Breaking into Emergency Shuttle Service: Aspects and Impacts of Retracting Buses from Existing Scheduled Bus Services

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ABSTRACT

Public transit is considered an essential service for any modern city, due to its indispensable role in supporting the daily activities of city residents. When unexpected interruptions to the public transit service occur, they reduce the quality of service provided to the public and diminish the system’s ability to retain existing customers and attract new ones. One of the main strategies that has been widely employed to deal with rail service interruptions is “bus bridging”, whereby buses from scheduled services are retracted and deployed to offer shuttle services along the interrupted rail segment. Nevertheless, very few efforts are found in the literature to assess the effectiveness of bus bridging and explore its impacts on the existing scheduled bus services. Therefore, this study aims at exploring the different aspects and impacts of retracting buses from scheduled services in response to subway and streetcar service interruptions in the City of Toronto. The paper explores the size and impacts of emergency shuttle service deployment, as well as the system response and recovery times using detailed subway and streetcar shuttle service reports collected in 2015 by the TTC, the public transit provider in the City of Toronto. The paper shows remarkable fluctuations not only in the utilized number of shuttle service buses over time, but also on the service response and recovery times. This study can be of interest to route management and service planning departments at transit agencies, as it provides new insights into the different aspects and effects of retracting buses from scheduled services.

Key words: subway, streetcars, system interruption, public transit, shuttle service, bus bridging
INTRODUCTION

Public transit is considered an essential service for any modern city, due to its indispensable role in supporting the daily activities of city residents. When unexpected interruptions to the public transit service occur, they reduce the quality of service provided to the public and diminish the system’s ability to retain existing customers and attract new ones. As discussed in the literature, transit users are usually concerned not only about their average travel and waiting times, but also about the uncertainty and variability in transit service, which affects their decision-making and time-planning processes (1-3). Thus, transit agencies and authorities implement several disruption management strategies (or emergency response plans) to mitigate and reduce the impact of unexpected disruptions and incidents on users’ costs. Several studies have been conducted around these issues, focusing mainly on proposing conceptual frameworks, testing different approaches for disruption management or categorizing incidents according to some criteria (4-7). To name just a few examples, Pender at al. (8) tested a new method to explore the economic viability of providing dedicated bus service reserved for bus bridging purposes for rail system disruption. Bus bridging refers to the strategy of providing temporary bus shuttle services that restore connectivity between disrupted subway or railway stations (5). Darmanin at al. (9) developed a mathematical model to minimize commuter discomfort when a service disruption occurs in the Metro system in Melbourne. Another recent study by van der Hurk et al.(10) proposed a mathematical model to estimate shuttle line frequencies under budget constraints for the Massachusetts Bay Transportation Authority, Boston, Massachusetts.

Notwithstanding the previous efforts concerning the provision of a dedicated bus fleet reserved for bus bridging purposes, according to a recent international survey of 71 transit agencies regarding disruption recovery strategies, about 45% of the responding transit agencies reported retracting buses from existing scheduled bus service to deal with rail transit service disruptions. This has been done with no reserved buses for bus-bridging purposes. Toronto Transit Commission (TTC), the public transit provider in the City of Toronto, Canada, is one of these transit agencies (11). Interestingly, the TTC noted in this survey that by doing that “you may in fact be simply shifting the problem or causing additional ones.” In view of that, and due to the fact that there has been little effort in the literature to document and explore the aspects and impacts of retracting buses from scheduled bus services, this research aims at filling this gap. In fact, this disruption recovery strategy presents a challenge to transit agencies, since sourcing of buses can be problematic at some locations and at some time periods. In addition, the effects of retracting buses from existing scheduled must be considered and integrated by transit planners during various operational stages to add the appropriate amount of recovery time, if possible, or to redirect bus system users to other routes that suffer no reduction in their frequencies.

