entries from the Java diagram objects. Action folder handles all the actions response to user's request and it uses the corresponding files in draw folder to relate the requested Java EObject with XML schema element. JAXB(Java Architecture for XML Binding) is used for handling the transmission between java object and xml element. JAXB provides marshalling (writing) Java content trees into XML instance documents and unmarshalling (reading) XML instance documents into Java content trees. In diagram generator, JAXB is used to generate XML schema from Java objects and unmarshall the

generated xml instance when the information is needed for java element, for example, when drawing the connection between ports, the location of different ports are unmarshalled from its xml instance.

Since the diagram generator creates a read only view, it's quite important to keep the diagram clean and clear, especially when it comes to a big system. For this reason, we have designed and developed a three column algorithm when locating the prototypes in its type. Since there are connectors link between different prototype ports or between prototype ports and the type ports as delegation connectors. The main purpose of the three column algorithm is by re-organizing the location of the prototypes to make connectors between elements more readable and understandable. As a result, the prototypes which only have outports or the ones only have the connections with the type's inports are located in the left column. The prototypes which have connections with type's both inports and outports or the ones have no connections with the type are located in the middle column. The rest prototypes which only have inports or the ones only have the connections with the type's outports are located in the right column. The piece of code of three columns algorithm is shown in *Appendix A – III Three Columns Algorithm.*

7.4 Summary

In general, diagram generator plugin is able to present several different views for visualizing the error propagation model together with the nominal model. And it addresses one possible solution according to RQ4, which is *How to visualize the error propagation model together with architecture model.* It fulfills the requirement of showing the tracing dependency line between error model and its targeted nominal model at both type and prototype levels. But it also provides a base support for all identifiable elements in EAST-ADL. The usage of three columns algorithm enhances the presentation of a large system's structure in a more reasonable and clear way. Depending on the support of diagram viewer, each generated file is easily opened and reviewed in EATOP. But there are inconveniences exist while using it. For example, the generated diagram is not editable, user has to go back to the model element in order to make a change. The generated file is not generic, they are parsed by diagram viewer in EATOP, and no other external tool support this visualizerdiagram xml schema. Besides, the non-standard schema does not support other kind of lines than solid lines, like dashed lines. This makes the tracing link and connections to be hard to differ in the diagram. From the above, we can tell that even flaws exist, but the diagram generator plugin in general is a quick and easy tool in providing specific visualization in EATOP.

Chapter 8 Consistency Checking between nominal model and error model

As described in the problem statement chapter, evolution is an unavoidable process during architecture design and safety checking. In this case, it is reflected as the changes in either nominal model or error model. When changes happen in either side and its related models are not updated in time, this normally leads to an inconsistency problem. Unfortunately, there is no automated feature to check the consistency in EATOP. Which means that after the models have been modified, there is no other way than checking all the related models manually which is time consuming and imprecise. In this chapter, we would address the solution of last research question as illustrated in Fig 8.0 by explaining how the inconsistency is prevented in our work in terms of EAST-ADL 2.1.12 function modeling and error modeling. The alternative design and final design for version control is elaborated in section 8.1. And the output from implementation are presented in section 8.2.

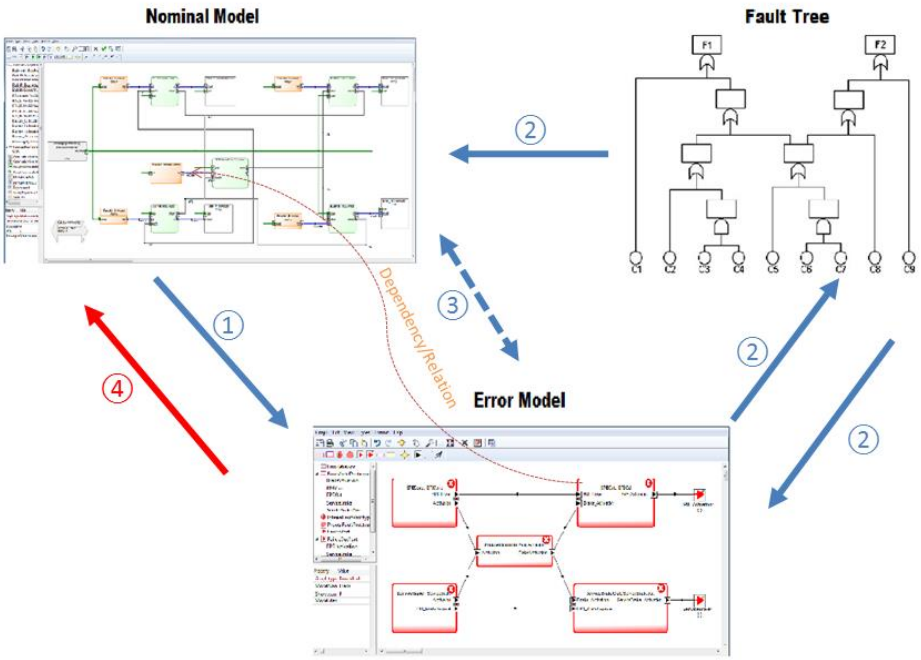


Fig 8.0 Safety Analysis Process - Evolving

8.1 Design Specification

8.1.1 Alternatives for consistency checking

Several alternatives are available for handling the consistency checking between function modeling and error modeling. EMF compare is an eclipse based model comparing tool for EMF model. In this case, the model before changes or after last consistency checking is stored for comparison. Whenever user requires checking the consistency, the current model is used to compare with the stored model and the result are the differences between those two models, for example, the deletion, addition or modification of elements. When inconsistence exists, the differences are reported to the user. But the problem here is that EMF compare only handles a settled complexity of evolution by the customized comparison strategy. While in real life work, not all the changes are able to be predicted in advance and there is no exact definition of being consistent or not for one element. For example, the function type "ABS_T" in BBW example could be consistent with one error model type with different structure in different situations. This makes the EMF compare not applicable for automate the consistency checking between heterogeneous targets. Another alternative is keeping a hash code for each element. Since the UUID as a unique ID for each element in EAST-ADL modeling is not fulfilled in EATOP in default. One alternative is keeping each element's generated time as the "hash code" in UUID attribute. And this can keep each element unique. So whenever the system detects there is one element have two different UUID, it informs the user as inconsistency may exist since the element has been updated. But considering the initial goal of UUID is not for save the time stamp and there might be other features read the elements by its UUID, we decided to drop this idea for consistency checking.

From the discussion above, the automatic detecting way seems not totally applicable for this situation. But there is one way called version control has been conducted in several automotive applications for checking the modeling consistency. It requires manual decision for the version increase and whether there is consistency or not is decided by the user. After setting the version for each element, system checks whether there is a different between the targeted version and the error model version. Comparing with other alternatives, version control do requires more manual work, but it is the most efficient way for handling the complex situation during consistency checking. Therefore, version control is designed to be the way for checking the consistency between nominal model and error model in this research.

8.1.2 Version Control Design Specification

Fig 8.1 illustrates one example workflow when applying consistency checking for the user's intended file. As shown in the Figure, if one "*.eaxml" file has not been version initiated, user has to run "Initiate version" function in order to set version element for all existing nominal and error elements. All the versions and targeted versions are set according to the user's input. The targeted version here is only available for the error model element, it is used for recording the matching targeted version to compare with the current target version, and more detail information will be explained in next section.

When all the elements needed for consistency checking contain a version number, they are available for consistency checking. If one element has been modified, user has the authority to either select increase the version of this element or stay the same as before. The version can be changed by manually typing or by automatically increasing. In manual typing, user needs to locate the new version number to the corresponding version element and the version can be modified to any number he needs, while letter is not allowed in a version number. In

automatic increasing, the version of each error/function type element are changed by right clicking the desired element. The function called “version increase” is used for modifying the element version while decreasing version number is not available for this situation. Two options are available for the automatic increasing, each click of “Major Increase” adds “1” to the precious version while “Minor Increase” adds “0.1” instead. For example, if the current version number is “1.2”, by selecting the major increase function, the version number becomes “2.2”. If take minor increase on the basis of “2.2”, the new version will be “2.3”. Both major increase and minor increase are repeatable. There is no defined meaning of the version number, but usually, each “1” increasing means a new release for this component while each “0.1” increase means small changes, but it is still open for users to specify the version meaning by their own. The advantage of manual typing is that user defines the version number by his own but it is hard to find the location of the version element for a large system since it has different hierarchy from the function or error modeling elements. Conversely, the auto increase function is available by simply right clicking the desired element, but it is only available for increasing a limited number for each time. So user chooses either way depending on the situation.

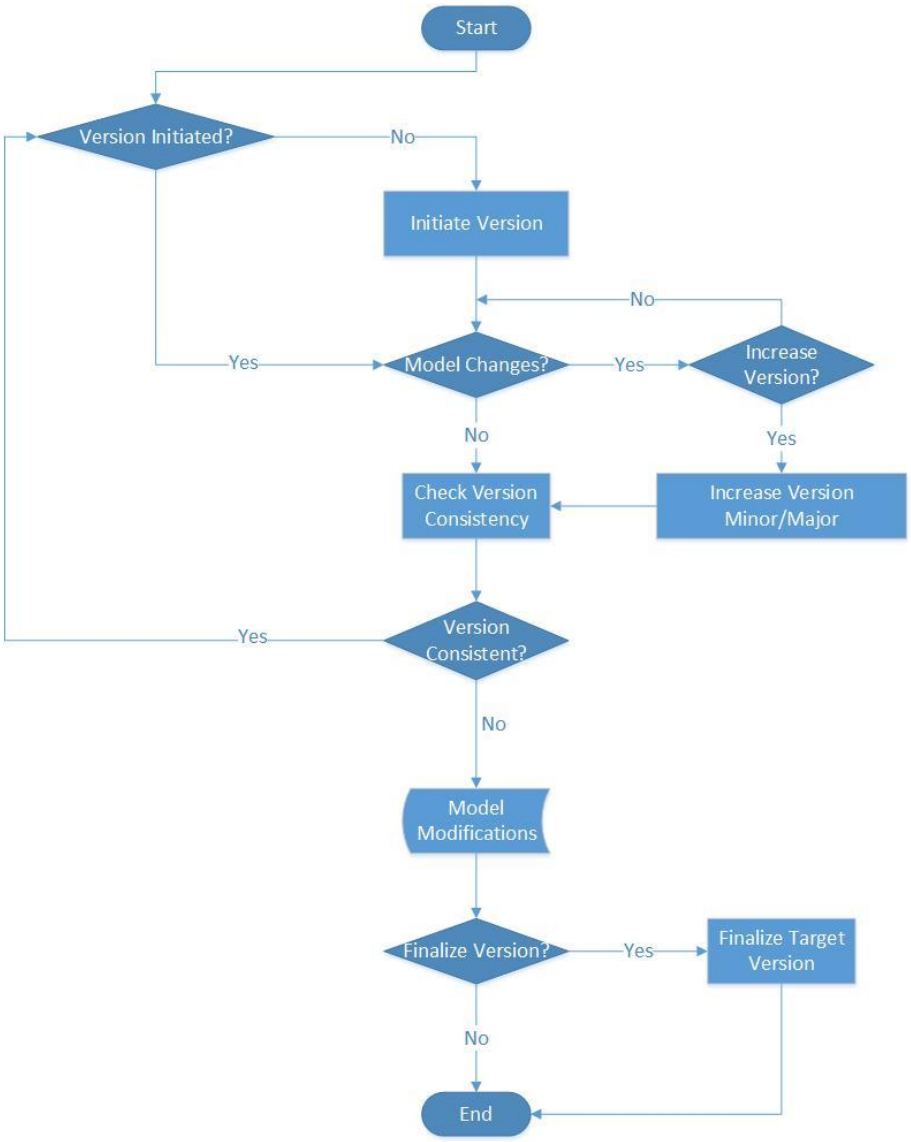


Fig 8.1 Consistency Checking Workflow Chart

User does not need to check consistency for each change, he/she could wait till it is time to revise the whole project or at any time he/she decide to be. But after running the consistency checking, the user will either be informed that all versions are consistent. Or get the inconsistency elements message in both information view in EATOP (same as Eclipse) and the tree view. The version consistency checking does not require any manual work, the system analyses each element's version and provide the result of whether it is consistent or not between the function modeling and nominal modeling. If the goal is to make sure all elements are consistent with each other, several modifications needed to be done, and after all, there is an option for the user to finalize the targeted version, which the system helps the user to make the selected error model elements version match their target versions. If user is satisfied with the current state of the project, they could start with a new working stage. Otherwise, they continue with the check consistency from beginning. The consistency checking in this work does not support the following situations:

1. No version number is set
2. Those error elements which have no target function model
3. Those function elements are not targeted in the error model

8.2 Result Specification

After the "why" has been explained in previous section, this section solves the "how" question for each function by a short description and one example use case. All use cases follow the working flow shown in Fig 8.1.Besides, sequence diagrams and the result snapshots will be presented assisting the explanation in order to make each case easy to understand.

8.2.1 Initiate Version

In order to create a version for each model element in EATOP, an Initiate Version step is needed. While it is only needed to be done once when an architecture design is currently finished. After running the initiate version function, each existing function and error element is attached with a version element. The version element attached to function element contains a version number which means the corresponding function element's current version number. While for each error model element, a target version number is also recorded in its version element which is used for pointing out the consistent target version number. So if the targeted function element has a version number not equaling to its error element's target version, then there must be an inconsistency between them. Any additional function or error element is allowed to be added into the system after running the initiate version function, but it requires rerunning the initiate version step. After each rerunning, a new set of version elements are added and new version number and target version number are required to be set by user.

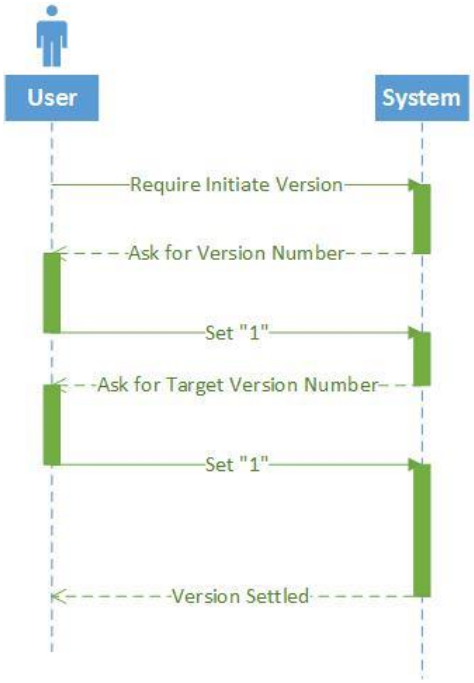


Fig 8.2 Initiate Version Sequence Diagram

As illustrated in Fig 8.2, a request to initiate version is sent by user right clicking on one EAST-ADL top level element and select “Initiate Version”, system responds by asking for version number and target version number, the target version number is only applicable for error element as explained above. In this case as shown in the figure, both versions are set as “1” as initial, which means all the function and error elements have a version number of “1”, and all the error model’s target version number should be “1”, so it is regarded as all elements are consistent in this example. It is designed to use the EAST-ADL 2.1.12 UserAttributedElement to record the version number. Each of this element contains one or two Numerical Value which is the value of the version number. One example of VersionType elements are depicted in the picture 8.3. “a_FT_VersionType” is the version element for element “a_FT” and it means element “a_FT” is currently in version “1”.

There is a distinction between the VersionType for function element and error element. Each error model element has one extra version number called “TargetVersion” as shown in Fig 8.4. This extra version is used to record this error element’s target version. In this example, the “a_FT_EMT” is in version “1” and its matching target element “a_FT” version should be “1”. So if “a_FT” has a version other than “1”, it means there is a version inconsistency exist between those two elements. This strategy is used for later consistency checking. According to user’s requirements, system sets the entire versions into different folders which separates the function modeling elements and error modeling elements.

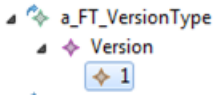


Fig 8.3 Error Modeling Version

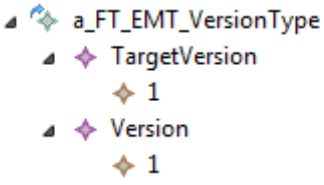


Fig 8.4 Function Modeling Version

8.2.2 Version Increase

The Version Increase function is used to increase the modeling version number. By selecting one element, user select whether major increase or minor increase the version number. The snapshot of this function can be seen in Fig 8.6(a). The reason of having two different increase levels is considering the version number is also responsible for representing the status of the element. A major increase means a new release while a minor increase means a modification. Since the version increase is only meaningful on a function type or error model type level, this function is not applicable for any other elements than those meaningful version increasable elements.

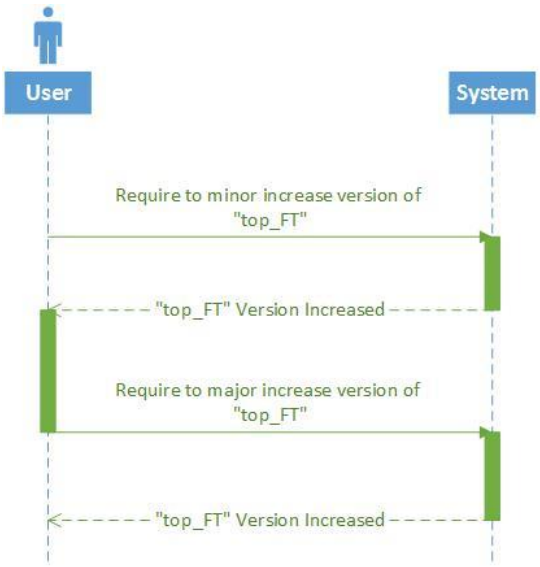


Fig 8.5 Increase Version Sequence Diagram

One example use case of increasing function element version is shown in figure 8.4. User first requires to minor increase the version of function type “top_FT” and then major increase the version of it. The result are presented in Fig 8.6(b1) and Fig 8.6(b2) respectively. After two times increase, the version number of “top_FT” comes to “2.1” from the initial “1”. Except increasing the defined number for each function type and error model type element, it is also possible for the user to decide and set a new version number for any element which has a corresponding version element. User could easily go to the selected element’s version and type the new version in property view. The reason of having the additional defined increasing version function is to keep the version in a more formal style and also it’s easier to reach than manual typing. Even the version number can be changed for all the version tagged elements, the only part affects the model consistency between nominal model and error model is when a function type’s version has been changed. The version of the other elements will not be considered in consistency checking since the version consistency is at function type and error model type level. While the version of error model type will not affect the model consistency whenever it’s TargetVersion equals to its targeted element’s version. More detailed information about consistency checking will be elaborated in checking version consistency section.

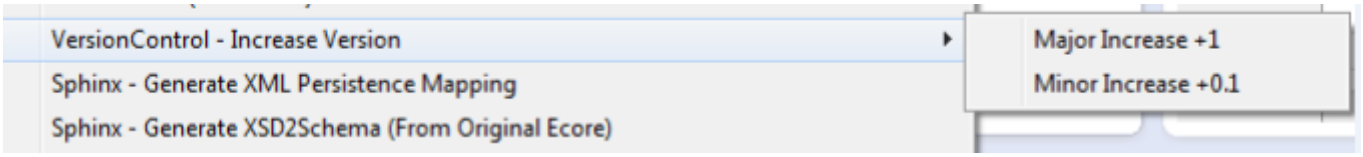


Fig 8.6(a) Increase Version SnapShot

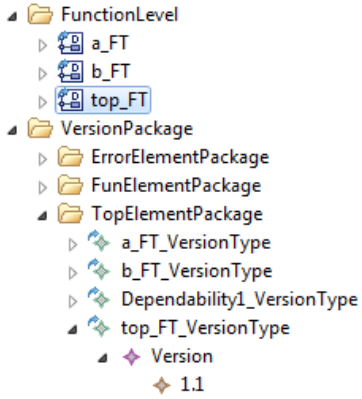


Fig 8.6(b1) Minor Increase Version

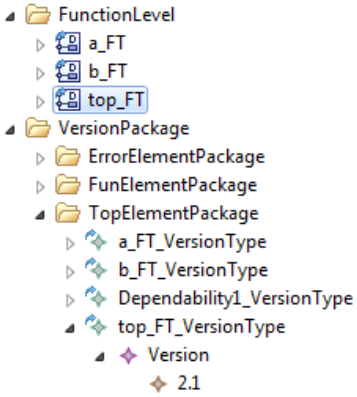


Fig 8.6(b2) Major Increase Version

Fig 8.6 Increase Version

8.2.3 Checking Version Consistency

The checking version consistency is the main function in this feature. In this function, user could simply right-click on one EAXML file element needs to be checked and select Check Version Consistency. As explained in initiate version, the way this function to check consistency is comparing all error element's TargetVersion with its target element's Version, an inconsistency exists when there is a difference between them.

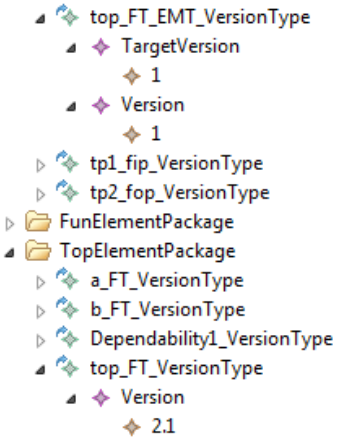


Fig 8.7 top_FT Version & top_FT_EMT TargetVersion

We use the same use case as above procedures, "top_FT" is the target element of "top_FT_EMT", the Error Model Type has a TargetVersion as "1" while the Function Type holds a Version as "2.1" as shown in Fig 8.7. When user run Check Consistency at this time, it shows both inconsistency error message and an inconsistency image on the error model side, those are seen in Fig 8.8.

