Comparing Transformation Possibilities of Topological Functioning Model and BPMN in the Context of Model Driven Architecture

Arturs Solomencevs

Department of Applied Computer Science, Riga Technical University, Latvia

Abstract – The approach called “Topological Functioning Model for Software Engineering” (TFM4SE) applies the Topological Functioning Model (TFM) for modelling the business system in the context of Model Driven Architecture. TFM is a mathematically formal computation independent model (CIM). TFM4SE is compared to an approach that uses BPMN as a CIM. The comparison focuses on CIM modelling and on transformation to UML Sequence diagram on the platform independent (PIM) level. The results show the advantages and drawbacks the formalism of TFM brings into the development.

Keywords – CIM to PIM transformation, formal CIM, model driven architecture, topological functioning model.

I. INTRODUCTION

OMG’s Model Driven Architecture (MDA) is a set of guidelines for system development, which pioneers application of models. MDA separates the viewpoints on the information system – it suggests three viewpoints with corresponding models: a computation independent model (CIM) focuses on information system’s environment and is used to specify requirements; platform independent model (PIM) focuses on the information system but hides platform specific details; and platform specific model (PSM) [1]. Model transformation is considered to be an important part of MDA. To get the source code, we need to go by the path: CIM → PIM → PSM → source code [1].

There is a belief that it is essential to start software development with modelling the business system, or in other words with modelling the environment of the planned information system [2], [3], [4]. Understanding of how the information system will interact with the business system leads to an appropriate design. Thus, CIM needs to be created at the beginning of the development process – this assertion is the basis of this article.

The *problem domain* is the part of the world in which the software is required to bring about some effect desired by the customer [2]. The *solution domain* is a system (e.g., business system), which is supported by the planned information system. Both problem domain and solution domain can be specified by CIM [5]. The solution domain CIM must conform to the problem domain CIM. It is possible to transform the solution domain CIM to PIM level design models [6].

There is a shortcoming in MDA guide [1]. OMG says nothing essential about the computation independent view and

accordingly about the CIM. The weakness of MDA is that there is nothing well formalised and/or transformable at the beginning of the software development life cycle [3].

Our group works on dealing with the mentioned issue and has developed an approach called “Topological Functioning Model for Software Engineering” (TFM4SE). This approach uses the Topological Functioning Model (TFM) as a formal CIM.

As prof. J. Osis states in [7], “TFM is a formal model which describes the functioning of a system. TFM has a solid mathematical base. It is represented in a form of a topological space (X, Θ) , where X is a finite set of functional features of the system under consideration, and Θ is topology that satisfies axioms of topological structures and is represented in a form of a directed graph. The TFM’s functional features describe the system’s physical or biological characteristics that are relevant for the normal functioning of the system. The TFM’s topology consists of cause-effect relations between functional features. Cause-effect relation means that appearance of one functional feature causes an appearance of the other one. Causal chains must form at least one functioning cycle within TFM.” All formal definitions of TFM elements are given in [8].

In the author’s opinion, the improvement of the results of object-oriented system analysis and modelling lays in using formal methods. Formal approaches allow defining formal or semi-formal model transformations (including reverse engineering [9]), which are the key part of MDA, and formal tracing of modelling artefacts. Furthermore, the power of traditional engineering is that engineers do trust in theory, mathematics and formal methods [3], and this power can be used in software development. TFM4SE is a formal method, which has a mathematical model – TFM – in its core.

The goal of the current research is to compare TFM4SE with other model-driven approaches that suggest creating CIM level models which can be transformed to PIM. For this paper, the author narrows the scope and reviews approaches that use BPMN models [10] on the CIM level. BPMN is widely used in software development for business modelling. This notation is easy to work with and is understandable for business people and software developers (training is required to freely use it). BPMN does not have mathematical basis. Therefore, the author is interested in comparing CIM-TFM to CIM-BPMN, and finding out the benefits and drawbacks caused by the

formalism of TFM comparing to informal BPMN business model in the field of software development.

The paper is structured as follows. In Section 2 approaches that provide CIM $\rightarrow$ PIM transformation discovered during the research are briefly reviewed; also the major opportunities of TFM4SE are represented. In Section 3 the comparison of TFM4SE with one of the CIM-BPMN approaches on the basis of an example is made. In Section 4 conclusions about the research are given.

