Decision Support Tool for Deploying Shuttle Buses during Major Rail Disruptions

A Case study of the Toronto Transit Commission (TTC)

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Introduction and Scope

Major rail disruptions are frequent and have a significant effect in large cities that depend on rail transit to move the mass of people. Where scheduled disruptions could be handled with older techniques while relying heavily on experience, unexpected disruptions incur very long delays and major losses to the economy. The Comptroller office of New York City estimated the economic cost of major subway delays, lasting for longer than 20 mins, to be around 389 million US Dollars annually (NYC Comptroller Scott M. Stringer 2017). As such, there is a need to use intelligent transportation systems and analytical tools to help agencies deploy theoretically sound and robust solutions to manage unplanned rail disruptions. In a large city like Toronto, data of subway disruptions from 2015 showed that shuttle buses were deployed in response to 144 unplanned incidents along the subway line operated by Toronto Transit Commission (TTC). Leading to a total of 6,500 buses to be used in bridging disrupted rail segments in their network, in which 70% of the used shuttle buses were pulled from operational routes (Diab, Feng, and Shalaby 2018). Thus, causing further disruptions to the bus route system and incurring extra delays on some bus riders.

This essay summarizes the recent advancements in managing unplanned rail disruptions, focusing on Bus Bridging, which is defined by (Kepaptsoglou and Karlaftis 2009) as "*establishing short-term bus routes to restore connectivity between disrupted stations affected by a disruption*". The essay will continue to give an overview of TTC subway disruptions in Toronto with a brief overview of agencies' response to major unplanned disruptions. The opportunities of improving the response to disruptions using intelligent transportation systems is presented. The essay concludes with my relation and connection to this work, and potential opportunities and use cases.

Unexpected Subway Disruptions in Toronto and Response Plan

Unplanned rail disruptions happen frequently in Toronto. On average, 0.4 incidents/day in the subway system operated by TTC would require shuttle buses to be dispatched to serve the stranded passengers at several subway stations (Diab, Feng, and Shalaby 2018). In fact, most agencies in North America and Europe rely on bus Bridging in response to unplanned disruptions. Due to the absence of frequent turn-back tracks at subway stations, a disruption in one station could lead to the closure of a whole segment, consisting of 4 to 8 stations in the network. This exacerbates the problem and urges TTC and other agencies to act quickly to mitigate the delays. In response to these disruptions, TTC follows a simple strategy to dispatch shuttle buses as shown in the table below.

Expected incident time		+30 MINS			1 - 30 MINS		
Closed subway stations		**1-4**	**5-9**	**10+**	**1-4**	**5-9**	**10+**
Percentage (%)		3.33%	6.66%	10%	1.67%	3.33%	5.00%
Time period	Number of buses for regular service	Number of required buses for the shuttle service					
6:00 – 9:00	1325	44	88	133	22	44	66
9:00 – 15:00	881	29	59	88	15	29	44
15:00 – 19:00	1426	47	95	143	24	47	71
19:00 – 22:00	819	27	55	82	14	27	41
22:00 – 1:00	506	17	34	51	8	17	25

Figure 1 Shuttle-Bus response strategy by TTC (Aboudina et al. 2018)

This strategy is solely based on the incident duration, time of day, and the number of affected subway stations. However, it lacks any information regarding the deployment of shuttle buses, namely, from which scheduled bus routes and how many buses should be pulled, and to which stations should the buses be dispatched to initially start their shuttle service. In many of the reported incidents, the buses would be dispatched, but the rail service would restore its operation before the buses make it on time. This results in wasted time to bus riders and affects subway passengers. An intelligent and fast response is needed, and it requires the use of proper tools and experience at the same time.

Another issue in unplanned disruptions is the cause of the disruption. Often, disruptions cannot be anticipated, when will it happen and how much time does it require to resolve the problem. The cause of incidents in rail systems can be due to a mechanical malfunctioning, severe weather, train derailments, and sometimes human emergencies on the track level or in the trains. A more detailed analysis of the cause of disruption is presented in (Diab, Feng, and Shalaby 2018). Experience and prediction models using past disruption data play a significant role in better estimating the duration of a disruption. A tool that could allow testing different scenarios under different duration options would better inform decision-makers. Moreover, the infrastructure, more specifically, the placement of turn-back tracks determines how many stations would be affected during a disruption. If a train-emergency at Runnymede station in the western part of the system operated by TTC occurs, but trains can only turn back bat Kipling and Keele stations, then the 8 stations between Kipling and Keele will be closed. This is a busy section of the TTC network, and it is more congested during the morning peak period where commuters coming from suburban west of Toronto to their jobs in the Downtown zone. A long disruption along this segment results in significant delays for the users.