The main aim of this study is to explore the different aspects and impacts of retracting buses from scheduled services in response to subway and streetcar service interruptions in the City of Toronto. The paper explores the size and impacts of emergency shuttle service deployment, as well as the system response and recovery times using detailed subway and streetcar shuttle service reports collected in 2015 by the TTC. This paper is organized as follows. It begins with a description of the data used in the analysis, followed by a description of the protocols employed by the TTC to provide shuttle services. The following sections explore the number of incidents, affected schedule routes, system response and recovery times, followed by
a discussion of the most frequent type of incidents. A conclusion section is introduced along with some recommendations at the end.

DATA AND RESEARCH METHOD

This study focuses on the City of Toronto, which is the largest city in Canada and the fourth largest in North America, with a total of 2.8 million inhabitants in 2015. The city’s population is expected to increase considerably by 32% to reach 3.7 million in 2041 (12), adding more pressure on the current public transport system. The TTC operates a multimodal transit system consisting of four subway lines, 11 streetcars lines, and 141 bus routes (13), serving more than 2.7 million passengers on a daily basis (14). The TTC subway network extends to a total length of 68 km serving 69 stations, while the streetcar route network extends to a total of 104 km serving 685 stops. Around 1.3 million passengers-trips per day used the subway system in 2013, while about 300,000 passenger-trips per day were made using the streetcar system (15). The TTC bus system is comprised of seven different divisions, where each bus route is operated and monitored by a specific division based on its geographic location. All bus routes are coloured in Figure 1 according to the division they are managed by.

The data used for this study includes the shuttle bus service reports acquired from the TTC’s Route Management Department for year 2015. A shuttle bus service log (or report) is generated when an incident in either the streetcar or subway systems occurs and the TTC deploys emergency shuttle service. Each incident is documented in one report which includes detailed information on both the incident and deployed shuttle bus service, specifically the incident type, date, time started, time cleared and location, as well as the number of shuttle buses requested and assigned from different divisions. The report also includes detailed information on each assigned shuttle bus including the vehicle number, original route number, assigned run number, time off route to serve in the shuttle service, arrival time to the shuttle route and returning time to its original route. These reports are filled manually (i.e., handwritten) in many cases by both the Route Management Department (the Control Centre) and bus division(s), and they are normally stored by the Control Centre for one calendar year before disposal. In total, more than 6000 pages, belonging to a total of 1094 shuttle service reports, were scanned, digitized and used in this study. This unique dataset represents a rich resource to better understand the aspects and impacts of retracting buses from scheduled service at the system level. The following analysis is based on the available data from all shuttle service reports; however, missing information can be found occasionally. To ensure accurate results, only data entries with complete information for a specific analysis were used. For instance, a record with no information on the time a given bus was retracted from its original route was used only in the geographical and incident analyses but not used in the response time analysis (discussed later).
This research employs various measures to explore the challenges associated with service resumption and recovery following subway and streetcar disruptions. It explores the magnitude of the problem by investigating the number of incidents, average delay per incident as well as the number of requested and assigned buses per incident. It also investigates the affected scheduled bus service by examining the number of buses retracted from each regular bus route. The system response time to service interruptions and system recovery time to return to normal operations are also explored. Finally, the paper explores the most frequent types of subway and streetcar incidents that impacted the scheduled bus service in 2015. To better understand the system response time, this study breaks it into three major components as illustrated in Figure 2. The first component is the Initial Response Time, which is the time it takes the TTC’s Route Management Department (Control Centre) from the incidents’ start time to react to incidents. This portion of time includes the incident reporting time to the Control Centre and the time it takes the Control Centre to call bus divisions placing a request for shuttle service. Indeed, transit agency internal communication efficiency and effectiveness is a crucial issue in responding successfully to service interruptions, which was highlighted by several transit agencies (11). The second component is the Bus Pull out Time, which is the time it takes the TTC’s bus divisions to unload and take buses off the scheduled service. The third component is Bus Deadhead time, which is the travel time of buses from their original routes to the location of shuttle service.
In this study, we also classify buses into three categories to better recognise the challenge of providing shuttle bus service. These categories include buses requested by the Control Centre, buses assigned by divisions, and buses that actually arrived to the shuttle service location and provided the required emergency service. The main reason for having these different types of buses is that not all requested buses by the Control Centre are normally provided by the bus divisions. Also, some incidents could be cleared before the assigned buses arrive at the shuttle service location. Thus, a Division response rate measure is developed to account for the number of buses assigned by divisions divided by the total number of buses requested by the Control Centre. Bus recovery time is the time it takes the buses to return to their scheduled service which includes the Bus Service Time on the shuttle service and Bus Retuning Time to original routes. A conceptual workflow cycle for a shuttle bus service implementation is shown in Figure 2.