II. RELATED STUDIES

There are a number of software development approaches that use BPMN for CIM modelling and provide CIM $\rightarrow$ PIM transformation. The approach described in [11] applies BPMN collaboration and business process diagrams on the CIM level, and defines rules for transformation to UML Class diagram and Use case diagram on the PIM level. Service-oriented approach [12] proposes transforming BPMN models into SoaML model [13] and into UML Component model. Method of [14] is also service-oriented and uses SoaML for PIM modelling. Another service-oriented approach – [15] – applies the use case model and activity diagram on the PIM level. Research of [16] focuses on security requirements and models security along with business processes. Approach [17] provides ways of getting class diagram and sequence diagrams from BPMN business process models.

Not only BPMN is applied to CIM modelling. An approach represented in [18] applies features as the elements of CIM, and components – as elements of PIM. Paper [19] proposes automatically generating an activity diagram from a use case description. Data warehouse development method [20] uses a UML profile for the *i** modelling framework [21] for CIM modelling, and provides transition to a conceptual model on the PIM level. Research of [22] proposes using UML activity diagram for business process modelling and for defining the requirements, and also for transforming CIM into PIM. Data flow diagrams are used on the CIM level by [23] approach, which also provides the obtaining of PIM models.

Finally, TFM4SE approach in brief. The approach provides ways of obtaining TFM from the knowledge about a business system [24]–[27]; derivation of use case diagrams from TFM [28]; transformations of TFM to the most popular UML [29] design models on PIM level, e.g., Class diagram, Sequence diagram, Communication diagram [30]–[32]; formalizing tracing links between modelling artefacts [33]; and other opportunities for formalized software development.

III. COMPARISON OF TFM4SE WITH CIM-BPMN APPROACH ON THE BASIS OF AN EXAMPLE

In the previous section, the author has reviewed approaches that use BPMN in CIM modelling and provide CIM $\rightarrow$ PIM transformation. The author finds that the approach represented in [17] is the most well-elaborated, because the article is deep and of good quality. Also, the approach is wide enough that its parts are covered by other articles: [34]–[37]. That is why this approach has been chosen to compare with TFM4SE. For

convenience, from now on this approach is called “CIM-BPMN approach”.

In CIM-BPMN approach, there are the following models on the CIM level: business process models (BPM) that are based on BPMN and a business use case model. High-level BPMs are distinguished from low-level BPMs. High-level models are more abstract and contain collapsed sub-processes. Low-level models describe in detail the expanded sub-processes from the high-level models. It is written in [17] that “PIM level contains three models: Domain class diagram; Business rules; and Sequence diagram of system’s external behaviour.” Domain class diagram is a UML Class diagram with attributes and relations, but without methods. Business rules focus on structural assertions and define structure, relationships and integrity constraints on data. “Sequence diagram of system’s external behavior is a UML Sequence diagram that shows interactions between actors and the whole system as unique entity” [17]. The approach also proposes a way to obtain the “Sequence diagram of system’s internal behaviour” [36]. However, this transformation requires developing additional descriptions.

CIM-BPMN approach provides construction of the following UML models from BPMN business model: use case diagram; sequence diagram; and class diagram. TFM4SE also supports obtaining of these models from TFM. However, it is not possible to review the creation of all the mentioned models in one article. Therefore, the scope is narrowed and the paper focuses on CIM modelling, and on transformation to PIM sequence diagram. The article of CIM-BPMN [17] represents an example (a case study) of BPMN modelling and of acquiring the mentioned models. This example is taken as the basis for the comparison.

A. Verbal Description of the System

Verbal description is given in [17]. It is a description of an e-commerce web site. It describes a solution domain (system “to-be”), i.e., a business system that is supported by the planned information system. Normally, a problem domain is described, i.e., a business system that has not been supported by the planned information system yet. However, e-commerce specific feature is that there is no business without the information system; hence, there is no problem domain. By studying BPMN models of the example from the article, the author has concluded that the verbal description is not complete. The author has refined the description so that it corresponds to the mentioned BPMN models. Comprehensive verbal description is needed for creation of TFM. The description is given below.

Designations used in the description are the following. *Italic* – nouns, real world objects and their attributes. **Bold** – verbs and conditions that define the appropriate actions.

