Model-driven Engineering in Support of Development, Test and Maintenance of Communication Middleware
A Preliminary Industrial Case-Study

Deniz Akdur[1,2] and Vahid Garousi[3]
[1]*ASELSAN Inc., Ankara, Turkey*
[2]*Department of Information Systems, METU, Ankara, Turkey*
[3]*System and Software Quality Engineering Research Group (SySoQual), Department of Software Engineering, Atilim University, Ankara, Turkey*

1 INTRODUCTION

Embedded real-time software and systems (ERTS[2]) are widespread and can be found in many devices in our everyday life (Ebert, 2009), e.g., in cars (Schäuffele and Zurawka, 2005), TVs (Paulin et al., 1997), aviation (Rushby, 2011), etc. Development and testing of embedded software is usually more challenging (Graaf et al., 2003; Broy, 2006) compared to regular software systems. Many ERTS[2] are also distributed systems in which collections of independent computers interoperate. It is crucial to systematically design, develop and test such distributed real-time and embedded (DRE) systems.

The scale and complexity of DRE systems makes it infeasible to deploy them in disconnected, standalone configurations (Gokhale et al., 2008). Therefore, communication is the heart of all distributed systems. The latest modern DRE systems have numerous components in which interfaces and middleware communication layer play crucial roles. A communication middleware provides an environment that enables two applications to set up a conversation and exchange data (Krafzig et al., 2004). Defects in those components could lead to minor issues or even life-threatening system failures. For example, message-communication-related faults such as wrong message sizes exchanged between the interfaces might be left uncovered during testing activities. Delays in integration can create huge costs and extra effort might be needed to verify all internal business logic and interfaces. Furthermore, late defect correction in live systems after deployment for these types of software systems costs much more compared to regular software systems due to the close hardware interactions. Thus, it is very crucial to verify communication interfaces between different hardware and software modules earlier to ensure proper interoperability. Moreover, it has been observed in several industrial contexts that when hardware, software modules and related communication interfaces evolve in those systems, synchronization of source code with other artifacts (e.g., documentation) becomes a major challenge.

In a specific industrial context, ASELSAN Inc., one of Turkey's leading defense companies (ASELSAN, 2014), all the above challenges were regularly faced and thus, to address them, we design, implement and evaluate a toolset in the context of Radar & Electronic Warfare Systems (REWS) division. In this paper, we report our progress in this ongoing R&D project. The solution approach is based on the Model-Driven Engineering (MDE) which is in support of development, test and maintenance of communication middleware. The toolset has been developed using the Eclipse Modeling Framework (EMF) and is titled: *Model-ComM*, standing for Model-driven Communication Middleware, which automatically generates code, document and test driver for communication interfaces of each component depending on the type of protocol and the architecture of the system. This tool is currently in use by many teams in the company, as we report in this paper.

The approach and the case study reported in this paper is only one component of the PhD dissertation of the first author. The thesis' overall plan is to focus on a comprehensive investigation of industrial and empirical evidence of using MDE, which has a multidisciplinary research methodology. Firstly, the thesis plans to investigate recent modeling usage and its adoption with describing and understanding the industrial experience, which is based on survey and exploratory & improving case study strategies with interviews. Secondly, to show the positive impact of MDE by addressing the lack of empirical results in the industry (Frankel, 2002; Hutchinson et al., 2014), this study uses an industrial evidence to ensure the cost effectiveness and benefit of MDE by

Akdur D. and Garousi V..
Model-driven Engineering in Support of Development, Test and Maintenance of Communication Middleware - A Preliminary Industrial Case-Study.

realizing technology transfer (Gorschek et al., 2006) via Model-ComM, which is based on Action Research (AR) (Santos and Travassos, 2009).

The remainder of this paper is organized as follows. Section 2 discusses the motivations and problem statement. Section 3 presents the related work and need for the proposed approach. In Section 4, the solution is presented. Section 5 examines the preliminary evaluation of the approach, in which the applicability and usefulness of the approach by applying it to prototype radar control software are shown. Finally, Section 6 presents conclusions and our ongoing/ future directions.

2 MOTIVATIONS AND PROBLEM STATEMENT

2.1 Context and Problem Domain

The industrial context in which our project is carried out focuses on developing radar software. The REWS division has approximately about 40 active projects as of 2014 and the expectation is to double this number within five years. In addition to this, developing hybrid systems, which are "systems of systems", will become another major challenge by combining various radars and electronic warfare systems in a single product. All of these will result in a major increase in complexity of software for new products and will highlight for importance of more systematic software engineering practices.

