Modeling of a Subterranean Rail Transport Network

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Abstract

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1 INTRODUCTION

Subways are a key form of transportation for people living in cities. This report investigates the role of subway passing tracks in ensuring that subway service is not adversely impacted by breakdowns.

Subway delay data from the Toronto Transit Commission (TTC) is used as a guide to determine the frequency and severity of delays for subways, how far trains are from one another when delayed and the delay cause.

Different simulation techniques for subway system scheduling and breakdown are explored in the background section. Petri nets and collision detection methods are compared for their ability to simulate subway breakdowns matching the important properties found in TTC data and for ease of use.

A Petri net method explored is explored for simulating train movement in the modeling section. The model is placed within the parallel DEVS formalism to clarify how the trains, stations and tracks interact with one another over time. Implementation of the simulation model in `DEVS-Suite` is also discussed.

Experiments are created to match scenarios with moderate delays (excluding flooding or other subway wide delays) found in the TTC data. Track configurations with different prevalences and placements of passing tracks are tested to see what impact configurations has on subway delays. All track configurations tested use a looping track layout without intersections.

Model results for track different track configurations are used to determine how important the prevalence and placement of passing tracks is in preventing delays.

2 PROBLEM DESCRIPTION

A subway system is composed of trains, passengers, tracks and stations. The purpose of the subway system is to transport passengers from one station to their desired station. Tracks connect stations and trains travel station to station. Trains may only overtake one another if the track section or station they are both on has a passing area. Trains have a passenger capacity. When a train arrives at a station it has a fixed amount of time for passengers to embark and disembark. It is assumed that everyone that wants to disembark gets an opportunity to do so before people are given an opportunity to embark. Since embarking and disembarking of passengers from a train takes time and the train has a fixed capacity not everyone that wants to embark or disembark may be get an opportunity to do so. Trains have a possibility to be delayed or broken down. Delayed trains take longer to reach their destination. Broken down trains force all passengers off the train when the train arrives at the nearest station and then delays the train until it is repaired. Passengers are assumed to enter stations at a fixed rate.

2.1 TRAIN MOVEMENT BETWEEN STATIONS

Train movement between stations must obey the physical layout of the track and stations. Petri nets and collision detection are explored here as ways to establish feasible and crash free subway dynamics.

Collision detection can ensure feasible, crash free subway dynamics by requiring trains to be far enough apart that if one train stops the trains behind it do not rear end it. Calculation of minimum distance between trains requires information about track layout and train velocity and acceleration. A model of a train traveling between stations has been done by Xu et al (2014). In their model of a train between stations there is an acceleration period, a cruising period and a deceleration period. Multiple trains traveling on the same track can be modeled as a difference equation. At each step trains proceed to the next station in a safe manner taking into account time and energy efficiency. The safety criterion requires that the minimum stopping distance of the rear train is less than the distance between the leader and follower train train plus the minimum stopping distance of the lead train and a safety factor.

Petri nets were chosen over collision detection for simulating subway train movement because Petri nets are simpler, more efficient require less data to calibrate and capture the dynamics of train break downs and delays.

Petri nets are simpler than collision detection because Petri nets do not have the detailed physics requirements of a collision detection model. In the collision detection model minimum safe distance needs to be calculated by every train at every time step. With a Petri net, minimum safe distance calculations can be avoided by discretizing the track into sections with length greater than the trains minimum stopping distance at maximum speed (or with a number of sections if a more than one track lookahead rule is used) which ensures that collisions are always avoidable.

Petri nets are more efficient because they do not require any physics calculations during simulation and can evaluated as discrete events which results in a fewer number of calculations being required so long as track sections are large relative to the size of the time steps in a collision model.

Petri nets are capable of modeling the break down and delay dynamics of interest because a train delay or breakdown will back up the trains behind it so long as the section of track the delayed or broken down train is on does not have a passing track.

More data is needed for a collision detection model because it has higher physics fidelity than a Petri net. With the Petri net you only need the time it takes to pass through a section of track and the minimum stopping distance at maximum speed. The collision model requires knowledge of train accelaration and deceleration and maximum speed at different locations on the track.