Any *web surfer* can **access** the *web site* and **search for** *product* of different *categories* (*Book, informatics...*) and **collect** them in *web surfer’s cart*. *Web surfer* can **manage** this *cart* at any time to **add/remove products** or to **change** the *quantity of product*. **When web surfer is convinced**, *web surfer* can **check out** the *order* and **pay for** the *order* that will

be shipped (delivered) to web surfer's shipping address. Web surfer must **login** with web surfer's account or **register a new account** if web surfer's does not have an account for the web site.

When clerk receives the payment, he **prepares order for shipping**. Web surfer can **check** the order status and **review** the order. Clerk **sends** the **prepared order**, and delivery company **delivers** the order to web surfer's shipping address. Finally, the web surfer **receives** his order.

Web surfer can **leave** the web site.

Order checkout expansion. All products in the web surfer's cart **are shown** to the web surfer. Web surfer **validates** the cart, and **if he is not satisfied**, he **cancels** the order. Otherwise, the web surfer **fills in** customer information. Web surfer **fills in** his shipping address. The information system **checks whether** web surfer's shipping address **is deliverable**. **If** web surfer's shipping address **is not deliverable**, web surfer is asked to **fill in another shipping address**, and information system **checks** it the same way. **If** the web surfer's shipping address **is deliverable**, then web surfer **fills in** web surfer's billing address. Web surfer **selects** shipping mode. Information system **checks whether** shipping mode **is available** for web surfer's shipping address; **if it is not available**, web surfer is asked to **select another shipping mode**, and information system **checks** it the same way. **If** the shipping mode **is available** for web surfer's shipping address, then web surfer **validates** the order. **If order validation is unsuccessful**, web surfer **cancels** the order. **If order validation is successful**, web surfer **pays for** the order (Payment sub-process is expanded later). Information system

registers order as a paid order, and **notifies** clerk about the new paid order.

Payment expansion. Web surfer **fills in** his credit card information. Web surfer **validates** his billing address, then **validates** his shipping address, then **confirms** payment. Banking system **checks whether** web surfer's credit card **is valid**. **If** web surfer's credit card **is not valid**, the banking system **rejects** the payment. **Otherwise**, the **banking system** makes the payment transaction and **saves** it, and **notifies** web surfer about the successful payment transaction.

B. Functional Features and High-Level Business Models

According to the formal method of TFM construction [24], in order to define functional features, verbs denoting actions, their preconditions and business rules are to be found in informal description of the system. Preconditions specify a set of conditions that allow triggering a functional feature. A business rule usually prevents, provokes or allows triggering certain processes and defines or constrains some business process aspects. Each action, precondition or business rule either has to introduce a new appropriate functional feature or it should be attached to the already defined one. Besides, entities that are responsible for performing an action of the functional feature are defined. "Functionality can be subordinated to the system under consideration (inner) or to other systems (external)" [24].

Functional feature is expressed in the following form [24]:

"<action>-ing the <result> [to, into, in, by, of, from] a(n) <object>"

e.g., Adding the product to a cart.

Object gets the result of the action. The obtained list of TFM's functional features is given in Table I.

TABLE I
FUNCTIONAL FEATURES OF E-COMMERCE WEB SHOP SYSTEM

ID	Functional feature	Preconditions	Entity	Inner / External
1	Accessing a web site		web surfer	external
2	Searching for a product		web surfer	inner
3	Adding the product to a cart		web surfer	inner
4	Managing a cart		web surfer	inner
5	Removing the product from a cart		web surfer	inner
6	Changing the quantity of a product		web surfer	inner
7	Checking out an order	[when web surfer is convinced]	web surfer	inner
8	Paying for an order	[if order validation is successful]	web surfer	inner
9	Delivering the order to a web surfer's shipping address		delivery company	external
10	Logging in with a web surfer's account	[if web surfer has an account]	web surfer	inner
11	Registering a new web surfer's account	[if web surfer does NOT have an account]	web surfer	inner
12	Preparing for shipping an order	[when clerk is notified about receiving the payment]	clerk	inner
13	Checking the status of an order		web surfer	external
14	Sending the prepared order to a delivery company	[when order is prepared for shipping]	clerk	inner
15	Receiving an order		web surfer	external
16	Showing the contents of cart to a web surfer		information system	inner
17	Validating a cart		web surfer	inner

