An Approach for Modeling Real-time Requirements with SysML and MARTE Stereotypes

Fabíola Gonçalves C. Ribeiro and Michel S. Soares
Faculty of Computing, Federal University of Uberlândia, Uberlândia, Brazil

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Abstract: The specification, analysis and design of real-time systems (RTS) are activities that are highly dependent on an effective understanding of the application domain and on the thorough representation of their basic requirements. The use of model-based approaches for the development of RTS systems tends to contribute to minimizing the complexity of the system development. UML has been used intensely in recent years for modeling requirements of real-time software. However, UML alone does not completely represent the important features associated with these systems. UML is a language that has several extension capabilities enabling the creation of specific profiles. This article will explore the use of UML profiles SysML and MARTE for the modeling of RTS software requirements, with its main area of application being the control of urban traffic. The main objective is to demonstrate the application of SysML with MARTE stereotypes, which enables the modeling and tracing of individual software requirements.

1 INTRODUCTION

Requirements engineering is the process by which the requirements for systems and software products are gathered, analyzed, documented and managed throughout the development life-cycle. UML (OMG, 2011c) has traditionally been used to document user requirements through Use Case diagrams (Xu et al., 2011), with the purpose of creating graphical specification to scenarios of software execution. This means that requirements are organized into stories of using the system that acts as a friendly point between users, technical and business stakeholders (Helming et al., 2010) (Heisel and Cote, 2011).

There are some issues involved with using Use Case diagrams for modeling real-time requirements. The main purpose of a Use Case diagram in the context of requirements is to describe scenarios of requirements, not individual requirements. In addition, Use Cases are specific to describing functional scenarios, without concerns about representing non-functional properties. Use Cases are extremely informal, and can be easily misused when too many details are modeled. According to (Bianco et al., 2002), temporal constraints and concurrent activities are not well-expressed in UML. As discussed in (Silvestre and Soares,), UML presents difficulty in expressing non-functional properties of the system, very important requirements for real-time applications.

Proposals to address the problems of UML in relation to modeling real-time software were created. These include the *profiles* SPT (OMG, 2005), MARTE (OMG, 2011a) and SysML (OMG, 2010). These profiles extend UML and add elements that model time requirements, system requirements and non-functional properties. The SPT profile (SPT stands for “Schedulability, Performance and Time”) provides a mechanism for the annotation of a set of pre-defined stereotypes and tagged values (Xu et al., 2003). SPT offers support for some of the annotations of non-functional properties (NFPs), such as support for symbolic variables and expressions through its specialized language Tag Value (TVL). SPT provides time related concepts such as the notions of instant and duration, concepts for modeling of events and time related stimulus (Bennett and Field, 2004). However, its approach was not formally defined enough to allow new definitions of NFPs by the user or for different specialized fields.

MARTE and SysML profiles have been studied and applied in practice in past years in domains such as product lines (Belategi et al., 2010), concurrent systems (Shousha et al., 2012), and in other industrial environments (Iqbal et al., 2011) (Iqbal et al., 2012). However, few approaches were proposed with a focus on applying MARTE and SysML together to de-

C. Ribeiro F. and S. Soares M..
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sign real-time systems. One of these approaches was published in (Quadri et al., 2012b), in which a systems modeling language is defined based on subsets of MARTE and SysML, allowing iterative refinement from high-level specifications all the way down to final implementation. Another approach was proposed in (Quadri et al., 2012a), but its focus was not based on requirements design. In addition, only functional requirements are described with the SysML Requirements diagram.

In this article the strategy is to combine the MARTE and the SysML profiles with the purpose of improving the specification of requirements for real-time systems. The main focus is to show how these profiles can be combined in order to demonstrate its applicability for the modeling of time, performance, system configuration, and of course, the functional and non-functional requirements of real-time systems. The created model is applied to modeling requirements of a Road Traffic Control System.

2 BACKGROUND ON MARTE AND SysML

Among the proposed UML profiles, two are used in this article. SysML, because of its Requirements diagram, and MARTE, with the many stereotypes used to specify non-functional properties. The profiles are briefly introduced in this section.

2.1 MARTE

The architecture of the MARTE *profile* consists of three main packages named **MARTE Foundations**, which aims at defining fundamental concepts for embedded real time systems and brings concepts that serve as a general basis for the description of most of the elements linked to the remainder of the specification, the **MARTE Design Model**, which provides the necessary support to conduct a detailed specification of a project for real time embedded systems and the **MARTE Analysis Model**, which provides concepts for verification and validation of models (Kumar and Jasperneite, 2010) (OMG, 2011b). (Silvestre and Soares,). In addition to these packages, the MARTE profile proposes numerous other sub-packages. The **MARTE Foundations** relates to the scope of this work (more specifically the first three sub-packages) and, for this reason, these are briefly described as follows.

- **Core Elements.** This sub-package has the basic elements for behavioral modeling and the semantic representation of its running time. The objective of this model is to provide a high-level view of the semantics of execution time for modeling elements.
- **Non-functional Properties Modeling - NFPs** This sub-package offers paths to specify non-functional properties of real-time systems, such as memory usage and power consumption. It also explains how the NFPs can be connected to elements of the model.
- **Time Modeling - Time.** This package allows the modeling of time and related structures over time. Concepts related to physical time, logical time, and representation of instants representing time bases, and occurrences of events over time, are clearly defined in this sub-package.
- **Generic Resource Modeling - GRM.** This sub-package provides all the necessary stereotypes and tagged values to represent features such as means of communication, computing resources and storage resources. It also includes resources that are needed to deal with the modeling of execution platforms with different levels of abstraction and modeling. The GRM package along with the package Time can be used to specify time constraints and, when used with the package NFP, can be used for specifying the quality of services.
- **Allocation Modeling - Alloc.** The MARTE profile allows designers to model the applications and execution platforms. An application element in MARTE can be a service, computation or a function of the operating system. An execution platform is a collection of connected resources representing the hardware architecture.

