# Matlab/Simulink functional tests with STB/AGATHA tool

J.Y. Pierron[1], A. Lapitre[1], J.P. Gallois[1], S. Devulder[2], T. Gueguen[2], P. Le Corre[3]

1: CEA, LIST, Boîte Courrier 94, Gif-sur-Yvette, F-91191 France
2: GEENSOFT, 120 Rue René Descartes, 29280 PLOUZANE
3: Johnson Controls, 10 av de l'Entreprise, BP 78587, 95892 Cergy Pontoise

**Abstract**: This paper first presents an overview of one work done in the EDONA project which proposes an open development platform to automotive standards. EDONA is a project of the System@tic cluster Paris-Area.

Then, the paper will in more presents details the results of an assessment of a test engineering workflow combining the AGATHA tool from CEA LIST and the STB tool from Geensoft. STB is connected to Matlab/Simulink platform used as modeller and test execution engine. This platform is used by Johnson-Controls in association with their AUTOSAR strategy.

**Keywords**: Matlab/Simulink specification, symbolic execution, test case generation

## 1. Introduction

Our test cases generation tool, integrated in the software development process, will help designer to improve the quality and robustness of their designed models for software development cost and time reduction.

Once developed, the designer can realize a V cycle on the model. The tool allows one to obtain structural and functional test coverage.

Users of the resulting tool box can work step by step for model testing by selecting coverage criteria then directly visualizing tests impact. These tests can be exported in Excel for reuse in other environments. For instance, in order to manage non regression tests or multiple automatic test sequences execution.

The generation of tests is based on symbolic automaton execution techniques and on constraint solving. The tool generates numerical test cases by building exhaustive execution trees from automata based specifications.

The use of criteria combined with symbolic execution techniques allows one to reduce the combinatorial explosion when generating test cases and then to build a set of exhaustive tests according the chosen criteria. The paper concludes on the quality and robustness for complex system improvements achievable with such a tests generation process.

This paper is divided into 6 sections:

Section 2 of the paper introduces an overview of the industrial (Johnson Controls Automotive Experience, named as Johnson Controls from now) expectations.

Section 3 presents the STB tool from Geensoft that interacts between designer, model and test cases generator (AGATHA).

Section 4 introduces AGATHA, background technology.

Section 5 and 6 focused on use cases to validate concepts on Johnson Controls examples and feedback of today results.

Section 7 is a conclusion.

## 2. Industrial needs overview

Electronics Control Unit (ECU) development, in Automotive, as in other domains, shall be performed in less and less time to follow rapid market evolutions. In addition costs should be reduced to increase competitiveness while maintaining the highest level of quality. These requirements have a strong impact on software development, which is a main activity in ECU development.

With the introduction of the Autosar® architecture, Johnson Controls is positioned as integrator and focuses on knowledge located on the application level. For many companies like Johnson Controls, application implementations go through modeling with tools like Matlab®/Simulink®/Stateflow® for earliest design verification and automatic C-Code generation.

As an example, we develop models used in Battery Management Systems (battery algorithm), Body Controller Modules (Tire Pressure Monitoring System, Autolearning) or Instrument Clusters (Fuel Tank Algorithm).

In generic software development, an impact analysis based on the software V-Model, shows that the majority of software defects are generated in analysis and design phases and are detected in coding/unitary tests and operational life (see Table 1 taken from [7]).

| Software cycle step | Errors produced (%) | Errors detected (%) |
|---|---|---|
| Analysis | **55** | 18 |
| Design | **30** | 10 |
| Coding and unitary tests | 10 | **50** |
| Operational life | 5 | **22** |

**Table 1 : Table of defects produced and detected vs. the software life cycle step**

Other studies (Figure 1) provide an idea of the relative cost impact in relation with the defect detection in this V-Model [8].

