Agent-based simulation of transportation nodes

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Introduction

Service systems or queuing systems represent a large group of real world systems. Service system accepts orders (jobs) from its customers and executes service activities bound to these orders, utilising set of service resources. Service activities can be (and usually are) executed in parallel manner. Since execution of one service activity can invoke orders for other subordinate services, service can be considered to have hierarchical structure. To the group of service systems belong for example banks, factories, hospitals, repair shops, railway stations, etc.

Transportation is one of the important service activities. Due to its complexity, it is realised by specialised service systems, called transportation systems. In a transportation system, transportation is primordial and dominant service activity (e.g. postal systems, railway system, courier service system, etc.).

Besides traffic infrastructure, expensive mobile service resources (e.g. locomotives, buses) are usually required to realise transportation of elements. In order to minimise costs for these resources, elements are not transported one by one, but are grouped together to form transport sets. This is the reason why there are more carriages in a train, more postal bags in a carriage, and more letters inside a postal bag. If there is only a limited amount of elements to be transported from the place of origin to the destination place, rather than create a special transport set for these two places, it could be more effective to transport the elements utilising multiple "changes", same way as we all know it from long distance travels using train. **Transportation terminals** are such places in transportation systems, where (besides other activities) changes of elements from one transportation set to another are performed. Process of grouping of the elements to suitable transportation sets, with regard to the destination place, is also called sorting or classification process.

To the widely known transportation systems belong:

- **Railway marshalling yards**, in which sorting of goods wagons to sets (goods trains) for respective destinations is performed.

- **Passenger transportation terminals**, in which passengers move from one transport vehicle to another. These terminals are often multi-modal, i.e. they comprise more means of transportations (railway, road, airborne, etc.).
- **Container terminals**, which also have multi-modal character (typically they connect railway, road and water transportation), but their main function lies in container sorting (transloading).

Besides terminals, in transportation systems there are also other places, which are important for their service function. To mention some of them:

- **Railway factory sidings**, which often combine railway and road traffic. They contain infrastructure, service resources and served elements of both types. In a heavy industry, sidings can be extraordinary large and they can contain separate sorting part. Complicated manipulations and movements are typical operations, as well as loading and unloading operations.
- **Specialised railway logistic centres** serve for maintenance, repair, cleaning and other services for vehicles, as well as for assembling of train sets (railway depots).
- **Combined centres**, which represent an integration of more centres of different types. An example is a need to combine passenger and goods railway station together with a nearby train depot.

In the mentioned centres, transportation or sorting are not necessarily primary or dominant services. However, the sequence of service operations like loading, unloading, repair, etc. invoke such complicated transfer processes, that these centres can be, due to their technological complexity, regarded as a part of the same group of service centres together with transportation terminals. Within this publication, we use the general term **transportation nodes** for transportation terminals, as well as for other mentioned centres. We are aware of the risk that the term might not be conforming to norms and customs within the fields of different types of transportation.

Transportation nodes with their expensive, complicated technical equipment and complex technological procedures belong to the most complicated service systems. They have to be designed and managed in such a way that the required capacity and quality of service be guaranteed with minimal costs spent on service resources. This goal can be achieved in various ways, e.g. by changes in infrastructure, utilisation of alternative resource types, improvement of the resource rosters, enhancement of the technological procedures, modification of decision strategies, or even by complete reengineering of the node.

The question is: what can the management of the transport node do to render its decisions as objective as possible and at the same time to avoid wrong decisions, which could have serious economic and operative impact on the node?

Due to the mentioned complexity of such systems, application of exact mathematical methods is quite limited. Standard expert studies, which do not use optimisation tools, do not provide management with objective enough arguments. This can in turn lead to a situation, in which management is reluctant to make decisions or even refuses to make any rationalisation measures at all.

Good way out of this situation could be utilisation of a supporting software interactive tool, which also includes exact solutions to some relatively easy sub-problems. Results provided by such a tool have to be understandable and credible enough to convince the management to accept these results as an argumentation base for its decisions.