ID	Functional feature	Preconditions	Entity	Inner / External
18	Cancelling an order	[if web surfer is NOT satisfied with the contents of the cart]	web surfer	inner
19	Filling in customer information	[if web surfer is satisfied with the contents of the cart]	web surfer	inner
20	Filling in a shipping address		web surfer	inner
21	Checking a shipping address		information system	inner
22	Asking to fill in another shipping address	[if web surfer's shipping address is NOT deliverable]	information system	inner
23	Filling in a billing address	[if web surfer's shipping address is deliverable]	web surfer	inner
24	Selecting the shipping mode of an order		web surfer	inner
25	Checking a shipping mode of an order		information system	inner
26	Asking to select another shipping mode	[if shipping mode is NOT available for web surfer's shipping address]	information system	inner
27	Validating an order	[if shipping mode is available for web surfer's shipping address]	web surfer	inner
28	Cancelling an order	[if order validation is unsuccessful]	web surfer	inner
29	Registering a paid order	[if payment was successful]	information system	
30	Notifying clerk about a new paid order		information system	
31	Filling in the information of a credit card		web surfer	inner
32	Validating a billing address		web surfer	inner
33	Validating a shipping address	[if billing address validation is successful]	web surfer	inner
34	Confirming a payment	[if shipping address validation is successful]	web surfer	inner
35	Checking a credit card		banking system	external
36	Rejecting a payment	[if web surfer's credit card is NOT valid]	banking system	external
37	Making a payment transaction	[if web surfer's credit card is valid]	banking system	external
38	Saving a payment transaction		banking system	external
39	Notifying web surfer about a successful payment transaction		banking system	external
40	Notifying information system about a successful payment transaction		banking system	external
41	Leaving a web site		web surfer	external
42	Reviewing an order		web surfer	external

“After definition of functional features topology Θ (cause-and-effect relationships) between them is introduced” [24]. At first, topological space on a higher abstraction level is constructed (see Fig. 1). It is possible to construct topological space by using TFM editor [38]. However, TFM editor is not used for this paper due to the limit of free space (figures with TFM would be much bigger).

Fig. 1. Topological space of the solution domain on high level of abstraction.

Topological space of the solution domain (Fig. 1) represents both web shop's inner functional features – set N , and external functional features – set M [38]. In the case of the example, set

$M = \{1, 9, 13, 15, 41, 42\}$; set $N = \{2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 14\}$. “To separate TFM of the system under consideration from the topological space, the closure operation over the set N is applied” [7], [24]:

$$X = [N] = \bigcup_{i=1}^n X_i. \quad (1)$$

“ X is a set of functional features of the system's TFM; X_i is an adherence vertex of the set N ; and n is a number of adherence vertices of N , i.e. capacity of X (1). An *adherence vertex* of the set N is a vertex each neighborhood of which includes at least one vertex from the set N ” [7], [24]. New definition of *neighbourhood* is introduced, because it positively affects the result of the closure operation. The neighbourhood of a vertex is a subset which contains this vertex and all vertices that are adjacent to it. To perform closure of set N , at first, neighbourhood of each vertex of N should be found. For example, in the case study:

$$(2) = \{2, 1, 3, 4, 14\}$$

$$(12) = \{12, 8, 14\}$$

$$(3) = \{3, 2, 4\} \dots$$

$$(14) = \{14, 2, 9, 12\}.$$

Fig. 2. BPMN business process model on high abstraction level, adapted from [17].

Then, a union of neighbourhoods is obtained. This union is the set $X = [N] = \{1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 41, 42\}$. Thus, TFM does not contain functional feature 15, and this functional feature is considered to be out of bounds of web shop's system.

The set M contains inputs and outputs [24]. Set of inputs = $\{1\}$. Set of outputs = $\{9, 13, 41, 42\}$. In this TFM, the main functional cycle is as follows: 2-3-4-7-10-8-12-14-2 (Fig. 1).

Figure 2 represents the BPMN business process model on high level of abstraction that is given in CIM-BPMN approach case study. This model corresponds to topological space shown in Fig. 1.

The expansion of the following processes is needed: order checkout and payment. To do this, a formal mechanism provided by topological modelling – *continuous mapping* – can be used. As it is stated in [7] and [39], “If some more detailed functioning system is formed by substitution of a subset of specialized functional features for some functional feature, then continuous mapping exists between a detailed model and a simplified parent topological model. In the topological digraph $G^*(X^*, U^*)$, the direction of arcs, which join the specialized point subset nodes with other nodes, is determined by the direction of the arcs, which join the replaced point with the corresponding nodes of the digraph $G(X, U)$ ”. To put it simply, continuous mapping allows substituting a subset of functional features with a more detailed subset, and vice versa.