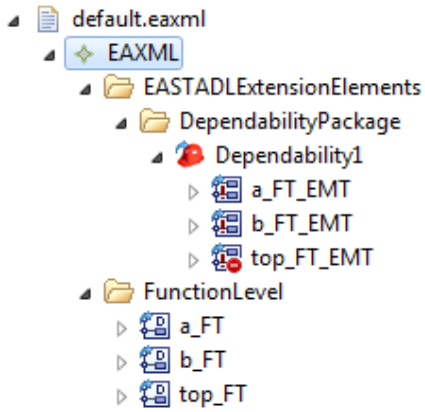


Fig 8.8(a) Inconsistency icon on top_FT_EMT

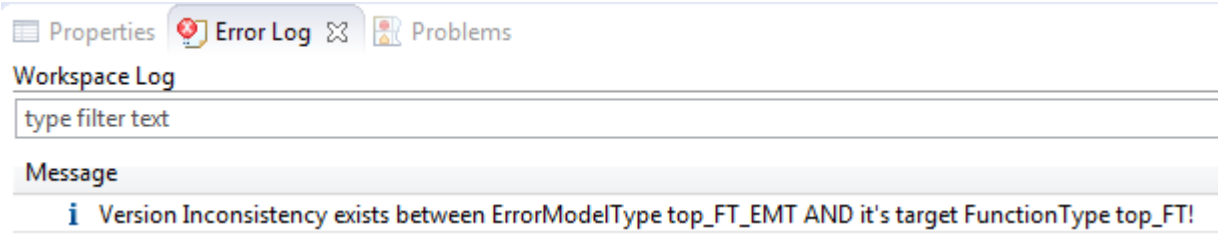


Fig 8.8(b) Inconsistency Message

Fig 8.8 Inconsistency checking Result

The descriptions above are all about when inconsistency exists, while if all elements' versions are consistent in the selected file, a message in the picture below will pop up showing the information.

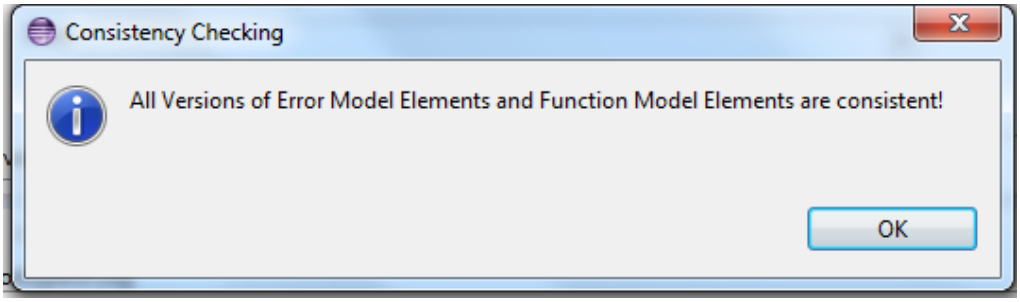


Fig 8.9 Consistent Message

8.2.4 Synchronizing Target Version

The synchronizing target version function is designed to improve the usability of the consistency checking feature. The user does not need to manually modify the version number to make the inconsistent ones consistent. Instead, he/she can select all the elements at once and run finalize target version to make all TargetVersion the same as the current targets' Version. In this case, user selects Error Model Type " top_FT_EMT" and run this function, the result is shown as follow. And when we run the check consistency again now, it shows all consistent and the inconsistent icon is removed from top_FT_EMT.

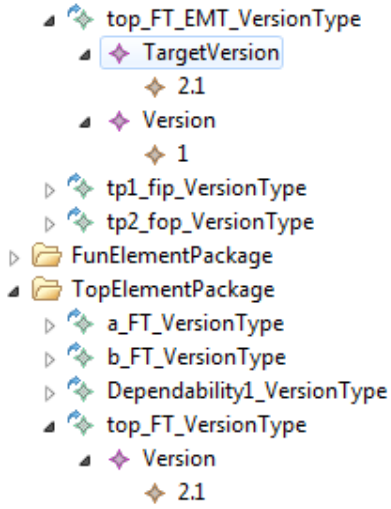


Fig 8.10 Synchronize Version of "top_FT_EMT"

8.3 Summary

In order to cope with the inconsistency problem addressed in RQ5 *How to ensure consistency between nominal architecture models and error* models, a version control concept is illustrated in this chapter. In general, version control concept provides the possibility of informing when inconsistency exists. But it doesn't avoid inconsistency from happening. It informs the current state of consistency when the function is triggered. But it doesn't detect and define any modification as inconsistency. On the one hand, it reduce the real-time performance of the function. But on the other hand, it provides the possibility for user to customize the definition of consistency since not every modification will cause an inconsistency. It fulfills in coping with inconsistency problems in a research level. But by adding the version tag elements, it increases the size of the model. And this will be an issue for a large system. Overall, it handles the problem raised by research question while evolving.

Chapter 9 Evaluation

As specified in the concept of design research, design and development processes take a main part of the whole research procedure and are responsible for generating the outcome. After the outcome is established, it is important to evaluate the successfulness in order for later modifying. At this point, different kinds of evaluation techniques, including observation, interviewing and questionnaire are conducted.

The goal of the evaluation process in this research is to get the expert feedback for measuring the successfulness of the current result. While, the success or failure of the outcome knowledge and artifact cannot simply be evaluated in terms of how much it fulfill the expected functionality. Carvalho, Alvaro and Azurem(Carvalho,Alvaro,Azurém 2012) provide a validation criteria for measuring the outcome of a design research and it will be applied in this research evaluation.

9.1 Evaluation Criteria

In Carvalho, Alvaro and Azurems' validation criteria, four general aspects of the outcome are measured, which are artifact success, generalization, novelty and explanation capability. Artifact success, as shown by name, is used for measuring whether the artifact is success or not from usefulness, efficacy and efficiency. An unsuccessful artifact also has the value of providing ways that are not worth of pursuing in later work. "Generalization" defines the range of applicability for the outcome, so whether the applicability is restricted to specific situations or universal is measured. "Novelty" indicates the improvements of the measured outcome comparing with existing knowledge. The evaluation result of novelty are usually phrased as: this outcome is better compare with before or this concept does not exist. The last element "explanation capability" considers whether the designed objects are explained well enough in the outcome description or not. And in this criterion, the best situation is the outcome meets the designed expectation in general. Considering the diversity and applicability of different works, detailed measurements for this research are provided as follow.

9.1.1 Artifact success

Usefulness

Since the goal of this research is to improve the current working flows for safety engineers and architecture engineers. The usefulness of the outcome is judged by those experts that whether it solve or mitigate the current problems or not.

Efficacy
The efficacy is defined as the degree to which the artifacts achieve the expected results (Carvalho,Alvaro,Azurém 2012). In this research, the efficacy is measured by comparing the research questions, user expectation and the outcome functions as described above in this section.

Efficiency
As specified in software quality standard metrics ISO-9126(Software Product Quality). Efficiency is considered in both amount of time and resources. This measurement is done by researcher. All the measured results are applied to the measurement algorithms provided in ISO-9126.

9.1.2 Novelty & Explanation capability
The novelty and explanation capability of the outcome is measured and evaluated through the feedback from experts. The result of former measurement reflects the significance of the new concept or knowledge revealed in this study. While the explanation capability is used to measure the researcher's capability of bringing ideas into practice and whether the designed objects are well explained. Those two metrics focus on evaluating the knowledge aspect of a study.

9.2 Data Collection
Based on the thesis progress and outcomes, the data collection together with data analysis is performed in two stages. The EAST-ADL and EATOP experts are involved in first stage and the Safety engineers participate the second stage. There are several reasons to have two evaluation stages. The first is in order to make sure everything goes on the right direction and speed, an evaluation is needed in the mid of the thesis to judge the completed work and reorder the later work. The second reason is time limitation, since it takes time to recruit interviewees from two departments, we decided to separate those experts into two groups. Besides, those two groups have different focuses, it also makes the data collection and analysis easier to perform. According to this, the interviews in first stage lays emphasis on the general process from nominal model to error model in EAST-ADL while the second focuses more on the usability of the auto-generated Fault Tree through HiP-HOPS.

Table 9.1 Outcomes to be presented in different Interview Stages

Outcomes	Stage 1	Stage 2
Auto-generating EAST-ADL nominal model from Simulink model	Concept	Concept
Auto-generating EAST-ADL error model out of existing nominal model	Artifact	Artifact
Re-patterning error model elements in EATOP	Artifact	Artifact
Use of HiP-HOPS for Fault Tree Analysis with EATOP	Concept	Artifact
Graphical representations for error model elements in EATOP	Concept	Concept
Version consistency checking between nominal model elements and error model elements	Artifact	Artifact

The outcomes of this research are divided into concept and artifact. The concept includes ideas for improving the working flow and the artifact outcome contains four eclipse EATOP plug-ins achieve different goals. The outcomes to be presented in different interview stages are depicted in Table 9.1 as either concept or artifact. And it is annotated under the stage column for each interview stage. Currently, EATOP is only used for research while Simulink is the tool has been widely used in practice. The interviewees may not be familiar with the EATOP or hard to relate the thesis work with their current working process. For this reason, we present the concept as auto generating EAST-ADL nominal model from Simulink model to link the gap. This concept presents a complete model transformation from current working Simulink model to the EAST-ADL nominal model and rest of the thesis work are depending on this concept.

9.2.1 Data Collection Method

There are several commonly used methods of collecting data in design research, which are observation, interview, experiment and survey. Considering the goal of this evaluation process and the amount of data are collected, we perform the data collection in qualitative methods. Among those qualitative methods, one to one semi-structured interview is chosen to be conducted in this research.

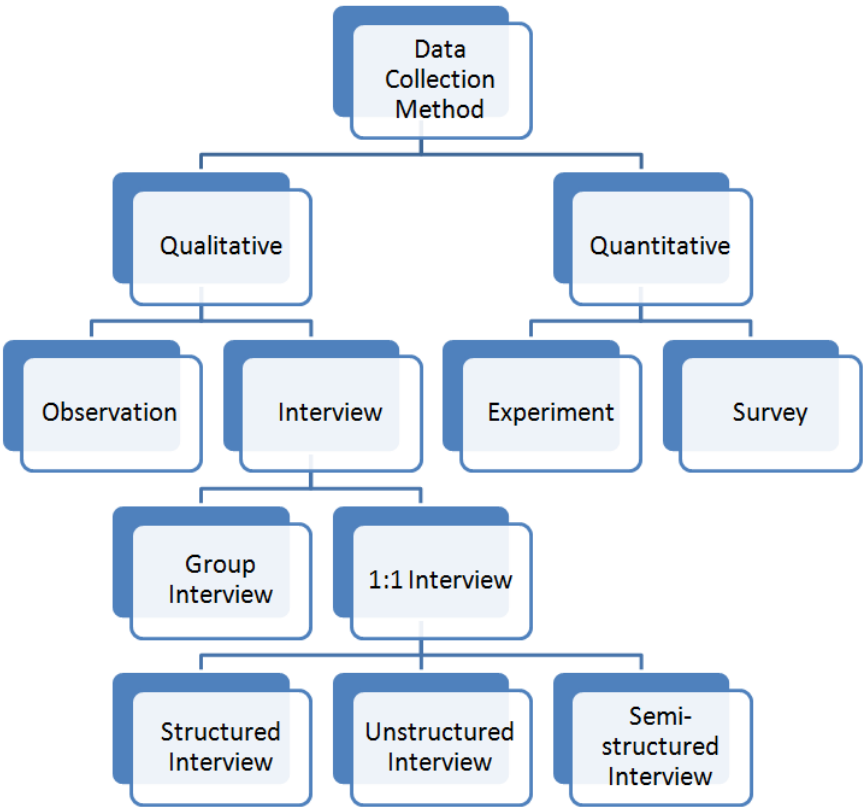


Fig 9.1 Data collection methods

The figure above illustrates the general ideas of narrowing down to one to one semi-structured interview to be the data collection method in this research. As explained before, the qualitative methods fit better in this research. Since the outcome of this result is in incubation stage and the whole evaluation period should not be too long during the thesis work, the observation is not applicable for this situation. When it comes to whether group or one to one, our consideration is the summer vacation is approaching and it's always easier to find a separate time for each participant than bring everyone together in a set amount of time. Besides, one to one interview guarantees the feedback reflect all the participants opinions and

the collected data are more objective. Before the interview, there are some prepared questions for each interviewee. However, different interviewee holds different background knowledge and a variety of perspectives are provided for the same issue. According to this, some follow-up questions are provided when necessary. For these reasons, the Semi-structured interview is selected.

9.2.2 Data Collection Procedure

As explained above, the data is collected by interviewing. The interviewer, who is also the researcher, starts each interview with a short self-introduction which provides a general concept of the research and background knowledge. Afterwards, all the outcomes described in table 9.1 are presented one by one. A short demo is conducted following the presentation for each artifact. In order to get both specific and general feedback, a set of specific questions are revealed in the end of each feature and the general questions are performed in the end of the presentation. The whole procedure could also be seen in Fig 9.2 and all the questions are depicted in section 9.2.4.

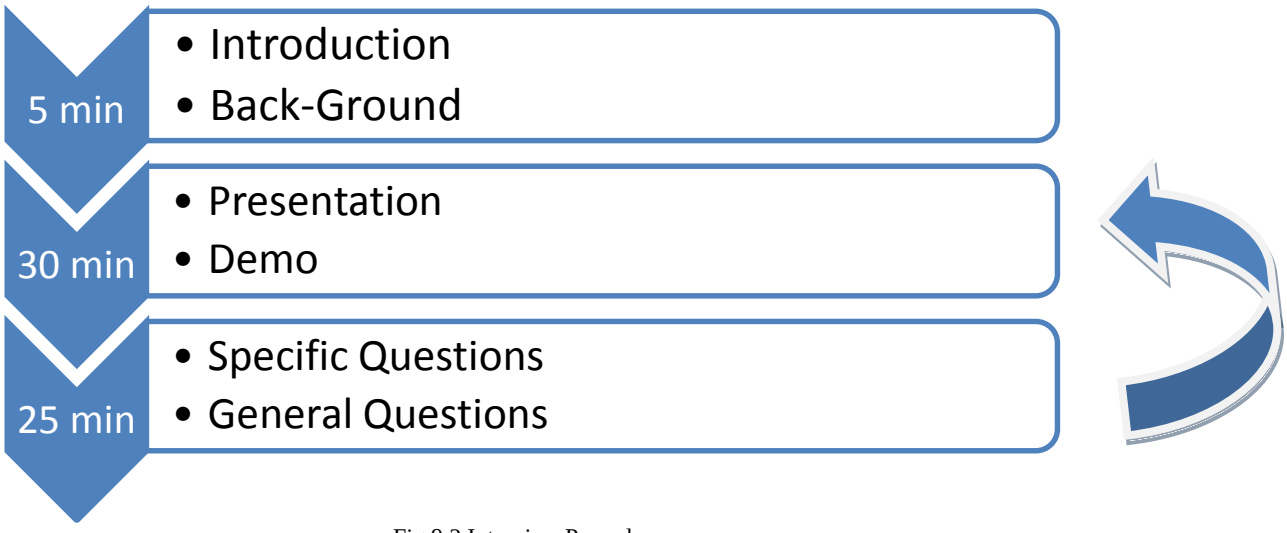


Fig 9.2 Interview Procedure

As shown above, the whole interview takes approximately one hour, among them, the question process takes totally 25 minutes and the other half an hour for presentation and demonstration. All the data from interviews are recorded and summarized.

9.2.3 Participants

All the participants are recruited by a gatekeeper in Volvo. The participants in the first stage are from the same team where the researcher works in, they are aware of the research work and are able to provide suggestions for later work. The second stage experts are all safety engineers, the selected participants are either have interests in or work closely to this thesis work.

- Interviewer: Researcher
- Background: Master program in Software Engineering in CHALMERS. Master thesis in Volvo GTT. Research work is about model transformation and safety analysis in EAST-ADL.

Stage 1:

- Interviewee A:
- Background: Systems Engineer, Methods Expert

- Interviewee B:
- Background: Systems Engineer, Tools Expert

- Interviewee C:
- Background: Systems Engineer, Safety Expert

- Interviewee D:
- Background: Systems Engineer, Methods Expert

Stage 2:

- Interviewee E:
- Background: Interviewee E is a Product Quality Assurer. He is working with assessing safety and quality of electrical and electronic functions by means of fault tree analysis, failure modes and effects analysis, etc.

- Interviewee F:
- Background: Interviewee F is a Diagnostic Engineer. He is working on a daily basis with modeling components and their error behavior, with the purpose of configuring error detection systems for use in workshops and during operation.

- Interviewee G:
- Background: Interviewee G is Diagnostics and Logging Technology Strategy responsible. He identifies and plans technology for detecting and recording errors as a basis for error correction in the field and in workshops.

9.2.4 Questions

Question, as an approach to get interviewee feedback, plays an important role in this data collection. The predefined questions are listed as follow. The questions revealed during interviews are recorded and depicted in data analysis section. In order to get a more measureable data from the interviewees, several features are graded corresponds to the evaluation criteria explained in section 9.1.

There are two kinds of questions among all outcomes corresponds to whether the presented outcome is a completed feature or a concept. For each outcome, the artifact success is measured by interviewees' grading. In addition, the graded feature needs to be compared with existing tools to get the benefits and drawbacks. What we care most is whether a feature or a product is applicable for the current working process, and if not, why it doesn't fit. Besides, general questions in the end are more open, they are used to get the interviewees' general feeling about this thesis work and their opinions of any improvements are applicable for this thesis or future work. The answers from interviewees are all valuable information to improve the current research and inspire the future work.

Since the presented outcomes of the thesis work vary for different evaluation stages. Besides, the focuses and interviewees' background of the two evaluation stages are different. Not all the questions are applicable for both stages. Some questions for the first evaluation stage are modified, added or deleted in the second one. The numbers "① ②" in front of each question indicate the evaluation stage the question is used for. In the second evaluation stage, no questions are performed for the features Generating Nominal Model from Simulink and Graphical Representation during the interview. The reason is that the participants in the second evaluation are safety engineers, they have more knowledge on Error Propagation and Fault Tree Analysis and also be able to provide more inputs in those two parts. Besides, some questions about the implementation and later expectation are not applicable anymore since the concept in the first stage evaluation are developed as artifacts in the second stage evaluation.

Question topic 1 : Generating Nominal Model from Simulink

- ① In your opinion, will this concept help the safety work?
- ① In order to get similar result, how the current working procedures look like for you?
- ① Is it necessary to bring this concept into reality? If not, why?

Question topic 2: Error Model Auto Generation

- ①② On a scale of 1 to 5, with 1 being poor and 5 being excellent, how satisfied are you with this product in terms of the following? And please specify the reason.
  - Ease of Use
  - Ease of Understanding(description)
  - How well the product achieves its goal
- ①② Is there any other product you know has a similar feature?
  - If yes, how does it work in this category? And compare with the presented artifact, what are the advantages and disadvantages?
  - If no, how satisfied are you with this product? Any improvements or suggestions?
- ①② Is this applicable for the current development process in your opinion? If not, what are the missing parts?

Question topic 3: Re-organize Error Model

- ①② On a scale of 1 to 5, with 1 being poor and 5 being excellent, how satisfied are you with this product in terms of the following? And please specify the reason.
  - Ease of Use
  - Ease of Understanding(description)
  - How well the product achieves its goal
- ①② Is this applicable for the current development process in your opinion? In not, what are the missing parts?
- ①② Any other manually done modifications you think is necessary to be automated?

Question topic 4: HiP-HOPS Fault Tree Analysis

- ①② In your opinion, will this concept help the safety work? How?
- ①② Is there anything you think is missing in the design or need to improve?
- ② On a scale of 1 to 5, with 1 being poor and 5 being excellent, how satisfied are you with this product in terms of the following? And please specify the reason.
  - Ease of Use
  - Ease of Understanding(description)

  - How well the product achieves its goal

Question topic 5: Graphical Representation

- ① In your opinion, does anything missing in the design?
- ① Is a graphical editor needed in order to understand the previous result and relations?

Question topic 6: Consistency Checking

- ①② On a scale of 1 to 5, with 1 being poor and 5 being excellent, how satisfied are you with this product in terms of the following? And please specify the reason.
  - Ease of Use
  - Ease of Understanding(description)
  - How well the product achieves its goal
- ① What do you think by using the user attribute to record the version? For feature "Increase Version"
- ①② Is there any other product you know has a similar feature?
  - If yes, how does it work in this category? And compare with the presented artifact, what are the advantages and disadvantages?
  - If no, how satisfied are you with this product? Any improvements or suggestions?
- ①② Is this applicable for the current development process in your opinion? In not, what are the missing parts?
- ② What do you think about this way of handling version control?

Question topic 1 is used to provide a background knowledge to bridge the gap between the current working knowledge and the technology developed in this research. Except topic 1, each question topic aims to solve one or several research questions. Question topic 2 aims to solve RQ1 which is *How to efficiently define an error propagation model from architecture model?* And RQ2 *How to reduce the manual work in refactoring the model?* is addressed in question topic 3. Hip-HOPS Fault Tree Analysis in question topic 4 aims to solve RQ3, which is *How to apply Fault Tree Analysis on EAST-ADL error model and relate the generated Fault Tree result with the model?* And RQ4 *How to visualize the error propagation model together with architecture model?* is covered in Question topic 5. Consistency Checking stated in Question topic 6 allows to collect feedbacks to answer RQ 5 *How to ensure consistency between nominal architecture models and error models?*

After all the RQs are addressed and features are presented, several general questions are performed in the end of each interview. The purpose of the general questions is getting a whole picture of the thesis work from the interviewees' point of view. Besides, this is also a step for the interviewee to order and prioritize the later work and provide any additional ideas they think are related and effect future work.