Figure 2: Regular workflow cycle for a shuttle bus service

TTC’S PROTOCOLS AND CURRENT PRACTICE

The TTC employs specific protocols to initiate the emergency shuttle bus service. These protocols mainly exist to deal with subway service interruptions. The decisions on shuttle service deployment and number of assigned shuttle buses are based on the location of service interruption along the subway system (central, east end, west end), subway line (main subway lines, Scarborough Line, and Sheppard Line), day of week (weekday, weekends), time period
(AM, Midday, PM, etc.), number of subway affected stations (1-4 stations, 5-9 stations, 10+ stations) and the expected duration of subway interruption (1 to 30 minutes, 30+ minutes). Table 1 presents one example from these protocols. It shows the percentage and number of required buses to deal with subway system service interruptions along the main subway lines (i.e. (Yonge-University-Spadina Line and Bloor-Danforth Line). The protocol categorizes the incidents by the expected duration of delay and number of affected (or closed) subway stations, and it provides the required percentage of shuttle buses for each category according to the time period of the day. For example, up to 10% of the buses serving on scheduled bus routes could be retracted for deployment as shuttle buses, when a subway interruption is expected to last more than 30 minutes and affects more than 10 subway stations. This percentage of buses is retracted equally from all bus divisions, with no spatial consideration of the location of incident. As different divisions have different numbers of buses in regular service, the number of buses to be retracted from different divisions may vary so as to minimize the impact on divisions with small fleets. Generally, similar protocols can be found requiring all divisions to source buses for service interruptions along the main subway lines, except for a few exceptions, irrespective of the incident location. This may lead to low efficiency in some cases where shuttle buses have to travel a long distance if provided by a division which is not adjacent to the incident location.

Bus divisions are advised to retract buses from high frequency routes first. Trippers, which stand for the extra buses scheduled for peak hour service, are always the first candidates. However, other factors may affect the decision making such as bus driver’s schedule and route ridership. Out of courtesy, Transit Control’s supervisors normally call the driver of the following bus to advise them of pulling the bus ahead out of service to expect more than normal riders. In some unusual cases, shuttle buses can be taken directly from garages, if spare drivers are available to operate these buses. The TTC has no strict geographical boundaries for “central”, “east end” and “west end” locations and it is left to the Transit Control’s supervisors to determine which shuttle guidelines to follow. Therefore, for the purpose of our study we divide the subway system into four different sections based on location to better understand the spatial impacts of the shuttle service (Figure 1). In contrast to the subway system shuttle service protocols, the TTC has no well-defined protocols for the streetcar shuttle service, and the decisions for deploying such a service are made usually on an ad-hoc basis.

### Table 1: Number of required buses to be retracted for the shuttle service

<table>
<thead>
<tr>
<th>Expected incident time</th>
<th>+30 MINS</th>
<th>1 - 30 MINS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed subway stations</td>
<td>1-4</td>
<td>5-9</td>
</tr>
<tr>
<td>Percentage (%)</td>
<td>3.33%</td>
<td>6.66%</td>
</tr>
<tr>
<td>Time period for regular service</td>
<td>Number of buses</td>
<td>Number of required buses for the shuttle service</td>
</tr>
<tr>
<td>6:00 – 9:00</td>
<td>1325</td>
<td>44</td>
</tr>
<tr>
<td>9:00 – 15:00</td>
<td>881</td>
<td>29</td>
</tr>
<tr>
<td>15:00 – 19:00</td>
<td>1426</td>
<td>47</td>
</tr>
<tr>
<td>19:00 – 22:00</td>
<td>819</td>
<td>27</td>
</tr>
<tr>
<td>22:00 – 1:00</td>
<td>506</td>
<td>17</td>
</tr>
</tbody>
</table>