As a DRE system, a radar system is an object detection system which uses electromagnetic waves to determine the range, altitude, direction or speed of objects such as aircrafts, ships and guided missiles (Stimson, 1998) by requiring several basic components, which are yet other embedded systems (Skolnik, 2001). A radar controller software receives inputs from a variety of sensors, such as temperature, rotation and radiation; and sends them to various display units.

In a typical ASELSAN radar system, the electromagnetic sub-system operate by radiating energy into space and detecting the echoed signal reflected from an object with the help of hardware units such as the Receiver Transmitter Unit (RTU), Digital Signal Processing (DSP)-based Field Programmable Gate Array (FPGA) and antenna. During this process, DSP algorithms are applied to determine objects' attributes and then the controller software sends the location of a potential target to the various displays like Control Display Unit (CDU), Transceiver Compatibility Unit (TCU) or Remote Display Unit (RDU). In this scenario, the radar controller software usually has a large number of both internal and external interfaces with different units via different communication protocols such as RS232, RS422, vxWork Message Queue (Vx MsgQ), TCP, UDP, Peripheral Component Interconnect Express (PCIe) to enable the system to have close communication with other embedded systems as shown in Figure 1.

To highlight the need for our approach to help development of these systems, a possible message-communication-related fault which could lead to system failures is discussed next. A possible scenario might occur in PCIe-based communication protocol with FPGA, which provide support for high sampling rate and low power consumption required by sophisticated radars (Skolnik, 2001). However this kind of protocol should be carefully used since it is directly related with memory in embedded systems (Bittner, 2012). If during message parsing, any parameter is wrongly read, it can easily lead to abnormalities and even a system crash, (Barry and Crowley, 2012), which might cause even a life-threatening situation when the radar is operating.

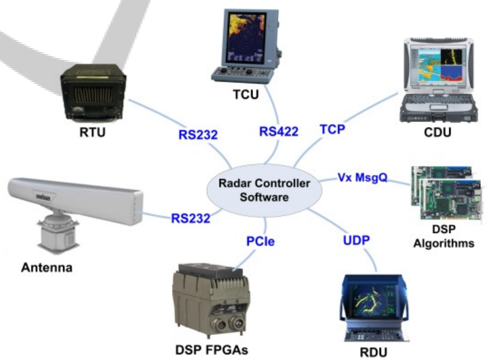


Figure 1: Architecture of the DRE system under study.

The above example clearly show that verification and validation of the message interface is important as well as fast implementation of these communication modules for the sake of proper interoperability. Therefore, it is obviously essential to guarantee that these interfaces should be compatible with each other and it is better to get all these data from one central source. Moreover, it has been observed that keeping source code and documentation synchronized becomes a major challenge. In other words, according to several sources, e.g., (Lindvall, 2003), software maintenance for DRE systems is challenging in general.

In summary, the real-world problem domain that our ongoing project and this paper intend to address is: the need for more systematic approaches in development, test and maintenance of communication middleware, as a subarea of DRE system, in the projects under study.

2.2 Challenges and Needs

We discuss in this section the industry challenges and needs, in further detail, that have triggered the need for this project. For confidentiality reasons, only non-classified information about the system and the project will be disclosed in this paper.

In the radar controller software projects under investigation, various types of software architecture models have been used and various types of interfaces were being designed, developed and utilized by various sub-systems. During the development process of the interfaces, the teams have faced several major challenges which, after systematic and extensive meetings with the engineering teams, we grouped and summarized them under the following four challenge areas:

- Challenge area 1: Inefficient usage of development effort: In development of the middleware, developers have regularly complained about unnecessary waste of time on manually writing communication interfaces, which include message parsing or assembling operations. They generally wanted to spend instead most of their time and effort on the actual system scenarios ("business logic"). It would have been nice to automate, as much as possible, the "mechanical" task of writing the code for communication interface modules by relieving the programmer from a very error-prone task.

