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Artificial immunity to control disturbances in public transportation systems: Concepts, mechanisms and a prototype implementation of a knowledge based decision support system

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ABSTRACT

In public transportation, the occurrence of unpredictable disturbances (e.g. accidents, delays, traffic congestion, etc.) may affect the expected execution of preset organization and pre-established timetables of transportation resources (buses, trains, metros, trams, etc.). Affected timetables may become useless, or at least deviate from expected behavior and/or performance. Unfortunately, existing literature suffers limitations with respect to the development of decision support approaches and tools that are able to help decision makers in monitoring and controlling public transportation systems, particularly at the occurrence of disturbances. Existing works are still limited with respect to dealing with several types of disturbances, and suggesting reactive decisions at execution time in such a way to maintain the performance of pre-established timetables and provide users with high quality of services (in terms of punctuality, frequency of programmed shuttles, etc.). In this paper, we show that biological immunity can provide useful principles and mechanisms that are pertinent for the management of disturbances in public transportation systems. We highlight these principles and mechanisms, associate them with application components and fully document them. To show their feasibility, we develop a prototype artificial immune system able to assist decision makers in performing several disturbance management functions, such as detection of disturbances, construction of reaction strategies, supervised learning and memory of previous experiences with disturbances. Through experimental validation, we show that immune concepts and mechanisms can yield to the design and implementation of knowledge based decision support tools that are able to deal with different kinds of disturbances, and to assist decision makers through the disturbance management process.

1. Introduction

Nowadays, public transportation of passengers is becoming an appealing economic solution to city life problems, like the requirements for mobility for an ever increasing population density, motorization, urban growth, and concerns about environmental issues, such as air and noise pollution [36]. Governments and public authorities are more and more investing in means and infrastructure for public transportation, such as roadways for buses, and railways for trains, metros and trams [53]. Investment also addresses multi modal transportation [42], which focuses on finding ways of interconnecting and managing networks of different means of transportation to insure an increased coverage of geographical space.

Exploiting and managing a public transportation system create a number of challenges for governments and local authorities. For example, managers of public transportation systems struggle to establish transportation timetables that satisfy passengers, who expect high levels of quality of service, in terms of timely and regular shuttles. Scheduling a transportation system refers to several activities, including crew time tabling, design of shuttle routes, assignment of transportation resources to routes, and assignment of visiting hours to stations [45,8]. Transportation timetables are initially established taking into account information about forecasts of traffic conditions, rush hours, demand for transportation,

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etc. [3]. It is common practice to consider that an efficient timetable is one that establishes an expected behavior so that the performance of the transportation system is optimized with regard to one or several objectives. Several works use either exact [25,29] or heuristic [10,11] methods to determine timetables that optimize one or several objectives, such as minimizing total trip time or cost [29], minimizing passenger waiting time at stop stations, minimizing passenger in-vehicle time [10,11], or minimizing passenger transfer time from one route to another [23].

However, during the execution of pre-established timetables, disturbances may appear that can make these timetables deviate from their expected course, causing them either to be delayed or to become obsolete [39]. When they occur, such disturbances like accidents, traffic congestion, absence of personnel, and bad weather conditions, degrade the expected performance of the transportation system, decrease its expected quality of service, yield to passenger dissatisfaction, and may cause the appearance of congestion at stations or on transportation pathways. Consequently, decision makers have to monitor the execution of pre-established timetables, and to make reaction decisions in order to bridge the gap between pre-established timetables and really executed ones. Disturbance management is a complex engineering task. Decision makers have to analyze complex flows of information (with respect to information sources, size, frequency, and processing requirements) concerning the state of the transportation system in order to detect any disturbances and assess their severity. Also, very often, decision makers have to rely only on their own experience, expertise and knowledge to select critical information and make control decisions taking into account requirements of quality of service and operational constraints [3]. These different tasks show the management complexity of transportation systems, especially if multiple disturbances appear and need to be managed simultaneously.