*Source: TTC’s Route Management Department*
OVERVIEW OF SUBWAY AND STREETCAR INCIDENTS

Number of Incidents and System Delay
In 2015, the TTC dispatched shuttle bus services in response to 924 and 144 incidents in the streetcar and subway networks, respectively. Averaging at about 2.5/0.4 incidents per day in the streetcar/subway system, these incidents caused a total daily delay of 216.7 and 34.4 minutes in the streetcar and subway systems, respectively (see Figure 3-A). Here, delay refers to the incident duration, which was calculated based on the incident clearance time minus the start time, as indicated by shuttle service reports. Nevertheless, a simple division suggests that the average delay per incident is 86.7 minute for streetcars and 86.0 minutes for subway, which are very close. These lengthy delays are expected, since the analyzed data come from the shuttle service reports which mainly deal with ‘Major’ incidents that triggered shuttle service deployment.

As expected, the TTC experienced more incidents per day on weekdays than weekends for the streetcar and subway systems (Figure 3-B). These incidents are not equally distributed over the different day periods for the subway system (Figure 3-C). More incidents occurred during the mid-day and evening periods, for both the subway and streetcars systems. Nevertheless, more delaying incidents occurred during the evening period for the streetcar system than the subway system. The south (or Central) section which lies within the downtown area had the lowest number of daily incidents (0.02 incidents per day) while the west section had the highest number of incidents (0.14 incidents per day). This indicates more major incidents occurring at the west section that required TTC to deploy the shuttle service. Also, this reflects the TTC’s used protocols of deploying less shuttle service along the south section where parallel streetcar service is available. It should be noted that some subway incidents were reported at the entire route or a portion of route, instead of at a stop level. Therefore, these incidents were removed from the spatial analysis because it was not possible to link them to a specific location along the subway lines. Figure 3-E illustrates a clear trend of more incidents and lengthier delays occurring during the winter season for both the streetcar and subway systems.

The Number of Requested and Assigned Buses
About 6500 buses were requested by the Control Centre to provide shuttle services in 2015, with an average of 23.1 and 3.5 buses per subway and streetcar incident, respectively (Figure 4-A). This is intuitive due to the more frequent subway services and higher capacity of subway trains (one subway train can carry up to 1100 passengers while one streetcar may only carry between 100-200 passengers). About 71% of the requested buses are assigned by bus divisions with a total of 17.1 and 2.3 buses per subway and streetcar incident, respectively. The breakdown of the number of requested and assigned buses by day of week and time of day (Figures 4-B and 4-C) depict similar patterns to those shown in the corresponding figures of the previous section. Nevertheless, the number of requested and assigned buses differ slightly according to the time of the day. A slightly higher division response rate during peak hours can be observed (Figure 3-C), with a low response rate during the evening time. This perhaps reflects the higher availability of trippers during the peak periods which could diverted for shuttle service.
Regarding the geographic location of the subway incidents (Figure 4-D), the results for west and north sections agree with previous section too, showing that more buses are requested and assigned due to incidents. The south section requires few buses compared to other sections. This is related, as discussed above, to the TTC’s used protocols that provide less number of buses at this central section due the availability of parallel regular service. Also, this can be attributed to the fact that incidents at this section are normally cleared faster than other sections (as discussed in the Recovery Time section of the paper).