- Challenge area 2: Unsynchronized interface artifacts across various software development lifecycle (SDLC) phases: Since the projects have various release cycles and are ongoing, it has happened many times that a new version for a particular artifact (e.g., interface) was released and this update was not broadcasted to all shareholders. Sometimes, the entire situation was becoming ad-hoc and caused last-minute surprise and chaos, e.g., "*It worked yesterday, but I don't know why it doesn't work today; did you change anything in the message interface?*" Thus, only in runtime and testing, such issues were surfaced which implied major delays and rework. The synchronization-related issue also occurred often in terms of documentation. Whenever a typical message interface was changed, the corresponding Interface Control Document (ICD) was often not updated (Parnas, 2011). In that situation, since the document update was not synchronously done with the implementation, they were often different.

- Challenge area 3. Insufficient unit testing of communication interfaces before integration: Because of the lack of simulator and test drivers, interfaces were insufficiently tested before system integration. There has been a need for a simulator, in which protocols and messages can be tested under various scenarios. Frequent stand-alone testing of a given interface is usually considered a quick *smoke* test (Kaner et al., 2001) from developers point of view and is often considered valuable for finding trivial defects, also for ensuring test-driven development (TDD). Also having such a simulator would allow developers to quickly test specific scenarios (Myers et al., 2012).

- Challenge area 4. Inefficient team communication and confusion of roles across different engineering roles, e.g., system engineers, developers: Any change request for the communication interface among modules might come from either system engineers or developers of inter-dependent modules. However, there have been issues in the past on how to properly take responsibility over ICD, which might cause troubling situations while propagating a change in interfaces to the all shareholders, e.g., quotes such as "*Who is going to change ICD?"*. System Engineer in one case said: *"Did you not change ICD after new implementation? I thought you had already changed it, but no one changed it although three months have passed"*.

2.3 Selection of the Solution Approach

Early in the project, after we identified the challenges and needs, based on AR, the first immediate step was to list the candidate solution approaches from the software engineering domain applicable to the problem and chose the solution approach that would best fit to the context.

Due to the exponentially growing complexity of software (Ganssle, 2008), it is agreed that the one of the ways to manage this complexity is to use abstraction (Kramer, 2007). Nowadays, the state-of-the-art in software abstraction is MDE, which can be seen as the systematic use of models as primary artifacts during the development process (Hutchinson et al., 2014). MDE has recently become a hot topic in both industry and academia; there are reports upon many years of successful experience in the development and application of MDE (Davies et al., 2014). It is agreed that advanced middleware technologies by itself will not deliver the capabilities envisioned for next-generation DRE systems and MDE is needed not only to assist developers in understanding their designs but also to reduce the costs associated with trial and error by enriching interoperability (Schantz and Schmidt, 2008). To meet extra-functional requirements, embedded systems development is shifting from programming to MDE (Liggesmeyer and Trapp, 2009). We thus decided to use MDE as our solution approach.

3 RELATED WORK AND NEED FOR THE PROPOSED APPROACH

After identifying the solution approach as MDE, we conducted a literature review to see if approaches or tools applicable to our context have been proposed before.

The area of MDE for ERTS² is quite active. There are several books, e.g., (Douglass, 2000; Douglass, 2004; Nicolescu, 2009), and many research articles in this area, e.g., (Pao-Ann et al., 2001). A popular variant of MDE is the Model Driven Architecture (MDA). The idea behind MDA is to be able to develop and manage the whole application life cycle by putting the focus to the model, in which the model itself is described in a meta-model (Moore et al., 2004). Moreover, there are also books, which include detailed examples from industry to illustrate real-world solutions by presenting Model-Based Testing (MBT) from various perspectives, which combine aspects of ERTS², e.g. (Zander et al., 2011) and also many papers e.g. (Stefan and Bruce, 2011; Iyenghar et al., 2011), which explore MBT in DRE systems.

Besides the technical challenges, non-technically, since a quick response to any change request is important for such a tool, it was necessary in the company under study to develop it in-house instead of adopting/buying or outsourcing. Therefore, a customized tool, which would generate both code and documentation from a central source, and would guarantee module's interoperability, was necessary. In MDE, new tools for a specific problem is always needed (Davies et al., 2014).

Closing the gap between software interfaces and related artifact generation is a challenging research problem. Our approach aims no interface errors, no unsynchronized software artifacts and guaranteeing of interface integrity after implementation, which is among the first effort to focus on MDE for error-prone part of communication middleware.