2.2 SysML

The SysML profile (OMG, 2010) allows the modeling of various types of applications in engineering systems, enabling the specification, analysis, design, verification and validation of complex systems (OMG, 2010). The introduction of the SysML Requirements diagram provided support for modeling individual requirements and their relationships. The basic graphical node to design requirements diagrams is shown in Figure 1. The SysML Requirements diagram allows the requirements relationships to be represented in various manners. These relationships are briefly described as follows.

The **Derive Requirement Relationship** is represented by the stereotype $<<$ *deriveReqt* $>>$. It describes a requirement that was derived from another requirement. This relationship explicitly shows when

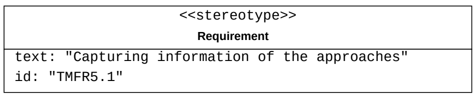


Figure 1: Basic node for SysML requirements diagrams.

a requirement can result in other requirements. The **hierarchy Requirement Relationship** describes a requirement that is contained within another requirement, which means that the relationship allows relating requirements in different hierarchical levels. For instance, high-level business requirements may be gradually broken down into more detailed software requirements, forming a hierarchy. This relationship is represented by a circle with a plus sign inside ($\bigoplus$). Each design element of the model has the purpose directly or indirectly to satisfy a requirement of the system. The **Satisfy Relationship** describes which design element performs/satisfies a particular requirement. The **Copy Relationship** describes a requirement that is a copy of another requirementt. This relationship is applicable when there is a need in the modeling of requirements for reusing a particular requirement in another context. The *Copy Relationship* is denoted as a dotted arrow pointing from the copy to the original and the stereotype $<< copy >>$.

The **Verify Relationship** connects a test case with the requirement that is verified by this test case. A test model usually defines a large number of test cases that test whether requirements are (or are not) properly implemented in the system. This relationship is denoted with a dashed arrow, pointing from the test case in the direction of a requirement, with the stereotype $<< verify >>$. The **Refine Relationship** specifies that one model element describes the properties of a requirement in more detail. For example, a functional requirement can be refined by one or more use cases. The **Trace Relationship** is a relationship between a requirement and an arbitrary model element. It describes a general relationship for reasons of traceability only. The trace relationship is very general and its semantics are therefore poor.

3 PROPOSED METAMODEL FOR SysML AND MARTE

Based on the concepts presented in the previous sections that provided the basics of SysML Requirements diagram and the broad power of expressiveness with the elements of MARTE, we have created a metamodel that extends SysML and MARTE and adds elements from the domain. The metamodel is depicted in Figure 2. The SysML Requirements diagram has been extended to allow a new representation for software requirements. The created attributes for the extended requirements take into account many of the specifications contained in the IEEE 830-1998 standard for describing software requirements (IEEE, 1998).

An extended requirement (represented by the stereotype $<<$ *ExtRequirement* $>>$) is proposed in this article, including additional attributes. In addition, derived from this extended requirement, an extended requirement for non-functional requirements is proposed (represented by $<<$ *ExtRequirementNRF* $>>$) with additional attributes. Three types of non-functional requirements were proposed in the meta-model, as seen in Figure 2. The attributes of Requirements are ID, title and text. The title is unique and briefly indicates the requirement context. The text attribute is a short explanation of the requirement.

The new defined attributes for ExtRequirement are: priority, type, classification, abstractLevel, constraint, scenario, creationDate, modificationDate, and versionNumber. The **priority** attribute defines the relevance of a requirement in relation to the other, i.e., indicating the order in which the requirements should be addressed. Values are of type String, including for instance, priority of type "must", "should", "could", and "won't". The **type** attribute indicates special features of a requirement, as for instance, if it sets a system's behavior, if it represents some special state, if it relates to events, or if it represents timed elements (clocks). It is important to note that for modeling with the SysML Requirements diagram with MARTE stereotypes', it is indispensable to import packages from MARTE Foundations that relate to the behavior of an element of the domain (CoreElements package), with non-functional properties (NFPs) and with the timing and structure of access time of modeling elements (package Time). The new **classification** attribute describes whether the requirement is functional, non-functional or if it is specific to the domain. The **level** attribute indicates the classification level of the requirement in the hierarchy. The **constraint** attribute enables showing requirements that have some type of restriction. This attribute is of type Boolean. If it is set to *true*, the identifier (ID) and the detailed description of this restriction are contained in a table of restrictions. **Scenario** is an attribute of type String which basically identifies the scenario to which the requirement is related. The attributes **creationDate** and **modificationDate** attributes are of type string and are related to the creation date of the requirement and the date on which it was modified. The attribute **versionNumber** is useful to keeping track of multiple ver-