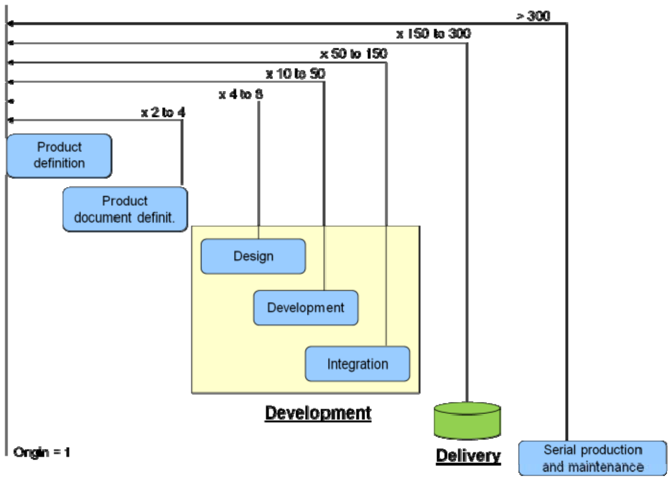


**Figure 1 : Cost for correction related to the detection process**

To support designers to improve the model design and robustness, Johnson Controls is associated to partners, in the EDONA project, for the development of a generic tool for automatic test cases generation at the model level. This tool shall be able to interact with a standard environment for automatic validation and link to home-made tools. We will be able to generate test cases to verify back to back tests between model and code, up to system validation (when possible).

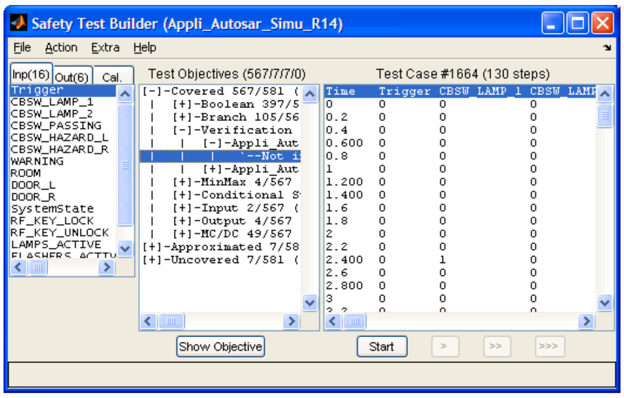
Once the model is developed and simulated, the designer performs the tests of the model. The tool takes on some structural test coverage such as dead lock detection, data overflow, unused algorithm part, Model Coverage/Decision Coverage or signal ranges.

In addition to functional validation, this tool associated to other market tool for model management shall enable us to improve analysis for model coverage (MIL) and code coverage (SIL). We will be able to detect dead code or deactivated code, analyse functions and calls coverage and to reduce time before obtaining the first results.

This fills some requirements of ISO26262 standard [4] (see examples provided previously) to be able to reach up to the safety ASIL D level.

## 3. Safety Test Builder

Safety Test Builder (STB) is a Geensoft's tool dedicated to automating the production of test cases for embedded software projects that have been modelled with Simulink® and/or Stateflow® from The MathWorks®. The tool, which is fully integrated with the Matlab environment, works with any standard Matlab blockset and provides easy extension using an "external tool" feature.



Safety Test Builder (Appli_Autosar_Simu_R14)
File
Action
Extra
Help
Inp(16)
Out(6)
Cal.
Test Objectives (567/7/7/0)
Test Case #1664 (130 steps)
Show Objective
Start
>
>>
>>>

```
Trigger
CBSW_LAMP_1
CBSW_LAMP_2
CBSW_PASSING
CBSW_HAZARD_L
CBSW_HAZARD_R
WARNING
ROOM
DOOR_L
DOOR_R
SystemState
RF_KEY_LOCK
RF_KEY_UNLOCK
LAMPS_ACTIVE
```

```
[-]-Covered 567/581 (
 |   [+]-Boolean 397/5
 |   [+]-Branch 105/56
 |   [-]-Verification
 |    |   [-]-Appli_Aut
 |    |    |    `--Not i
 |    |   [+]-Appli_Aut
 |   [+]-MinMax 4/567
 |   [+]-Conditional S
 |   [+]-Input 2/567 (
 |   [+]-Output 4/567
 |   [+]-MC/DC 49/567
[+]-Approximated 7/58
[+]-Uncovered 7/581 (
```