4 SOLUTION

We have recently finished the development of our MDE-based tool called Model-ComM to support development, test and maintenance of communication middleware.

Model-ComM is an Eclipse-based model-driven tool for auto generation of code, document and test driver for communication interfaces depending on the type of protocol and the architecture in the system. The inputs are specifications of the interface messages and their parameters. We discuss the tool's usage overview and then its design and development aspects next.

4.1 Usage Overview

The tool offers the following features:

- Code generation for communication interfaces: The modeler can generate Java, C++ source files and input *(in SBS format)* for the IBM Rational Rhapsody tool *(widely used in the company)*, which is a MDE environment for ERTS² (IBM, 2013).
- Document generation for all messages.
- Test driver generation for interfaces: The engineer can use such a driver to test all messages in a specific scenario by issuing test inputs and expected return values.

Workflow and usage is shown in Figure 2.

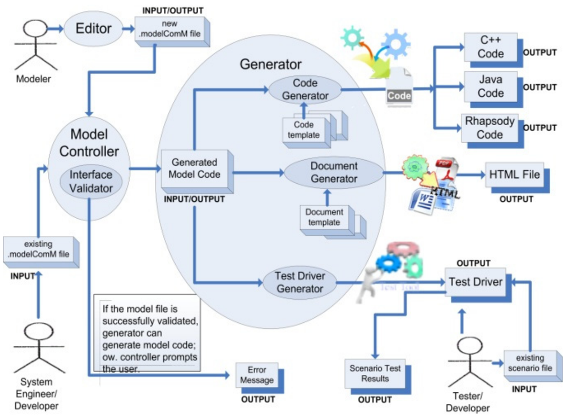


Figure 2: Workflow and usage of the tool.

4.2 Design and Development Aspects

Model-ComM has been developed using EMF, which is designed to ease the design and implementation of structured models (Moore et al., 2004). EMF unifies Java, XML and UML. In Figure 3, a meta-model for Model-ComM is shown.

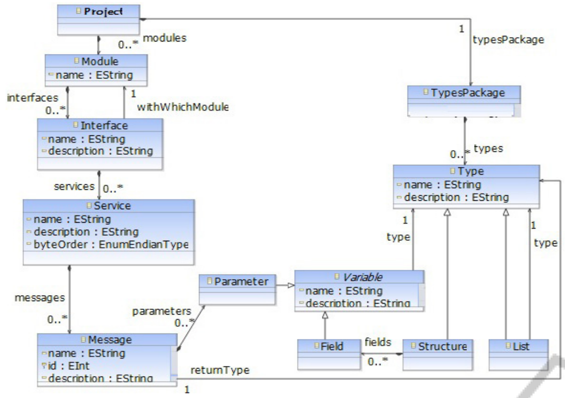


Figure 3: Meta-model of Model-ComM.

By providing the linkage between the modeling and programming domains, EMF offers an infrastructure to use models effectively in code. The meta-model in Figure 3 provides model-to-model (M2M) transformation, in which one can define any *"interface"*, *"service"*, *"message*" and *"parameter"* between any *"module"* in any *"project"* for any communication protocol. As message parameter, one can use "already defined types" as well as "user defined" structure, list, etc.

The generated test driver consists of three units: the generated communication middleware, which provides communication interfaces with the module tested; the test controller unit and its own UI. All these units are generated by the tool, which might make Model-ComM a meta-tool. When the test driver runs, it takes all information about the module tested from the XML file, which is generated by meta-model. Then, by using Java Reflection (McCluskey, 1998), the test driver finds all relations between the generated communication middleware and the test controller unit at run time, without knowing the classes or methods. By this way, to ease changeability and maintainability, the test controller unit and UI are made independent from customized middleware implementation.

In term of the generated documentation, the HTML format is currently supported and it is planned to add Word and PDF support as well. The content is generated by the tool and to separate appearance from content, Cascaded Style Sheet (CSS) file format is used.

4.3 GUI and Features

Model-ComM is developed as an Eclipse Rich Client Platform (RCP) project andit looks like the standard Eclipse UI. It includes a menu toolbar and three different panes: Project Explorer, Interface/Model Definition and Properties, as shown in Figure 4.