Improving the Response to Major Rail Disruptions

The literature has a handful of studies on the resilience of the transit networks and response research on managing unplanned disruptions. Diab and Shalaby, (2018) studied the impact of the subway system's interruption in Toronto on the speed performance of streetcar and bus routes. The latter uses AVL data to study the effect of subway incidents in an integrated transit network (Diab and Shalaby 2018). Recent publications on bus bridging scenario assessment (Itani et al. 2019) and optimization (Itani, Srikukenthiran, and Shalaby 2020) were developed by our team at the University of Toronto.

A lot of methods could be used in monitoring unplanned rail disruptions and improving transit agencies' response. Whether real-time tracking and communication between bus drivers and rail operators, optimized response plans, or exact predictions of disruption time. The real-time tracking technology makes it easier to track the transit vehicles, mainly track the exact location of the shuttle buses. The Automatic Passenger Count (APC) systems allow better information on their occupancy, and finally, seamless communication between the drivers and the central route management could allow a better bus deployment in case of an unplanned disruption. The current TTC strategy in shuttle bus deployment requests buses from all existing bus divisions and then it is based on the bus division to respond to the request, based on the bus availability. The lack of a unique and integrated platform and communication system that connects the bus drivers, bus divisions, and central TTC route management is necessary to minimize the lost time in communication while selecting the needed shuttle buses. A technological platform would benefit largely from centralized management of information regarding the location and occupancy of all buses in real-time.

Nevertheless, a tool that allows transit agencies to make better decisions in responding to rail disruptions, even in the absence of this technological platform, is still needed. A toolkit that allows post-incident analysis and suggests an optimal bus bridging plan is pertinent for improving the response strategy. The tool could also be used for assessing the different segment closures and carry on economic analysis to assess whether installing more frequent turn-back tracks at some stations is financially viable or not. The turn-back tracks and the incident duration are two factors that highly impact the disruption and the response plan. Moreover, the demand at the time of disruption is also critical, and agencies can utilize tools to prepare for the worst-case scenarios. Some studies in the literature developed models to predict the percentage reduction in the demand at subway stations due to disruptions. A study in 2017 modeled the mode choice during metro disruptions and highlighted the major factors that affect the chosen mode, including shuttle buses (Lin et al. 2018).

Moreover, tools that could optimize the bus bridging response and suggest the best scenario based on predefined criteria is needed by agencies operating rail service. The criteria could be based on optimizing the riders' experience or minimizing the inconvenience. This could be achieved by minimizing the subway passengers' delay and bus users' delay. Agencies can also optimize the operator's experience and response. Maximizing the shuttle buses efficiency, presented by the number of un-utilized shuttle buses, percentage of time spent by shuttle buses serving the disrupted segment, and the wasted time. An intelligent solution would provide a balance between both, providing efficient shuttle performance, minimize inconvenience for subway users, and minimize delays experienced by bus riders.

Personal Connection and Reflection

During my research of master's degree, I did analysis using TTC unplanned disruption data from 2015 where shuttle buses were dispatched to temporarily replace transit service, using an assessment tool that was developed by researchers at the University of Toronto (Aboudina et al. 2018). This tool estimates the total user delay under a user-defined bus bridging scenario and outputs several metrics that I used for the analysis. I carried on sensitivity analysis using the "User Delay Modelling Tool" for several attributes, including the incident duration, demand reduction ratio, proximity to the incident, and the end stations to which shuttle buses are dispatched.

This figure is an example of some of the work we have done in analyzing and assessing a disruption between Bloor-Yonge and Eglinton stations. More disruptions are analyzed in (Itani et al. 2019).