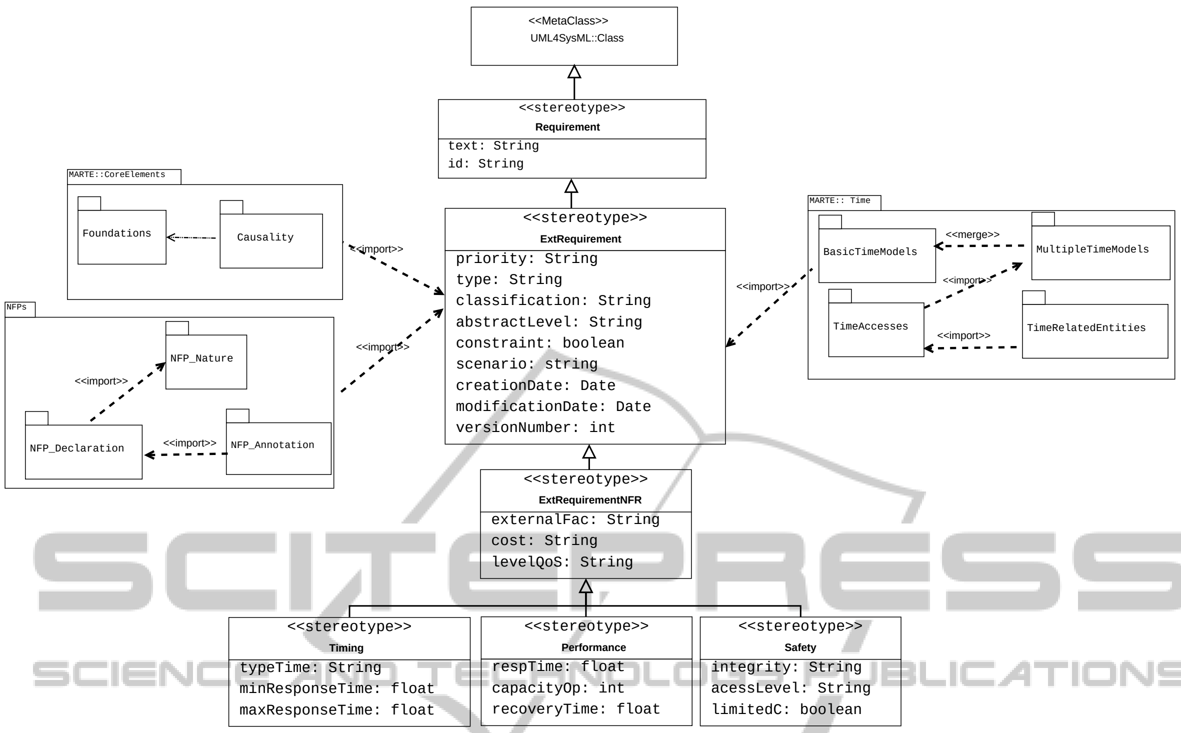


Figure 2: Metamodel for SysML and MARTE.

sions of the requirement. The last three requirements are very important for defining an extension of control to check the integrity of a requirement from changes performed throughout the specification.

The stereotype ExtRequirementNFR is used to describe non-functional requirements of software. The proposed attributes are externalFac, cost, and levelQoS. **ExternalFac** determines whether a requirement is dependent on an external factor in order to be developed. It is an attribute of type string and gives a brief description of the dependency factor. The **cost** attribute allows for the establishment of criteria of costs to satisfy a requirement that influences directly in those decisions concerning the viability of its development. Possible values to be assigned include High, Medium, or Low. The **levelQos** demonstrates the level of quality required for the requirement.

The timing type of non-functional requirement relates to the description of time of a software. Its attributes are **typeTime**, which can assume the values physical time or logical time, **minResponseTime** and **maxResponseTime**, which are used to describe timing constraints of a requirement.

The performance type has three attributes. **RespTime** indicates the maximum response time associated with a requirement. Its value allows for the establishment of which level of performance is to be associated or is to be guaranteed by the requirement. The **capacityOp** attribute indicates the possible number of simultaneous operations that are allowed in a given time period (e.g., number of reports generated for storage, operations per second, and so on). The attribute **recoveryTime** describes the maximum time required for recovery from a failure.

The safety type of non-functional requirement has attributes **integrity** (level of integrity that must be guaranteed), **acessLevel** (establish the level of access of stakeholders to a function), and **limitedC** (enables the demonstration of whether communication should be limited between this requirement and other functions/modules of the system.

3.1 MARTE Stereotypes

In most cases, the concepts defined in the domain, both for the sub-package of MARTE *CoreElements*, the sub-package *Non-Functional Properties* and, the sub-package *Time* presented in the last section are represented in MARTE through a stereotype that extends a UML modeling element. Thus, the UML extensions required for supporting the concepts defined in MARTE and the stereotypes are described in this section.

The set of extensions used to support *Core Elements* (Table 1), *NFPs* (Table 2) and *Time* (Table 3) for UML modeling is organized and addressed ac-

Table 1: Package MARTE *Foundations*: Stereotypes of *CoreElements*.

Package	Domain Model	Stereotype Name	Definition
Causality	Modal Behavior	Configuration	Representing the system configuration, can be defined by a set of elements system assets(for instance, application components, the components of the platform, hardware resource), and/or by a set of operating parameters (for instance, the QoS parameters or functionalparameters).
Causality	Modal Behavior	Mode	Identifies an operating segment within the runtime system that is characterized for a determined configuration. Work in a particular way can imply that a set of system entities are active during that operational fragment.
Causality	Modal Behavior	ModeBehavior	Specifies a set of mutually exclusive modes. Its dynamics is represented by connection modes by means of *Mode Transsitions*.
Causality	Modal Behavior	ModeTransition	Describes the modeled system in switching mode. *ModeTransition* may be produced in response to a *Trigger*.

Table 2: Package MARTE *Foundations*: Stereotypes of *Non-Functional Properties*.

Domain Model	Stereotype Name	Definition
NFP_Anotation	Nfp_Constraint	Aims to apply a condition or restriction to the elements modeled. Specifically, restrictions for NFP support textual expressions to specify assertions about programming, performance and other characteristics of embedded systems and their relationship with others by means of mathematical or logical variables and expressions of time.
NFP_Declaration	Nfp	It is intended to declare, qualify and assign data types extended to NPFs values.
NFP_Declaration	NfpType	A NfpType is a type whose instances are identified only by specifications of NFPs values. A NfpType contains specific attributes to support the modeling of types of NFPs tuples.
NFP_Nature	Dimension	Establishing a relationship between a quantity and a set of base quantities in a given system quantity.
NFP_Nature	Unit	It is a qualifier of values measured in terms of which magnitudes of other quantities (which has the same physical dimension) may be declared.

cording to the application context of domain concepts. In section 4, only the elements relating to the specification requirements for real-time systems are used.

4 CASE STUDY IN TRAFFIC SYSTEMS CONTROL

4.1 Background on Road Traffic Control Systems

With the growth in traffic volume, drivers are faced with many decisions that need to be made in order to safely proceed on to their designated right of way. The primary form of control and release of right of way is through traffic signals. Current control equipment can provide a wide variety of resource capabilities usually organized in fixed time, actuated time and adaptative time.

In the **Fixed-Time Signals** the values of the cycle time, duration and sequence of phases have fixed calculated values based on historical intersection flow. Any change in programming should be modified mechanically in the controller. According to (Roger et al., 2003), traffic signals that use fixed time are more affordable to purchase, install and maintain than actuated time. A deficiency associated with this type of control is that it is not possible to adjust the fluctuation of traffic throughout the day.