As it will be discussed in the next section (dedicated to the literature review), existing transportation management and control systems offer limited capabilities to deal with disturbances in a public transportation system. Despite the existence of several studies that are concerned with the development of decision support systems (DSSs) to control public transportation systems, Davidsson et al. [19] pointed out that, at least until year 2005, 64% of the existing research focuses mainly on design issues and architectural aspects. Only a few approaches explicitly address the disturbance management issue, and they are still limited with regard to genericity (ability to take into account different kinds of disturbances), integration (ability to insure both detection, identification of consequences, reaction and evaluation of residual consequences of disturbances), and computerization (ability to suggest computer based decision support systems). Balbo and Pinson [3] emphasize that, despite the wide use of Operations Research (OR) models and Interactive Decision Support frameworks in modeling decision-making processes, the details of the decision-making process itself are often hidden or not fully described. Consequently, more effort has to be spent on developing decision support tools that are able to assist decision makers in monitoring and controlling the execution of pre-established timetables of public transportation systems. Such tools should be particularly able to take into account different kinds of disturbances, and to help decision makers in finding suitable control decisions that allow reacting to disturbances and maintaining acceptable levels of performance and quality of service.

In this work, we are investigating the potential of biological immunity to provide an approach and to guide both the design and development of decision support tools that are particularly able to handle disturbances in public transportation systems. The biological immune system relies on a reduced set of concepts, principles and mechanisms that, despite their limited number, are yet able to protect the host organism efficiently against a great variety of disease causing elements threatening its normal functioning. Although several artificial immune system applications exist, to the best of our knowledge, we are not aware of any applications to public transportation systems. Therefore, we draw analogies, and we highlight useful biological immune concepts, principles and mechanisms pertinent for the design of decision support systems that are able to help in monitoring and controlling a public transportation system, especially at the occurrence of disturbances.

To show the feasibility and effectiveness of our suggestions, we develop a prototype implementation of a knowledge based decision support system. This prototype relies on previously identified immune concepts and mechanisms to detect the occurrences of disturbances and to suggest control strategies that maintain acceptable performance of pre-established transportation timetables. We illustrate our approach and evaluate our decision support tools considering a particular public transportation system, i.e. a network of buses. Although our suggestions can easily be extended to other transportation means, we are considering a uni-modal public transportation system of buses, which is a set of vehicles (buses) that move between different stations along predefined routes to serve a set of passengers. We do not consider trains, metros, tramways, and other transportation means. Also, interconnection between different means of transportation (i.e. multi modal transportation) is out of the scope of this work. We are interested neither in designing routes, nor in establishing initial timetables for buses. Instead, we are interested in monitoring and controlling the execution of pre-established timetables along routes that were already defined in order to detect disturbances and to find, in a reactive manner, control decisions that allow maintaining, as much as possible, expected performance and quality of service.

In this respect, this paper is organized as follows: Section 2 reviews existing transportation control systems and discusses their limitations with regard to disturbance management. Section 3 introduces the main features of the biological immune system and describes some of their applications, known as artificial immune systems. Section 4 introduces our approach to deal with disturbances of a transportation system based on immune principles and mechanisms. Section 5 presents a prototype implementation of an artificial immune decision support system (DSS). The simulation results of this approach are presented in Section 6. Section 7 discusses some key features of our suggestions. Finally, a conclusion and future research perspectives are presented.

2. A review of existing transportation control systems (TCSs)

To manage a network of public transportation means (buses, trains, metros, tramways, etc.), many studies proposed several methods to generate efficient timetables that schedule the vehicles of the transportation system [8,10,11,25,29,45]. Timetables represent inputs to transportation control systems (TCSs), which are software tools that are concerned with monitoring and controlling the execution of pre-established transportation timetables [7]. In the following sections, the scientific literature is reviewed with regard to several aspects of TCSs, including architectures and enabling technologies, disturbance management capabilities, and control strategies. Then a critical analysis is conducted and our problem statement is given.

2.1. Architectures and enabling technologies

Several studies were proposed to design architectures of TCSs [3]. These architectures integrate the decision maker in the decision loop, and rely on several information and communication technologies to perform their tasks, including Geographic Information Systems (GISs), Global Positioning Systems (GPSs), Automatic