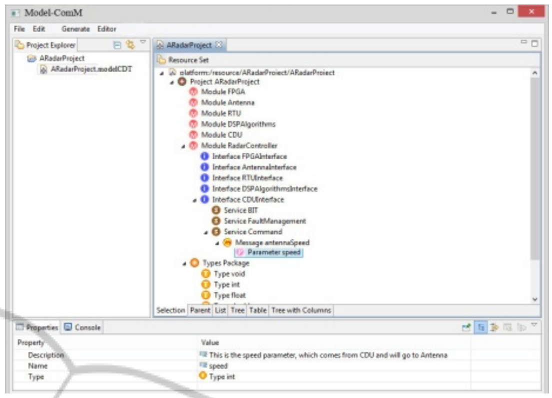


Figure 4: A screenshot of Model-ComM.

In the "Interface/Model Definition" pane, one can hierarchically add all meta-model components and save it in XML. All attribute's properties can be editable via "Properties" pane.

In the menu tool bar, there are "File", "Edit", "Generate" and "Editor" options. Before generating artifacts, the model can be validated to check whether there is a missing obligatory attribute like missing parameter name or type, etc.

In "Generate", you have 3 submenus: Generate Code, Generate Document and Generate Test Driver. During generation stage, configuration details like the module, which is wanted to generate the code, programming language type, endian type, destination directory etc. should be selected.

The engineer can use generated test driver to prepare independently runnable test blocks by sending messages with the input parameters, which can be given via its UI. It is possible to generate test scenarios, which can be saved and loaded later. Comparing the incoming messages with the expected results and presenting test results with a colorful pass/fail status are some other features.

5 PRELIMINARY EVALUATION IN THE INDUSTRIAL CONTEXT

Due to confidentiality reasons, we are unable to report the application of our tool on a real sub-system of the case-study projects. Instead, to demonstrate the applicability and usefulness of our approach, we report next its evaluation on a realistic prototype radar control software.

5.1 Usage of the Approach on a Prototype Radar Control Software

By using meta-model in Figure 3, a running example object diagram for a radar control software is shown in Figure 5.

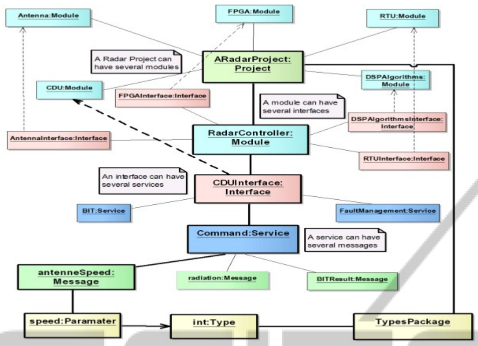
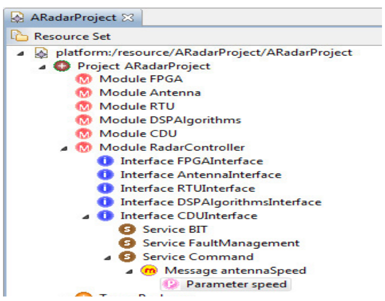


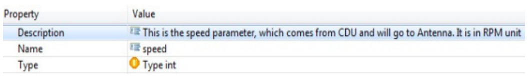
Figure 5: Object Diagram.

For brevity, instead of expressing all details, the path of bold lines is discussed. *ARadarProject* can have several modules and *RadarController* is one of them. This module can have several interfaces and *CDUInterface*, which has TCP connection with *CDU* (as mentioned in Figure 1) is one of these interfaces. Among various services, Command has *antennaSpeed* message, which has one parameter named "*speed*". This parameter's type is integer and belongs to *TypesPackage*. After getting this "speed" parameter, *RadarController* can send it to *Antenna* module by using its *AntennaInterface*, which has RS232 connection (as mentioned in Figure 1).

In order to satisfy M2M transformation by EMF, which uses this object diagram at the background and generates code, document and test driver, it is sufficient to model the scenario as given in Figure 6(a) and Figure 6(b).



(a): "Interface/model definition" pane



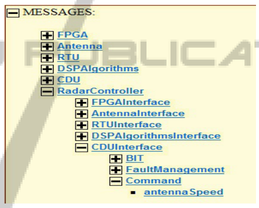
(b): "Properties" pane for "speed" parameter

Figure 6: Using Model-CDT for the prototype.

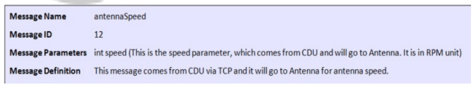
By using "Generate Code" submenu and selecting necessary configuration, Java, C++ or IBM Rhapsody implementation is generated.