Actuated Traffic Signals vary at the green phase based on demand from the intersection as measured in detectors installed in an approach. Actuated traffic signals are composed of four components: the sensors, the control unit, the traffic lights and the con-

Table 3: Package MARTE *Foundations*: Stereotypes of *Time*.

Domain Model	Stereotype Name	Definition
TimedRelatedEntities	TimedElement	Abstract stereotype to be used for associating/ referencing one(s) Clock(s) to one model element.
TimeAccess	Clock	Introduces a general concept of clock. Represents an instance of clockType which provides access to time.
-	ClockType	A classifier for Clock and is related with time. Defines attributes to specify the nature of time (discrete/dense) or system of time(physical/logical).
TimeAccess	TimedValueSpecification	Specification of a set of instances of the TimeValue. The property interpretation can force the interpretation of this value as a duration or specification of instants. Like a *TimedElement* one *TimedValueSpecification* makes references to Clock.
TimedRelatedEntities	TimedConstraint	Represents constraints imposed at any value instant or in duration value associated with the model elements linked to clocks.
TimedRelatedEntities	ClockConstraint	The objective is to impose dependencies between Clocks or among types of Clocks. Like a *TimedElement* one *ClockConstraint* makes references to Clock.
TimedRelatedEntities:: TimedEventsModels	TimedEvent	Represents events whose occurrences are explicitly related to Clocks. The attribute repetition refers to a repetition factor, i.e., the number of occurrences successive from *TimedElement*.
TimedRelatedEntities:: TimedProcessingModels	TimedProcessing	Represents activities where there is knowledge of the start time and end or with a known duration whose instants are explicitly linked to clock.
TimedRelatedEntities:: TimedObservation	TimedInstantObservation	Denotes an instant in time associated with the occurrence of an event and observed for a given clock.
TimedRelatedEntities:: TimedObservation	TimedDurationObservation	Denotes some time interval associated with the execution, request or occurrence events observed in one or two clocks. For being specialization of *TimedElement* the *TimedDurationObservation* makes references to Clock.
-	TimedDomain	These refer to model elements that can refer to clocks to express that their behavior depends on time.

necting cables. These detectors vary in technology, but the most common are the inductive loop detectors where a wire loop is installed in the street and is carried with a mild electric current that creates an electric field.

For an actuated control, there are three parameters of time: the minimum time for the green phase, the extension of green phase, and the maximum time for the green phase. Independent of demand, the green phase is defined for the minimum time. Depending on the flow of vehicles, and if the maximum duration of the green phase is not achieved, then the green phase time can be extended.

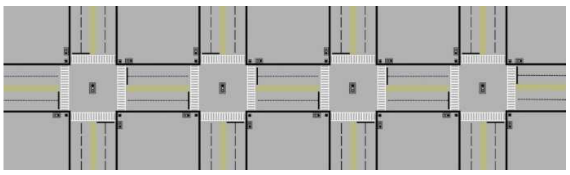


Figure 3: Road Intersections.

This paper focuses on the requirements needed to provide control capability for actuated intersections with interconnection of traffic signals, i.e., the operation of traffic signals in a network. Figure 3 depicts a graphical representation for a road with *n*-intersections. The set of requirements for the design of a coordinated traffic control system is presented in section 4.2.

4.2 Systems Requirements

In this section, a subset of a list of requirements for a Road Traffic Management System (RTMS) is presented, using natural language to be further modeled and analyzed. The list of requirements presented in Table 4 is a subset from a document which contains 137 atomic requirements for a RTMS. This subset of requirements focuses on demonstrating the capabilities of an actuated controller and, also, the functional and non-functional requirements involved with the synchronization of actuated controllers in a road network.

4.3 Proposed scenarios

The SysML Use Case diagram is derived without modifications from UML. Figure 4 presents major functions for the proposed system and allows for the representation of external entities exercising influence in a scenario (which describes a set of requirements).

It is possible to represent the interconnection of a use case with SysML by using the relationship refine (Figure 5). Figure 5 shows an example in which a use case proposed in Figure 5 is refined by a set of requirements described in the SysML Requirements diagram. Table 1 demonstrates a proposal for the tracing of all the scenarios described in Figure 4.

The classification proposed in Table 5 improves the representativeness of the SysML refine relationship. Thus, relationships between requirements are documented from the early definition of requirements. The proposed framework/metamodel (whose application is shown in 7) covers completely several inherent features important for real-time systems.

4.4 Modeling Requirements for a Road Traffic Control System

Figure 7 demonstrates how to apply the SysML Requirements diagram with MARTE stereotypes for modeling non-functional properties, runtime semantics that are suitable for real-time and embedded systems, more specifically to the proposed requirements for a Traffic Control system as specified in Table 4. In Figure 7, the main requirements and the respective modeling using the SysML Requirements diagram extended with MARTE stereotypes are presented.

The requirement *TM1* has as type the stereotype *Mode* (of *Causality::ModalBehavior*). It demonstrates the necessary logic to represent and control an operating segment as, for instance, a traffic control system for all active entities/elements of the operational fragment. This requirement has a SysML relationship $<<$ *hierarchy* $>>$ with the basic requirements for a traffic control system, including requirements *TM3*, *TM4*, *TM5 TM7*, *TM8*, *TM9*, *TM11*, *TM15* and *TM17*. It is worth noting that the *modePreemp* requirement (*TM7*) has a constraint represented by the $<< nfp\_Constraint >>$ stereotype (from *NFPs::Nfp_Constraint*) which applies a temporal restriction to “ensure the performance” of a critical requirement. For instance, the priority passage of emergency vehicles is indicated by the attribute *kind = offered*, which demonstrates the value space to support/restrict this requirement (this modeling could also be achieved by using VSL annotations from these restrictions in the model). The requirement *TM7* is of type TimedEvent (of *TimedRelatedEntities:: TimedEventsModels*) since it relates to an event whose start and end are not defined as a priori. However, the decision to attend this occurrence is directly linked to a Clock.