**Figure 3:** A- Daily incidents and total daily delay by mode, B- Daily subway incidents by weekday vs weekend, C- Daily incidents and average delay by time period, D- Daily subway incidents by location, and E- Daily incidents and total daily delay by month
Figure 4: A- Buses requested and assigned per incident by mode, B- Daily buses requested and assigned by weekday vs. weekend, C- Daily buses requested and assigned by time period, D- Daily buses requested and assigned by location (for the subway system), E- Daily buses requested and assigned by month, and F- Daily shuttle bus service analysis for February 2015
Figure 4-E gives the year’s profile of the number of buses requested and assigned per month, which agree with number of incidents in Figure 3-E. The response rate, however, does not have a clear trend, and February shows an overall low response rate, despite having the greatest number of incidents and requested buses. Therefore, a new figure was generated to explore the daily trends during this month (Figure 4-F). As seen in the figure, an inconsistent response rate can be observed over the days of the month. This may highlight the need for more consistent policies for bus assignment.

To summarize, several temporal, monthly and spatial trends in the number of incidents and their total delays can be observed across the subway and streetcar systems. The TTC’s protocols have been used to source the requested number of buses but monthly variations have been observed, suggesting a thorough review of applying the used protocols may be in order. There may be a need for more flexible protocols that enhance the system capacity of sourcing buses during the winter season while relaxing these protocols during the other less demanding seasons, such as summer.

**IMPACTED BUS ROUTES**

In 2015, an average of 1.25 buses per route and incident were retracted from 82 buses routes, with a standard deviation of 0.3 buses. These routes represented a total of 65% of TTC’s bus routes in regular service. The analysis of 4,568 shuttle buses used in 900 incidents is presented in this section. Figure 5-A shows that not all buses retracted from regular routes were fully deployed to the target shuttle service location, due to some incidents getting cleared before the shuttle bus arrival. Around 88% (5.2/5.9) and 85% (5.8/6.8) of the assigned buses were actually utilized as a shuttle service for the streetcar and subway system, respectively. Some buses are deployed from remote routes which may explain the less than perfect utilization rate. In addition, the higher percentage of utilization for the streetcar system reflects its shorter response time (discussed in the following section).

As shown in Figure 5-B, a percentage of buses were dispatched from garages as opposed to scheduled route services. However, this percentage varies by the time period of day, with the smallest parentage of buses dispatched from garages during the morning peak hour (14%) and the evening period (15%), while the largest during the midday period (22%) and the afternoon peak (23%). This is expected and highlight the problem of sourcing buses during some periods of the day due to the availability of spare drivers, which has been discussed in the literature (11). In order to get a better idea about the impacts of retracting buses from regular bus routes, the following discussion focuses on the top 20 bus routes from which shuttle buses were sourced most frequently. From these 20 routes, around 2,000 shuttle buses were extracted in 2015 (Figure 5-C), ranging from 53 to 209 buses per route. The figure also shows the daily ridership per route in thousands, which is a reflection of the route offered capacity and headway. The routes daily ridership ranges from 6,400 to 45,700 riders per day. The figure shows that the number of assigned buses per route is not always proportionate to its ridership level. On average, about 1.5 buses were retracted from each bus route during incident days (Figure 5-D), despite differences in ridership levels. This practice may have considerable impacts on the users of low frequency bus routes. The increase in users’ waiting and travel times along the routes would likely have
negative impacts on users’ perceptions and loyalty (16). In order to better understand the impacts of retracting buses from scheduled route service on the performance and users of those routes, a separate study is recommended.

Figure 5: A- Daily assigned and in-shuttle buses by mode, B- Daily buses retracted from scheduled service and garages by time period, C- Top 20 bus routes that supplied buses for shuttle service in 2015, and D- Buses retracted from scheduled service on the incident days.
**RESPONSE TIME**

The response time is analyzed by mode, weekday vs. weekend, time period, month and location for a total of 3,293 shuttle buses that covered 700 incidents. As seen in Figure 6-A, the total response time to subway incidents is longer than the response time to streetcar incidents for all three time components, with an average total time of 37.5 and 26.2 minutes per bus for the subway and streetcar systems, respectively. These values are considerably shorter than the average response time reported for rail transit bus-bridging of 90 minutes for a case study in Australia (8). The difference between the subway and streetcar shuttle bus response time can be attributed to the fewer shuttle buses required per streetcar incident, the sources of which could be decided upon quickly (shorter initial response and pull out times) and deployed from nearby bus routes (shorter deadhead times) relative to subway incidents which are more complex and large-scale. The response time per bus on weekends is longer than weekdays (Figure 6-B). This may be due to the limited staff resources and reduced bus fleet in service on weekends which could limit shuttle bus options and delay the overall decision making process.