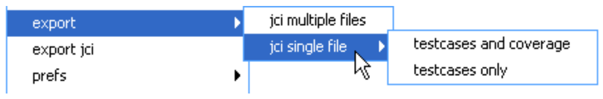
```
Time     Trigger CBSW_LAMP_1 CBSW_LAMP
0        0       0           0
0.2      0       0           0
0.4      0       0           0
0.600    0       0           0
0.8      0       0           0
1        0       0           0
1.200    0       0           0
1.400    0       0           0
1.6      0       0           0
1.8      0       0           0
2        0       0           0
2.2      0       0           0
2.400    0       1           0
2.6      0       0           0
2.800    0       0           0
3        0       0           0
```

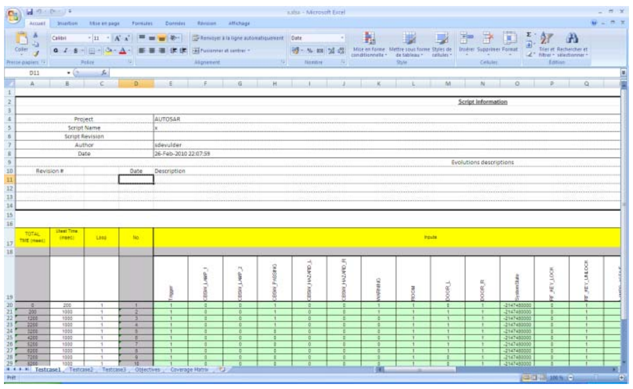
Test cases generated by STB are defined according to coverage objectives derived from user-defined criteria. Typical coverage criteria are:

- Functional coverage, where only the functions of the model are covered (i.e. the inputs/outputs, global MC/DC, etc). This is a kind of *black-box* strategy.
- Structural coverage, in which the test objectives are selected to exercise some or all of the model internal blocks. This is a typical *white box* strategy.

Once test cases are found, STB is able to export and optimize them either in number or size, to call the Simulink's coverage tool to produce a coverage report, generate a Simulink test harness that can check the model (or any implementation of it) against the expected inputs/outputs and to replay a specific test case step-by-step in order to find out why a model diverges from the expected behavior, etc.

This list is actually open: by using the external tool feature, one can freely add new functions to STB. For instance in EDONA/WP3 we have developed a tool that exports the test case database into spread-sheets used by Johnson Controls' tool chain (see section 5).





In order to find test cases, the model is automatically instrumented with extra Simulink blocks that detect when an objective is covered. Then STB uses Simulink's native simulation modes (normal, accelerated or rtw-generated c-code) to execute heuristically-driven random walks in the model's state space. This approach allows STB to cope with any standard block present in the model without worrying about the numerous parameters that can alter its semantics. Indeed, the scenarios found by STB accurately represent by construction the exact behavior of the model.

The speed of the heuristically-driven random search is rather good (half hundred thousand steps per second on a typical application like the ones of section 5). Therefore, in a few-seconds search, many millions steps are examined. This brute-force approach allows covering most test objectives very quickly (>80% coverage ratio is usually observed on industrial models). Obviously, hard-to find corner cases require longer search time.

Plotting a typical coverage ratio against the time-spent (see Figure 2) shows that it asymptotically converges to a limit. This means that if covering the first 80% of the test objectives is fairly easy, the remaining 20% will require much more effort (not counting for unreachable objectives).