It is worth noting that the requirement *TM1* is related to the requirement *Chronometric* using the stereotype $<< TimedElement >>$ (of *Time::TimedRelatedEntities*) which is a specialization of *ClockType*, both belonging to the package *Time::TimeAcess*. The stereotype $<< TimedElement >>$ is important in this context, as it should be used whenever it is necessary to associate a (few) Clock(s) to a model element (in this case the *TM1* requirement). The *TM1* requirement should be elaborated within time constraints to ensure several important non-functional requirements for traffic control systems. Thus, it is necessary to create a $<<$ *clock* $>>$ *Chronometric* $>>$ stereotype enabling the *TM1* the access to time structure. The attributes of this clock are *nature*, an enumeration of *TimeNatureKind of TimeTypesLibrary library*, which serves to specify the discrete or dense nature of a time value (in this case the time is discrete), *unitType*, a *TimeUnitKing* dimension imported from *modelLibrary::MARTE_Library::MeasuremenUnits*, which defines the supported unit type (in this case the unit is ms), and the resolution which expresses the clock granularity (in this case by default it was set to 1.0).

The control logic of the controller is of type actuated time. The *TM5* requirement relates hierarchically to *TM1*. It defines the configuration of the control system. This is represented through the stereotype $<< Configuration >>$ (*of CoreElements:: Causality::ModalBehavior*). This stereotype shows the system configuration that can be defined by a set of ac-

Table 4: Requirements for a Road Traffic Control System.

ID	Requirement Name
TM1	The system must control the standard of vehicular traffic at the intersection.
TM2	The system must allow synchronization of traffic signals.
TM3	The system should collect all kinds of information of the road approaches in order to properly evaluate these data.
TM4	The system must allow management of traffic history.
TM5	The system must actuate in response to intersection traffic flow.
TM6	The system must coordinate green time of intersections in a synchronous way.
TM7	The system must have the emergency preemption mode, i.e., preferential movement of emergency vehicles.
TM8	The system must allow control of intersection in response to manual commands.
TM9	The system must allow control of intersection in response to replace remote commands.
TM10	The system must control the semaphore of the intersections.
TM11	The system of the intersection should be able to interact with the software control panel.
TM12	The system must calculate the delay to the controllers of intersections.
TM13	The system must optimize the flow of traffic.
TM14	The system must set the mode/state flag in response to the current processing of intersection control.
TM15	The system must minimize blockages along the highway.
TM16	The system must efficiently changeplans for liberation of platoons.
TM17	The system must check traffic demand with maximum precision.
TM18	The system must allow for incident management.
TM19	The system must configure green phase time for intersections.
TM20	The system must coordinate the green phase time of the intersections precisely. With minimum time of 50ms and maximum time of 150ms.

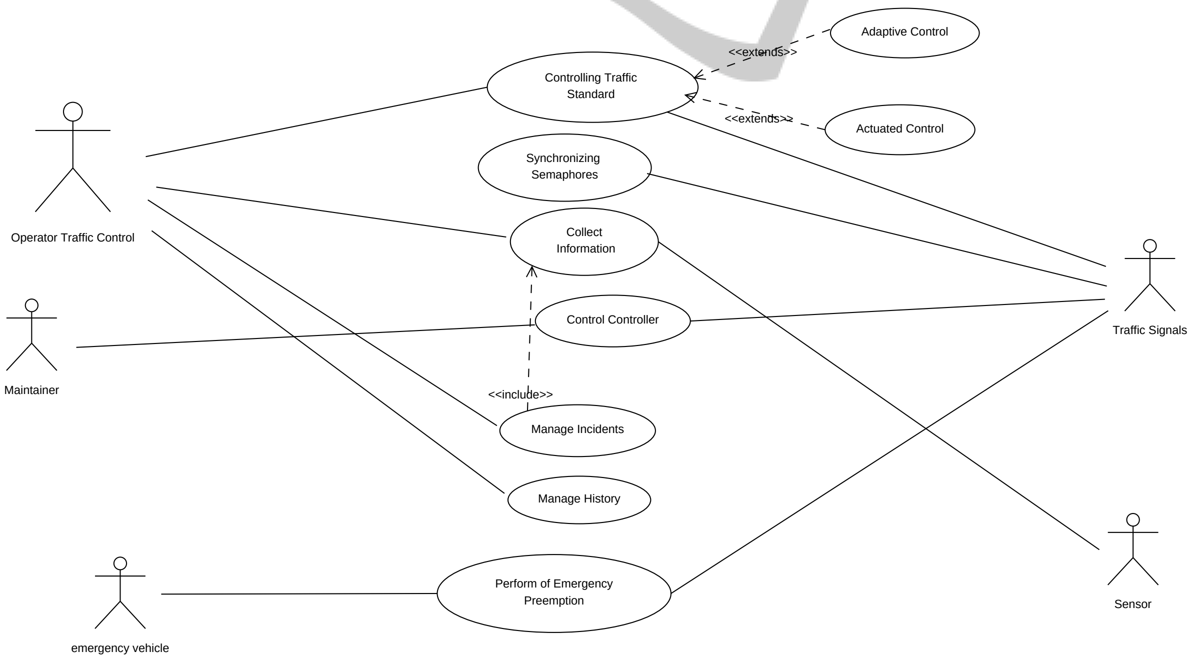


Figure 4: Scenarios for Traffic Control System.

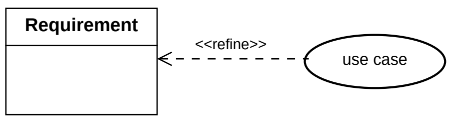


Figure 5: Relationship Refine.