Furthermore, by using "Generate Document" submenu, an HTML-based ICD document, which takes properties of all objects is generated. Figure 7(a) shows all messages within all modules by expressing hierarchical ordering via modules, interfaces and services at the left pane in generated document, whereas Figure 7(b) shows the message details when clicking on *antennaSpeed* message.

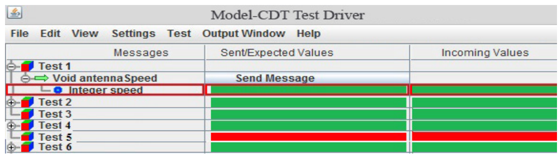
On the other hand, "Generate Test Driver" submenu generates test driver. After running it, the first screen is module selection to test. After selecting it, all messages on that module can be tested either manually by adding existing messages from the upper menu or loading an existing test scenario, which was already saved. Then, by running all tests, the test driver UI shows pass/fail status in colorful format as shown in Figure 7(c).



(a): Left Pane, which shows all messages



(b): Message details for "antennaSpeed" message



(c): Test driver output

Figure 7: Generated Artifacts.

5.2 Impacts, Challenges and Lessons Learned

As discussed, MDE framework was developed to support of embedded software development and maintenance in the context of ASELSAN.

The usage of Model-ComM is grouped into two categories. The first group includes the projects, which have been using Model-ComM from the beginning. The other group includes the projects, which had already an existing communication middleware technologies, decided to adopt tool. The first group includes three projects and 10 modules;

whereas the second group includes one project, whose four modules use the tool and two modules do not. Due to confidentiality reasons, we are unable to report the real names of these projects and modules. As a convention, module names begin with project names initial letter to be more understandable. ProjectX, which is in the first group, has three modules; whereas, ProjectY, which is in the second group, has four modules that use the tool.

Besides presenting quantitative data in that section, informal question & answer session results are also presented with verbatim quotes of ProjectX and ProjectY shareholders, which include project managers, developers, system engineers and also testers. All these quotes have been translated from Turkish, as precise as possible, by the authors.

Impacts for the challenge area 1: In Table 1, lines of code (LOC) statistics of the auto-generated code for communication interfaces are given for ProjectX and ProjectY. Depending on the interface number and messages, LOC generated by Model-ComM varies between ~3500 and ~9500. It is clear that this saves inefficient usage of development effort compared to before tool usage. A verbatim quote from ProjectX manager: "*As a pioneer, we started to use Model-ComM. In our implementation effort so far, we have gained ~15% effort savings with code generation*".

Table 1: LOC statistics of the auto-generated code for the communication interfaces.

ProjectX	ModuleX1	ModuleX2	ModuleX3	
LOC	~7520	~5500	~4680	
ProjectY	ModuleY1	ModuleY2	ModuleY3	ModuleY4
LOC	~9450	~6370	~5240	~3520

Impacts for Challenge area 2: ProjectX shareholders' common idea is that with the help of automated ICD, they can focus on more "business logic" without worrying about synchronization of code and documentation. Moreover, ProjectX developer says that "*Since there is only one–hand generated code for all inter-dependent modules based on single model, there is no last-minute surprise during integration and we do not worry about whether inter-dependent module's developer changed or not the message interface implementation*".

ProjectY manager states: "*The bonus is that we have now a reliable and one-minute-ready HTML-based ICD; and we do not worry about the unsynchronized artifacts*". ProjectY developer, who has more interfaces than the other inter-dependent modules states *"I benefited more than the others not just because of code generation but also documentation. Because, whenever I change the code, the document is also updated and I do not worry about any change is not reflected in ICD."*

Impacts for the challenge area 3: Auto-generated code also significantly affected the effort to write simulators. Table 2 gives LOC statistics to simulate ModuleX1's inter-dependent modules: ModuleX2 and ModuleX3. This also saves the necessary time for implementation of simulator. The best thing is that, the implementation details in simulator are generic since the generated test driver is based on the model; not on any specific message.

Table 2: LOC statistics to implement ModuleX2's and ModuleX3's simulator to test ModuleX1 in ProjectX.

ProjectX	ModuleX2Sim	ModuleX3Sim
LOC	~5650	~4750

Table 3: RQs planned in our ongoing and future efforts.