Figure 6-C indicates that the shuttle bus service is delivered more rapidly during peak hours, with an average response time of 27 minutes per bus, compared to an average of 34 minutes per bus during off-peak periods. This may be due to the availability of trippers in most routes during peak periods, offering rich and wide access to shuttle bus options. The shorter deadhead times in peak periods, shown in the figure, supports this proposition. As expected, longer response time can be observed during the winter months and into April (Figure 6-D) mainly due to increases in pull out and deadhead times, reflecting the negative impacts of weather conditions on bus service operations (17). In contrast, the initial response time does not vary much by season.

Figure 6-E breaks down spatially the response time according to the location along the subway system and bus division. This figure was constructed using a total of 71 subway incidents that caused the closure of 5 or more subway stations and required all bus divisions to provide a similar percentage of buses (see Table 1). As seen in the figure, some buses from some bus divisions can take an enormous amount of time to provide such a shuttle service. For instance, for incidents in the north section of the subway, the average response time of buses deployed from routes belonging to the Queensway division (which a southern-eastern bus division) was 78 minutes while the average delay for the subway system was around 87 minutes. There is a large probability that an incident in the north section could be cleared before shuttle buses arrive from the Queensway division. Longer response times inevitably increase the total waiting time for users that are stuck and frustrated while waiting for shuttle service, and they also increase the overall “clearance” time of incidents. As indicated previously, the southern (or central) section is a special case. Due to the ubiquity of transit service in that part of the city, the TTC seems to request and assign less shuttle buses in response to subway incidents there (Figure 4-D). These buses are normally sourced from nearby routes, resulting in less response time (Figure 6-E). It is noteworthy that shuttle buses were not assigned from some divisions when the subway incidents were in the southern section.
RECOVERY TIME FOR REGULAR BUS ROUTES

Recovery time, a key element of the overall shuttle service process, should be examined carefully by transit agencies, since clearing incidents swiftly will mean quicker return of shuttle buses to their original routes. Recovery time includes two components, namely service time on the shuttle service and retuning time to the scheduled service after the incident is cleared. A total of 2,859 shuttle bus runs for 650 incidents were analyzed in this section. Interestingly, Figure 7-A and B show that the returning time was relatively longer than the response time in the previous section. This might be because many shuttle buses did not return immediately after the incidents were cleared, since they probably had to transport passengers on board to the shuttle route terminal point before they could go back to their original routes. However, a study that investigates the average speed, ridership and driver’s behaviour using the actual bus operational (AVL) data is recommended to identify the causes of this increase in retuning time. Indeed, understanding the reasons behind that would help in implementing actions to reduce the returning time. Similar patterns can be observed regarding the average recovery time per bus by weekdays vs. weekends, by time period, and by month, relative to the system response time, with longer retuning times being observed. The higher efficiency observed for weekdays and for peak hours is also shown in the incident recovery time, highlighting the need to further improve recovery times for incidents on non-peak periods and weekends.
Figure 6: A- Average bus response time by mode, B- Average bus response time by weekday vs. weekend, C- Average bus response time by time period, D- Average bus response time by months, and E. Average bus response time by location in subway network and division

Figure 7: A- Average recovery time by mode, B- Average recovery time by weekday vs. weekend, C- Average recovery time by time period, and D- Average recovery time per bus over the months of year
INCIDENT ANALYSIS