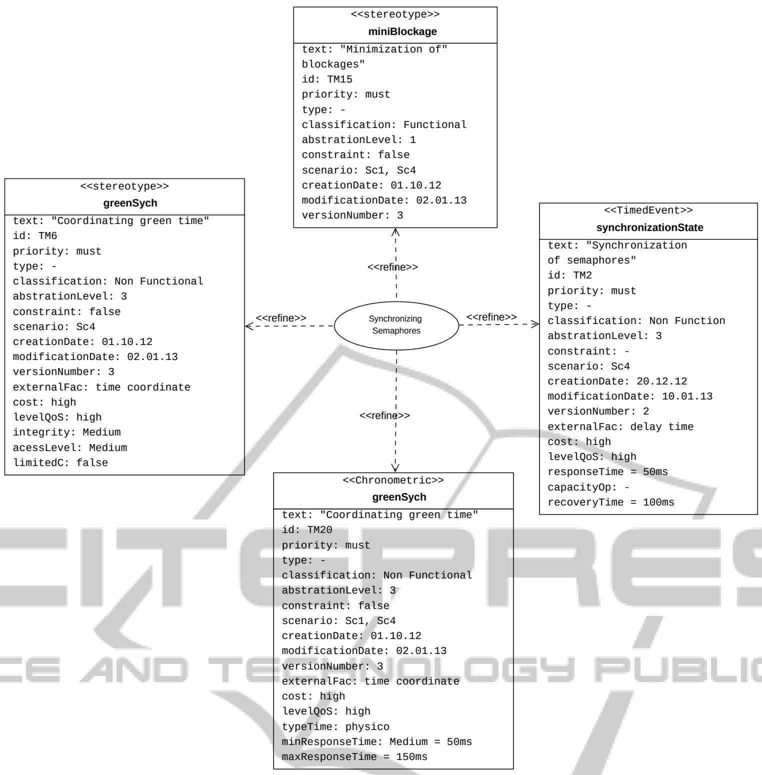


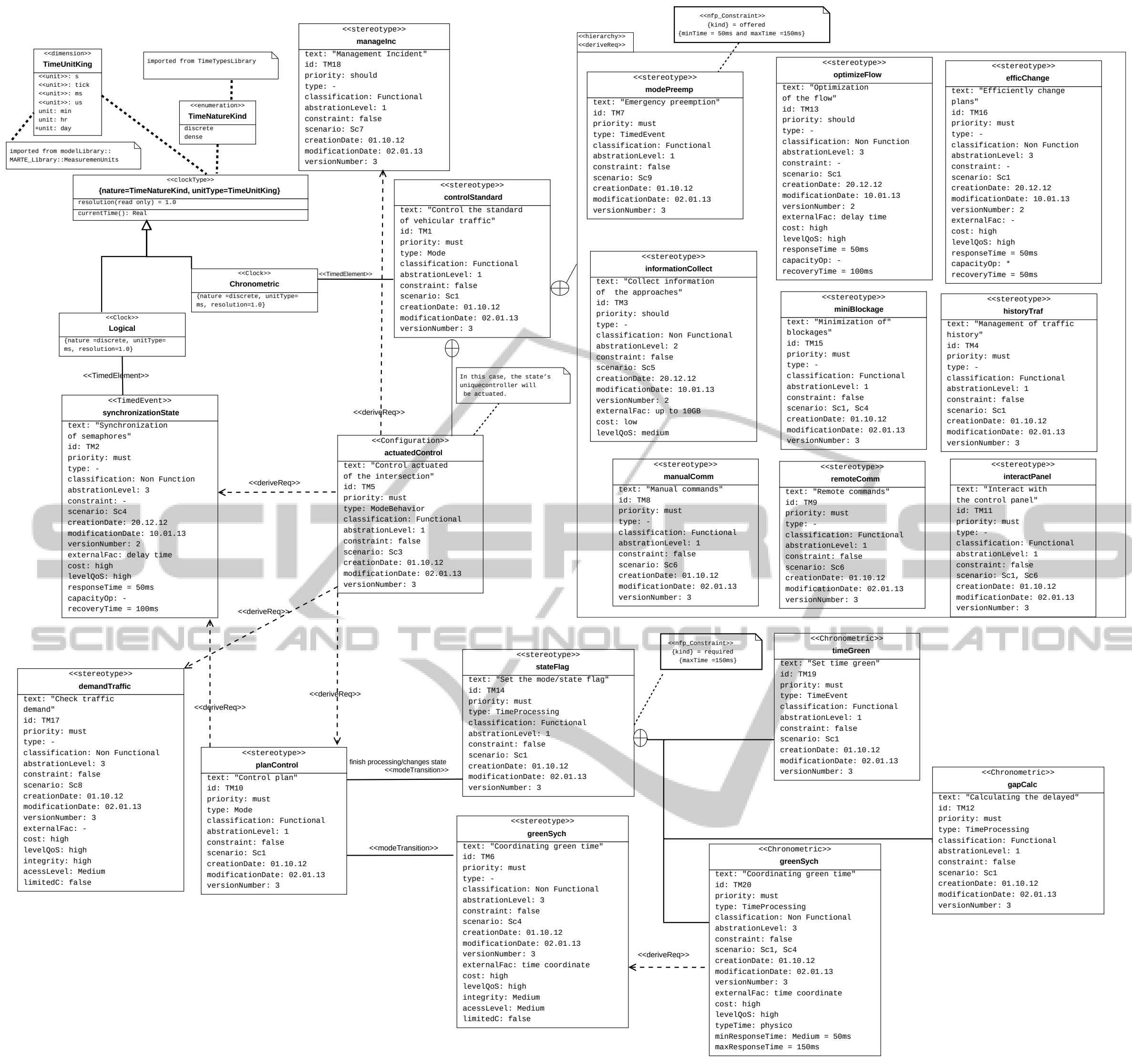
Figure 6: Synchronizing Semaphores and their requirements.

Table 5: Tracing Scenarios.

Scenario Name	Scenario ID	Actor Related	Requirement ID Related
Controlling Standard	Sc1	Operator	TM1, TM4, TM10, TM11, TM12, TM13,TM14, TM15, TM16, TM19, TM20
Adaptive Control	Sc2	Traffic Signals	-
Actuated control	Sc3	Traffic Signals	TM5
Synchronizing semaphores	Sc4	Traffic Signals	TM2, TM6, TM15, TM20
Collect Information	Sc5	Operator, Sensor	TM3
Control Controller	Sc6	Maintainer, Traffic Signals	TM8, TM9, TM11
Manage Incidents	Sc7	Operator	TM18
Manage History	Sc8	Operator	TM17
Emergency Preemption	Sc9	Emergency Vehicle, Traffic Signals	TM7

tive elements from the system. The type attribute of requirement *TM5* is *ModeBehavior* (*of CoreElements::Causality::ModalBehavior*), because the actuated control mode is unique to the control system, i.e., it is the only one considered at the intersections of this case study.