Question topic 7: General

- ① Pritorize the concept to be implementated(Importance)
  - Concistency Checking
    - Increase Version
  - HiP-HOPS FTA
    - Generating .hipxml in EATOP by clicking generating button
    - Showing the Fault Tree and Cut sets result in eclipse instead of a web browser

        - Marking the cut sets on the model tree
        - Save the generated files in a path decided by user
    - Graphical Representation
        - Showing a view of the error modeling and function modeling element
        - Showing the target relation between error and function model
- ① Improvements for short/long term
- ② General feeling of this thesis work
- ② Future expectation

9.3 Data Analysis

As a way of deriving conclusion from the collected data, data analysis is carried out in parallel with data collection in order to adjust and improve later design and implementation process (Runeson, Höst 2009). Commonly used qualitative data analysis methods are generation of theory and confirmation of theory (Seaman 1999). Generation of theory is intend to find theory or hypotheses from the collected data while confirmation of theory is applied to confirm a predefined hypothesis is true or not. Since several experts opinions are reflected in the design and implementation, some hypothesis are highly predictable. In this case, confirmation of theory is selected as the data analysis method in this evaluation.

9.3.1 Hypotheses

The hypotheses are mostly generated according to the research questions. The purpose of these hypotheses is to predict the feedbacks of the interviews and narrow them to a more structured conclusion. Each of the hypothesis corresponds to one or several research questions and one general hypothesis in the end indicating the acceptableness of the thesis work. Hypothesis 2 refers to RQ 1 and hypothesis 3 relate with RQ1 and RQ2. Hypothesis 4 corresponds to RQ3 while hypothesis 5 states the importance of RQ5. RQ4 is related with hypothesis 6. There is no question about the last hypothesis, but it will be validated by checking the confirmed rate of all hypotheses and the average score in evaluation criteria. Since confirmation of the theory is selected as the analysis method, after all feedbacks are collected, there will be a section in the end drawing the conclusion and confirm the hypotheses.

1. *The transformation between Simulink and EATOP is a must in future work*
2. *Error model generation feature is easy to use and understand. There is no existing tool which has a similar function.*
3. *Error model generation and reorganization will be useful for future work*
4. *Integrating HiP-HOPS to EATOP will enhance the usability of EATOP when applying Fault Tree Analysis*
5. *The consistency checking is quite necessary for both architecture design and safety analysis.*
6. *Graphical Representation is the most important feature to be implemented and it makes the modeling in EATOP much easier to work with.*
7. *The whole thesis research is acceptable in general.* (*On a scale of 1 to 5, with 1 being poor and 5 being excellent, if the overall average scale is more than 3, it is regarded as acceptable.)*

9.3.2 Data analysis framework

As a research study, the outcomes will not directly affect the current work. So the goal of this evaluation is to know whether this study provides a better understanding and improvements for later work. Besides, the feedbacks we are collecting are mostly about whether the outcome is acceptable and improvements for this study, the terms are mentioned by the interviewee are limited and mostly predictable. A summary for each topic is concluded and compared. As illustrated in Fig 9.3, the whole evaluation is a bottom-up procedure. The acceptableness is measured through summaries and conclusions. The summary is derived from the feedback for each question and the hypothesis is concluded from all summaries. The acceptableness also reflects whether the hypotheses are confirmed or not.

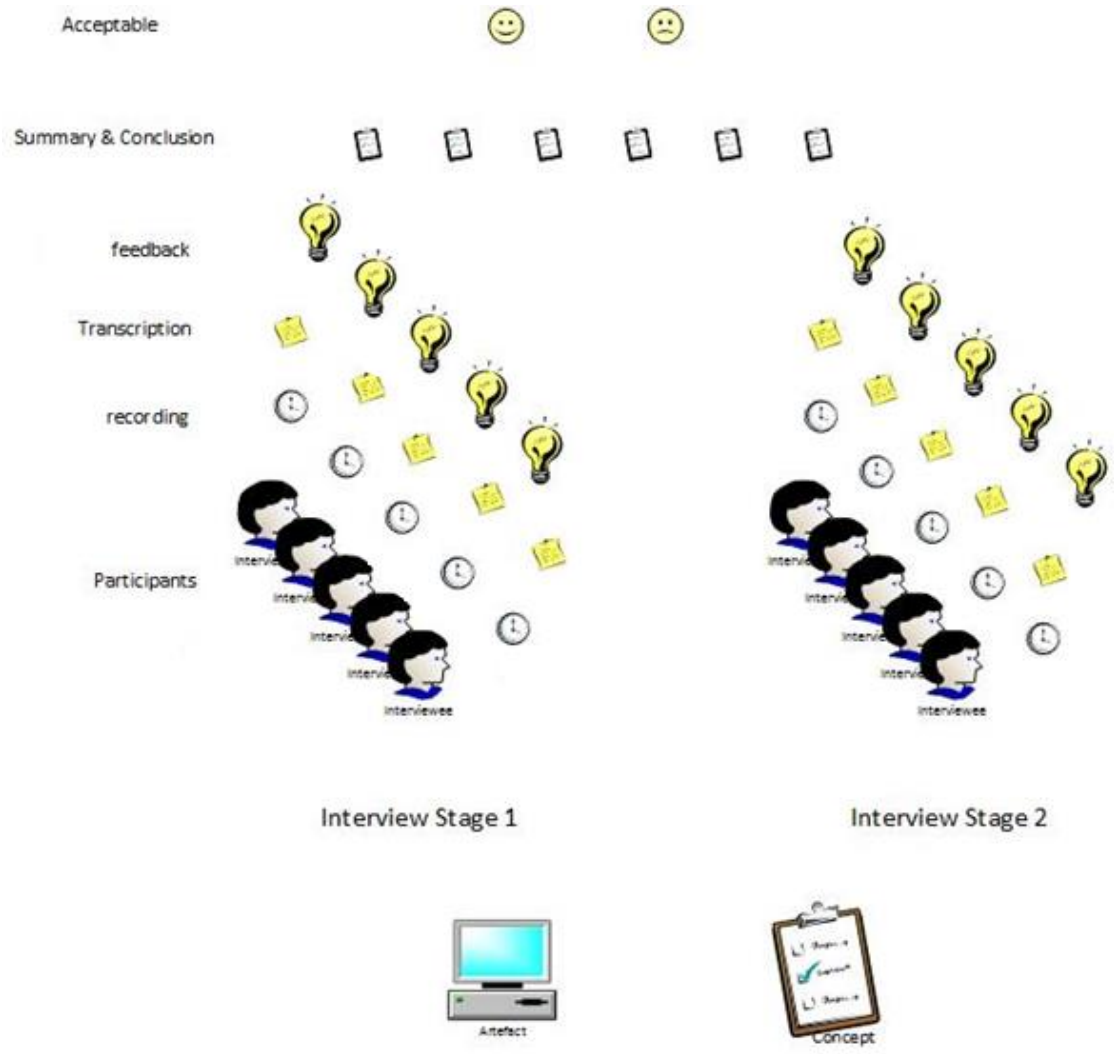


Fig 9.3 Data Analysis Framework

9.3.3 Summary of interview findings

For each topic, a list of transcripts from each interviewee is presented. Those transcripts have been rephrased by the interviewer without changing the meaning of interviewees' statements. All the questions for both evaluation stages are listed at the beginning of each feature with the applicable stage numbers and the transcripts are divided into each interviewee, the number of answered question are listed at the beginning of each answer. A summary is summarized from

those transcripts in the end of each topic and these summaries are the basis of later hypothesis confirmation.

Question topic 1: Generating Nominal Model from Simulink

1. ① *In your opinion, will this concept help the safety work?*
2. ① *In order to get similar result, how the current working procedures look like for you?*
3. ① *Is it necessary to bring this concept into reality? If not, why?*

Interviewee A:
1. This concept will enhance the model traceability in general. There should be some standard to support this transformation.
2 & 3. As far as I know, there is no similar features like that, but we do have some tools could work for the other way around, from EAST-ADL model to Simulink. But I guess, this is quite hard to do, especially difficult to integrate for the whole truck. So it's not so necessary.

Interviewee B:
1. This concept could help the safety work, but there are still several steps to take.
2. There is no existing EATOP plugin does this function. As I remember, Meta Edit may have something similar.
3. It's hard to say whether it's necessary or not, since it will change the way we work.

Interviewee C:
1. It makes EAST-ADL easier to work with, but the question is how? How to relate those two models.
2. As far as I know, there is no such tool doing this work.
3. Isn't the final goal of the safety work is to generate Fault Tree. HiP-HOPs already supports the Simulink model, so why we would take more effort to get the same result. While, anyway, I think this is a good idea in general.

Interviewee D:
1. It's hard to say whether it would help or not, but I would guess it would influence the future work. And it depends on how it would be implemented.
2. I'm not so familiar with this area actually, there is no such tool from my experience
3. I couldn't tell whether it's necessary or not to bring this concept into reality.

Summary:
The generating nominal model from Simulink would make EAST-ADL easier to understand and work with. But it may not be necessary to be implemented since how much it would affect the later work is still unknown and how to relate those two models would be a big challenge.

Question topic 2: Error Model Auto-generation

1. ①② *On a scale of 1 to 5, with 1 being poor and 5 being excellent, how satisfied are you with this product in terms of the following? And please specify the reason.*
    a. *Ease of Use*
    b. *Ease of Understanding(description)*
    c. *How well the product achieves its goal*

2. ①② *Is there any other product you know has a similar feature?*
    a. *If yes, how does it work in this category? And compare with the presented artifact, what are the advantages and disadvantages?*
    b. *If no, how satisfied are you with this product? Any improvements or suggestions?*
3. ①② *Is this applicable for the current development process in your opinion? If not, what are the missing parts?*

Table 9.2 List of results for Error Model AutoGeneration Question 1(Itve. Short for Interviewee)

	Itve. A	Itve. B	Itve. C	Itve. D	Itve. E	Itve. F	Itve. G
Ease of Use	5	4	4	4	4	4	3
Ease of Understanding	5	5	4	4	4	4	3
Achieving its Goal	4	4	4	5	4	4	3

Interviewee A:
2. No, there is no such tool does the error model generation. If what I understand correctly, this nominal model and error model do not handle the model behavior, so it would be good to have some kind of skeleton to contain the model behavior.
3. It should be a part of development process in the future.

Interviewee B:
2. Yes, there are error model tools existing, but I'm not sure whether it has this feature. For this case which you have been implemented, I think it would be good to have a progress bar when generating, this may not be necessary for a small model, but when it comes to the whole truck, the user need something to indicate this is working and how much left. Besides, it would be good to contain the model behavior which is similar as the ones in Simulink. But of course, this would be a big project to do, I just provide some ideas for future work.
3. It would be quite useful if also takes the memory consumption and big models into consideration.

Interviewee C:
1. I'm not so familiar with this tool, so I could only measure it and give suggestions depends on the first impression.
2. I don't know if there is any other product has a similar feature. One thing I think would make it more understandable for me is adding Internal Fault for each Error Model Type.

Interviewee D:
1. Everything looks fine for me. It's easy to use by clicking one button and easy to understand from your explanation. And it does what the requirement says.
2. But it would be better to have a graphical view showing the different models. Besides, I have no other comments.

Interviewee E:
1. It's not too difficult to use and learn. The description is understandable and yes, achieve its goal, so give it a 4 for each of them

2. Yes, absolutely. If there is a view of showing overview and layout would be nice. For the missing parts, I don't know and hard to think any for now.
3. Generating error modeling elements could also be done in SE tool, SystemWeaver and Simulink, but of course, those have to be done manually. So we can manually create error model and add fault probability for any of them if needed. But it would be good if we can also set the probability in this tool.

Interviewee F:
1. It seems easy to use and I understand what it does. But it's quite hard to say or give it a number for how well achieves its goal, but if the goal is auto generating the error model, yes it does.
2. Since there are many people working with this concept in another way, it would be hard to create or change the process. But it's possible to apply. I would like to see how the Fault Tree Analysis works before I find out the missing parts. But hardware is missing and I guess whenever an error model has been changed, and I use the automatic feature to regenerate a new version of error model, the previous change would not be able to reuse, this is not that convenient.
3. While, SE tool does not support this. But Rodon is able to handle that, manually. This kind of generation can be very complex for a big project.

Interviewee G:
1. I'm not so familiar with this area or concept. So it's not that easy for me to use, at least I need to learn the knowledge first. But it's also not that hard, so I would say it's at an average level. For achieving its goal, the auto-generation is one thing(goal), but whether it fits the current process is another thing(goal).
2. It's not possible to report DTCs(Diagnostic Trouble Code) from the error event and neither to generate the variant information.
3. I don't think there is any current tool has this feature, as far as I know.

Summary:
- Ease of Use: 4 in Average
- Ease of Understanding: 4.1 in Average
- Achieving its goal: 4 in Average

The feature Error Model Auto-generation is easy to understand and use and it achieves its goal from automate the error model generation perspective. The current tool has limited functions in this feature and it would help the current process by applying this feature. It would be better to take the model behavior into account in the future.

Question topic 3 : Re-organize Error Model

1. ①② *On a scale of 1 to 5, with 1 being poor and 5 being excellent, how satisfied are you with this product in terms of the following? And please specify the reason.*
    a. *Ease of Use*
    b. *Ease of Understanding(description)*
    c. *How well the product achieves its goal*
2. ①② *Is this applicable for the current development process in your opinion? In not, what are the missing parts?*
3. ①② *Any other manually done modifications you think is necessary to be automated?*

Table 9.3 List of results for Re-organize Error Model Question 1(Itve. Short for Interviewee)

	Itve. A	Itve. B	Itve. C	Itve. D	Itve. E	Itve. F	Itve. G
Ease of Use	5	3	4	4	4	n/a	n/a
Ease of Understanding	1&4	2	2	4	3	n/a	n/a
Achieving its Goal	4&5	4	4	4	4	n/a	n/a

Interviewee A:
1. It's quite easy to use in general and both features achieve their goals. But I don't get where the collapsing ports would be used for, so I give it "1", while collapsing prototypes is easy to understand.
2 & 3. I'm not involved in this part of work, so I don't know whether this feature is applicable for the current development process and no other manual modifications I could think about.

Interviewee B:
1. This feature is hard to understand, but it achieves its goal in general.
2. We don't use EAST-ADL in practice, so it's hard to measure the applicability. But graphical view would make it easier to understand the concept.
3. I'm relating this to Eclipse, there is a function called "Refactor" in eclipse, which would change all the related functions and so on. So I think it would be nice to have something similar in this model modification.

Interviewee C:
1. The "collapsing ports" is hard to understand.
2. I have no idea of whether this would be applicable for the safety work. But it would be better to show not only what, but how the error propagates.

Interviewee D:
1. It's clear in general.
2. I think it would be applicable for the later development.
3. I couldn't name any of the manual modifications to be automated.

Interviewee E:
1. I don't really get the collapsing ports, but it seems work as it suppose to
2. Yes, it is.
3. Yeah, there are a lot modifications needed to be done manually. When need to update the model, add or move hardware or functions, those changes are quite common. But it may not be able to automate since the machine cannot make decision for that. But it would be good to have something automatic for a complex project.

Interviwee F:
This feature is not shown during the interview. We skipped this feature according to the reasons below:
1. Time Limitation
2. The interviewee requested to focus more on fault tree analysis

Interviwee G:
This feature is not shown during the interview. We skipped this feature according to the reasons below:

1. Time Limitation
2. The interviewee's background knowledge does not support this feature

Summary:

- Ease of Use: 4 in Average
- Ease of Understanding: 2.7 in Average
- Achieving its goal: 4.2 in Average

The feature Re-organize Error Model is easy to use and it achieves its goal in general. But "Collapsing Ports" function is hard to understand. Since this tool is not widely used yet, it's hard to measure the applicability and name any improvements.

Question topic 4: HiP-HOPS Fault Tree Analysis

1. ①② *In your opinion, will this concept help the safety work? How?*
2. ①② *Is there anything you think is missing in the design or need to improve?*
3. ② *On a scale of 1 to 5, with 1 being poor and 5 being excellent, how satisfied are you with this product in terms of the following? And please specify the reason.*
    a. *Ease of Use*
    b. *Ease of Understanding(description)*
    c. *How well the product achieves its goal*

Table 9.4 List of results for HiP-HOPS Fault Tree Analysis Question 3(Itve. Short for Interviewee)

	Itve. A	Itve. B	Itve. C	Itve. D	Itve. E	Itve. F	Itve. G
Ease of Use	n/a	n/a	n/a	n/a	4	3.5	4
Ease of Understanding	n/a	n/a	n/a	n/a	4	3.5	4
Achieving its Goal	n/a	n/a	n/a	n/a	4	4	4

Interviewee A:

1. Yes, I think it would make the error model easier to work with. I would like this feature to be straightforward. The best would be showing the corresponding Fault Tree by clicking one button. Besides, how to save the generated file would be a problem.
2. It would be nice to somehow navigate or relate error model and Fault Tree Analysis.

Interviewee B:

1. Yes, in my opinion, it's useful to connect between error model and Fault Tree.
2. A progress bar would also be an improvement here. In addition, decorating the graphical tree and visualize the cut sets would be interesting to see.

Interviewee C:

1. Yes, if all the elements fit together.
2. Right now I couldn't think any to improve.

Interviewee D:

1. Yes, it saves time in general.
2. I'm not sure if this is possible, but relating the Fault Tree with nominal model would give the user some inspiration.

Interviewee E:
1. Definitely! Showing the minimal cutsets is good and it's actually better than the tool we use today since it brings the fault tree analysis and the model designing and modification to the same tool.
2. I don't know if anything is needed to improve. But it's really good to have this picture and it helps to understand the error propagation and improve the current working process.

Interviewee F:
1. This concept will help for sure. We have problems in current working, for example, timing issue is hard to catch from FTA, so it would be great help if it does help to find those kind of problems.
2. Still the probability issue, the error logic for severability of each error.
3. This feature is easy to use, but setting the logic probability is hard to achieve. But it achieves its goal quite well.

Interviewee G:
1. There are two perspectives I consider in safety work, one is hardware and one is logic. So it helps the safety work from the logic way. It's always hard to get everything in one tool, this tool makes it better at this point.
2. It would be good to provide suggestions and improvements to the system. Something like optimizer provides the optimization solution for the system.

Summary:
- Ease of Use: 3.8 in Average
- Ease of Understanding: 3.8 in Average
- Achieving its goal: 4 in Average

The HiP-HOPS Fault Tree Analysis is a useful feature to be integrated into EATOP. It's an improvement to bring the fault tree analysis and the model designing and modification to the same tool.

Question topic 5: Graphical Representation

1. ① *In your opinion, does anything missing in the design?*
2. ① *Is a graphical editor needed in order to understand the previous result and relations?*

Interviewee A:
1. In my opinion, it would be better to highlight the corresponding element in the tree view when clicking its graphical representation. Otherwise, it seems good enough.
2. Well, this graphical editor may not help too much for understanding since it is clear enough from the tree view and it requires quite a lot work, but it would make the modeling better to work with.

Interviewee B:
1. The connection between the graphical view and the tree view is a weak part here.
2. Yes, it's necessary to have this graphical view to support the manual work. But consider the working effort needed in this, bring a better design is more important for a thesis work.

Interviewee C:
1. Nothing missing as what I can think about.

2. It is quite important, at least for me, to understand the models and relations.

Interviewee D:
1. Showing the failures would be good to relate this with the previous Fault Tree Analysis. Besides, provide different colours for different elements or properties would be a plus for user to understand.
2. This graphical view is pretty much needed from my point of view.

Summary:
Graphical Representation is highly needed for easy understanding. But considering the work requires for graphical editor, it would be good to bring a concept for future work.

Question topic 6 : Consistency Checking

1. ①② *On a scale of 1 to 5, with 1 being poor and 5 being excellent, how satisfied are you with this product in terms of the following? And please specify the reason.*
    a. *Ease of Use*
    b. *Ease of Understanding(description)*
    c. *How well the product achieves its goal*
2. ① *What do you think by using the user attribute to record the version? For feature "Increase Version"*
3. ①② *Is there any other product you know has a similar feature?*
    a. *If yes, how does it work in this category? And compare with the presented artifact, what are the advantages and disadvantages?*
    b. *If no, how satisfied are you with this product? Any improvements or suggestions?*
4. ①② *Is this applicable for the current development process in your opinion? If not, what are the missing parts?*
5. ② *What do you think about this way of handling version control?*

Table 9.5 List of results for Consistency Checking Question 1 (Itve. Short for Interviewee)

	Itve. A	Itve. B	Itve. C	Itve. D	Itve. E	Itve. F	Itve. G
Ease of Use	3	3	5	4	4	4	4
Ease of Understanding	4	4	4	4	4	4	4
Achieving its Goal	4	3	4	4	4	4	4

Interviewee A:
1. There are several procedures needed in order to check the consistency, so not so easy to use for me at least. But easy to understand and do achieve its goal.
2. By using user attribute to set the version is quite clear.
3. "SE tool" which is a customized version of SystemWeaver has something to check the version. So inspired from this, it would be good to be able to check the history of versions.
4. The version control is definitely applicable for the current work and it is always a big issue to handle.

Interviewee B:

2. From what I understand, it may have time consuming issue when comes to a big model and the set version procedure is a little bit too manual.
3. There are lots of tools are doing the version control. I would like to get a warning message says "Changes happen in element X", for example, when X has been changed, and ask the user whether you would like to increase the version or not. So it's like auto-updating version.

Interviewee C:
1. It seems easy to use and easy to understand.
2. I have no opinion about using this user attribute element to record the version.
3. "SE tool", as I know, has the version control function.
4. Yes, this feature is useful everywhere and highly needed.

Interviewee D:
1. Works well for me in general.
2. Using this way to set version is easy to understand and seems easy to control.
3. In SE tools, there are several working stages which control the version, there are working stages, frozen stage and release stage. In working stage, the version could be modified, but when it comes to the frozen stage, everything should be freezed, but it's possible to unfreeze it to working stage. The last stage is release, at this level, everything should be settled and no more changes are needed.
4. I'm sure the version control feature would be quite useful for later work, but this is a big issue to manage.

Interviewee E:
3. SE tool can do the version control, but not in this way. The part is different or I would say which is missing here is checking more detailed information in the version control, for example, check if the calibration, connections have been changed.
4. Yes, this way is good and applicable.