RQ #	Sub-RQ #	RQ
1	What are quantitative benefits of the model-driven engineering approach and its associated tool-support in the case study context?	
	1.1	Does using the approach reduce development, test and maintenance efforts compared to the ad-hoc baseline?
	1.2	Does using the approach reduce defects across the SDLC compared to the ad-hoc baseline?
	1.3	Is the approach cost effective (with respect to cost-benefit analysis and value-based software engineering (Biffl et al., 2005))?
2	What are qualitative benefits of the model-driven engineering approach and its associated tool-support?	
	2.1	What types of challenges have been resolved using the approach and its tool-support?
3	How usable is the approach and how convenient is to integrate it into the SDLC lifecycle and processes in the industrial context under study?	
4	What are the further development areas of the approach and its tool-support?	
5	What are the generalizability and external validity aspects of the approach?	
	5.1	To what extent the approach and the tools can be used in other contexts and companies?
	5.2	How are out findings compare with the related work in the area of exploiting model-driven engineering in support of software development and maintenance?

A verbatim quote from ProjectX manager: *"Moreover, to test our message interfaces; we no longer need to wait for [completion of] their simulators"*. ProjectX tester continues *"With the help of Model-ComM test driver, I do not need to manually implement simulators; I can use my time more efficiently. Before the tool, we implemented simulators according to ICD and whenever anything is changed in ICD, we had to change our simulator."*

<u>Impacts for Challenge area 4:</u> The challenge of taking responsibility over the ICD has started to be resolved with auto-generation. ProjectX manager, who had some conflicts with other shareholders on that issue states that "*it is also very helpful for non-users of Model-ComM since they know that Model-ComM user's implementation is exactly what generated HTML says. By this way, we got rid of the document responsibility problem among shareholders; we took this while generating code."*

6 CONCLUSIONS AND ONGOING/FUTURE DIRECTIONS

In the upcoming phases of our R&D project, we plan to conduct more rigorous empirical case studies to ensure the cost effectiveness and benefit of our approach to the context and problem domain.

To this end, by following Goal, Question, Metric (GQM) approach (Basili, 1994), we have already planned a set of upcoming RQs to be studied and addressed as shown in Table 3. The goal will be to assess the benefits of the MDE approach and its associated tool-support in improvement of development and maintenance tasks in the embedded software projects under study from the point of view of researchers, software engineers and managers working in the company.

REFERENCES

ASELSAN. (2014). *ASELSAN*. URL: www.aselsan.com.tr [14/05/2014].

Barry, P. & Crowley, P. (2012). Embedded Platform Architecture. *In:* Barry, P. & Crowley, P. (eds.) *Modern Embedded Computing.* Boston: Morgan Kaufmann.

Basili, V. C., G.; Rombach, D.H. (1994). The Goal Question Metric Approach. *Encyclopedia of Software Engineering.* Wiley.

Biffl, S., Aurum, A., Boehm, B., Erdogmus, H. & Grünbacher, P. (2005). *Value-Based Software Engineering.* Springer-Verlag New York, Inc.

Bittner, R. (2012). Speedy bus mastering PCI express. *In:* 22nd International Conference on Field Programmable Logic and Applications (FPL), 523-526.

Broy, M. (2006). Challenges in automotive software engineering. *Proceedings of the 28th international conference on Software engineering*, China: ACM.

Davies, J., Gibbons, J., Welch, J. & Crichton, E. (2014). Model-driven engineering of information systems: 10 years and 1000 versions. *Science of Computer Programming,* 89, Part B, 88-104.

Douglass, B. P. (2000). *Real-time UML: Developing Efficient Objects for Embedded Systems.* Addison-Wesley.

Douglass, B. P. (2004). *Real Time UML: Advances in the UML for Real-time Systems.* Addison-Wesley.

Ebert, C. J., Capers (2009). Embedded Software: Facts, Figures, and Future. *IEEE Computer Society,* 42, 42-52.

Frankel, D. (2002). *Model Driven Architecture: Applying MDA to Enterprise Computing.* John Wiley & Sons.

Ganssle, J. (2008). *A trillion lines of code?* URL: http://www.ganssle.com/rants/atrillionlinesofcode.htm [13/06/2014].

