Use of Petri Nets and Business Processes Management Notation in Modelling and Simulation of Multimodal Logistics Chains

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Abstract— **The paper proposes the use of Petri Nets (PN) and Business Processes Management Notation (BPMN) formalisms for building the models of multimodal logistics chains. The business processes related to logistics operations are defined and represented in BPMN model. This model is then expressed in terms of Petri Nets. Finally, the PN formalism is used to build a simulation model of the entire multimodal logistics chain of operations. Some examples of the formalisms used are presented**

I. Introduction

The problems of modelling and simulation of multimodal logistics chains seems to be an important issue in modern economic and engineering considerations. However, it is not so easy to model and then to simulate the direct link that exists between the business processes part of the logistics chain and its representations in the simulation model. This paper is an early attempt to employ the rigorous Business Process Modelling Notation to represent the business processes and then to translate them into the language of discrete events modelling nad simulation i.e., Petri Nets. In Section II we present the basics of multimodal logistics chain modelling using the BPMN. In Section III the process of translating the BPMN onto Petri nets formalism is introduced and discussed. Finally, in Section IV some simulation experiments with the models introduced are described.

II. Modelling of Multimodal Logistics Chains

In each logistic problem there exist transportation nodes, and connections among them. Particular nodes, in classical problems, differ from each other only in values of parameters. However in more detailed analysis such level of distinction is insufficient. Therefore the precise description of behavior of each element type in multimodal logistic chain is needed.

In this article will be presented a problem of multimodal logistic chain, where the transportation unit is a single container. In such a situation we can distinguish three basic types of nodes.

- Road terminal.
- Railway terminal

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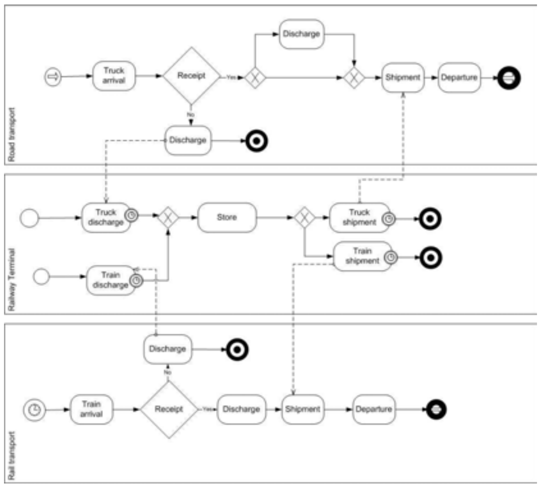

Fig. 1. Model of railway terminal defined in BPMN

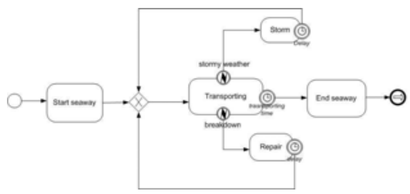

Fig. 2. Model of seaway in BPMN

- Sea port

Within the framework of each node a single container is processed (one container is a seed of process). Operations in each terminal type are defined with the use of BPMN [7] (example figure 1). Difference between two terminals is defined by the parameters (for example port of Hamburg, and Gdansk have different MPU's).

To connect two single nodes three types of transport facilities are used :

- Truck
- Train
- Ship

Each mean of transport is described by process in BPMN (for example look in figure 2). A single connection between two terminals can be described by one or more processes, depending on number of phases of transportation stage.

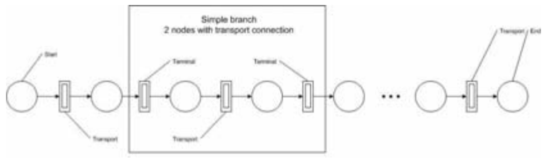

Fig. 3. Generic flow of the Multimodal Logistic Chain

III. Definition of model in terms of Petri Nets

In previous Section there was presented information about models of single elements of logistic chain. Each of them was described with the use of BPMN. This notation have some elements similar to Petri Net (states/places event/transitions).