Fig. 3. Topological space part that represents detailed functionality of checkout sub-process.

Figure 3 shows the part of topological space that represents detailed functionality of checkout. This part of TFM has been obtained by applying continuous mapping. A subset of functional features “7: Checking out an order”, “10: Logging in with a web surfer's account” and “11: Registering a new web surfer's account” is continuously mapped onto the set of functional features that is represented in Fig. 3. Also, all cause-effect relations with surrounding functional features, i.e., “4: Managing a cart” and “8: Paying for an order”, are retained. Since all functional features in Fig. 3 belong to system's inner functional features, they also belong to set X of web shop's TFM. By increasing the level of detail, a new precondition for functional feature was found “8: Paying for an order” – [if order validation is successful].

Fig. 4. Topological space part that represents detailed functionality of payment sub-process.

Figure 4 illustrates the part of topological space that represents detailed functionality of payment. Functional feature “8: Paying for an order” is continuously mapped to the represented set. Functional feature “27: Validating an order” is used instead of “10: Logging in with a web surfer's account” to conform to the more detailed functionality description of the checkout (see Fig. 3). $X_{\text{Payment}} = [N_{\text{Payment}}] = \{4, 12, 13, 27, 29, 30, 31, 32, 33, 34, 35, 36, 40, 42\}$. Thus, TFM does not contain functional features $\{37, 38, 39\}$.

Fig. 5. BPMN model of expanded checkout sub-process, adapted from [17].

Fig. 6. BPMN model of expanded payment sub-process, adapted from [17].

In CIM-BPMN, more detailed models – low-level BPMs – are obtained by expanding collapsed sub-processes of high-level BPM [17]. Figure 5 displays a BPM of the expanded checkout sub-process, and Figure 6 – of the expanded payment sub-process.

The main difference between the approaches concerning the expansion of sub-processes is the following. In TFM, the formal operation is used – continuous mapping. The new subset must keep all cause-effect relations that the substituted subset had with other functional features in TFM. In BPMN, there is no such a strict rule. Therefore, an ambiguity may arise in BPMN model. Let us consider a case when the payment is rejected by a banking system (payment expansion). Low-level BPM model (see Fig. 6) does not make it clear what should happen after the payment rejection, and high-level BPM (see Fig. 2) also does not help. In TFM there is no such ambiguity. High-level TFM (see Fig. 1) tells us nothing

about payment rejection, so the rejection must be handled by a subset of functional features that substitutes “8: Paying for an order”. Figure 1 shows us a cause-effect relation between “8: Paying for an order” and “4: Managing a cart”, and this relation must be retained in the expanded TFM. After the payment rejection, it makes sense to give web surfer an opportunity to fill credit card information once again, or to go back to cart management. In Figure 4, after “36: Rejecting a payment” an execution goes to “31: Filling in the information of a credit card”. Web surfer can refill data or skip this step. During validation of billing and shipping addresses (features 32 and 33) web surfer can go back to “4: Managing a cart”. Therefore, processing of payment will be cancelled. Thus, dealing with the payment rejection is explicitly and unambiguously described. It can be seen that formalism of TFM helps to achieve consistency between abstract and detailed models.

C. Transformation to PIM Sequence Diagram

TFM4SE defines the obtaining of UML Sequence diagram from TFM [40]. Each functional feature will be supported by a class method. So for each functional feature architect must come up with the name of a class and the name of a method, which will realize the functional feature [41]. There is no point in assigning classes and methods to functional features that are not realised by the information system. Examples are given in Table II. The rows starting with ID = 29 are used in construction of sequence diagram later in this section.

TABLE II
EXAMPLES OF CLASS AND METHOD NAMES

ID	Class	Method
1	Cart	accessWebSite()
2	ProductSearcher	searchForProduct()
29	OrderRegistry	registerPaidOrder()
31	WebSurferAccount	fillInCreditCardInfo()
32	Order	waitForValidation()
33	Order	waitForValidation()
34	Order	confirmPayment()
35	Order	sendOrderInfoToBank()
36	Order	rejectPayment()
40	Order	successfulPayment()

In TFM4SE, the scope of sequence diagram is determined by system goal or by functional requirement. For each system goal or requirement one sequence diagram should be developed [40]. For this comparison, the obtaining of one sequence diagram is shown. Thus, a corresponding system goal needs to be defined. Guidelines for identifying system goals are published in [28]. This process consists of the 5 following steps.