The requirement *TM5* derives from *TM10*, which is responsible for controlling the control plans for signaling the intersections. The signaling plan changes depending on the volume of road traffic. Thus, through an association with *TM14* with $<< modeTransition >>$ stereotype (of *CoreElements::Causality::ModalBehavior*), the signaling plan transitions to a certain state of the signals (red, green, yellow, green expanded, and so on) specified at *TM14*. The requirement *TM14* is of type *TimeProcessing* (of *Time::TimedRelatedEntities::TimedProcessing*). This is interesting for clarifying that the change of states signaled is an activity where there is great importance in knowing the time of start and finish for each state, and thus create strategies to ensure/get higher performance. The timing restriction for this requirement precisely demonstrates that the same process-



<<dimension>> TimeUnitKing
imported from TimeTypesLibrary
<<enumeration>> TimeNatureKind
imported from modelLibrary:: MARTE_Library::MeasurementUnits
<<clockType>> {nature=TimeNatureKind, unitType=TimeUnitKing}
<<Clock>> Chronometric
<<Clock>> Logical
<<TimedElement>>
<<TimedEvent>> synchronizationState
<<stereotype>> manageInc
<<stereotype>> controlStandard
<<Configuration>> actuatedControl
<<deriveReq>>
<<hierarchy>> <<deriveReq>>
<<nfp_Constraint>> {kind} = offered {minTime = 50ms and maxTime =150ms}
<<stereotype>> modePreemp
<<stereotype>> optimizeFlow
<<stereotype>> efficChange
<<stereotype>> informationCollect
<<stereotype>> miniBlockage
<<stereotype>> historyTraf
<<stereotype>> manualComm
<<stereotype>> remoteComm
<<stereotype>> interactPanel
In this case, the state's uniquecontroller will be actuated.
<<stereotype>> demandTraffic
<<stereotype>> planControl
<<stereotype>> stateFlag
<<nfp_Constraint>> {kind} = required {maxTime =150ms}
<<Chronometric>> timeGreen
<<Chronometric>> gapCalc
<<stereotype>> greenSych
<<Chronometric>> greenSych
finish processing/changes state <<modeTransition>>
<<modeTransition>>

Figure 7: Final Model.

ing must have a minimum quantitative level (specified with *kind* = *required*) to run with at most 150*ms*.

Requirements *TM19* and *TM20* are stereotyped with $<<$ *Chronometric* $>>$ characterizing them as requirements that exist in a physical time, and are of type *TimedEvent* (of *TimedRelatedEntities:: TimedEventsModels*), due to the fact that they are linked to *TM14* (by *hierarchy* relationship of SysML) and represent specific *Events* of change of the flag state. Its type is *TimedEvent*, whose occurrences are directly linked to a *Clock* (in this case Clock Chronometric). The requirement *TM12*, of type *TimeProcessing* (because its processing time instant refers explicitly to clocks), refers to a structure of physical time. It is through this requirement that the delay (delay/offset) is acknowledged between a controller of an intersection and the subsequent intersections.

As observed, much of this specification refers to the time structure access through physical clocks. MARTE also enables logical time modeling. For this reason, a structure of time that specializes $<<$ *clockType* $>>$ and sets the logical time necessary to demonstrate that the *TM2* requirement relates to synchronizing semaphores is created at an intersection network. It does not carry a long pre-signed physical time; it can only be seen as reading and detecting the flow of the processing approaches, the setting of the control plan strategy, and so on. Therefore, there is an explicit physical time and it depends on the processing logic of several other elements.

5 DISCUSSION

There are two works that combine SyML and MARTE profiles, and which can be compared to this work. In the works of (Quadri et al., 2012a) and (Quadri et al., 2012b), the project MADES is presented. This methodology was developed after current practices for developing embedded real-time systems are applied in the field of aviation industries and surveillance. A major contribution relates to the presentation of a complete methodology based on the combined use of SysML and MARTE for design, validation, simulation and automatic code generation while integrating aspects such as component reuse.

The work of (Gomez et al., 2012) proposes a multi-view approach based on SysML and MARTE for modeling views of energy consumption and their relationships with other functional/non-functional and structural/behavioral elements. In this approach, each domain can be treated separately in different views while maintaining strong connections towards other views. To this end, the MARTE profile is used to define the model of hardware architecture. In addition, the MARTE package of Non-Functional Properties is used for setting properties such as power, voltage and frequency. SysML is used to specify, through the parametric model, the equations that define mathematical relationships between non-functional interests of different views. The approach proposed in MADES (Quadri et al., 2012a) differs from the proposal of this study, first by contemplating a comprehensive methodology for developing embedded systems and real-time. Second, in this methodology by joining a consistent set of diagrams MADES (extension of the diagrams belonging to the profiles related to the project) for specification of system requirements, initial behavior specification, functional specification, refined functional specification, specification of hardware / software, detailed specification of hardware / software and specification of allocation.

According to the extensive bibliographic research conducted until the present moment, there are studies in scientific literature which focuses on demonstrating the applicability of UML and SysML with MARTE stereotypes for documentation, classification and modeling of software requirements for real-time systems. Despite the existence of several approaches for modeling software requirements and for modeling specific requirements of real-time, as described in previous sections, requirements engineering for real-time systems still lacks representative models that are expressive, complete and correct. As described by (Espinoza et al., 2009), despite an increasing number of profiles being built in many areas for the design of some types of systems, a single profile may not be adequate to cover all aspects required as, for example, the multidisciplinary aspects in the field of real-time systems.