Gokhale, A., Balasubramanian, K., Krishna, A. S., Balasubramanian, J., Edwards, G., Deng, G., Turkay, E., Parsons, J. & Schmidt, D. C. (2008). Model driven middleware: A new paradigm for developing distributed real-time and embedded systems. *Science of Computer Programming,* 73, 39-58.

Gorschek, T., Wohlin, C., Carre, P. & Larsson, S. (2006). A Model for Technology Transfer in Practice. *Software, IEEE,* 23, 88-95.

Graaf, B., Lormans, M. & Toetenel, H. (2003). Embedded software engineering: the state of the practice. *Software, IEEE,* 20, 61-69.

Hutchinson, J., Whittle, J. & Rouncefield, M. (2014). Model-driven engineering practices in industry: Social, organizational and managerial factors that lead to success or failure. *Science of Computer Programming,* 89, Part B, 144-161.

Iyenghar, P., Pulvermueller, E. & Westerkamp, C. (2011). Towards Model-Based Test automation for embedded systems using UML and UTP. *In:* Emerging Technologies & Factory Automation (ETFA), 1-9.

Kaner, C., Bach, J. & Pettichord, B. (2001). *Lessons Learned in Software Testing: A Context Driven Approach.* New York: John Wiley & Sons Inc.

Krafzig, D., Banke, K. & Slama, D. (2004). *Enterprise SOA: Service-Oriented Architecture Best Practices (The Coad Series).* Prentice Hall PTR.

Kramer, J. (2007). Is abstraction the key to computing? *Commun. ACM,* 50, 36-42.

Liggesmeyer, P. & Trapp, M. (2009). Trends in Embedded Software Engineering. *Software, IEEE,* 26, 19-25.

Lindvall, M. K.-S., S.; Costa, P.; Seaman, C. (2003). *Embedded Software Maintenance.* Data and Analysis Center for Software.

McCluskey, G. (1998). *Using Java Reflection*. URL: http://www.oracle.com/technetwork/articles/java/javareflection-1536171.html.

Moore, B., Dean, D., Gerber, A., Wagenknecht, G. & Vanderheyden, P. (2004). *Eclipse development using the graphical editing framework and the eclipse modeling framework.* IBM Corp.

Myers, G. J., Sandler, C. & Badgett, T. (2012). *The art of software testing.* 3rd ed. Hoboken, N.J.: John Wiley & Sons.

Nicolescu, G. M., P. J. (2009). *Model-Based Design for Embedded Systems* CRC Press.

Pao-Ann, H., Win-Bin, S., Trong-Yen, L., Jin-Ming, F. & Sao-Jie, C. (2001). Formal verification of embedded real-time software in component-based application frameworks. *In:* Asia-Pacific Software Engineering Conference, 71-78.

Parnas, D. (2011). Precise Documentation: The Key to Better Software. *In:* Nanz, S. (ed.) *The Future of Software Engineering.* Springer Berlin Heidelberg.

Paulin, P. G., Liem, C., Cornero, M., Nacabal, F. & Goossens, G. (1997). Embedded software in real-time signal processing systems: application and architecture trends. *Proceedings of the IEEE,* 85, 419-435.

Rushby, J. (2011). New challenges in certification for aircraft software. *In:* Embedded Software, 211-218.

Santos, P. S. M. d. & Travassos, G. H. (2009). Action research use in software engineering: An initial survey. *Proceedings of the 2009 3rd International Symposium on Empirical Software Engineering and Measurement.* IEEE Computer Society.

Schantz, R. & Schmidt, D. C. (2008). Middleware for Distributed Systems. *In:* Wah, B. (ed.) *Encyclopedia of Computer Science and Engineering.*

Schäuffele, J. & Zurawka, T. (2005). *Automotive Software Engineering: Principles, Processes, Methods, and Tools.* SAE International.

Skolnik, M. I. (2001). *Introduction to radar systems.* 3rd ed. Boston: McGraw Hill.

Stefan, G. & Bruce, W. (2011). Model-Based Passive Testing of Safety-Critical Components. *Model-Based Testing for Embedded Systems.* CRC Press.

Stimson, G. W. (1998). *Introduction to airborne radar.* 2nd ed. Mendham, N.J.: SciTech Pub.

Zander, J., Schieferdecker, I. & Mosterman, P. J. (2011). *Model-Based Testing for Embedded Systems.* CRC Press.