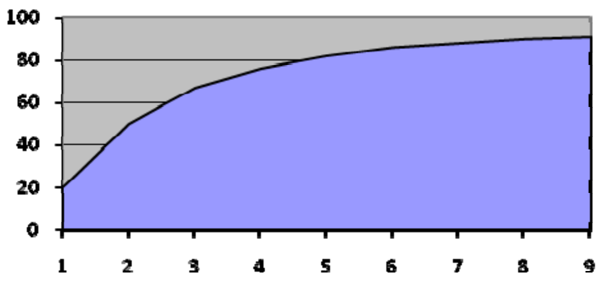
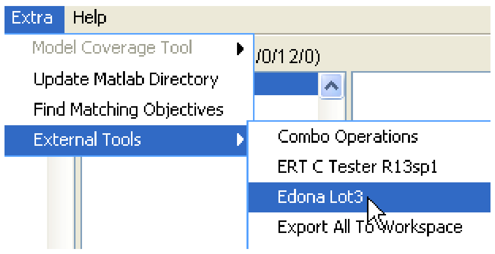


**Figure 2: Coverage ratio in function of the time spent for random search**

This stated, it appeared that in order to improve STB performance, a different technique should be used. Hence, in EDONA/WP3, an external tool has been developed, that uses the AGATHA engine by the CEA LIST (see section 4) in order to perform symbolic execution of the model, to reach corner cases and possibly prove which test objective is reachable or not.



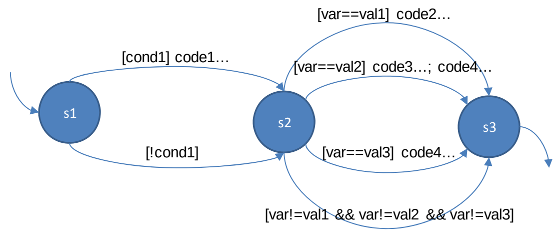
As the AGATHA tool is not able to natively understand Simulink models, we had to find a way to translate Simulink's semantics into the proper representation.

The formal semantic of Simulink models is hard to define because it is an industrial standard that contains many variants. It also slightly evolves with Matlab's versions and is not publically available. However, when using the embedded coder of Real-Time Workshop, one gets C code that is semantically correct with respect to the model. Since the semantic of embedded C is rather clean, we have designed a technology that is able to transform (a subset of) C into AGATHA-compliant automata.

This works in several steps. First the C code is read and an abstract syntax tree is constructed. That tree is then formally transformed in an internal form that represents an automaton, the states of which are the condition points present in the C code and the guarded out-transitions contain the decision executed according to the condition. For instance, the following C code:

```
if(cond1) {code1…;}
switch(var) {
  case val1: code2…; break;
  case val2: code3…;
  case val3: code4…; break;
}
```

is translated into the following states and guarded transitions:



The C variables read and written in transitions coming out of different states are transformed into global state variables. Others are represented as transition specific local variables. Nested conditions (e.g. `If()` statements) simply add extra states in a way that prevents the explosion of the number of states. Globally the size of the produced automaton grows almost linearly with the size of the C code.

Actually the defined technology is flexible enough to work on C code generated by other C-code generators such as Geneauto2 [6].

Overall the formal tool-chain added to STB works as follows:

1. Instrument the model using extra Simulink blocks, as usually done by STB.
2. Call a C generator (ERT coder or Geneauto2).
3. Read the C code with the proper reader (one for ERT, one for Geneauto2) and build an internal representation of the C code that is not generator dependent.
4. Translate that internal representation and all objectives into AGATHA's format.
5. Launch the AGATHA tool.
6. Read the scenarios that have been found by AGATHA and inject them into STB's database.

Using this tool-chain, we are now able to symbolically execute the Simulink model looking for corner cases not found with STB native algorithm and export them into Johnson Controls' format, in order to perform hardware-in-the-loop simulations.

## 4. Test generation with AGATHA

The goal of the AGATHA tool-set is to help engineers to check if a model based on concurrent automata fits the user informal requirements. The idea is to symbolically execute ([1], [5]) the model in order to obtain a synoptic view of its behaviours.