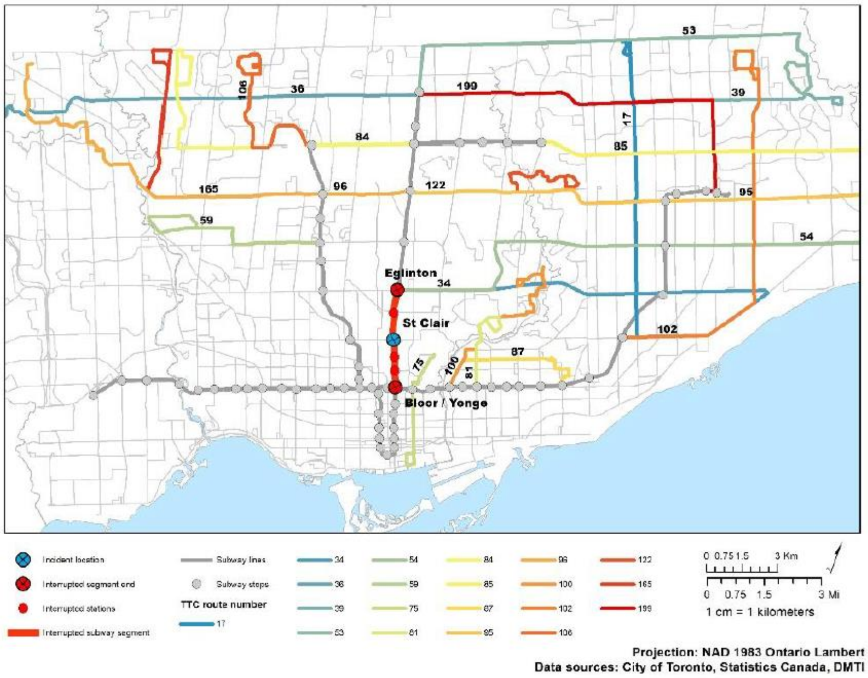

Figure 2: Disrupted Segment between Bloor-Yonge and Eglinton station with the selected bus routes

After the sensitivity analysis using the developed modeling tool, I developed an optimization tool using Genetic Algorithm, to produce the best bus bridging scenario under a given unplanned disruption. Evolutionary algorithms have been widely used to solve smart mobility and transportation problems. These algorithms provide near-optimal solutions to problems with undefined and non-linear objective functions. The methodology used is novel as it considered the bus-bay capacity along the disrupted segments to limit the maximum number of shuttle buses that could serve along a disrupted line. The decision support toolkit we developed provided better results from the ad-hoc and experience-based decisions at various levels. The new artificial intelligence and optimization technique can help transit agencies optimize and improve their response to unplanned disruptions. This tool could also be used for post-incident analysis to assess the agency's current policies.

Key performance metrics were analyzed from the operator's perspective, such as the deadhead time of shuttle buses, which is the time spent by the buses traveling from their scheduled route service to the incident location and back. On the other hand, the total user delays witnessed by bus riders and subway passengers are estimated. We also analyzed the delays at individual disrupted subway stations and individual bus routes. This allowed us to carry a disaggregate analysis on the maximum wait time and queue length at subway stations and bus routes. Web-user interphase was developed with our industry partner for this project, Trapeze, to allow a more interactive and user-friendly platform that transit agencies can use to assess the different scenarios.

Conclusion and Potential usage

Intelligent decision support tools can be helpful for cities and transit operators at various levels and aid them in making better and advised decisions at different operational levels of the transit network. These tools could also be used for emergency planning. The recent outbreak of COVID-19 pandemic caused a severe decline in ridership causing transit agencies a lot of financial losses. As economies around the world are re-opening, transit ridership is increasing again, putting pressure on the operator to provide safe travel for users. Providing a safe travel is a key to restore confidence in the transit system and planning tools would bridge the gap. A key challenge that face transit operators as economies restart is managing the flows of passengers in the transit network. Many agencies are looking into ways to manage overcrowding on platforms and inside the vehicles. Managing overcrowding in subway systems, that hold the highest number of passengers in normal conditions, can be done more intelligently using this decision support toolkit. Shuttle buses could be deployed to relieve overcrowding during certain times and at some segments in the system. The Bus Bridging toolkit can aid transit agencies in selecting these shuttle buses and minimize the overall effect on the city while maintaining safety measures.

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