Interviewee F:
3. Other tools have similar features, but not for this propose. For example, Rodon also does version control.
4. Very applicable

Interviewee G:
3. I'm not involved in this area, so I'm not aware of any tools with this feature
4. Yes, I would say it is applicable in many areas
4. It's a good way of doing it for me, easy to understand.

Summary:

- Ease of Use: 3.9 in Average
- Ease of Understanding: 4 in Average
- Achieving its goal: 3.9 in Average

Checking the consistency is a common feature for most of the work and it is highly needed. The way of checking the consistency between nominal model and error model is easy to understand and well achieve its goal. But it requires a little bit more procedures to do. Among all the current tools, SE tool has been mentioned as a good example of handling consistency by version control.

Question topic 7: General

1. ① *Prioritize the concept to be implemented(Importance/ Step to do)*
    a. *Consistency Checking*
        i. *Increase Version*
    b. *HiP-HOPS FTA*
        i. *Generating .hipxml in EATOP by clicking generating button*
        ii. *Showing the Fault Tree and Cut sets result in eclipse instead of a web browser*
        iii. *Marking the cut sets on the model tree*
        iv. *Save the generated files in a path decided by user*
    c. *Graphical Representation*
        i. *Showing a view of the error modeling and function modeling element*
        ii. *Showing the target relation between error and function model*
2. ① *Improvements for*
    a. *Short term*
    b. *Long term*
3. ② *General feeling of this thesis work*
4. ② *Future expectation*

The two tables below list the feedback for the first question. The numbers in the first table indicates the importance of each feature for the current process according to the interviewees' opinions. "1" means most important while "3" means least important. The numbers in the second table indicates the feature to do for later work by interviewees' suggestion. "1" here means first to do and "3" means last to do.

Table 9.6(a) Order of Feature importance

Importance	Interviewee A	Interviewee B	Interviewee C	Interviewee D
Consistency Checking	3	3	3	3
HiP-HOPS FTA	1	2	2	2
Graphical Representation	2	1	1	1

Table 9.6(b) Order of feature implementation

Step To Do	Interviewee A	Interviewee B	Interviewee C	Interviewee D
Consistency Checking	2	1	x	2
HiP-HOPS FTA	1	2	x	1
Graphical Representation	3	3	x	3

Interviewee A:
1. The most important I would say is HiP-HOPS Fault Tree Analysis, since this is the last step to finish the whole safety analysis procedure. And then it's graphical view to help user to understand. The last is consistency checking. But for what to do next, I would say HiP-HOPS is still the first one, but since not so much left in consistency checking at this stage, so this should be the second. Consider the amount of effort to put in a graphical editor, this could be in the end or even for later work.

Interviewee B:
1. As importance, I would give it bottom-up, so the most important is graphical editor, follow with Fault Tree Analysis and Consistency Checking. But if I'm the one doing it, I would do the other way around, finish Consistency Checking first, and then is Fault Tree Analysis and last if possible is Graphical Editor, considering the time I have the effort each feature is needed.
2. For later, it would be good to provide a manual or documentation for the user.

Interviewee C:
2. For the short term, I would like to have an Internal Fault for each Error Model Type as I said before. For long term, it would be nice to have some logical analysis which takes the actual functions to fault tree analysis with, for example, strong/weak relation and so on.

Interviewee D:
1. I would give graphical representation as most important, since the understanding is an issue here for beginners.
2. As a thesis work, the more important is to reveal concept and design than developing a fine product, so a good design is better than partly done for this graphical editor.

Interviewee E:
3. Yes, it's good and quite advanced and completed. Compare to the manual way, it's definitely an improvement and especially when model is needed to be updated. It requires a lot manual work when updating a model, so this is really helpful at least for my work.
4. Maybe should talk to the function developer to get more ideas and inputs. For the future, it would be good to have some features handles eliminating the possibility or causes to the failure.

Interviewee F:
3. It's good and useful in general. Easy to perform and seems matching the current work. And I'm looking forward to see the final result.
4. First is setting probability and severability in Fault Tree Analysis, which means a complete logic can be contained in the tool.

Interviewee G:
4. The work is good in general. It would be nice if you can make a demo showing the steps you've done today and we would like to have a group meeting with you which involve more related persons or if you would like to perform a presentation for us. It would be interesting to see for us all.

Summary:
Order of Feature Importance:

1. Graphical Representation 75% (3/4)
2. HiP-HOPS FTA 75% (3/4)
3. Consistency Checking 100%(4/4)

Order of Feature Implementation:

1. HiP-HOPS FTA 66.7% (2/3)
2. Consistency Checking 66.7% (2/3)
3. Graphical Representation 100% (3/3)

From the above statistic we can see even Graphical Representation is rated as the most important feature, it is listed by 3 out of 4 interviewees to be the last to be implemented consider the workload it requires. And HiP-HOPS Fault Tree Analysis is the first feature for later implementation. Besides, documentation and several modifications in auto-generating Error Model are the future improvements mentioned by the participants.

All participants in the second stage evaluation show their interests in this thesis work and accept this research and development as useful and helpful in general for safety work. Further expectations are related to the current working problems and it's highly expected to be solved in future work.

9.3.4 Hypotheses Confirmation and Reflection

The previous hypotheses are confirmed or modified in this section according to the feedback and summaries. Since several problems are revealed from the interviewees' comments, there will be a researcher's reflection section in the end to address the solutions to corresponding problems.

Confirmed Hypotheses

2. Error model generation feature is easy to use and understand. There is no existing tool which has a similar function

From the score all the interviewees provided, the Error Model Generation is easy to use and understand. Except interviewee B said there are error model tools existing, which does not mean those tools have auto-generating function, the other interviewees all agreed with no current tool has a similar function.

4. Integrating HiP-HOPS to EATOP will enhance the usability of EATOP when applying Fault Tree Analysis

Seven out of seven interviewees agreed the HiP-HOPS Fault Tree Analysis feature will help the safety work and enhancing the usability of EATOP.

5. The consistency checking is quite necessary for both architecture design and safety analysis.

Consistency Checking is mentioned by interviewee A, C, D and F as a highly useful feature in most of the current tools. Besides, interviewee A and D bring one example which handles consistency checking by version control to address the relation with the thesis work and they point out consistency checking is and will be a big issue to work with in the future.

7. The whole thesis research is acceptable in general. (*On a scale of 1 to 5, with 1 being poor and 5 being excellent, if the overall average scale is more than 3, it is regarded as acceptable.)*

As a general hypothesis, this item will be confirmed using the **evaluation criteria** explained in section 9.1.

- Artifact success

For all tree artifacts presented in the interview, they get an average 4 out of 5 as the ease of use. So in general, the outcome artifacts are easy to use.

$$Ease\ Of\ Use\ Average = (feature1)_{Avg} + (feature2)_{Avg} + (feature3)_{Avg} + (feature4)_{Avg}$$
$$= (4 + 4 + 3.8 + 4.9)/4 = 3.925$$

Since the efficacy is defined as the degree to which the artifacts achieve the expected results, the answer of question "how well the feature achieves its goal" answers this question. The general efficacy got 4.07 out of 5 in general, so we could say it is success in efficacy.

$$Achievegoal\ Average = (feature1)_{Avg} + (feature2)_{Avg} + (feature3)_{Avg} + (feature4)_{Avg} = (4 + 4.2 + 4 + 3.9)/4 = 4.025$$

- Efficiency

Efficiency in this evaluation is measured according to the metrics in ISO-9126(Software Product Quality-Part2), an international standard for the evaluation of software quality. In this standard, efficiency is divided into three parts, which are time behavior, resource usage and efficiency compliance. In this study, we measure the response time in time behavior for each feature. The response time is defined as the wait time the user experiences when issuing a request till the application finishing the process. Since the response time is applicable for many functions in one feature, we randomly sample one function in each feature for this efficiency measurement. The selected samples are "Create Error Model" in error model generation, the "Collapsing the selected prototypes" in re-organize error model, "HiP-HOPS Fault Tree Analysis" in HiP-HOPS integration and "Check Consistency" in consistency checking. Since the size of the model is a factor which affects the response time. We perform the evaluation shots under each feature's example model. They can be traced and found from Chapter 5 to Chapter 8 and this is also for easy understanding.

Response time(T):

T(second) = (time of gaining the result) - (time of command entry finished)

Table 9.7 Response Time(time unit: second)

	T(shot 1)	T(shot 2)	T(shot 3)
Create Error Model	4:21	4:09	3:78
Collapsing Prototypes	2:56	2:54	2:67
HiP-HOPS FTA	3:05	3:12	2:42
Check Consistency	0:90	0:76	0:72

Mean response fulfillment ratio(X):

Ti = response time for i-th evaluation(shot)
N = number of evaluations(sampled shots) = 3
Tmean = (Ti)/N, (for i=1 to N)
TXmean = required mean response time
X = Tmean / TXmean

Table 9.8 Mean response fulfillment ratio(time unit: second)

	Ti	Tmean	TXmean	X
Create Error Model	12:08	4:02	5	0.804
Collapsing Prototypes	7:77	2:59	2	1.295
HiP-HOPS FTA	8:59	2:86	2	1.43
Check Consistency	2.38	0:79	1	0.79

The TXmean value in Table 9.8 is provided by researcher according to the general feedback from participants. For interpretation of measured value, the response time is explained as 0<T, the sooner is the better. And the mean response fulfillment ratio is explained as 0<X, The nearer to 1 and less than 1 is the better. So as we can see all response times are less than 4

seconds, among them, the check consistency is even under 1 second. For the ratio X, two of them are less than 1 while the other two are over. But all of them are close to 1 and under 0.45 difference. It is unavoidable that it takes longer time for a bigger size model and this is common for all current tools. But according to the data above and participants' feedback, the response time of each feature is under a tolerance time.

- Novelty

"Novelty" indicates the improvements of the measured outcome comparing with existing knowledge. In this research, totally five concepts are provided in the interviews. Among all, except "consistency checking" and "graphical representation" has been handled in other existing tools, the rest are new knowledge in this area. While, even those two features have similar realization in other tools, but there is no existing knowledge support the same tool. So we could draw a conclusion that this research designed and created new knowledge in automotive field.

- Explanation capability

"Explanation capability" considers whether the designed objects are explained well enough in the outcome description or not.

$$Ease\ Of\ Understanding\ Average$$
$$= (feature1)_{Avg} + (feature2)_{Avg} + (feature3)_{Avg} + (feature4)_{Avg}$$
$$= (4.1 + 2.7 + 3.8 + 4)/4 = 3.65$$

Most artifacts and all concepts are reflected as easy to understand according to the feedback. But feature "collapsing ports" is pointed out as hard to understand by most interviewees, which means the description is not clear enough for the user to understand in general.

Since the ease of use and achieve goal averages are both over 3 and close to 4, the artifact success metric is adequately acceptable. Each feature's response time is under a tolerance time and the overall ease of understanding gets 3.64. There are flaws needed to be solved in the future design and implementation, but this thesis work is successful and acceptable in general. So we can draw the conclusion as "The whole thesis research is acceptable in general".

Rejected Hypotheses

1. Rejected: The transformation between Simulink and EATOP is a must in future work

1. Reformed: The transformation between Simulink and EATOP may not be necessary in a short term

The transformation makes EAST-ADL easier to understand and work with. But it may not be necessary to be implemented since how much it will affect the later work is still unknown and how to relate those two models is a big challenge.

3. Rejected: Error model generation and reorganization will be useful for their work

3. Reformed: Error Model generation will be useful for their work

Indicated by the score, error model auto-generation is quite useful for later work. But none of the participant is aware of whether the error model reorganization will be applicable or not in the future.

6. Rejected: Graphical Representation is the most important feature to be implemented and it makes the modeling in EATOP much easier to work with.

6. Reformed: Graphical Representation is the most important feature and it makes the modeling in EATOP much easier to work with. But according to the workload, it is not needed to be implemented in the thesis work

All interviewees indicate this fact in the graphical representation section. Besides, interviewee D brought this idea in Error Model generating section and emphasis it again in the end of the interview. In general question section, 75% of the interviewees prioritize graphical representation as the most important feature. While, three out of three interviewees suggest to provide a graphical design than implementing it in this thesis work.

Reflection

- Error Model Generation:

Interviewee A, B, C and E, F all mentioned to add the model behavior information in the nominal model or error model will be a future work. While currently, the failure logic is complete, i.e. all inputs affect all outputs, and the user is expected to tidy this manually. A refinement to be explained but not implemented is to parse the Simulink model (as this is a relevant source) to establish internal connectivity between ports as a basis for the failure logic expressions. It will still require manual intervention, as it is not possible to know which faults generate which failures, but it is a more precise starting point than now.

- Re-organize Error Model:

The goal of collapsing ports seems not easy for people to understand. This may due to the example demonstrated in the interviewees does not address the real problem this feature handles.

- HiP-HOPS Fault Tree Analysis:

Fault Tree Analysis is the final goal of building the error models. In this work, it gathers the architecture design, error model building and fault tree analysis into the same tool, this is regarded as a step forward compare with the current tool. More information about the failure type and possibility is needed to add in later work.

- Consistency Checking:

Several participants mentioned SE tool is a good example handling the consistency checking, it has three states of versions called work, frozen and release. The work version means this element is possible to modify. Frozen stage freezes the possibility of modification but it's possible to change it back to work stage. The release stage is a strict stage which cannot be transferred to other version stage nor modify the element. In the thesis work, we have two kinds of versions, since all the versions are specified in number, so each increase in integer is a release and the increase in decimal part indicates the working stage.

- Later work:

In short term, we focus on enhance the usability of EATOP and create better connection between HiP-HOPS and EATOP. For long term which is also future work, more attention will be paid on different aspects including enhancing the graphical representation and adding error behavior, possibility, severability for example, to the error logic.

9.3.5 Threats to Validity

Several threats to validity are taken into consideration in this evaluation. Those threats which could affect the validity result are categorized into threats to construct validity, to external

validity and to reliability. This validity category is provided in a guideline article of conducting and reporting case study research in software engineering (Runeson and Höst, 2009). Since the interview data collection and data analysis processes presented by Runeson and Höst are taken as a reference in this evaluation. The threats to validity provided by them then is regarded as highly related with this research evaluation and worth to be referred. Since the threats to validity are considered at the beginning of the evaluation, several adjustments have been applied in order to mitigate or avoid the expectable threats.

Construct validity is defined as how well the operational measures that are studied has captured the concepts under study (Bjarnason et al., 2013). One possible threat to construct validity is that the design of the interview may mislead the interviewees which affects the evaluation result. In order to reduce this risk, the interview is designed based on 5 research questions and reviewed for applicableness and consistency by both supervisors. Besides, a test interview between the researcher and the industry supervisor is conducted before any official evaluation is performed. All the variables in the interview design are kept the same in the test. The problems discovered during the test interview are avoided when it comes to later evaluation.

External validity refers to how well the findings are able to be generalized and to what extent the findings are of interest to other people outside the investigated case (Runeson and Höst, 2009). It's obvious that the selection bias is the main threat in this evaluation which prevent the findings to be generalized. To mitigate the selection bias, experts with different backgrounds from system area and safety area are selected as sampling. Even though, there might still be bias since all the interviewees are selected from the same company, but since most of the interviewees only hold the background knowledge but not the technology presented in this research, it is possible to assert that the analysis result can also be applied to other companies within the same area.

Reliability is also stated as one kind of validity which refers to how well the data and the analysis are independent from the specific researchers (Runeson and Höst, 2009). The threats to reliability are usually due to, for example, unclear questions during the interview or the unstructured coding. To increase the reliability in this evaluation, each question presented in the interview has been revised several times until get confirmation by both supervisors. Besides, to reduce the influence by single researcher, each transcript objectively depends on the record taking from each interview. So few researcher's subjective opinions affected the analysis result.

Chapter 10 Conclusion

10.1 Summary

The gaining complexity of architecture modeling in automotive industry makes the safety analysis error prone and hard to applying in an early phase. At the same time, safety analysis also faces the time consuming issue when all processes are done manually. The purpose of this study is investigating and improving EAST-ADL safety analysis working process. Five research questions are raised in four safety analysis working steps and each of them is addressed from Chapter 5 to Chapter 8. By performing design research methodology, four feature artifacts have been designed, implemented and evaluated. Each artifact is implemented as an Eclipse EATOP plugin coping with research questions in each safety analysis process. The evaluation of research outputs is performed as one to one interviews with system engineers and safety engineers in Volvo Group Trucks Technology. The whole evaluation is addressed as a data collection phase and data analysis phase in Chapter 9.

RQ1: How to efficiently define an error propagation model from architecture model
A one to one mapping is defined in order to match the architecture model element into error propagation model element. Besides, an error model auto generation feature is implemented based on the one to one mapping. The error model auto generation feature is evaluated as easy to understand and use and it achieves its goal to answer RQ1.

RQ2: How to reduce the manual work in refactoring the model?
This research focuses on reducing the manual work regards to collapsing error model prototypes and fault failure ports. A feature is designed and developed to automate the collapsing function. During the evaluation session, several interviewees pointed out that it will take time till applying this feature into their daily work, but this is useful for their future work and it does reduce the manual work while refactoring the model. So we draw the conclusion that the manual work is reduced to some extent in this research.

RQ3: How to apply Fault Tree Analysis on EAST-ADL error model and relate the generated Fault Tree result with the model?
By integrating HiP-HOPS into EATOP, it makes Fault Tree Analysis possible to be applied on EAST-ADL error model. At the same time, the Fault Tree Analysis result cutsets are related from Fault Tree perspective to EAST-ADL modeling perspective. This feature is evaluated as highly useful during safety analysis and it improves the current safety analysis status from late stage of an architecture design into early stage. RQ3 is well answered in this research.

RQ4: How to visualize the error propagation model together with architecture model?
By providing a graphical representation feature, the structure and relation between error propagation model and architecture model are visualized to some extent. The feedback from

evaluation proves that visualization is highly needed in order to better understand an architecture design and safety analysis.

RQ5: How to ensure consistency between nominal architecture models and error models?
The Version Control plugin handles the inconsistency problem between nominal models and error models by checking the version number. The majority of the interviewees state that version inconsistency is one of the biggest problem during system development and this research provides one possible solution while coping with model inconsistency.

10.2 Contribution and Limitation

This research improves safety analysis process in the automotive domain. It automates the manual work in different safety analysis processes and bridges the gap between system design and safety design in EAST-ADL. It provides a new concept and artifact for handling model inconsistency and visualize the model dependency at a certain level. In addition, it brings fault tree analysis to an early stage of a system design which reduce the flaws in later work.

At the same time, there are limitations in this research. No other experts than the research supervisors and interviewees are involved in providing feedback. EATOP is selected as the research platform and only limited attention is given to other tooling. Besides, during the given period of time, the design and implementation are not able to cover all possible reality situations. The resources that have been collected and analyzed are also in a limited amount.

10.3 Future Work

The research presented in this thesis has raised some further questions that are needed to be answered. From the evaluation feedback, error logic will be taken into consideration in addressing the error probability for error model generation and further investigation is needed for proving the usability of error model reorganization. Currently, different cutsets by Fault Tree Analysis cannot be different from the cutset decoration. So the future work will include finding a way to efficiently present different cutsets in EAST-ADL Fault Tree Analysis. As Interviewee A mentioned, consistency checking is and will always be a big issue to handle in system architecture design area, the artifact developed in this research is needed to be improved from both performance and functionality perspectives. And the future work for graphical support could be seen in two approaches. The first is applying the generated diagram to a generic schema, which can be imported and exported through a third party tool for diagram editing. Another approach is integrating the existing graphical editor to be compatible with the latest EAST-ADL version.