### 4.1. Symbolic Execution

AGATHA derives a tree-like structure denoting all behaviours of the model. The tree nodes are snapshots which represent the symbolic states of the system during the execution at a given step. Here, a snapshot is a data structure named *Execution Context* (Figure 3) which includes:

- a *Control State*,
- a *Path Condition*, conjunction of the encountered guard to reach this context,
- all symbolic variables values,

$$\mathbf{EC} = \begin{cases} \mathrm{CS} : \mathrm{s} \\ \mathrm{PC} : x_1 > y_0 \\ x = 2 * x_1 \\ y = y_0 + x_1 \end{cases}$$

**Figure 3: Execution Context**

Let **t** be a transition like in Figure 4 which the source state **s** is include in the control state of **EC**.

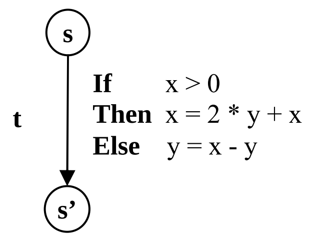


**Figure 4: Transition**

Symbolic evaluation of **t** provides two new execution contexts described by the Figure 5 which corresponds of the two behaviours been inferred from a classical *if-then-else* statement.

$$\mathbf{EC_1} = \begin{cases} CS : s' \\ PC : x_1 > 0 \land x_1 > y_0 \\ x = 2 * y_0 + 4 * x_1 \\ y = y_0 + x_1 \end{cases}$$

$$\mathbf{EC_2} = \begin{cases} CS : s' \\ PC : x_1 \leq 0 \land x_1 > y_0 \\ x = 2 * x_1 \\ y = 3 * x_1 - y_0 \end{cases}$$

**Figure 5: Symbolic Execution**

## 4.2. AGATHA workflow

In order to check the model according to the user objectives or connected tools like STB, AGATHA offers a set of execution (or behaviour) filters which can be configured to do structural or functional coverage among others. For example, the formula checker (verifier) filter needs a set of algebraic formula provided by the user.

The Figure 6 shows the AGATHA workflow perform behaviours selection according to user configuration (for filters) during an evaluation step. Three main agents sequentially work:

1. A *Queue* is used to store the waiting execution contexts. A Selector deals with the model search strategy like depth first, breadth first or random.
2. A *Symbolic Execution* engine.
3. A *Controller* manages filters.

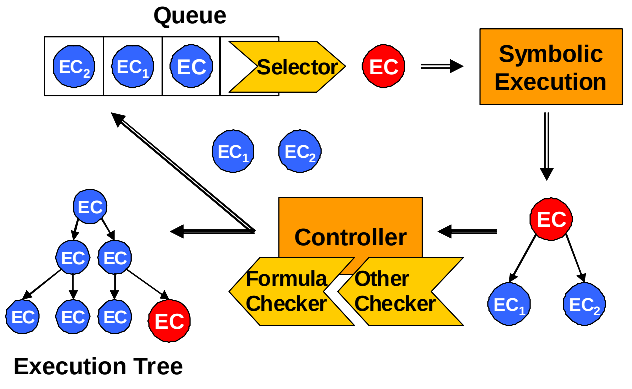


**Figure 6: AGATHA workfow**

## 4.3. Test generation

From the symbolic execution tree generated by AGATHA, we consider each behaviour path as a symbolic test case which represents an equivalence class of numerical tests. A constraint solver is used to numerize each symbolic path which is a sequence of execution contexts. A test case contains one sequence of system cycles. Each cycle is made of values for all input / output system parameters.

## 5. Use cases description

### 5.1. Overview of models perimeter used

To check the validity of concept, the perimeter taken into account is the product for battery management systems and body controller modules. More precisely some algorithms developed for the Johnson Controls Autosar prototype, the Tire Pressure Monitoring System (TPMS) and battery algorithm.

These models cover the typical use-cases algorithms we find in our company using Stateflow or Simulink blocks. Added to them we take into account some other models from Delphi and Renault.