Simulation model of a transport node is probably the most effective tool for solution of transport nodes problems, which fulfils given requirements. The main principle of the simulation technique is the replacement of a real (existing or planned) transport node with its dynamic computer model, which truly enough reproduces the processes in the real system. This method allows the experimenter to verify on computer the whole series of different operational scenarios and then recommend the realisation of such measures, which lead to required qualitative and quantitative performance of the node.

Utilisation of the mentioned simulation model of transport node can be linked with planning within various time frames:

- **Strategic** (long term) planning can utilise simulation, which investigates, for example, extensive node reconstruction and its consequences for future operation; changes in network technology (related to cancellation of selected nodes and resulting significant increase of input traffic flows to investigated node); operation of newly designed node, etc.
- **Tactical** (medium term) planning can be based for example on results of simulation of node's operation, with different traffic plans, or during various stages of reconstruction and so on.
- For the need of **operational** (short term) planning/control, simulation models can be utilised as a training equipment (simulator), using which for dispatchers who can train their abilities to manage node's operation under difficult and challenging circumstances. The gained experiences are then applied in real operation (to support operational management of the node, there is also the chance to utilise so called on-line/real-time types of simulation models, however, properties of such models are beyond the scope of this publication).

From the technical point of view, design and usage of simulation model of any dynamic system is limited only by the computing power of the computer used. However, when simulating highly complex systems, other factors and limitations need to be taken into account:

- methodological and mental mastering of the whole model with its complexity,
- mastering the management of changes of the realised product – simulation model, which requires the highest level of model's flexibility

To master given tasks, highly modular and flexible architectures are being developed. These architectures are based mainly on paradigm of autonomous software agents.

Subject of this monograph book is a methodology for design of highly flexible simulation models of complex service systems focusing especially on transportation systems models. Transportation systems are service systems, dominant function of which is transportation of elements. The explication presented in this book is based on original proprietary agent-based simulation architecture ABAsim (which has been verified on commercially successful projects) and is illustrated on a case study of marshalling yard simulation model. Marshalling yard was selected intentionally as one of the most complicated transportation nodes. Besides progressive agent architecture, the book deals also with other modern techniques (e.g. Petri nets), which support the design of flexible and sufficiently universal simulation models.

The text is dealing with, at first sight, two relatively distant disciplines. First and crucial area is the field of information technologies, namely technologies for design, development and utilisation of simulation models of complex service systems. Second covered area is the field of transportation technologies. Although such a connection might seem to be a little bit unusual, in this case it is intentional .Close cooperation of experts from both fields (informatics and technological procedures of the system) is vital to successful application of simulation models of complex service systems. This interdisciplinary team has the best chance for success if the simulation software designer is highly familiar with technological procedures carried out inside the real system being modelled; and vice-versa, if the technologist of the service system understands (and knows the potential of) the simulation methodology applied.

This publication is intended for readers, who are applied informatics experts and students, who want to study design, development and utilisation of simulation models of transportation systems. The book should also be of interest to experts and students of railway operation and management, since it provides an explanation of simulation techniques used for rationalisation of transportation systems operation.

In the first chapter, structure and technological (service) processes of marshalling yard, which is the subject of our case study, are explained.

Second chapter explains basic simulation terminology and techniques, utilising service systems of a marshalling yard as an example.

Following two chapters are devoted to the simulation models architecture, which was inspired by the paradigm of reactive agents and also to the principles of simulation model design using this architecture.

The fifth chapter deals in detail with declarative notation of decision algorithms using Petri nets. Petri nets provide vital support for building simulation models of service systems, especially in cases when these systems are highly complex. This chapter is of particular interest to readers, who are, or who want to become active creators of simulation software. Readers focused on technological processes do not need to study this chapter in detail.

In the sixth chapter, the gained knowledge is applied to the design and usage of marshalling yard simulation model, which turns this chapter (together with methodological instructions in previous chapters) into a notably complex case study.

Last chapter is focused on problems linked to implementation of simulation models based on ABAsim architecture. Marshalling yard, which was used for explanation of simulation model design, is far too complex to be used for explanation of implementation issues. Therefore we use a simple simulation model of locomotive repair shop to demonstrate basic techniques not only for analysis and design, but also for implementation of agent-based simulation models. Source codes of repair shop simulation model are an integral part of this chapter.