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Appendix A – I
BBW_4Wheel ErrorModelGeneration Screenshot

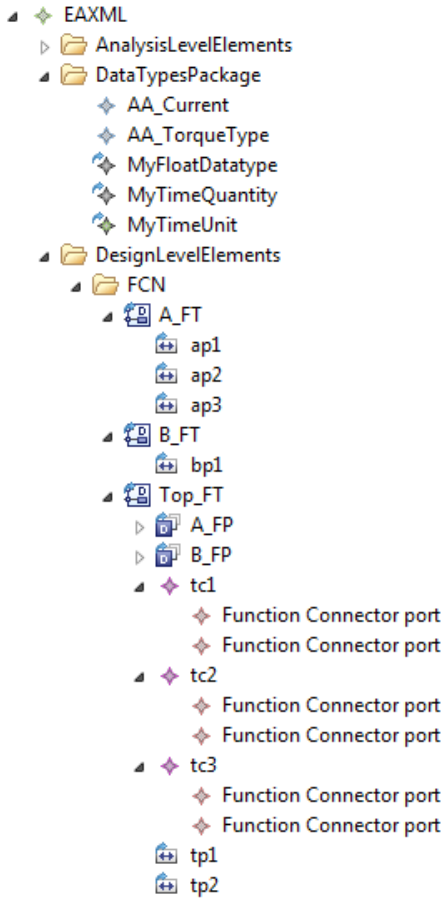


Fig A.1 Example Function Model

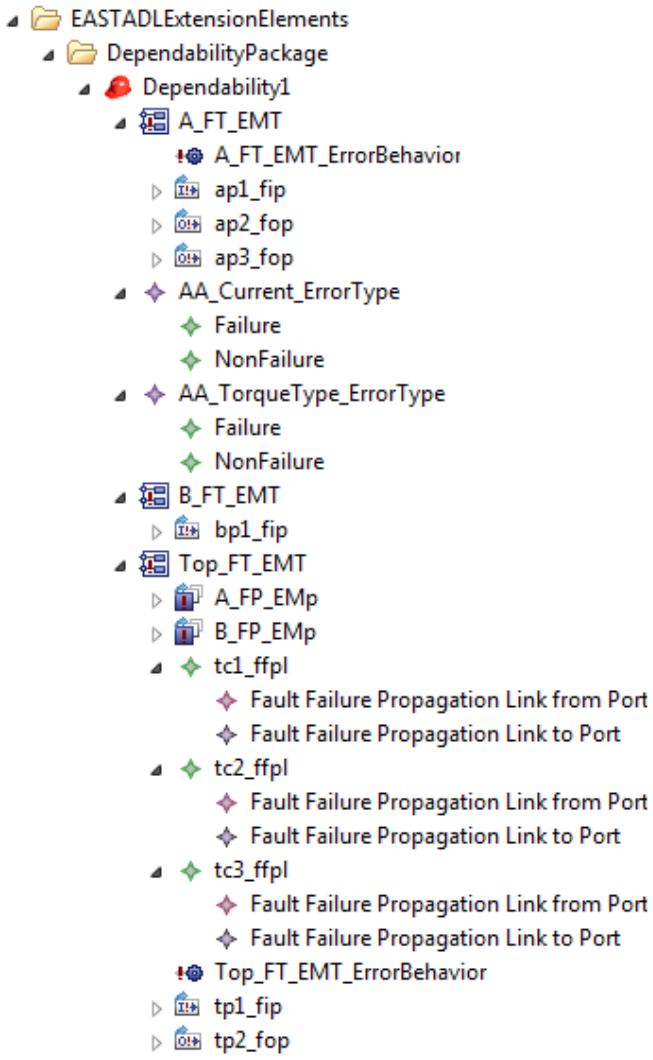


Fig A.2 Example Error Model

Appendix A – II
BBW_4Wheel ErrorModel Re-organization Screenshot

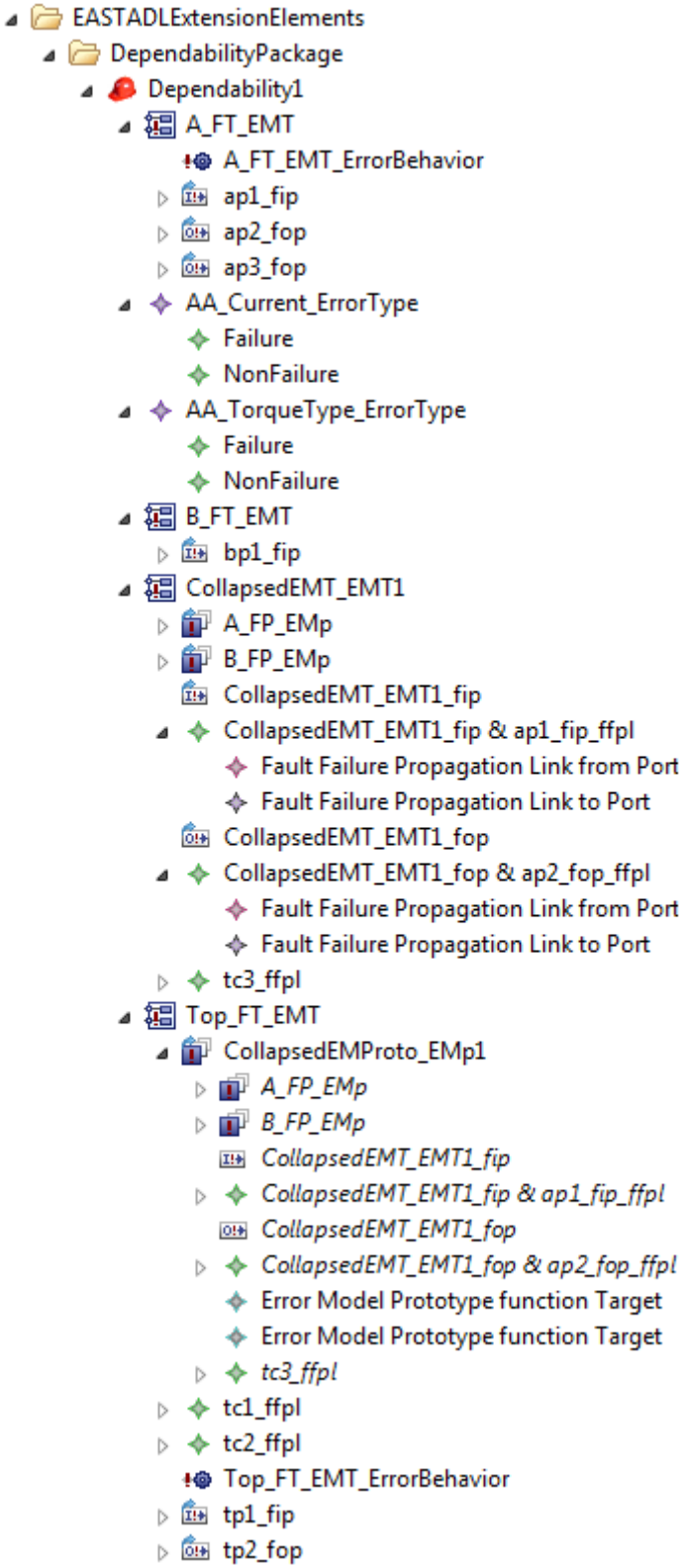


Fig A.3 Collapsed ErrorModelPrototypes

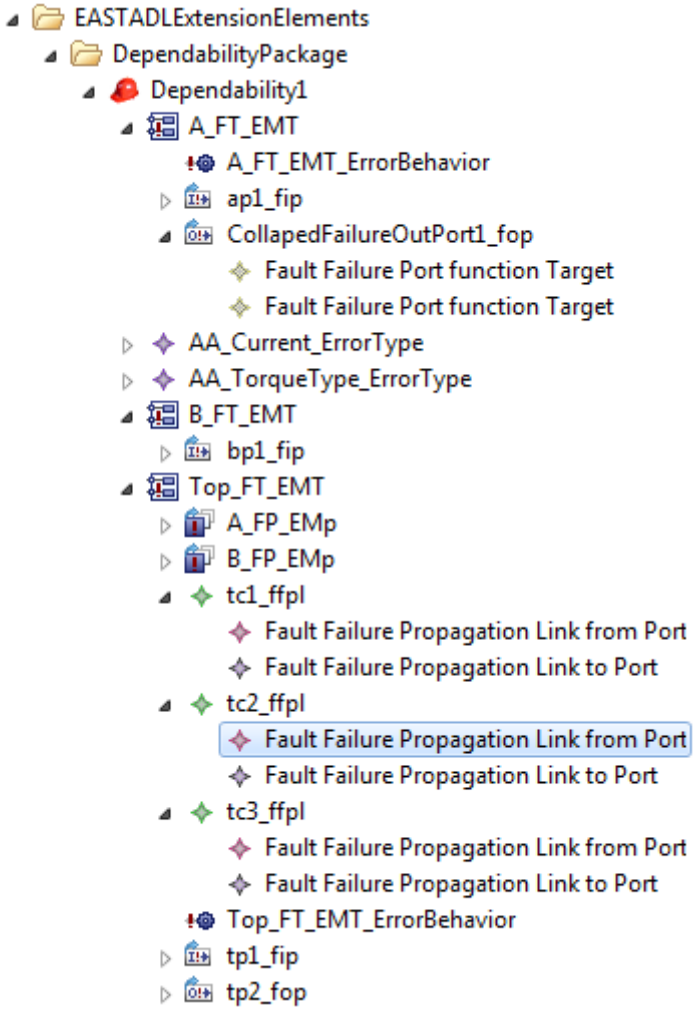


Fig A.4 Collapsed FaultFailurePorts

Appendix A – III
Three Columns Algorithm

```
/***
* Reorganize the ErrorModelPrototype to empLeft,empMid,empRight according to the
connection
***/
private void ReorganizeEMP(ErrorModelType selectedEMT) {
            EList<FaultInPort> emtInPorts = selectedEMT.getExternalFault();
            EList<FailureOutPort> emtOutPorts = selectedEMT.getFailure();
            EList<FaultFailurePropagationLink> ffCs =
            selectedEMT.getFaultFailureConnector();
            for(FaultFailurePropagationLink ffC: ffCs){
                        FaultFailurePropagationLink_fromPort fromPort =
                        ffC.getFromPort();
                        FaultFailurePropagationLink_toPort toPort =
                        ffC.getToPort();
                        FaultFailurePort fromffPort =
                        fromPort.getFaultFailurePort();
                        FaultFailurePort toffPort =toPort.getFaultFailurePort();
                        EList<ErrorModelPrototype> fromPortEMPs =
                        fromPort.getErrorModelPrototype();
                        EList<ErrorModelPrototype> toPortEMPs =
                        toPort.getErrorModelPrototype();
                        if(emtInPorts.contains(fromffPort)){
                                    empLeft.add(toPortEMPs.get(0));
                        }
                        if(emtInPorts.contains(toffPort)){
                                    empLeft.add(fromPortEMPs.get(0));
                        }
                        if(emtOutPorts.contains(fromffPort)){
                                    empRight.add(toPortEMPs.get(0));
                        }
                        if(emtOutPorts.contains(toffPort)){
                                    empRight.add(fromPortEMPs.get(0));
                        }
            }// End of each FaultFailurePropagationLink ffCs

            EList<ErrorModelPrototype> emps = selectedEMT.getPart();
            for(ErrorModelPrototype emp:emps){
                        ErrorModelType empType = emp.getType();
                        // When one prototype only has outports
                        if(empType.getFailure().size()>0 &&
                        empType.getExternalFault().size()==0){
                                    // Get the elements for empExactLeft
                                    empExactLeft.add(emp);
                        }
                        // When one prototype only has inports
                        if(empType.getFailure().size()==0 &&
                        empType.getExternalFault().size()>0){
                                    // Get the elements for empExactLeft
                                    empExactRight.add(emp);
                        }
            }
            empAll = selectedEMT.getPart();
            //intersection of empLeft amd empRight
            Set interLR = new HashSet();
```

```
            interLR.addAll(empLeft);
            interLR.retainAll(empRight);
            // Union of empLeft and empRight
            Set unionLR = new HashSet();
            unionLR.addAll(empLeft);
            unionLR.addAll(empRight);
            // Remove the intersection from both Left and Rigth and add to Mid
            empLeft.removeAll(interLR);
            empRight.removeAll(interLR);
            empMid.addAll(interLR);
            // Add the complementary set of union to Mid
            Set compLR = new HashSet();
            compLR.addAll(empAll);
            compLR.removeAll(unionLR);
            empMid.addAll(compLR);
            // Resolve Repetition in each collection
            empLeft = ResolveCollectionRepetition(empLeft);
            empMid = ResolveCollectionRepetition(empMid);
            empRight = ResolveCollectionRepetition(empRight);
            // Remove all empExactLeft from Mid and add to Left
            empMid.removeAll(empExactLeft);
            empLeft.addAll(empExactLeft);
            // Remove all empExactRight from Mid and add to Right
            empMid.removeAll(empExactRight);
            empRight.addAll(empExactRight);

            }

            /***
             * Resolve Repetition in each collection

            ***/
            private Collection<ErrorModelPrototype> ResolveCollectionRepetition(
                                    Collection<ErrorModelPrototype> col) {
            // TODO Auto-generated method stub
            HashSet hs = new HashSet();
            hs.addAll(col);
            col.clear();
            col.addAll(hs);
            return col;
}
```