Step 1: Identification of business actors. “Actors are external entities interacting directly with the business system that establish business goals within the business system” [28]. Actors are external entities in the TFM, where they can be represented as an external system itself (e.g., a company, a customer) or as an entity that is responsible for initiation of a functional feature from the external environment, or a functional feature that describes system interaction with the external environment [28]. In the case study, by analysing Table I (paying the most attention to columns “Entity” and “Inner/External”), the following business actors were identified: web surfer, delivery company, banking system.

Step 2: Identification of business workers. “Workers are inner entities interacting directly with the business system that either establish system goals or realize some business goals. Workers are people, roles, etc. that work within the business system and can be identified from the TFM” [28]. Again, after analysing Table I, the identified business workers are: clerk and information system.

Step 3: Identification of business goals. Each identified business user (actor or worker) that interacts with the business system has his business goal [28]. The author does not identify business goals for all users, only for the banking system. Its

only business goal is to “Make a payment transaction for the order,” which has two sub-goals: “Get order and credit card information” and “Make payment transaction or reject payment.” Therefore, the banking system needs to get information about order and web surfer’s credit card, and then either make payment transaction or reject payment.

Step 4: Associating functionality with business goals. “Each direct goal is to be corresponded to the functional features (one or many) of the system. For each user’s goal, an input functional feature (input transaction), an output functional feature (output transaction), and a functional feature chain between them should be identified. Transaction may consist of the only one functional feature” [28]. The author identified the following functional feature chain for getting information about the order and the credit card information: “31-32-33-34-35.” Here, “31: Filling in the information of a credit card” is considered to be an input functional feature. In its turn, “35: Checking a credit card” is an output functional feature (output data are order and credit card details which are received by the banking system). If the payment is processed successfully, functional features “40: Notifying information system about a successful payment transaction” and “29: Registering a paid order” are executed; otherwise – “36: Rejecting a payment.”

Fig. 7. Sequence diagram of making a payment transaction for the order, obtained by applying TFM4SE.

Step 5: Identification of system goals. “Both actors and workers can be users of the computerized system. Functional features to be implemented that are associated with a business goal constitute functionality that is dedicated to reach a corresponding system goal. Thus, each system goal is mapped to a corresponding business goal” [28]. The author has

identified the system goal “Make a payment transaction for the order,” which maps to the business goal with the same name (defined during the 3rd step). Functional features to be implemented to satisfy this system goal are: {29, 31, 32, 33, 34, 35, 36, 40} (all that were mentioned in the 4th step).

After defining a system goal and identifying the functional features that correspond to it, we can create a sequence diagram for this goal. Vertices of TFM with the same class names (see Table II) should be merged, and, while merging, all relationships between vertices (see Fig. 4) should be kept. The relations from TFM serve as message sending between objects in sequence diagram [40]. Figure 7 shows the resulting sequence diagram. This transformation requires partial participation of the architect, i.e., information exchange between the system and actors needs to be specified, and interaction operators, e.g., alternative and loop, need to be properly described.

In CIM-BPMN, a sequence diagram is created for each low-level BPM, which will be supported by the information system. Authors of the approach define mapping rules from low-level BPM to sequence diagram of system’s external behaviour (SDESB) [17]. These rules are presented in Table III.

TABLE III

MAPPING OF LOW-LEVEL BUSINESS PROCESS MODEL TO SEQUENCE DIAGRAM OF SYSTEM’S EXTERNAL BEHAVIOUR, ADAPTED FROM [17]

Element in low-level BPM	Corresponding element in SDESB
Swimlane in high-level BPM	Principal actor
Swimlane in low-level BPM	Secondary actor
Task performed by actor	Message sent to system
Task performed by the system for calculation or validation	Internal message
Task performed by the system for getting/displaying information from/for actor	Response from the system to the actor
Flow of activities after an exclusive gateway	Successful flow is mapped to actions/responses. While, other flows that terminate process correctly are mapped to alternative scenario, flows that terminate process with errors or cancelation are mapped to error scenario. Both errors and alternatives are represented by notes.
Flow that returns to previous task	A “loop” interaction operand
Sub-process	A “ref” interaction operand

Paper [17] gives an example of obtaining a sequence diagram for checkout sub-process (see Fig. 5). It is identified that the principal actor is the customer. The lower level BPM (Fig. 5) does not show any supplier secondary actors. Three internal messages are found: “validate shipping address”, “check delivery mode” and “save order”. The other tasks are transformed to actions/responses from/to system. The collapsed sub-process “Payment” is mapped to a “ref” interaction operand [17]. Figure 8 shows the obtained SDESB after the transformation.