6 CONCLUSIONS

The main objective of the approach proposed in this article is to demonstrate the application of SysML Requirements diagram with MARTE stereotypes, which enables the modeling of individual software requirements for real-time systems. The focus is to create an approach for modeling specific software requirements which allow the representation of the necessary features of real-time systems (based on research demonstrating the specific requirements) and, also, timing requirements and performance requirements. As previously reported, the SysML Requirements diagram shows explicitly the various types of relationships between different requirements, increasing the spectrum of understanding and defining the requirements of a real-time system. However, the SysML profile by itself does not guarantee the representation of temporal, behavioral, and performance requirements, nor provides elements for explicit representation of system configurations. The MARTE profile provides key resources to specify non-functional requirements for real-time systems, generally time requirements. In this paper, these features were made explicit by means of classification and use of MARTE stereotypes. Thus, the combination of these profiles in the presented approach demonstrated the complete and expressive nature of the representation of various requirements. SysML contributes with constructors to define requirements and their relationships. Besides, MARTE completes the precision of the scenario with well-formed non-functional annotations. The concepts of SysML and MARTE, articulated in the SysML Requirements diagram are complementary covering many of the purposes of specifying requirements for real-time systems.

As each requirement is described separately, the complexity of changes is minimized, since a change in any requirement can be made completely and consistently maintaining the structure and style of the set of requirements. Expressing each requirement separately is highly desirable. This feature is addressed in this article by modeling requirements using the SysML Requirements diagram, and by organizing the relationships between requirements. The MARTE profile provides, in the proposed representation, a clear description of the various relevant aspects of requirements definition of real-time systems, as for instance, temporal aspects and constraints.

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REFERENCES

Belategi, L., Sagardui, G., and Etxeberria, L. (2010). Marte mechanisms to model variability when analyzing embedded software product lines. In *14th Proceedings of the International Conference on Software Product Lines*, pages 466 – 470.

Bennett, A. J. and Field, A. J. (2004). Performance Engineering with the UML Profile for Schedulability, Performance and Time: a Case Study. In *12th Annual International Symposium on the IEEE Computer Society's*, pages 67–75.

Bianco, V. D., Lavazza, L., and Mauri, M. (2002). A formalization of uml statecharts for real-time software modeling. In *Integrate Design and Process Technoly (IDPT)*, pages 1 – 8.

Espinoza, H., Cancila, D., Selic, B., and Gerard, S. (2009). Challenges in combining sysml and marte for model - based design of embedded systems. In *5th European Conference (ECMDA-FA)*, pages 98 – 113.

Gomez, C., DeAntoni, J., and Mallet, F. (2012). Multi-view power modeling based on uml, marte and sysml. In *EUROMICRO-SEAA*, pages 17 – 20.

Heisel, M. and Cote, I. (2011). A UML Profile and Tool Support for Evolutionary Requirements Engineering. In *15th Software Maintenance and Reengineering*, pages 161–179.

Helming, J., Schneider, F., Haeger, M., Kaminski, C., Bruegge, B., and Berenbach, B. (2010). Towards a unified requirements modeling language. In *15th International Workshop on Requirements Engineering Visualization (REV)*, pages 53–57.

IEEE (1998). *IEEE Recommended Practice for Software Requirements Specifications*.

Iqbal, M. Z., Arcuri, A., and Briand, L. (2011). Code Generation from UML/MARTE/OCL Environment Models to Support Automated System Testing of Real-Time Embedded Software. Technical Report 2011-04, Version 2, Simula Research Laboratory.

Iqbal, M. Z. Z., Ali, S., and Yue, T. ad Briand, L. C. (2012). Experiences of Applying UML/MARTE on Three Industrial Projects. In *15th Model Driven Engineering Languages and Systems (MoDELS)*, pages 642 – 658.

Kumar, B. and Jasperneite, J. (2010). Uml profiles for modeling real-time communication protocols. *Journal of Object Technology*, 9:178–198.

OMG (2005). UML Profile for Schedulability, Performance, and Time, Version 1.1. Technical report, OMG.

OMG (2011a). UML Profile for MARTE: Modeling and Analysis of Real-time Embedded Systems Version, 1.1. Technical report, OMG.

OMG, M. (2011b). *Modeling and Analysis of Real-Time and Embedded Systems (MARTE)- version 1.1*. Technical Report Formal/2011-06-02.

OMG, S. (2010). *Systems Modeling Language (SysML) Specification - version 1.1*.

OMG, U. (2011c). *Linguagem de Modelagem Unificada - version 2.3*. verso 2.3.

Quadri, I. R., Brosse, E., Gray, I., Matragkas, N. D., Indrusiak, L. S., Rossi, M., and Bagnato, A. Sadovykh, A. (2012a). MADES FP7 EU project: Effective high level SysML/MARTE methodology for real-time and embedded avionics systems. In *7th Int. Workshop on Reconfigurable Communication-centric Systems-on-Chip (ReCoSoC)*, pages 1 – 8.

Quadri, I. R., Soares, L., Gray, I., Indrusiak, L. S., and Bagnato, A. Sadovykh, A. (2012b). MADES: A $SysML/MARTE$ high level methodology for real-time and embedded systems. In *7th Int. Conf. on High-Performance and Embedded Architectures and Compilers*, pages 1 – 2.

Roger, P. R., Elena, S. P., and William, R. M. (2003). *Traffic Engineering*. Prentice Hall, New Jersey, NJ, USA, 3 edition.

Shousha, M., Briand, L. C., and Labiche, Y. (2012). A uml/marte model analysis method for uncovering scenarios leading to starvation and deadlocks in concurrent systems. *IEEE Transactions on Software Engineering*, 38(2):354–374.

Silvestre, E. A. and Soares, M. S. Multiple view architecture model for distributed real-time systems using marte.

Xu, J., Li, T., Xie, Z., and Gao, T. (2011). Use cases and feedback in functional requirements analysis. In *Information Technology, Computer Engineering and Management Sciences (ICM)*, volume 2, pages 54–57.

Xu, J., Woodside, M., and Petriu, D. (2003). Performance analysis of a software design using the uml profile for schedulability, performance and time. In *Int. Conf. on Modelling Techniques and Tools for Computer Performance Evaluation*, pages 291 – 310.