### 5.2. Use case #1

In the first use case, we need to test an Autosar model developed with Simulink and dedicated to management of room, flashing and front/rear lamps. It is built with around 400 blocks, representing 19 kinds of block types.

This model is used in the prototype developed by Johnson Controls to evaluate the migration from legacy architecture to Autosar architecture. This prototype is built with Simulink model for Autosar, C-Code generation and plugged on an Autosar ICC3 Basic Software. The whole software is tested into a standard validation environment at model level, and used for verification of tools migration for PC simulation and validation (XCAR), see Figure 7.

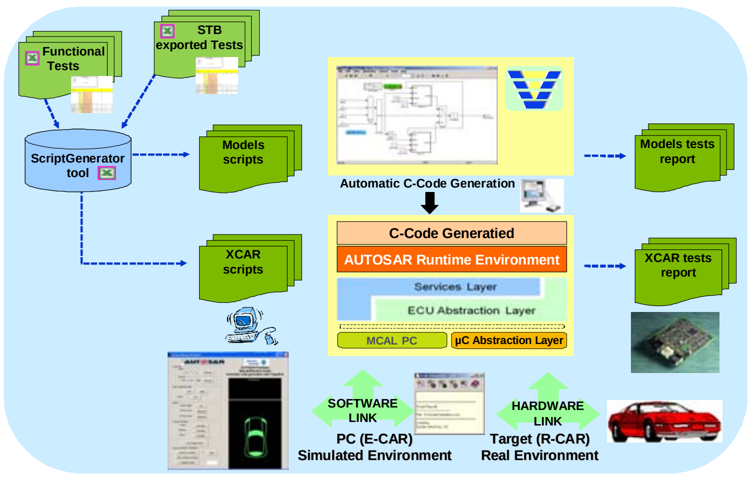


**Figure 7: Johnson Controls Autosar PC and target validation overview**

In association with the validation environment, STB/AGATHA tool, described in Figure 8, provides some tests and is connected to the Johnson Controls environment through the file exchange format.

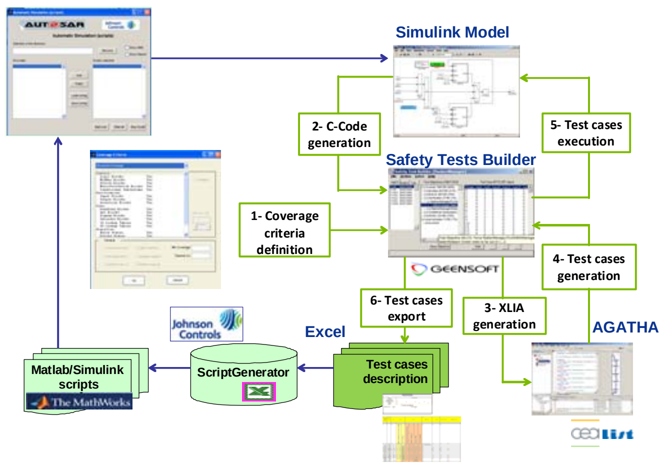
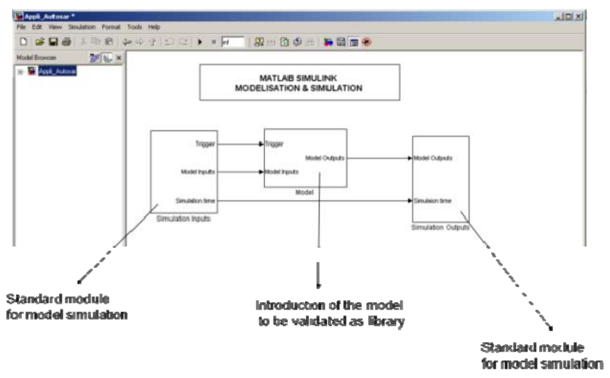


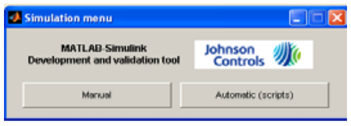
**Figure 8: Test environment at model level**

This test environment is divided into 2 parts:

- STB/AGATHA tool: helps user to define tests coverage criteria, interact with the model (display test impact, test case execution) and generates test cases for Johnson Controls use. AGATHA produces test cases.
- Johnson Controls modeling test environment: a tool converts test cases to Matlab scripts then automatic execution in standard HMI interface which display execution and impact in a dedicated project window (figure 9).