Fig. 8. Sequence diagram of system’s external behaviour for the checkout sub-process, obtained by applying CIM-BPMN.

By studying the example given in Fig. 8, the author concludes that this transformation requires partial participation of the architect, i.e., coming up with appropriate text for messages.

The biggest difference between the approaches concerning the obtaining of sequence diagram is the following. In TFM4SE, a sequence diagram represents interaction between actors and the system, as well as sending messages between objects of the system. In its turn, CIM-BPMN sequence diagram shows communication between actors and the system which is presented as one object. Thus, TFM4SE sequence diagram is on lower level of abstraction. CIM-BPMN defines the transition to a low-level sequence diagram [36], but it requires additional design and description of the system’s internal behaviour. The common characteristic is that both transformations require partial participation of the architect, so they are not 100 % formal. However, TFM4SE also requires additional effort in coming up with names of classes and methods that will realise the functional features; and additional processing of the knowledge about the business system and the planned information system to identify system goals and corresponding functional features – this processing is directed by guidelines, but the results may vary depending on the thinking of the architect. Nevertheless, variation of the result is limited, because topology of TFM must be retained.

TABLE IV
COMPARISON SUMMARY BETWEEN TFM4SE AND CIM-BPMN APPROACHES

	TFM4SE (Osis et al.)	CIM-BPMN (Bousetta et al.)
Business model	TFM. Formal guidelines how to get TFM from system's verbal description. Comprehensive verbal description is needed.	BPMN high-level and low-level BPMs. No formal guidelines for creating the model. Comprehensive verbal description is not needed, but knowledge is still required.
Increasing the level of detail of business model	Formal operation – continuous mapping – ensures consistency between abstract and detailed models.	Expanding the sub-process is done rather intuitively which may lead to inconsistency with more abstract model.
Transformation to sequence diagram	Model shows sending messages between objects and interactions between the system and actors. Coming up with names for classes and methods is required. Identifying system goals and corresponding functional features is required. Transformation requires partial participation of the architect.	Model shows interactions between actors and the system, but does not show system's internal behaviour. Transformation requires partial participation of the architect.

IV. CONCLUSION

The discussion in this paper has been directed to the comparison of TFM4SE with model driven approaches that use BPMN for CIM modelling and provide CIM → PIM transformation. From the discovered ones, the author has chosen the most well-elaborated one to compare it with TFM4SE concerning CIM modelling and transformation to a sequence diagram on the PIM level. The comparison has been performed on the basis of an example (case study). The result of the research is summarised in Table IV.

As emphasised in the introduction, the main difference between TFM and BPMN model is that TFM is a formal model with mathematical background, and BPMN is not. The author believes that the improvement of the object-oriented system analysis and modelling lays in using formal methods. The author has been interested in finding out the benefits and drawbacks the formalism of TFM brings in comparison with CIM-BPMN approach. Let us start with the drawbacks. Since the comprehensive description of the system must be developed, analysis stage requires more effort than in CIM-BPMN approach. Concerning transformation to PIM, the obtaining of sequence diagrams also requires more effort: the architect must come up with the names for classes and methods that will realise the corresponding functional features; also, additional analysis of knowledge about the business system and the planned information system is required to identify the system goals. On the other hand, the advantages of TFM4SE are the following. On the CIM level, the consistency between abstract and detailed models is ensured, because formal operation for manipulating the level of detail is applied. On the PIM level, the obtained sequence diagram represents inner behaviour of the information system – it shows message sending between objects. This description of inner behaviour is obtained without making any design specification, except names of classes and methods that are assigned to functional features of TFM. Only the knowledge that is obtained during the analysis phase is used.

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Arturs Solomencevs is currently Master’s student and Research Assistant at the Department of Applied Computer Science, Riga Technical University. He actively participates in the scientific research project called Topological Functioning Model for Software Engineering (TFM4SE).
E-mail: Arturs.Solomencevs@gmail.com