Appendix B – EAST-ADL 2.1.12 Class Diagram

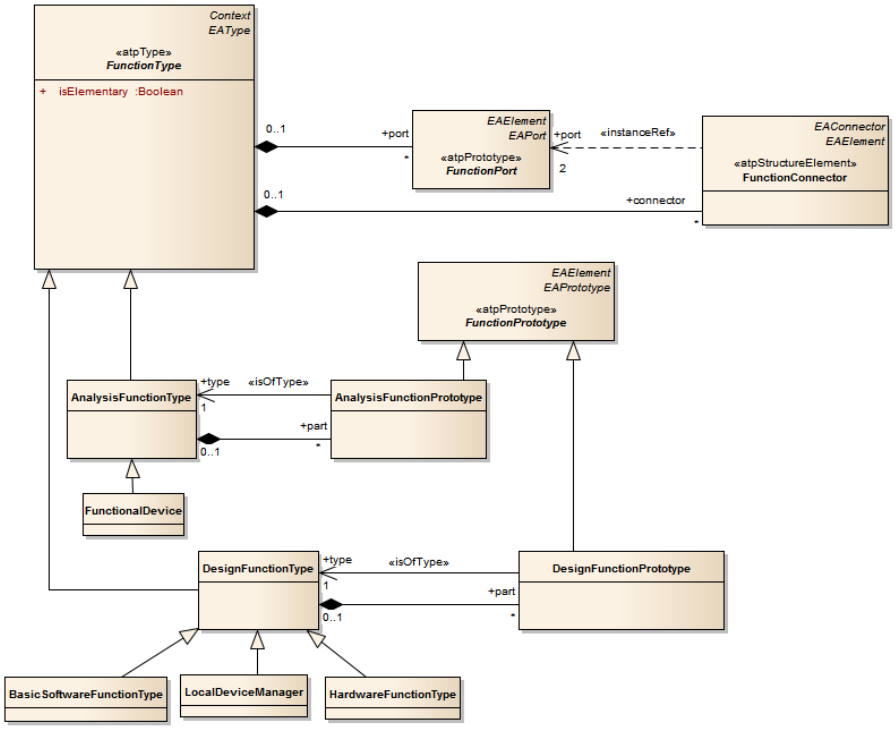


Fig B.1 Function Modeling

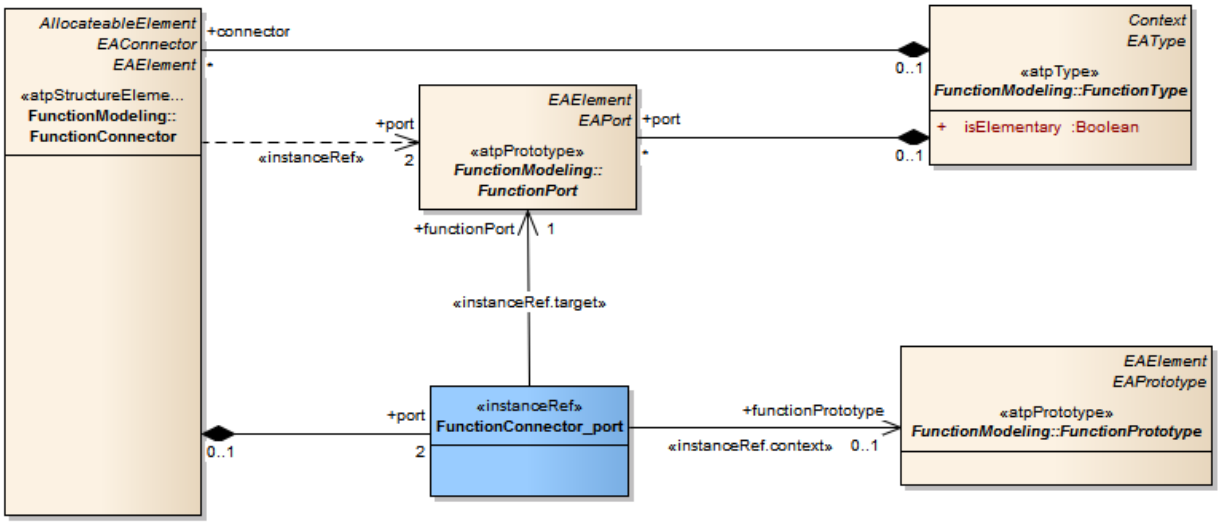


Fig B.2 Function Connector

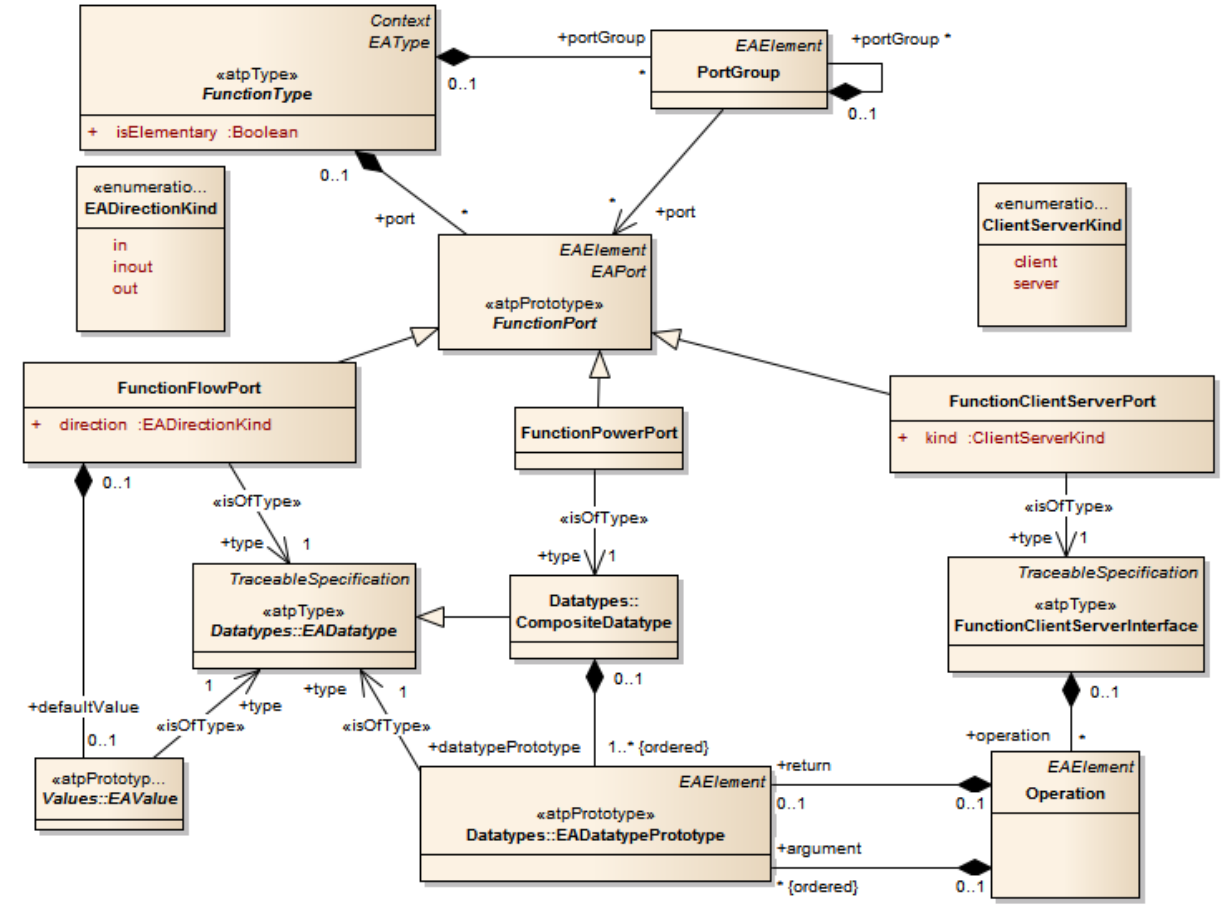


Fig B.3 Function Port

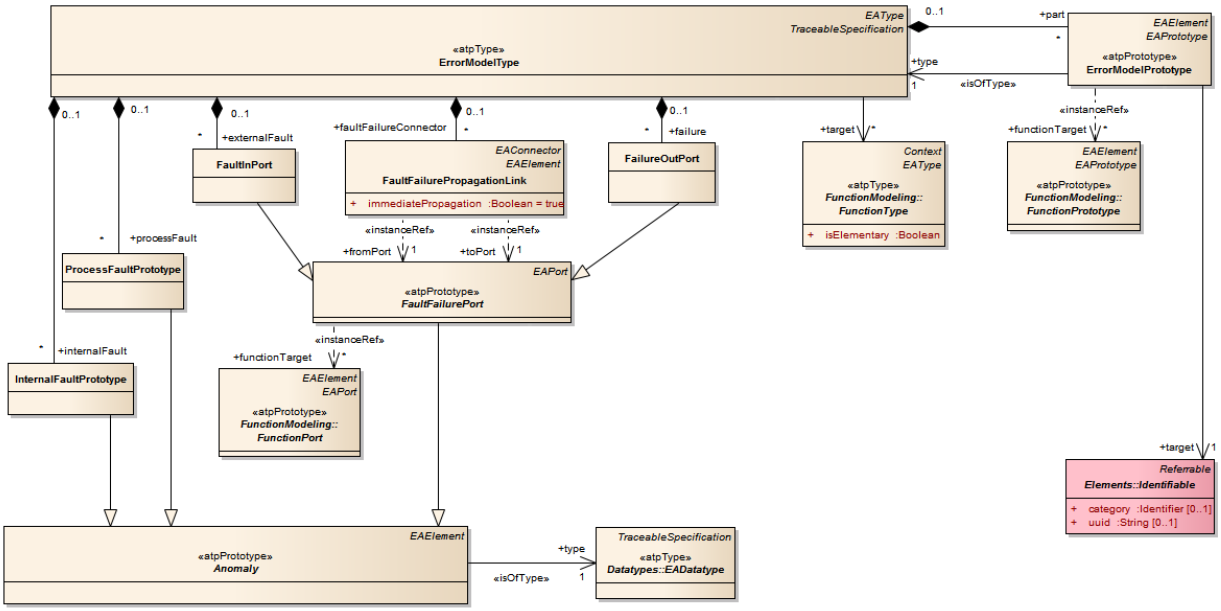


Fig B.4 Error Modeling

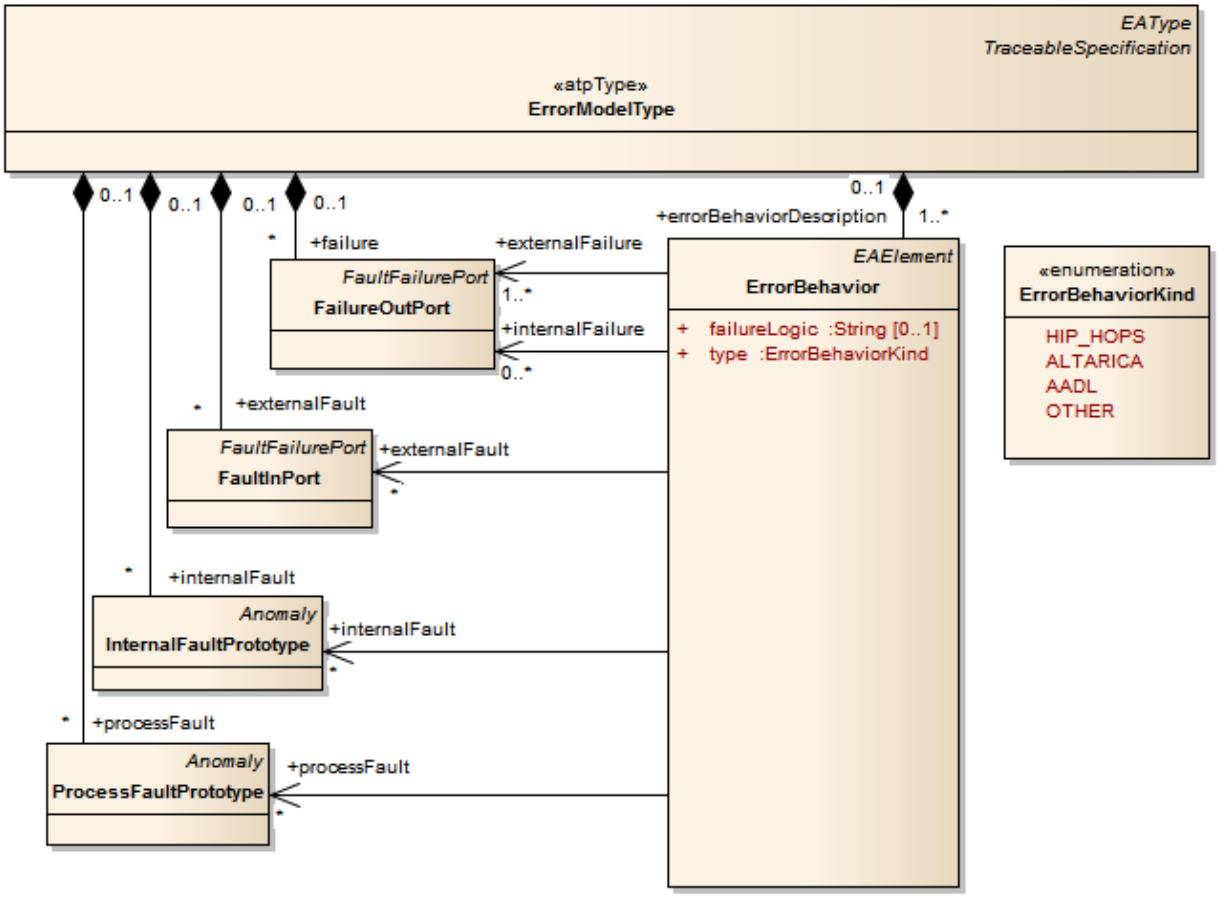
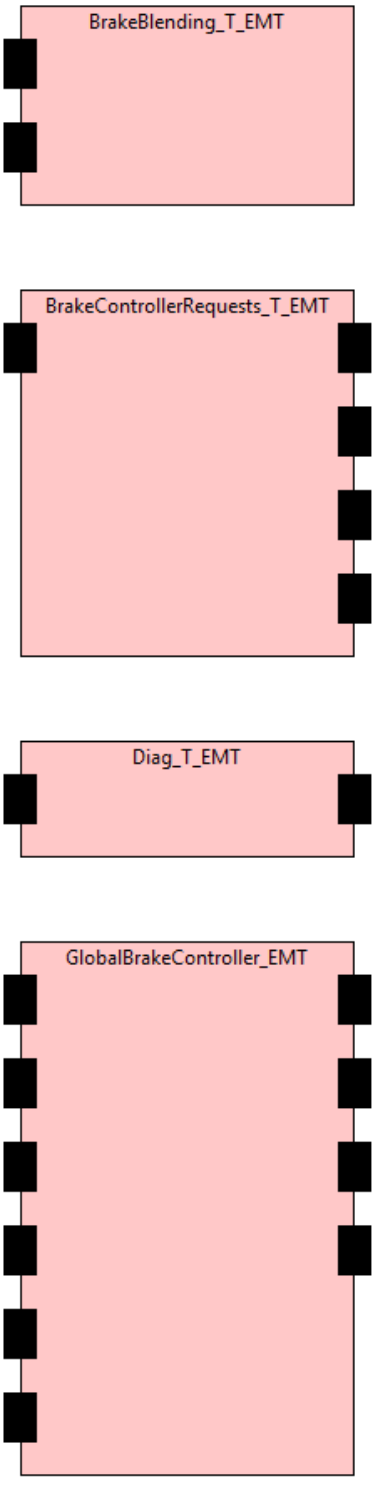


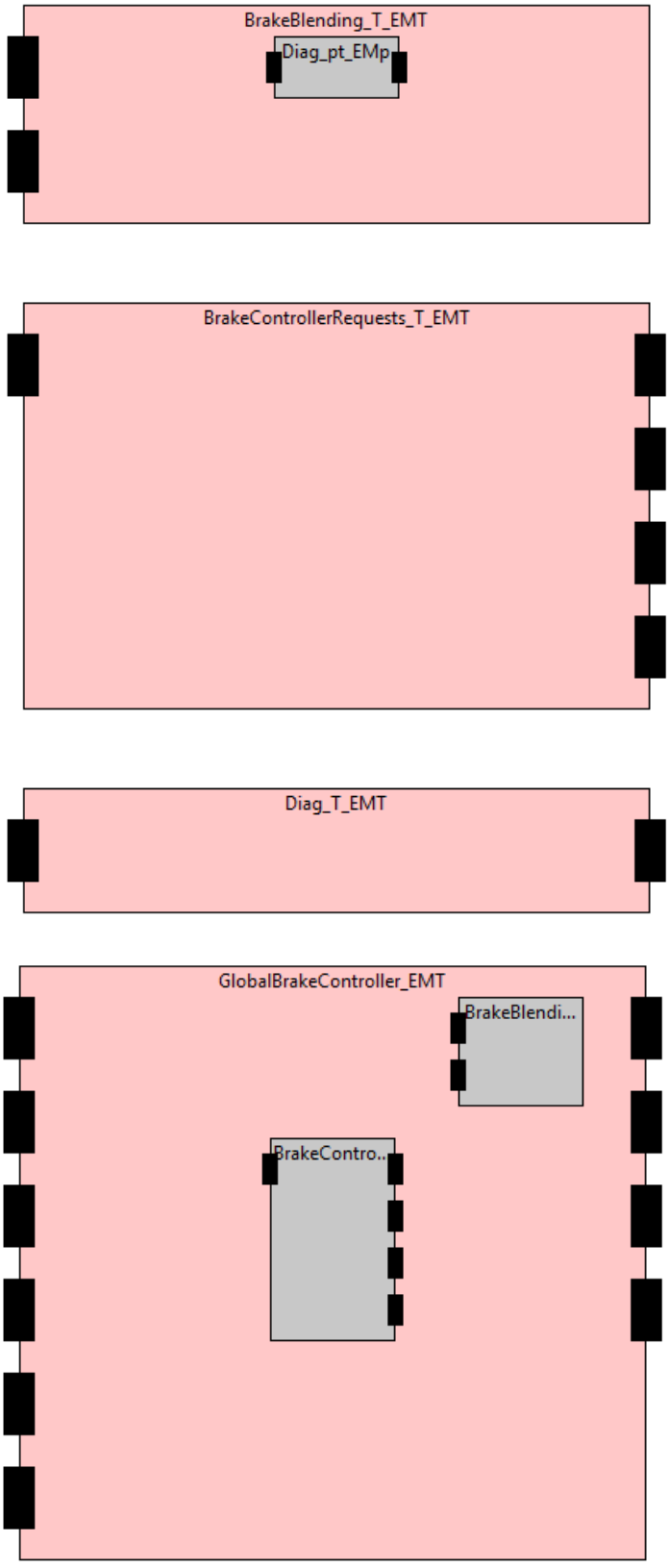
Fig B.5 Error Behavior

Appendix C – I Example Views in GlobalBrakeController Model – Diagram

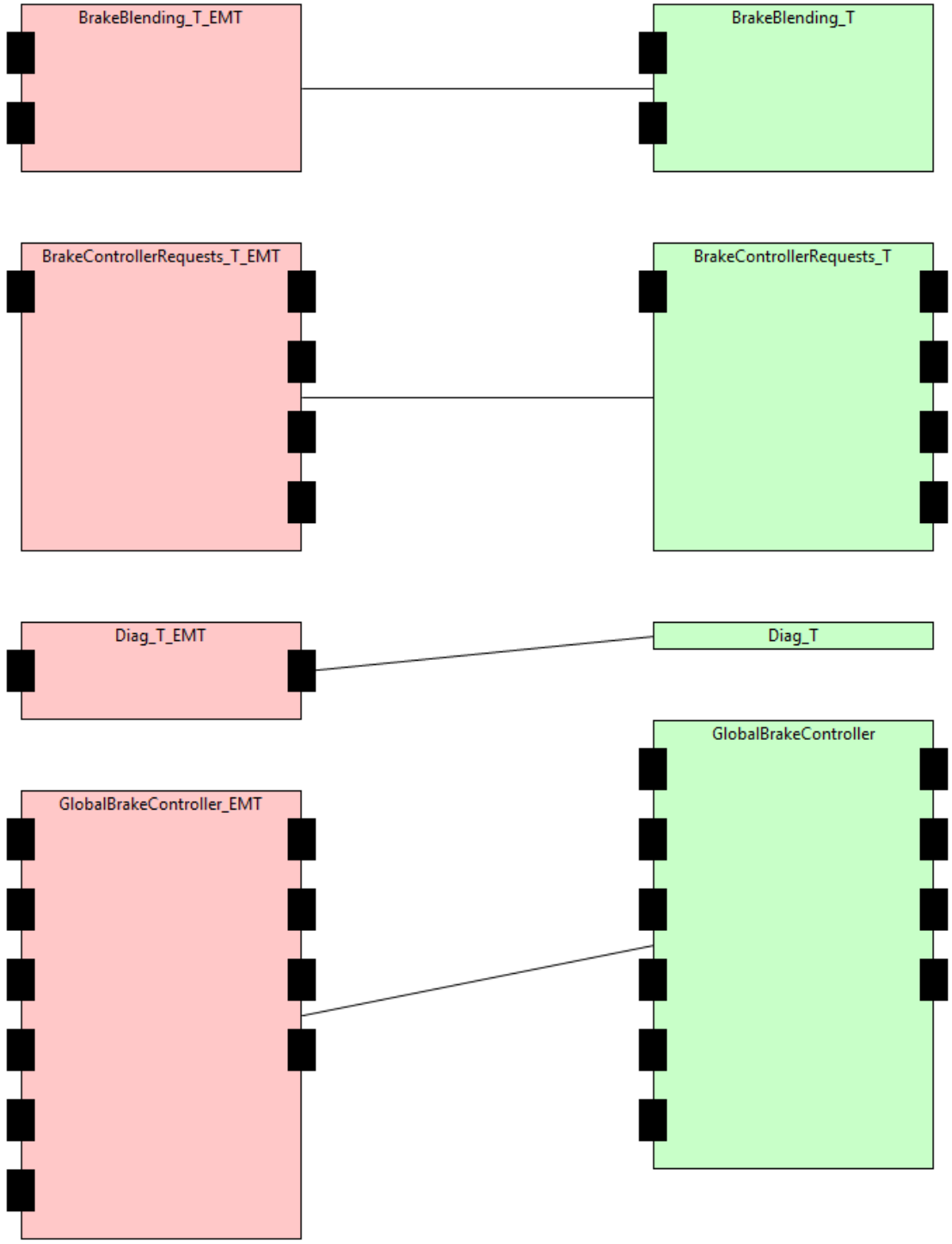
ErrorModelType view



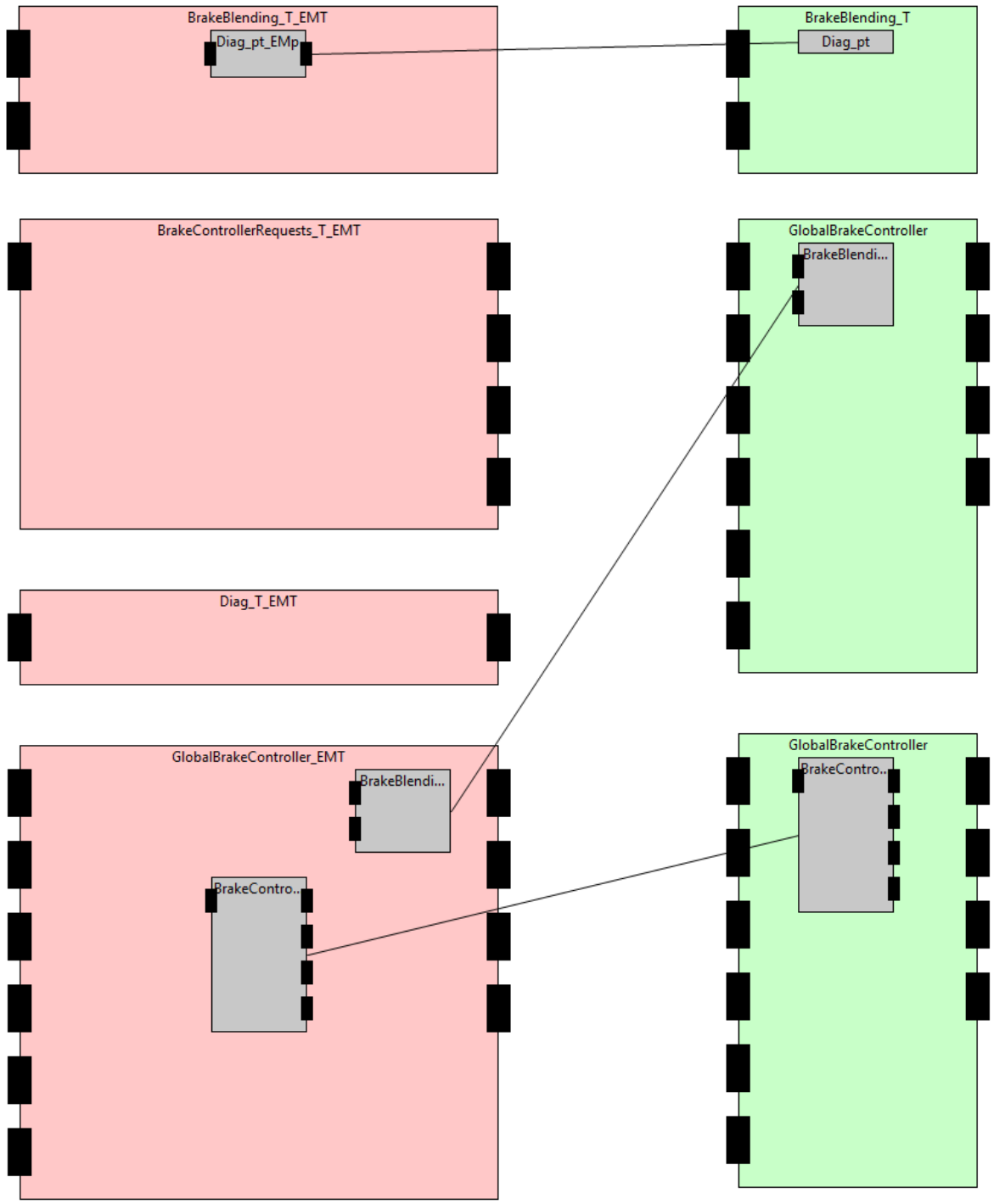
ErrorModelPrototype view



ErrorModelType with Target view



ErrorModelPrototype with Target view



Appendix C – II Example Views in GlobalBrakeController Model – XML

The XML generated and presented follow a preliminary graphical exchange format.

ErrorModelType view

```
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<Diagram>
    <ModelFile>BBW_4Wheel_2.1.12EM.eaxml</ModelFile>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/BrakeBlending_T_
EMT</Element-Ref>
        <Name>BrakeBlending_T_EMT</Name>
        <Box>
            <xPos>400</xPos>
            <yPos>50</yPos>
            <zPos>0</zPos>
            <Size x="200" y="120"/>
            <Color r="255" g="200" b="200"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/BrakeBlending_T_
EMT/BrakeRequest_fip</Element-Ref>
        <Name>BrakeRequest_fip</Name>
        <Box>
            <xPos>390</xPos>
            <yPos>70</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/BrakeBlending_T_
EMT/BrakeRequestBlended_fip</Element-Ref>
        <Name>BrakeRequestBlended_fip</Name>
        <Box>
            <xPos>390</xPos>
            <yPos>120</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
```

```
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/BrakeControllerR
equests_T_EMT</Element-Ref>
        <Name>BrakeControllerRequests_T_EMT</Name>
        <Box>
            <xPos>400</xPos>
            <yPos>220</yPos>
            <zPos>0</zPos>
            <Size x="200" y="220"/>
            <Color r="255" g="200" b="200"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/BrakeControllerR
equests_T_EMT/BrakeRequest_fip</Element-Ref>
        <Name>BrakeRequest_fip</Name>
        <Box>
            <xPos>390</xPos>
            <yPos>240</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/BrakeControllerR
equests_T_EMT/BrakeTorqueFL_fop</Element-Ref>
        <Name>BrakeTorqueFL_fop</Name>
        <Box>
            <xPos>590</xPos>
            <yPos>240</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/BrakeControllerR
equests_T_EMT/BrakeTorqueFR_fop</Element-Ref>
        <Name>BrakeTorqueFR_fop</Name>
        <Box>
            <xPos>590</xPos>
            <yPos>290</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/BrakeControllerR
equests_T_EMT/BrakeTorqueRL_fop</Element-Ref>
```

```
        <Name>BrakeTorqueRL_fop</Name>
        <Box>
            <xPos>590</xPos>
            <yPos>340</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/BrakeControllerR
equests_T_EMT/BrakeTorqueRR_fop</Element-Ref>
        <Name>BrakeTorqueRR_fop</Name>
        <Box>
            <xPos>590</xPos>
            <yPos>390</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/Diag_T_EMT</Elem
ent-Ref>
        <Name>Diag_T_EMT</Name>
        <Box>
            <xPos>400</xPos>
            <yPos>490</yPos>
            <zPos>0</zPos>
            <Size x="200" y="70"/>
            <Color r="255" g="200" b="200"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/Diag_T_EMT/DiagR
equest_receive_fip</Element-Ref>
        <Name>DiagRequest_receive_fip</Name>
        <Box>
            <xPos>390</xPos>
            <yPos>510</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/Diag_T_EMT/DiagR
equest_request_fop</Element-Ref>
        <Name>DiagRequest_request_fop</Name>
        <Box>
            <xPos>590</xPos>
```

```
            <yPos>510</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/GlobalBrakeContr
oller_EMT</Element-Ref>
        <Name>GlobalBrakeController_EMT</Name>
        <Box>
            <xPos>400</xPos>
            <yPos>610</yPos>
            <zPos>0</zPos>
            <Size x="200" y="320"/>
            <Color r="255" g="200" b="200"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/GlobalBrakeContr
oller_EMT/BrakeRequest_fip</Element-Ref>
        <Name>BrakeRequest_fip</Name>
        <Box>
            <xPos>390</xPos>
            <yPos>630</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/GlobalBrakeContr
oller_EMT/DriverReqTorqueIn_fip</Element-Ref>
        <Name>DriverReqTorqueIn_fip</Name>
        <Box>
            <xPos>390</xPos>
            <yPos>680</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/GlobalBrakeContr
oller_EMT/WheelSpeed_FLIn_fip</Element-Ref>
        <Name>WheelSpeed_FLIn_fip</Name>
        <Box>
            <xPos>390</xPos>
            <yPos>730</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
```

```
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/GlobalBrakeContr
oller_EMT/WheelSpeed_FRIn_fip</Element-Ref>
        <Name>WheelSpeed_FRIn_fip</Name>
        <Box>
            <xPos>390</xPos>
            <yPos>780</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/GlobalBrakeContr
oller_EMT/WheelSpeed_RLIn_fip</Element-Ref>
        <Name>WheelSpeed_RLIn_fip</Name>
        <Box>
            <xPos>390</xPos>
            <yPos>830</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/GlobalBrakeContr
oller_EMT/WheelSpeed_RRIn_fip</Element-Ref>
        <Name>WheelSpeed_RRIn_fip</Name>
        <Box>
            <xPos>390</xPos>
            <yPos>880</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/GlobalBrakeContr
oller_EMT/BrakeTorqueFL_fop</Element-Ref>
        <Name>BrakeTorqueFL_fop</Name>
        <Box>
            <xPos>590</xPos>
            <yPos>630</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
```

```
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/GlobalBrakeContr
oller_EMT/BrakeTorqueFR_fop</Element-Ref>
        <Name>BrakeTorqueFR_fop</Name>
        <Box>
            <xPos>590</xPos>
            <yPos>680</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/GlobalBrakeContr
oller_EMT/BrakeTorqueRL_fop</Element-Ref>
        <Name>BrakeTorqueRL_fop</Name>
        <Box>
            <xPos>590</xPos>
            <yPos>730</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/GlobalBrakeContr
oller_EMT/BrakeTorqueRR_fop</Element-Ref>
        <Name>BrakeTorqueRR_fop</Name>
        <Box>
            <xPos>590</xPos>
            <yPos>780</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
</Diagram>
```