This section presents a summary of the most frequent incidents that occurred in Toronto’s streetcar and subway networks in 2015. The analysis reports on the average incident delay, number of buses requested and assigned, and response time by incident type. Data on 2,034 shuttle buses were analyzed in this section. Table 2-A indicates that over 30% of major streetcar incidents were caused by surface traffic accidents. However, these incidents were cleared rapidly, resulting in shorter delays (53.6 min per incident) and requiring fewer shuttle buses (1.8 buses per incident) than the average values for all major streetcar incidents (87 minutes and 2.3 buses, respectively). On the other hand, the overhead wire problem, resulting in a 2.5-hour delay (152 minutes) on average, led to the largest number of shuttle buses utilized. However, cold weather (including snow conditions) was to blame for the highest rate of delay for streetcars, with an average delay of more than 7 hours per incident. To give an example, on January 7<sup>th</sup> 2015, a large segment of streetcar Route 506 was down from 11:06 AM to 7:43 PM due to cold weather and snow on the ground. In response to that, the TTC requested 20 shuttle buses, 17 of which arrived and served on the temporary shuttle route. Such long service delays could undoubtedly have substantial impacts on the perception of passengers, both streetcar users travelling on the shuttle service and riders of bus routes from which shuttle buses were deployed. This is particularly important in the winter season, where passengers are more sensitive to any increase in their outdoor times including their waiting and walking times (8). Table 2-B shows that power problems, which is often related to cold weather and system level failures, led to the longest delay in the subway system. Fire, smoke and burning odour was the most frequent subway incident type, but each incident was cleared swiftly for most of the cases.

Table 2: Five most frequent reasons for streetcar and subway incidents

<table>
<thead>
<tr>
<th>Reason</th>
<th>Incidents</th>
<th>Buses Requested</th>
<th>Buses Assigned</th>
<th>Average Response Time (min)</th>
<th>Average Clear Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Streetcar incidents</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auto/Pedestrian Accident</td>
<td>372</td>
<td>1.9</td>
<td>1.8</td>
<td>21.7</td>
<td>53.6</td>
</tr>
<tr>
<td>Disabled Streetcar</td>
<td>145</td>
<td>1.9</td>
<td>1.7</td>
<td>18.0</td>
<td>52.9</td>
</tr>
<tr>
<td>Cold Weather</td>
<td>83</td>
<td>2.6</td>
<td>2.3</td>
<td>61.3</td>
<td>453.6</td>
</tr>
<tr>
<td>Overhead Wire Down</td>
<td>30</td>
<td>3</td>
<td>2.4</td>
<td>31.6</td>
<td>152.8</td>
</tr>
<tr>
<td>Working Fire/Fire on Streetcars</td>
<td>15</td>
<td>2.2</td>
<td>2</td>
<td>36.8</td>
<td>85.2</td>
</tr>
<tr>
<td>Medical Emergency</td>
<td>11</td>
<td>1.9</td>
<td>1.7</td>
<td>16.8</td>
<td>21.8</td>
</tr>
<tr>
<td><strong>B. Subway incidents</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fire, Smoke or Burning Odour</td>
<td>32</td>
<td>6.3</td>
<td>6.2</td>
<td>31.5</td>
<td>60.8</td>
</tr>
<tr>
<td>Power Problem</td>
<td>14</td>
<td>12.5</td>
<td>9.9</td>
<td>52.5</td>
<td>307.2</td>
</tr>
<tr>
<td>Suicides on the Subway Tracks</td>
<td>12</td>
<td>9.6</td>
<td>9.4</td>
<td>40.1</td>
<td>111.8</td>
</tr>
<tr>
<td>Unauthorized at Track Level</td>
<td>10</td>
<td>6.3</td>
<td>5.6</td>
<td>23.3</td>
<td>51.8</td>
</tr>
<tr>
<td>Medical Emergency</td>
<td>10</td>
<td>6.7</td>
<td>7.5</td>
<td>44.6</td>
<td>111</td>
</tr>
<tr>
<td>Cold Weather</td>
<td>7</td>
<td>5</td>
<td>4.7</td>
<td>20.8</td>
<td>41.6</td>
</tr>
</tbody>
</table>
CONCLUSIONS AND RECOMMENDATIONS

