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Searching feasible resources to reduce false-positive situations for resolving deadlocks with the Banker's algorithm in railway simulation

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A B S T R A C T

The deadlock problem is a well-known challenge in synchronous simulation for railway planning and operations. The Banker's algorithm is a classical solution for deadlock avoidance, and has also been applied in the field of railway simulation. Once a train passes the deadlock-free test with the Banker's algorithm, a deadlock-free situation can be guaranteed.

However, any false-positive situation in resolving deadlocks will limit the efficiency and the usability of railway simulation. In a false-positive situation, a request, which may not actually lead to a deadlock, will still be rejected due to a failed deadlock-free test. Hence, waiting time is unnecessarily increased, and the efficiency of the simulated railway operations is reduced.

In this paper, a method to determine feasible resources is developed to reduce these false-positive situations. Through applying the Banker's algorithm and feasible resources, the developed method can be conceived as a combination of deadlock prevention and deadlock avoidance. As a complement with limited computational efforts and simple logic, the method to identify feasible resources with deadlock prevention can efficiently decrease the waiting time caused by false-positive situations. Since the developed method using deadlock prevention is only applied from the current position of the tested train to the feasible resources, the inflexibility of being blocked by the entire line with deadlock prevention can be avoided.

The implemented case study shows that the applied method can avoid deadlocks and reduce false-positive situations efficiently. Within it, the rate of rejected requests is reduced from an initial value of 38.35%–3.23%, and the rate of reduction of false-positive situations is 22.22% for the total requests of infrastructure resources. Its usability has been proven for a large scale network with a high density of train movements.

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1. Introduction

Today, various simulation approaches are widely used in railway planning and operations. Among them, synchronous simulation is a very popular type of railway simulation, by which all train runs are simulated simultaneously along the passage of time. It realistically represents the behaviour of railway systems and the interaction among trains and infrastructure. Synchronous simulation is applied in many railway simulation tools, including RailSys and OpenTrack (Watson and Medeossi, 2014).

A well-known challenge for synchronous simulation is the deadlock problem. An example of the deadlock problem is shown in Fig. 1. The path of the train is marked with a dashed line. During the simulation, if train T2 occupies the route from S4 to S6, all trains T1, T2 and T3 are blocked. A deadlock situation takes place, although all safety rules have been considered.

In Pachl (2011), the deadlock problem in railway simulation is defined as:

> “A deadlock is a self-blockade in a control system in which two or more tasks are waiting for each other to release a resource in a circular chain. In rail traffic, a deadlock is a situation in which a number of trains cannot continue their path at all because every train is blocked by another one.”

Four conditions necessary to produce deadlocks are given by Coffman et al. (1971). In Pachl (2011), the conditions are analysed for railway operations:

1) Mutual exclusion: a train will occupy an infrastructure resource exclusively.
2) Wait for: a train holds the occupied resources when it waits for the new re-quested infrastructure resources.
3) No preemption: it is impossible to remove occupied infrastructure resources from a train forcibly.
4) Circular wait: a cyclic wait is formed among two or more trains. Each train waits on other trains to release the required infrastructure resources; meanwhile the train occupies the infrastructure resources requested by other trains.

Three principles can be applied to resolve deadlocks:

- Deadlock detection
- Deadlock prevention
- Deadlock avoidance

With deadlock detection, the system will be rolled back to a previous status in case of deadlocks. For some simulation tools, deadlocks are solved manually through deadlock detection. However, this method of rolling back frequently is not efficient for railway simulation.

A straightforward idea to resolve deadlocks is to eliminate one of the four necessary conditions mentioned above. This approach is called deadlock prevention. In railway operations, the conditions 1), 2) and 3) are always in effect. Therefore, the issue of circular wait is to be considered within this method of preventing deadlocks. Due to the simple nature of the logic involved in systematically preventing circular wait, deadlock prevention can be implemented with low computational efforts.

Clarified with an example, a potential circular wait situation can be prevented with the principle of deadlock prevention by forbidding bidirectional operations or by reserving all of the required infrastructure resources for a given train. However, it is inefficient to simply apply deadlock prevention for the entire process of railway simulation. For lines with bidirectional operations, it is unrealistic or even impossible to prevent circular wait by blocking the entire line for only one direction. With deadlock prevention, more resources for a train will be unnecessarily reserved in advance to prevent circular wait for bidirectional operations. It will reduce the system capacity with a poor level of resource utilisation. Therefore, to resolve deadlocks solely with deadlock prevention for railway simulation is impractical and inefficient.

The principle of deadlock avoidance is the most practical approach in the resolution of deadlocks. For any given request, the current operational situation will be investigated. The request for an infrastructure resource can only be granted in the case of a safe state, which ensures deadlock-free operation. Within the principle of deadlock avoidance, the elimination of

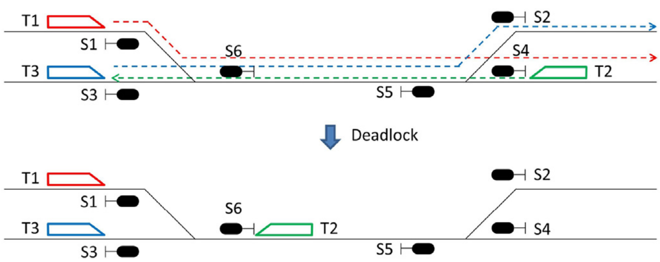

Fig. 1. Example of the deadlock problem in railway synchronous simulation.

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