Additionally in Petri Nets there exists a mechanism which allows dynamic building of complicated nets from group of subnets. Such mechanism is defined in hierarchical Petri Nets[1],[2].

A. Hierarchical Petri Nets

Whole structure of the net can be divided into levels. High level of the net is called a superpage, and lower a subpage. The superpage, contains socket, and each subpage contains ports. Each socket must be assigned to a port with an identical color set. There is no need to assign all ports to a socket.

There exist many types of hierarchical Petri Nets, but the most popular are two of them:
Substitution Transitions - in this case a single transition is substituted by a subpage. That means that all sockets and ports are described as places.
Substitution places - is similar to substitution transitions but substituted is single place. In this case sockets and ports are described as transitions.

It is also possible to join this two solutions. But in this situation it is impossible to substitute two adjacent elements.

So, there exists simple method of joining several nets (subpages), using one superpage. That means, that to build a generic simulator of multimodal logistic chain, based on Petri Nets, we must define: generic superpage (3), and all basic elements of the chain with their parameters. In current stage we have presented patterns of business process of particular modes. The next stage is to present them in terms of Petri Nets, and then join suitable components with use of superpage.

B. Mapping BPMN diagrams into terms of PN.

It is possible to distinguish on BPMN diagrams elements characteristic to Petri Nets: states and events. However, it is not possible to built a Petri Net in precise and unequivocal way on the grounds of BPMN diagrams some operations can be made automatically and they can simplify subsequent activities. Hence, there are two stages of mapping BPMN diagrams to Petri Nets.

The first stage delivers a skeleton of Petri Net. All operations which must be executed are simple and do

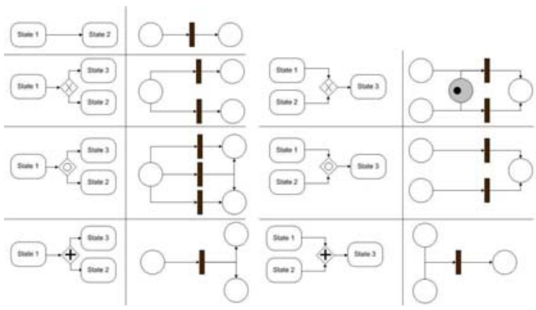

Fig. 4. Replacement of gates in BPMN diagram

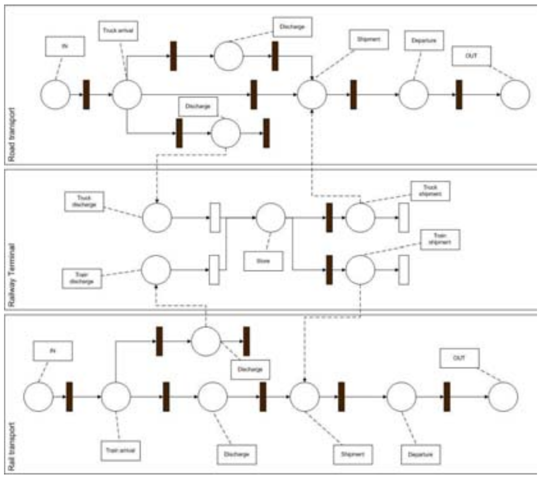

Fig. 5. Petri Net skeleton for railway terminal

not require expert knowledge.

To create Petri Net skeleton, the following operation must be made:
1. Create Places up to the pattern in BPMN diagram.
2. If next to state there is defined an event then: add event to Petri Net skeleton and link it with the state.
3. All links in BPMN diagram must be replaced by links between suitable elements of the skeleton (look in Figure 4). If link is leading from an event then make an assumption that the event was created in previous step.
4. In gate XOR exists additional synchronization state, which can appear. This additional state is linked with an event form other fork gate XOR or another fork gate.
5. When link is leading from event to gate then there must be added a state after the event. After that a proper rule from the figure 4 can be used.
6. In the skeleton ther must be denoted the message flow. It is not presented as an element of Petri Net, but by a dashed arrow. This notation is used by an expert in the next stage of creating Petri Net.

As a result of the presented operations the skeleton of Petri Net is received . It will be used in the next stage of generation of final net. For example, in Figure 5 is presented a skeleton, which was generated from BPMN diagram of railway terminal.