Transit agencies are constantly faced with the challenges of managing disrupted transit service, which often requires utilizing additional resources and diverting existing ones from one location to another in an effort to minimize user discomfort and delays. The primary aim of this study was to explore in more detail one of the common disruption management strategies, namely bus bridging, which transit agencies employ in response to major service interruptions in their urban rail systems. This strategy involves retracting buses from existing scheduled services to offer an emergency shuttle service to compensate for rail service interruptions. This strategy has been used widely by transit agencies, with no thorough analysis of its diverse aspects and impacts. Thus, a major contribution of this research is its examination of the different aspects and impacts of employing this strategy using the large-case multimodal transit system of Toronto as a case study, which provides a unique opportunity to understand the effects of not only subway service interruptions but also streetcar interruptions. In order to do that, the paper explored the magnitude and impacts of emergency shuttle service deployment, as well as the system response and recovery times using detailed subway and streetcar shuttle service reports collected in 2015 by the TTC. Such a dataset, which is usually hard to access, provided very detailed information regarding the bus service retracting problem at the system level.

The paper shows considerable fluctuations in the number of incidents, number of requested and assigned buses as well as the system’s response and recovery times. These fluctuations are not only within mode, but also across the two modes analyzed in this paper (i.e., subway and streetcar), highlighting the challenge of managing disruption along the two systems. Furthermore, this research highlights the need of more flexible protocols that recognize the variations in system response time over the year, especially during the winter season. In fact, additional categories, or different protocols, are needed to be added to previous emergency response frameworks proposed in the literature as well as to the one used by the TTC, which are based only on disruption characteristics of duration, cause, time, and location (11). Furthermore, a study that develops new protocols for an integrated approach to retracting buses from regular routes in combination with reserved spare buses (and drivers) according to the city context is recommended. This would be important for some cities that experience special weather conditions, such as the City of Toronto. Thus, providing new protocols that facilitate faster response and recovery times during the winter months is suggested, since passengers during this time of year are more sensitive to any increase in their outdoor times including their waiting and walking times (18).

One of the contributions of this study is providing a detailed framework to understand different aspects of the shuttle bus service workflow. For example, this study broke down the system response time into three major components: Initial Response Time, Bus Pull out Time and Bus Deadhead time, while breaking the bus system recovery time into Bus Service Time on the shuttle service and Bus Retuning Time to original routes. It also classified buses into three categories to better examine the challenge of providing shuttle bus service, including buses requested by the control centre, buses assigned by divisions, and buses that actually arrived to the shuttle service location and provided the required emergency service. Also it developed Division Response Rate measure to account for the number of assigned vs. requested buses by divisions. This framework could be adapted for other transit agencies to compare the relative performance across agencies, monitor trends over time for individual agencies, and understand the impacts of new response management strategies.
Another policy implication of this study is the need to employ a specific protocol to initiate the emergency shuttle bus service by sourcing buses from scheduled service. An effective communication plan is required in order to alert promptly the passengers of the affected bus routes about the removal of several trips. This is an important issue since, as indicated in the literature, passengers overestimate their waiting time compared to the actual wait time when it is imposed by others (e.g., transit system) whereas they accurately estimate their waiting time when they themselves choose to wait (11). Thus, by informing passengers, through social media for example or by using bus stop variable message signs, about the removal of some trips and the reason behind that, that would help reduce the negative impact of service cancellation on users’ perception.

While the challenge of sourcing the adequate number of buses from the existing scheduled service is well-understood, another policy implication of this paper is to reconsider the number of buses taken from certain divisions (or locations). For example, instead of having a fixed percentage of buses that should be sourced from a division, new criteria that weight the percentage of buses according to the division’s average response and recovery times can be explored. In other words, fewer buses should be retracted from far locations, since these buses would take more response and recovery times, leading to longer cancelled times for their users than users of nearby routes. Thus, providing more flexibility in the percentage of required buses from each division according to its location and incident location will mean a higher overall system efficiency. Finally, this study conducted only a limited analysis of the impacts of bus bridging on the source bus routes providing shuttle bus resources. A more thorough investigation of the effects on route performance (both speed and reliability) and user delays is warranted in a separate study, using actual operational data from automatic vehicle location (AVL) and automatic passenger counting (APC) systems.

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