MATLAB SIMULINK MODELISATION & SIMULATION
Trigger
Model Inputs
Simulation time
Simulation Inputs
Model Outputs
Model
Simulation Outputs
Standard module for model simulation
Introduction of the model to be validated as library
Standard module for model simulation

Global validation model environment view



Standard HMI

Automatic script management

AUTOSAR
Johnson Controls
AUTOSAR Prototype MatLab/Simulink model Automatic code generation with Targetlink
Dashboard
STOP SIMULATION

Dedicated project HMI

**Figure 9: Johnson Controls standard HMI and model validation environment**

5.3. Use case #2

In the second use case, we test an algorithm developed with Simulink blocks for the Tire Pressure Monitoring System function. In this model we manage miscellaneous algorithms for tire pressure state monitoring (low or high pressure thresholds management, leakage detection, tire pressure associated to vehicle speed, sensor status verification) to provide alarm to the vehicle driver. The last release of this algorithm was used as specification then hand coded and integrated in serial ECU production since 2008 (300 000 parts per year).

This model is built with around 3300 blocks, representing 24 kinds of block types.

The environment is the same as described for the use case #1.

The goal of this use case is to check with the tool, a model developed in the past for serial production without association to automatic C-Code generation and to increase the perimeter of the model size taken into account.

## 6. Tool evaluation and feedback

From the industrial point of view, the STB/AGATHA tool in development, is user friendly and can be used intuitively.

The HMI enables to define easily the coverage criteria (even with possibility to create specific user menus for predefined coverage criteria), to generate the test cases, to view the impact on the model and to export to pre-defined format (.xls, .pdf, etc). The user can integrate new functionalities in the tool (inside the menu) using Matlab scripts (for example automatic rework of model for data typing, model check or rework for specific constraints, etc).

The current results of the evaluation phase, are promising regarding the potential of the tool to help in development for time saving, cost reduction and quality improvement.

The results seen on some example models need to be confirmed by using this tool on more models. Nevertheless, the tool needs to continue to be improved.

## 7. Conclusion and perspectives

The work which is described in this paper has the objective to provide an automated test generator, with a user friendly interface, and whose performances allow to be used in an industrial context. This objective must be reached in the year 2010, and the actual results confirm this planning.

A possible extension of the tool is the verification of properties, because the use of the symbolic execution is a good way to verify temporal properties [10].

Another extension can be the use of the symbolic tree produced by symbolic execution to analyse the models ([2], [9]), and before generating test to choose the best test purposes [3].

With these extensions, the proposed toolset could offer more possibilities to different users and would allow them to give their feedback to the proposed verification and validation process.

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## 9. Glossary

| | |
|---|---|
| *AGATHA* | : Atelier de Génération Automatique de Test Holistique d'Automate |
| *Autosar* | : AUtomotive Open System ARchitecture |
| *ASIL* | : Automotive Safety Integrity Level |
| *ECU* | : Electronic Control Unit |
| *MIL* | : Model In the Loop |
| *SIL* | : Software In the Loop |
| *ISO* | : International Standard Organization |
| *MC* | : Model Coverage |
| *DC* | : Decision Coverage |
| *EDONA* | : Environnement de Développement Ouvert aux Normes de l'Automobile. |
| *HMI* | : Human Machine Interface |
| *TPMS* | : Tire Pressure Monitoring System |
| *PC* | : Personal Computer |
| *STB* | : Safety Tests Builder |
| *ICC3* | : Implementation Conformance Class 3 |