Second stage consists of adapting Petri Net's skeleton to real system and its characteristics. In this stage it is possible to distinguish two phases: integration of skele-

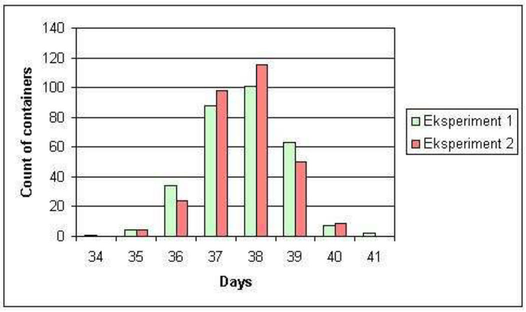

Fig. 6. Two experiments with 300 independent samples

	Exp. 1	Exp. 2	Total
EX	37.2131	37.2277	37.2204
VarX	1.1119	0.9077	1.0081
Minimum	33.4984	34.0648	33.4984
Maximum	40.4440	39.6891	40.4440

TABLE I: Experiments results in days.

tons created from BPMN diagrams and adding configuration elements of the net. These elements are used for example to: define time, delays, weights of events and arcs. This phase is strongly connected with gathered data about the system, and also with validation of the model.

Unfortunately it is not possible to describe how the net must look like after final changes, and what operation should be made to get proper net. Final net is strongly contingent to modeled system and expert knowledge about it and about Petri Net.

IV. Simulation Examples

To validate the proposed model some simple simulations were made. They proved that the theoretical model of generic multimodal transportation chain works in the proper way. All modes have been joined together in one Petri Network, which was ready to work. It was necessary to configure initial marking.

For simulation purposes a theoretical transportation model was prepared. The model presents transportation chain from Hong Kong to Narvik through Shanghai and Rotterdam. The model did not give consideration to ports nodes. Ship which transports containers passes the middle ports without coming alongside. The model was also dependent on the influence of weather.

Two major experiments were made. In each one 300 independent test were made. The result of these experiments is presented in Figure 6. The final result shows, that the mean transportation time of the container equals to 37 days with one day variance (look at table I for more details). In Figure 7 it can be noticed that the lots of containers may be delayed one or two days. The results of simulation are close to the timing of real ships and they look very promising for future works.

The next step is to gather proper information about single modes of transportation, and nodes in transportation network. After this operations the verification of model will be made. It is possible that some more elements can appear in BPMN diagrams, but with usage of presented algorithms they can be easily transformed to new Petri Nets. The most important is that the single mode can be expanded, without modification of the others.

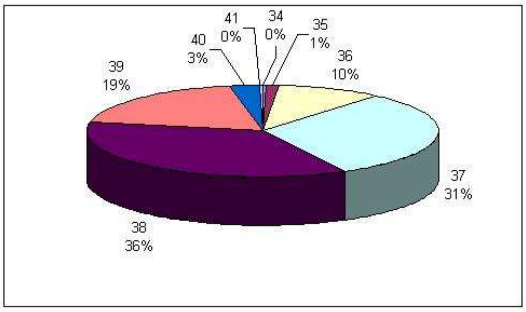

Fig. 7. Total simulations result

V. Conclusions and future works

In the article the part of simulation model was presented. It was created to study multimodal transportation processes. The model was preliminarily defined in terms of BPMN. On the ground of it were created several Petri Net. Each net defines a single phase of a complicated logistic chain. Proper union of this nets gives a generic simulation model, which can be used in experiments.

In this article we have presented a set of rules, which can help in conversion of BPMN to Petri Net. In future works this set can be supplemented with additional ones, and perhaps a Petri Net skeleton which is created during this process will be more advanced.

Presented model, depends on level of complication, and number of transportation modes, it can be a big composition of places and events. It can cause computational problems, but in such a situation methods for distributed simulation ([4], [6]) can be used.

The main goal of future works is to verify the model (for large multimodal chains), and to perform greater number of simulations for real transportation problems.

VI. Acknowledgement

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