ErrorModelType with Target view

```
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<Diagram>
    <ModelFile>BBW_4Wheel_2.1.12EM.eaxml</ModelFile>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/BrakeBlending_T_
EMT</Element-Ref>
        <Name>BrakeBlending_T_EMT</Name>
        <Box>
            <xPos>150</xPos>
            <yPos>50</yPos>
            <zPos>0</zPos>
```

```
            <Size x="200" y="120"/>
            <Color r="255" g="200" b="200"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/BrakeBlending_T_
EMT/BrakeRequest_fip</Element-Ref>
        <Name>BrakeRequest_fip</Name>
        <Box>
            <xPos>140</xPos>
            <yPos>70</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/BrakeBlending_T_
EMT/BrakeRequestBlended_fip</Element-Ref>
        <Name>BrakeRequestBlended_fip</Name>
        <Box>
            <xPos>140</xPos>
            <yPos>120</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-Ref>/DesignLevelElements/FCN/BrakeBlending_T</Element-Ref>
        <Name>BrakeBlending_T</Name>
        <Box>
            <xPos>600</xPos>
            <yPos>50</yPos>
            <zPos>0</zPos>
            <Size x="200" y="120"/>
            <Color r="200" g="255" b="200"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/DesignLevelElements/FCN/BrakeBlending_T/BrakeRequest</Element-Ref>
        <Name>BrakeRequest</Name>
        <Box>
            <xPos>590</xPos>
            <yPos>70</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
```

```
        <Element-
Ref>/DesignLevelElements/FCN/BrakeBlending_T/BrakeRequestBlended</Element-Ref>
        <Name>BrakeRequestBlended</Name>
        <Box>
            <xPos>590</xPos>
            <yPos>120</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/BrakeControllerR
equests_T_EMT</Element-Ref>
        <Name>BrakeControllerRequests_T_EMT</Name>
        <Box>
            <xPos>150</xPos>
            <yPos>220</yPos>
            <zPos>0</zPos>
            <Size x="200" y="220"/>
            <Color r="255" g="200" b="200"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/BrakeControllerR
equests_T_EMT/BrakeRequest_fip</Element-Ref>
        <Name>BrakeRequest_fip</Name>
        <Box>
            <xPos>140</xPos>
            <yPos>240</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/BrakeControllerR
equests_T_EMT/BrakeTorqueFL_fop</Element-Ref>
        <Name>BrakeTorqueFL_fop</Name>
        <Box>
            <xPos>340</xPos>
            <yPos>240</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/BrakeControllerR
equests_T_EMT/BrakeTorqueFR_fop</Element-Ref>
        <Name>BrakeTorqueFR_fop</Name>
```

```
        <Box>
            <xPos>340</xPos>
            <yPos>290</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/BrakeControllerR
equests_T_EMT/BrakeTorqueRL_fop</Element-Ref>
        <Name>BrakeTorqueRL_fop</Name>
        <Box>
            <xPos>340</xPos>
            <yPos>340</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/BrakeControllerR
equests_T_EMT/BrakeTorqueRR_fop</Element-Ref>
        <Name>BrakeTorqueRR_fop</Name>
        <Box>
            <xPos>340</xPos>
            <yPos>390</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-Ref>/DesignLevelElements/FCN/BrakeControllerRequests_T</Element-
Ref>
        <Name>BrakeControllerRequests_T</Name>
        <Box>
            <xPos>600</xPos>
            <yPos>220</yPos>
            <zPos>0</zPos>
            <Size x="200" y="220"/>
            <Color r="200" g="255" b="200"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/DesignLevelElements/FCN/BrakeControllerRequests_T/BrakeRequest</Element-Ref>
        <Name>BrakeRequest</Name>
        <Box>
            <xPos>590</xPos>
            <yPos>240</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
```

```
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/DesignLevelElements/FCN/BrakeControllerRequests_T/BrakeTorqueFL</Element-Ref>
        <Name>BrakeTorqueFL</Name>
        <Box>
            <xPos>790</xPos>
            <yPos>240</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/DesignLevelElements/FCN/BrakeControllerRequests_T/BrakeTorqueFR</Element-Ref>
        <Name>BrakeTorqueFR</Name>
        <Box>
            <xPos>790</xPos>
            <yPos>290</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/DesignLevelElements/FCN/BrakeControllerRequests_T/BrakeTorqueRL</Element-Ref>
        <Name>BrakeTorqueRL</Name>
        <Box>
            <xPos>790</xPos>
            <yPos>340</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/DesignLevelElements/FCN/BrakeControllerRequests_T/BrakeTorqueRR</Element-Ref>
        <Name>BrakeTorqueRR</Name>
        <Box>
            <xPos>790</xPos>
            <yPos>390</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
```

```
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/Diag_T_EMT</Elem
ent-Ref>
        <Name>Diag_T_EMT</Name>
        <Box>
            <xPos>150</xPos>
            <yPos>490</yPos>
            <zPos>0</zPos>
            <Size x="200" y="70"/>
            <Color r="255" g="200" b="200"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/Diag_T_EMT/DiagR
equest_receive_fip</Element-Ref>
        <Name>DiagRequest_receive_fip</Name>
        <Box>
            <xPos>140</xPos>
            <yPos>510</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/Diag_T_EMT/DiagR
equest_request_fop</Element-Ref>
        <Name>DiagRequest_request_fop</Name>
        <Box>
            <xPos>340</xPos>
            <yPos>510</yPos>
            <zPos>0</zPos>
            <Size x="20" y="30"/>
            <Color r="0" g="0" b="0"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-Ref>/DesignLevelElements/FCN/Diag_T</Element-Ref>
        <Name>Diag_T</Name>
        <Box>
            <xPos>600</xPos>
            <yPos>490</yPos>
            <zPos>0</zPos>
            <Size x="200" y="20"/>
            <Color r="200" g="255" b="200"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/GlobalBrakeContr
oller_EMT</Element-Ref>
        <Name>GlobalBrakeController_EMT</Name>
        <Box>
```

```
            <xPos>150</xPos>
            <yPos>610</yPos>
            <zPos>0</zPos>
            <Size x="200" y="320"/>
            <Color r="255" g="200" b="200"/>
            <Outline>true</Outline>
        </Box>
    </Element>
    <Element>
        <Element-
Ref>/EASTADLExtensionElements/DependabilityPackage/Dependability2/GlobalBrakeContr
oller_EMT/BrakeRequest_fip</Element-Ref>
        <Name>BrakeRequest_fip</Name>
        <Box>
            <xPos>140</xPos>
            <yPos>630</yPos>
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Appendix D – I Interview Presentation Slides

Model Based Safety Analysis

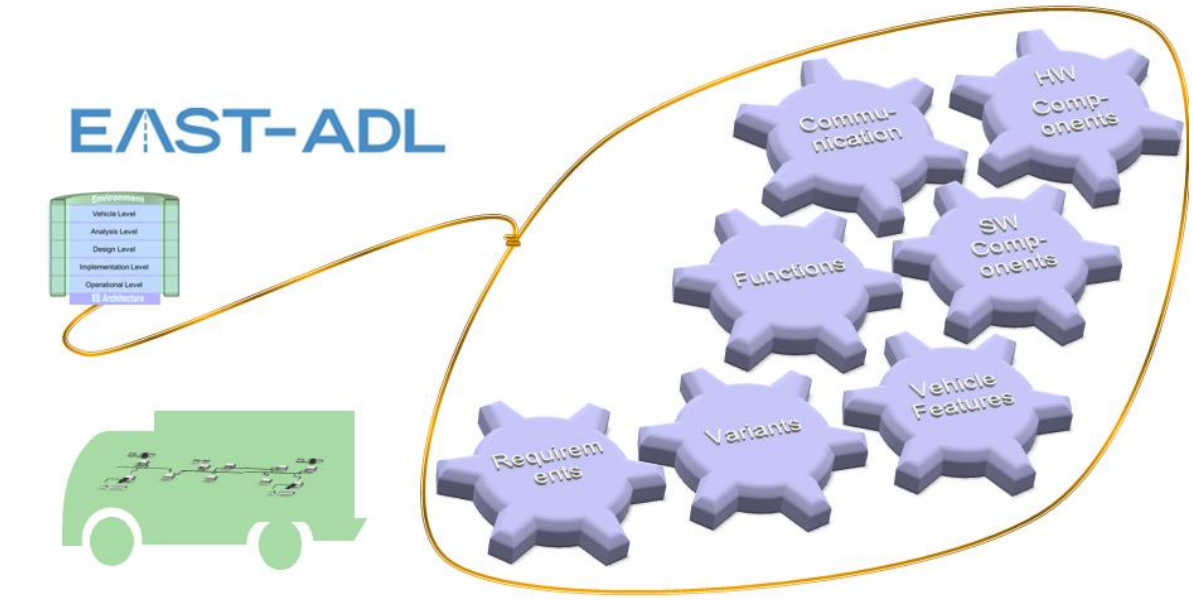
Autogeneration and tool assistance for FTA and FMEA in EAST-ADL context

Evaluation

Wenjing Yuan

Goal

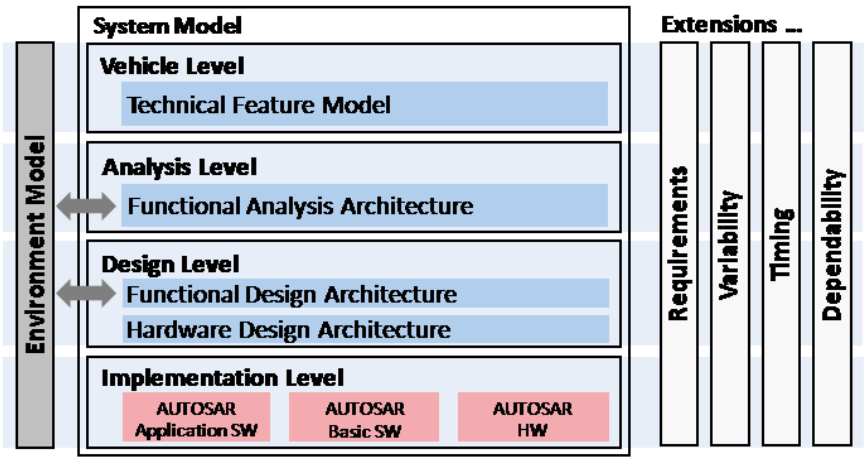
- Present the current thesis working outcomes
- Find existing problems
- Evaluate and get feedback
- Collect ideas for future work



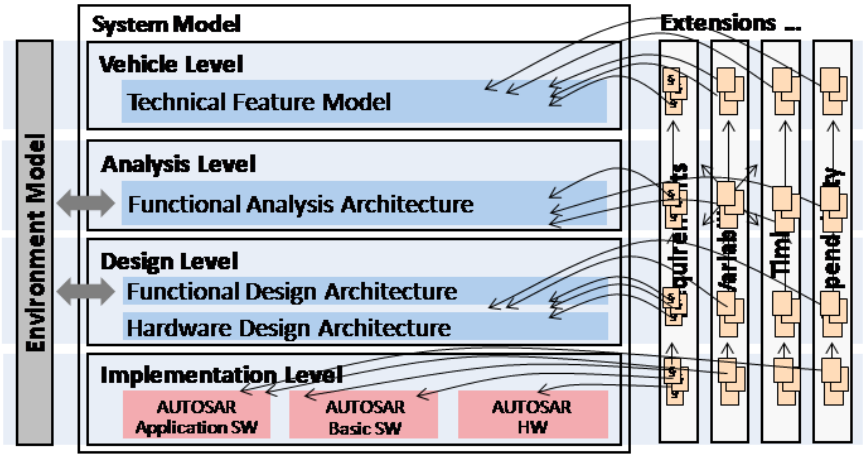
Architecture Description Language

An information model that captures engineering information in a standardized way

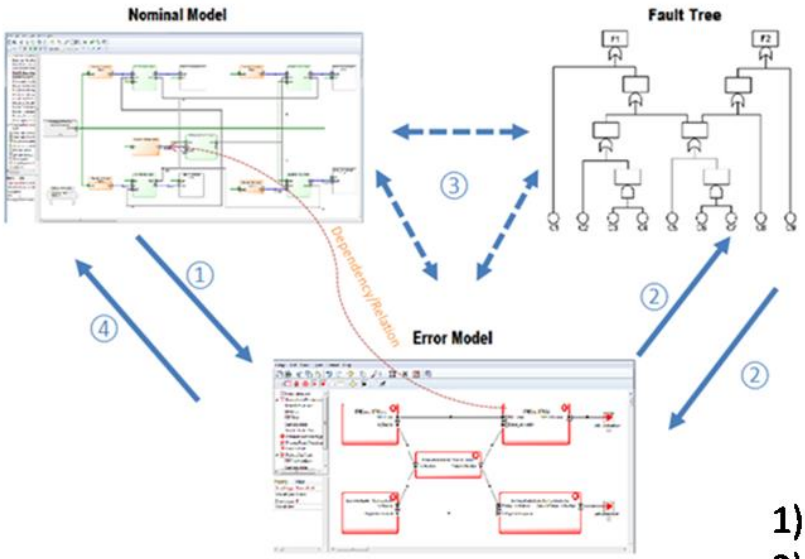
EAST-ADL Model Organization



EAST-ADL Model Organization

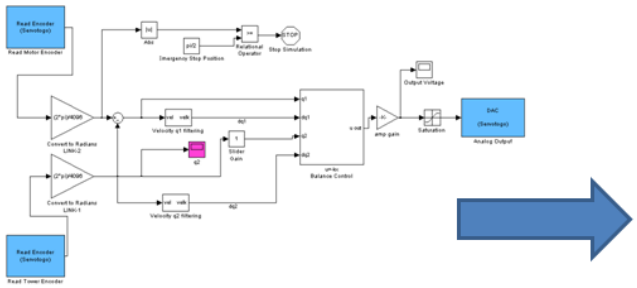


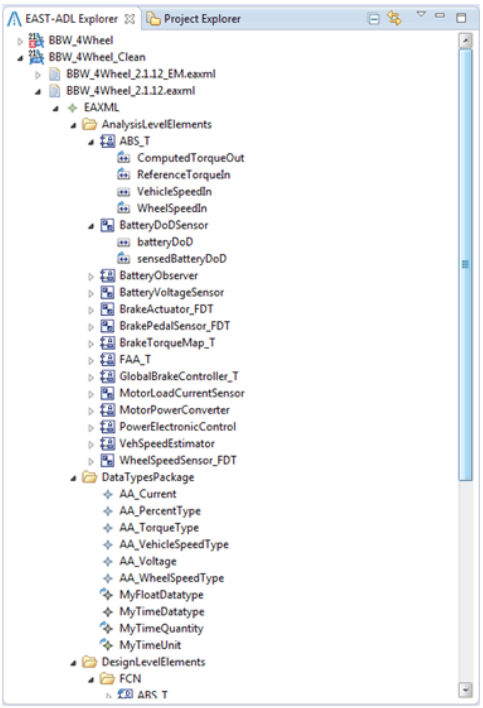
Four Working Steps



1) Defining
2) Analyzing
3) Understanding
4) Evolving

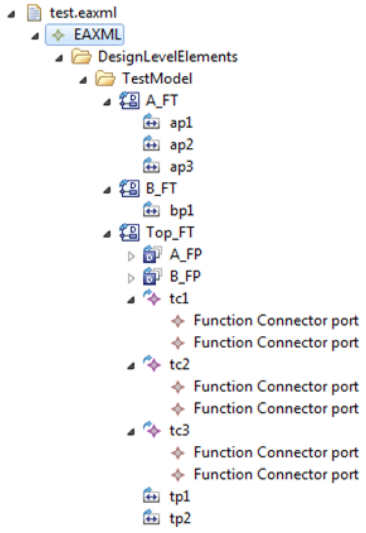
Defining the Nominal Model

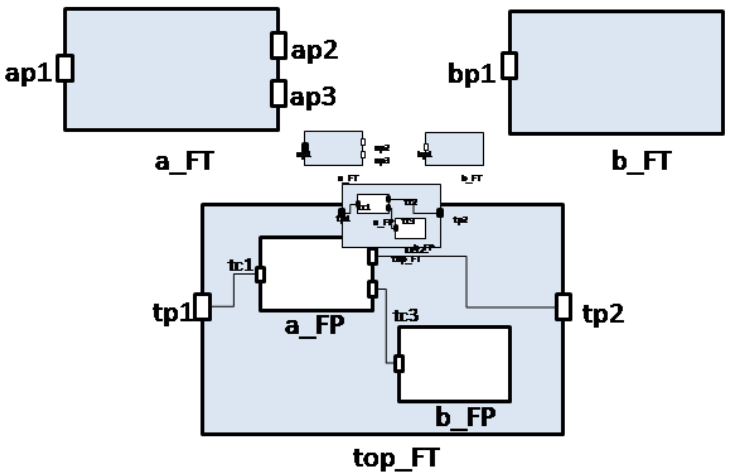




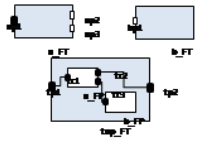
- **Auto-generate EAST-ADL Nominal Model From existing models (Simulink, SE tool, ...) to increase productivity**
- **Why change representation?**
  - **Error Propagation and other annotations can be properly organized with EAST-ADL**
  - **Modification and restructuring are supported in EAST-ADL**

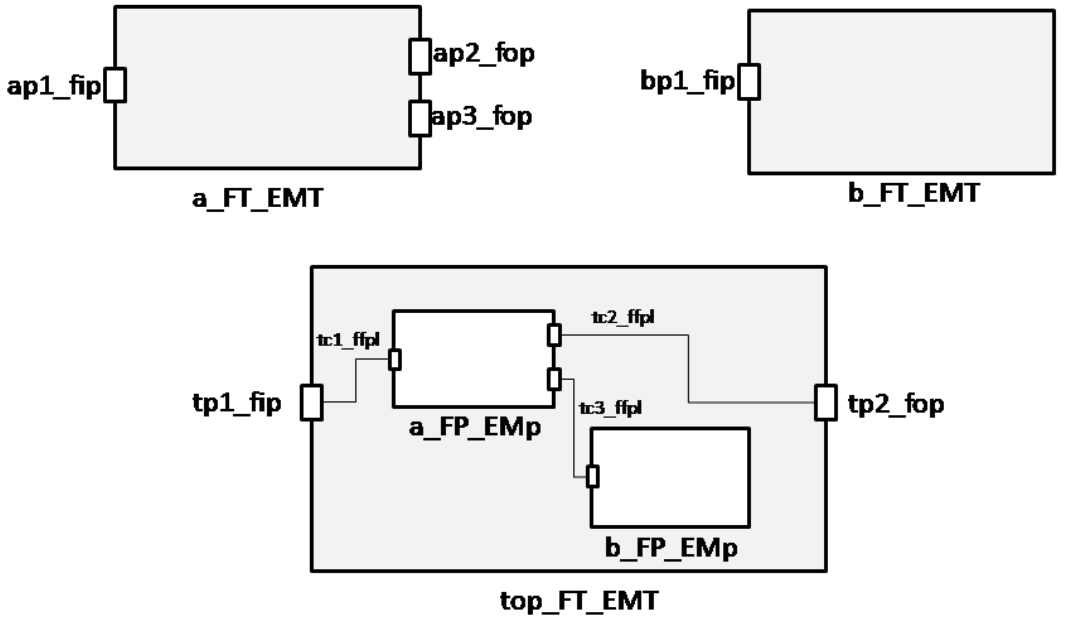
Error Model AutoGeneration





Error Model AutoGeneration

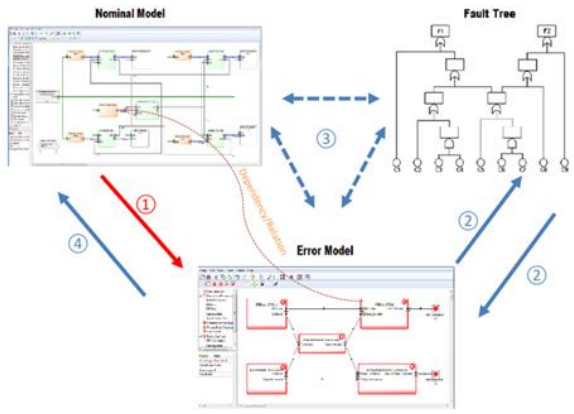




Error Model AutoGeneration

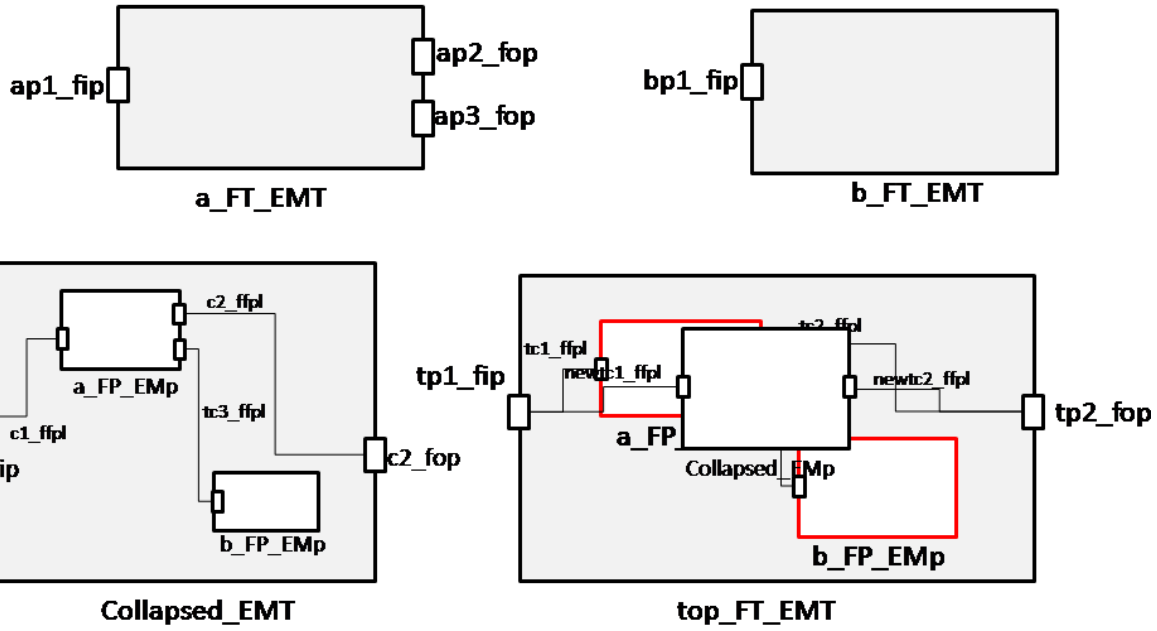
- On a scale of 1 to 5, with 1 being poor and 5 being excellent, how satisfied are you with this product in terms of the following? And please specify the reason.
  - Ease of Use
  - Ease of Understanding(description)
  - How well the product achieves its goal
- Is this applicable for the current development process in your opinion? If not, what are the missing parts?
- Is there any other product you know has a similar feature?
  - If yes, how does it work in this category? And compare with the presented artifact, what are the advantages and disadvantages?
  - If no, how satisfied are you with this product? Any improvements or suggestions?

Reorganize Error Model

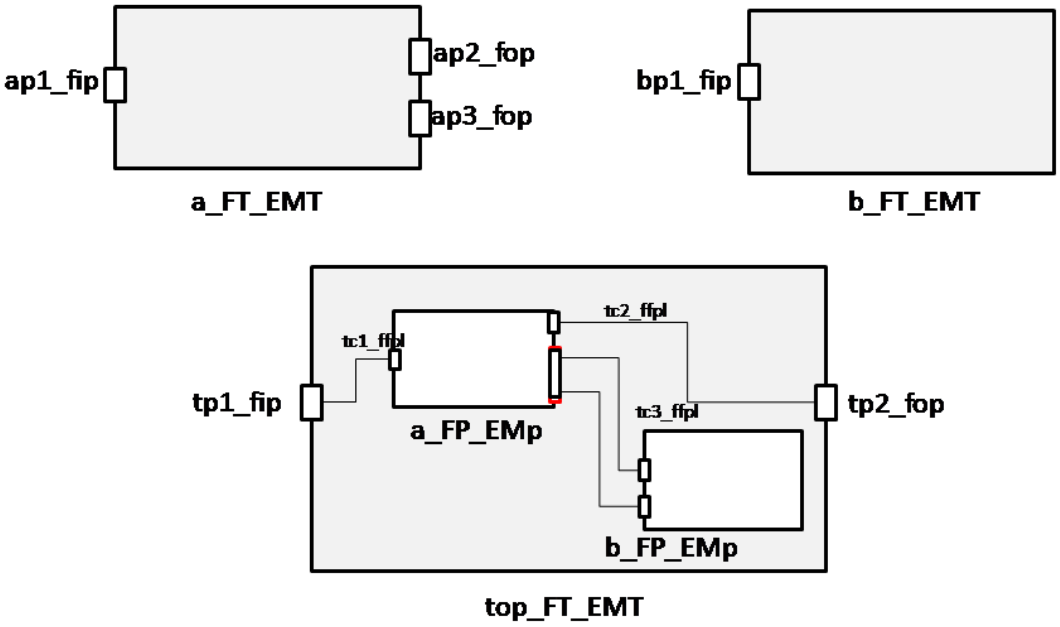


- One to one mapping pattern is not specific or customized enough for real work
- Project is rather big, time consuming to deploy changes by hand
- The frequently manually routine modifications could be done by machine
- At the error propagation perspective, engineers may not care about the original ports, only whether there is a failure propagated from the element

Reorganize Error Model: Collapse Components



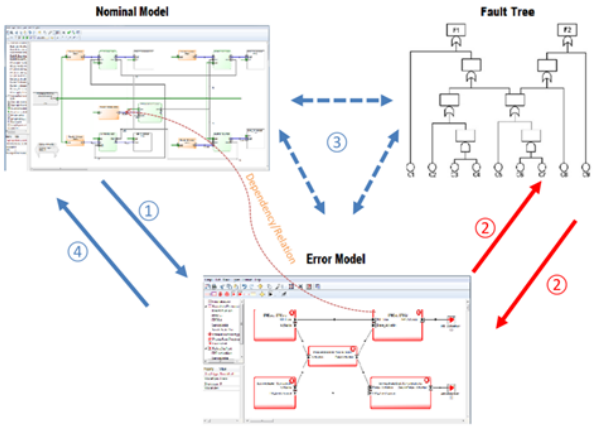
Reorganize Error Model: Collapse Ports



Reorganize Error Model

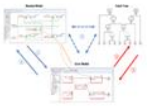
- On a scale of 1 to 5, with 1 being poor and 5 being excellent, how satisfied are you with this product in terms of the following? And please specify the reason.
  - Ease of Use
  - Ease of Understanding(description)
  - How well the product achieves its goal
- Is this applicable for the current development process in your opinion? In not, what are the missing parts?
- Any other manually done modifications you think is necessary to be automated?

HiP-HOPS Fault Tree Analysis

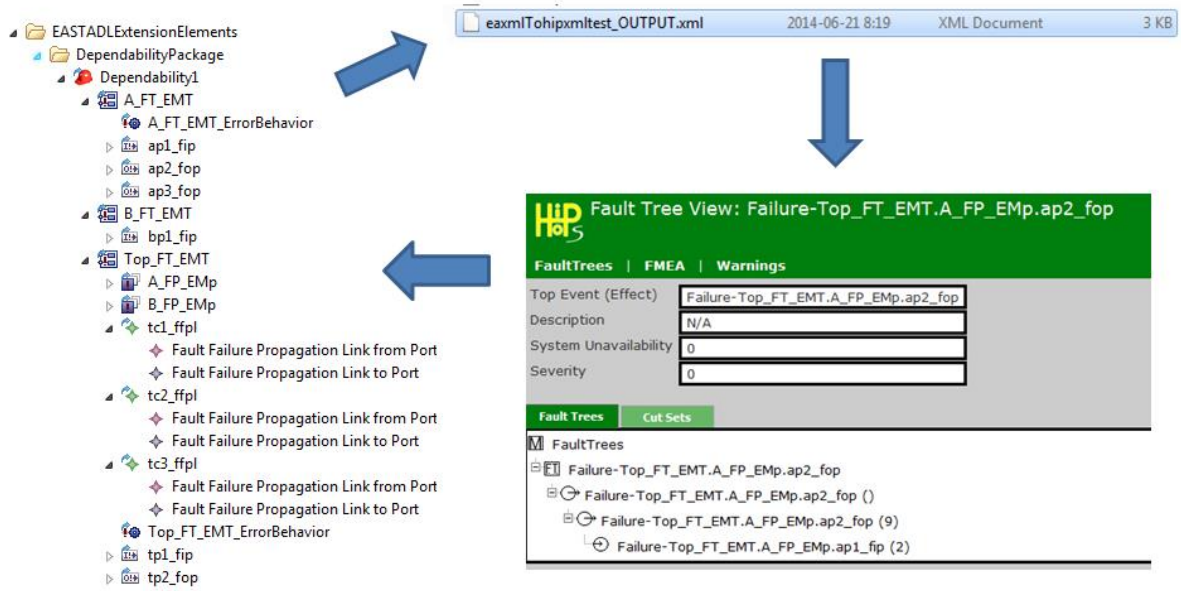


- **Fault Tree Analysis is needed to analyse the failures from Error Model**
- **An easy and efficient way to represent the FTA result**

*** Generating *.hipxml from *.eaxml is contributed by University of Hull, Thanks to Septavera Sharvia**

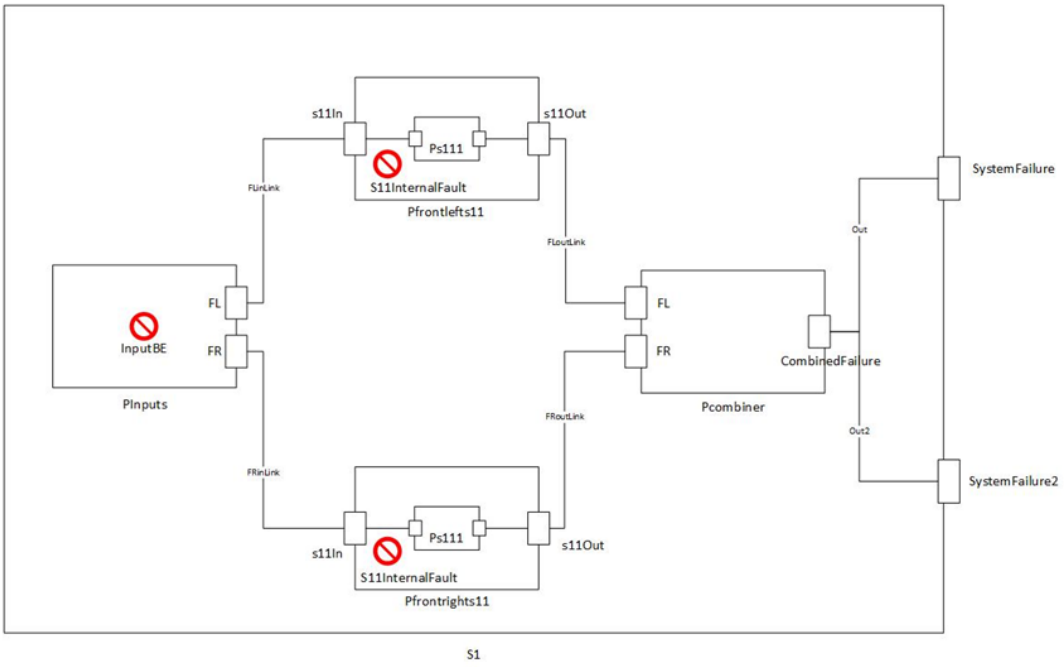


HiP-HOPS Fault Tree Analysis



*** Generating *.hipxml from *.eaxml is contributed by University of Hull, Thanks to Septa**

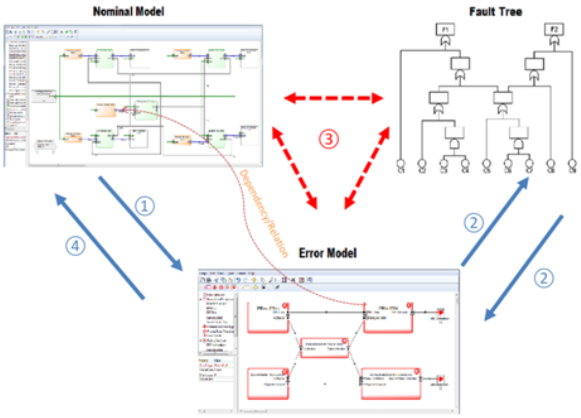
HiP-HOPS Fault Tree Analysis



HiP-HOPS Fault Tree Analysis

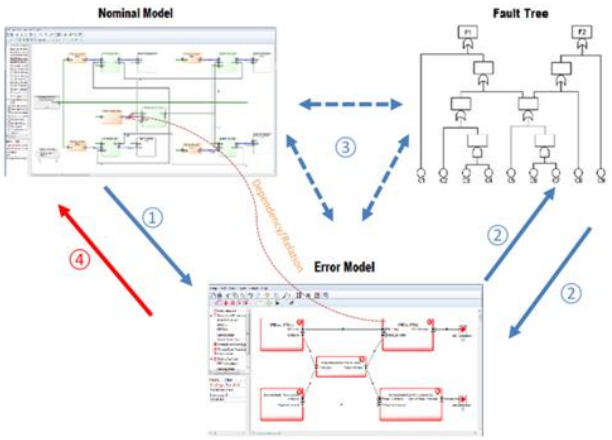
- On a scale of 1 to 5, with 1 being poor and 5 being excellent, how satisfied are you with this product in terms of the following? And please specify the reason.
  - Ease of Use
  - Ease of Understanding(description)
  - How well the product achieves its goal
- In your opinion, will this concept help the safety work? How?
- Is there anything you think is missing in the design or need to improve?

Graphical Representation



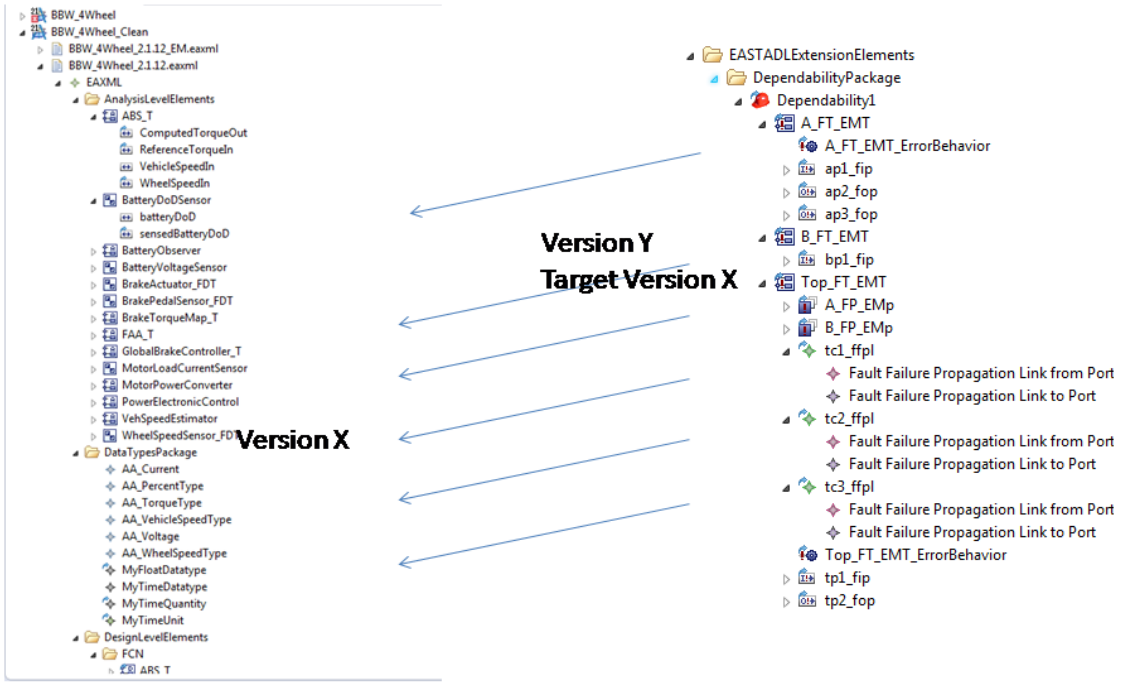
- Currently, there is only a tree view of the error model
- A grahical view is planned to
  - Make the models more understanble
  - Simplify editing
  - Allow visualization of relations between function model and error model

Version Consistency Checking



- Changes in nominal Model or Error Model may cause inconsistency
- Tool support is needed to manage consistency:
  - Define a version of each element nominal and error model
  - Error Model keeps track of version of target element

Nominal Model vs. Error Model



Version Consistency Checking

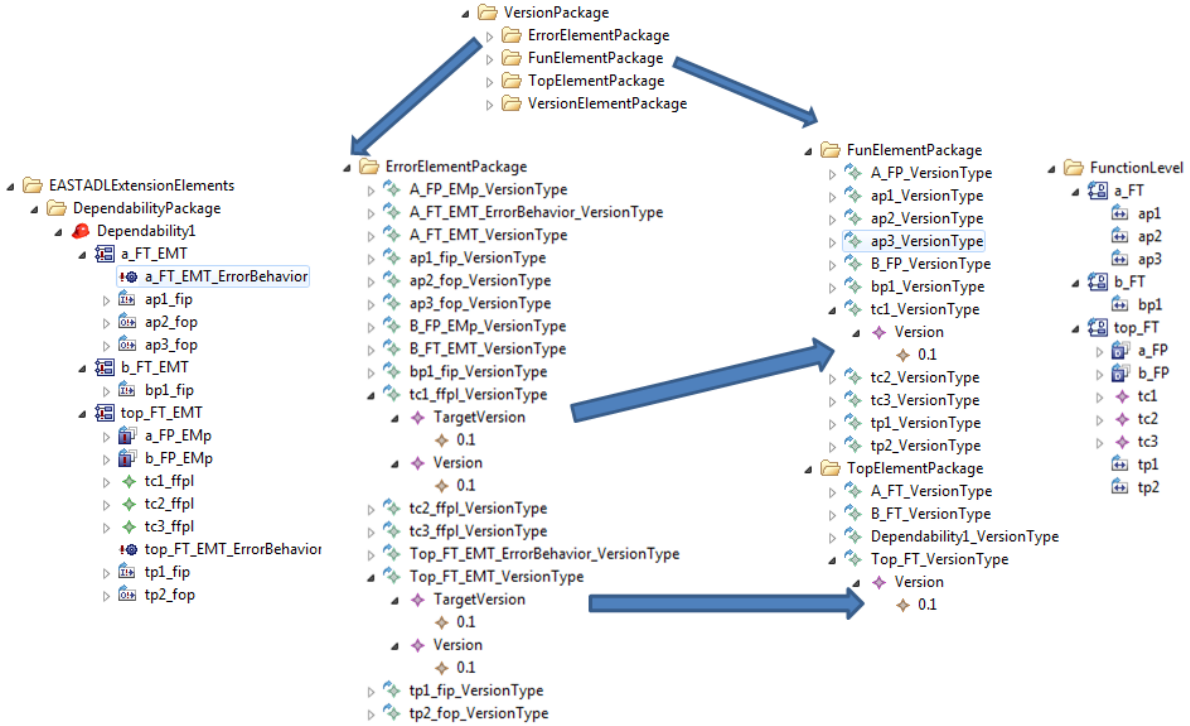
- On a scale of 1 to 5, with 1 being poor and 5 being excellent, how satisfied are you with this product in terms of the following? And please specify the reason.
  - Ease of Use
  - Ease of Understanding(description)
  - How well the product achieves its goal
- What do you think this way of handling version control? Is this applicable for the current development process in your opinion? In not, what are the missing parts?
- Is there any other product you know has a similar feature?
  - If yes, how does it work in this category? And compare with the presented artifact, what are the advantages and disadvantages?
  - If no, how satisfied are you with this product? Any improvements or suggestions?

In General

- General feeling of this thesis work

- Future expectation

Version Consistency Checking



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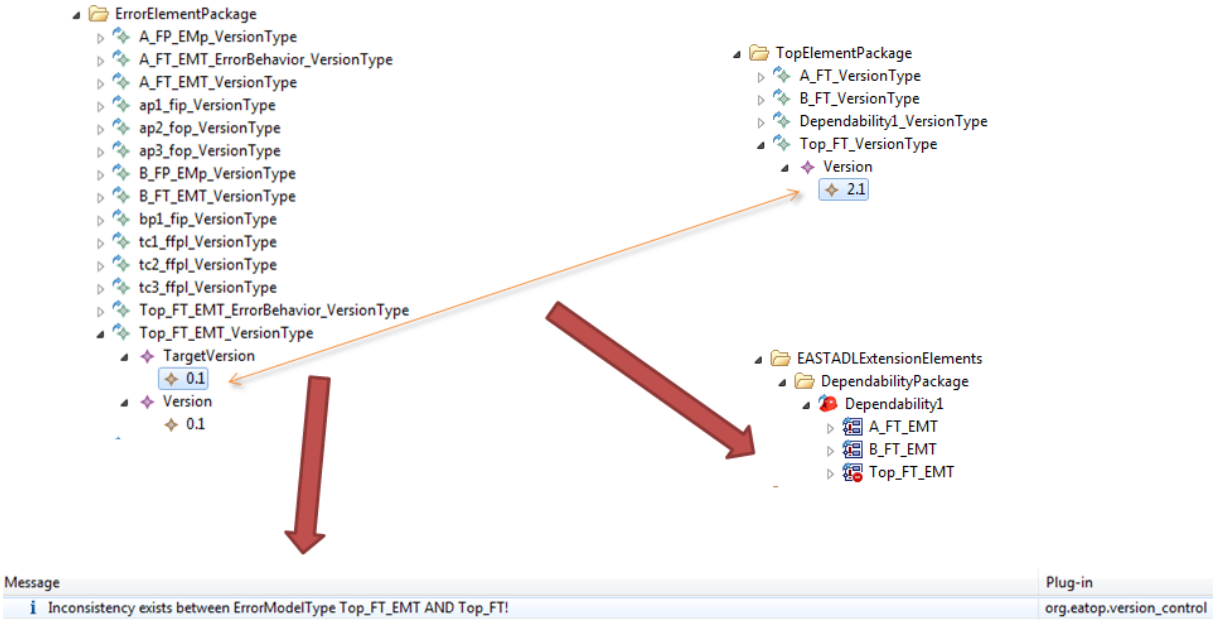

Thank you!

Appendix D – II Interview Questionaire

Date: Participant:

Question : Error Model Auto Generation

- On a scale of 1 to 5, with 1 being poor and 5 being excellent, how satisfied are you with this product in terms of the following? And please specify the reason.
  - Ease of Use
  - Ease of Understanding(description)
  - How well the product achieves its goal

- Is this applicable for the current development process in your opinion? If not, what are the missing parts?

- Is there any other product you know has a similar feature?
  - If yes, how does it work in this category? And compare with the presented artifact, what are the advantages and disadvantages?
  - If no, how satisfied are you with this product? Any improvements or suggestions?

Question : Re-organize Error Model

- On a scale of 1 to 5, with 1 being poor and 5 being excellent, how satisfied are you with this product in terms of the following? And please specify the reason.
  - Ease of Use
  - Ease of Understanding(description)
  - How well the product achieves its goal

- Is this applicable for the current development process in your opinion? In not, what are the missing parts?

- Any other manually done modifications you think is necessary to be automated?

Question : HiP-HOPS Fault Tree Analysis

- On a scale of 1 to 5, with 1 being poor and 5 being excellent, how satisfied are you with this product in terms of the following? And please specify the reason.
  - Ease of Use
  - Ease of Understanding(description)
  - How well the product achieves its goal

- In your opinion, will this concept help the safety work? How?

- Is there anything you think is missing in the design or need to improve?

Question : Consistency Checking

- On a scale of 1 to 5, with 1 being poor and 5 being excellent, how satisfied are you with this product in terms of the following? And please specify the reason.
  - Ease of Use
  - Ease of Understanding(description)
  - How well the product achieves its goal

- What do you think this way of handling version control? Is this applicable for the current development process in your opinion? In not, what are the missing parts?

- Is there any other product you know has a similar feature?
  - If yes, how does it work in this category? And compare with the presented artifact, what are the advantages and disadvantages?
  - If no, how satisfied are you with this product? Any improvements or suggestions?

Question : General

- General feeling of this thesis work

- Future expectation