A SURVEY-BASED APPROACH TO UNDERSTANDING RESILIENCE
IMPLICATIONS OF DISRUPTION TO TRANSIT OPERATION

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ABSTRACT

Recent surge in academic and industry-related interest in transit resilience can be partly attributed to the occurrence and impact of disruptive events like Hurricane Sandy, Hurricane Katrina and the July 2005 London bombings. Such events have served not only to highlight the vulnerabilities of our public transit systems to natural disasters, targeted attacks and, broadly speaking, unexpected conditions, but also to garner interest in resilience-based approaches to mitigate and recover from the damage caused. In spite of recent gains in developing better understanding of transit resilience, substantial gaps remain in establishing a clear relationship between resilience and transit planning. This relationship is explored through means of an expert survey, with survey responses used to identify disruptive events to transit operation, critical transit infrastructure, disruption mitigation strategies, and the future relevance of transit resilience. The survey was administered to various individuals in academia and in the transportation consulting and transit planning and operation industries. Responses were received from experts from over 15 Canadian institutions and agencies. Survey findings indicate a common industry interest in the implications of enhancing resilience, and a shared regard of resilience as not merely a relevant topic of consideration in planning and operating future transit systems, but also a critical subject of focus

Keywords: Resilience, Transit resilience, Public transit, Expert survey, Disruption management

1. INTRODUCTION

Recent surge in popular, academic and industry-related interest in resilience can be partly attributed to the occurrence and impact of disruptive events like Hurricane Sandy, Hurricane Katrina and the July 2005 London bombings. Such events have served not only to highlight the vulnerabilities of our urban environments to natural disasters, targeted attacks and, broadly speaking, unexpected conditions, but also to garner interest in resilience-based approaches to mitigate and recover from the damage caused. Given the visibility and publicity associated with large disruptions, the resilience implications of extreme events tend to receive more attention in academic discourse, leaving the implications of smaller disruptions less studied. However, focus on these smaller disruptions is warranted, given their higher frequency and because the total impact of numerous such disruptions can equal that of a single large disruption.

Public transit systems are subject to the impact of a wide spectrum of events ranging from extreme weather events to day-to-day operational breakdowns. The threats posed by these disruptions, when considered against a backdrop of global trends of increased transit use and deteriorating state of transportation infrastructure in many regions worldwide, indicate a pressing need for proper consideration of resilience in transit system planning, design, management and operation. While this need is acknowledged by many in the public transit field, the incorporation of
resilience in practice is, at best, nascent. Strategies for enhancing transit resilience, if implemented, are typically ad-hoc and reactive. Moreover, an understanding of methods for systematically improving transit resilience remains fragmented; few transit agencies and operators possess coordinated plans for building transit resilience and the sparse existing research related to transit resilience tends to focus on implications of severe disruptions.

This study explores the concept of transit resilience and measures the interest and understanding of the transit community of transit resilience. Attempts are made to define, through an expert survey, what constitutes improving resilience of transit operation in the face of disruptions. Ultimately, this study contributes to the transportation resilience literature by establishing a baseline summary of expert knowledge on transit resilience.

2. ORIGINS OF RESILIENCE

The concept of resilience is applied across numerous contexts in the literature; a cursory review illustrates the range in which resilience is defined and measured. At a high-level, however, the modern notion of resilience can be generalized with respect to two schools of thought.

The first school of thought, drawing from studies conducted by ecologist C.S. Holling in the 1970s, describes resilience as “the ability of … systems to absorb changes … [and] still persist” (Holling 1973). Resilience is measured by “the magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control behaviour” (Holling 1996). This view of resilience emphasizes the uncertain, non-linear aspects of a complex system, and presumes the existence of multiple stable states or regimes that a system may flip between. This view is termed ‘ecological resilience’. The second school of thought is based in the work of ecologist S.L. Pimm (Pimm 1984). Pimm presents a more traditional definition of resilience, one based on principles studied in the fields of physics and engineering. This definition “concentrates on stability near an equilibrium steady state” and is measured as the “speed of return to the equilibrium”. This view is thus termed ‘engineering resilience’ (Holling 1996). Ecological and engineering resilience serve as the bases for many other context-specific interpretations of the concept. A survey of resilience definitions from various disciplinary perspectives is presented in Table 1.

<table>
<thead>
<tr>
<th>Source</th>
<th>Discipline</th>
<th>Proposed Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bruneau et al., 2003</td>
<td>Earthquake engineering</td>
<td>The ability of a system to reduce the chances of a shock, to absorb such a shock if it occurs (abrupt reduction of performance) and to recover quickly after a shock (re-establish normal performance)</td>
</tr>
<tr>
<td>Foster, 1997</td>
<td>General</td>
<td>The capacity of a system to absorb shocks gracefully</td>
</tr>
<tr>
<td>Francis et al., 2014</td>
<td>Reliability &amp; safety engineering</td>
<td>The endowed or enriched ability of a system to anticipate and absorb potential disruptions, develop adaptive means to accommodate changes within or around the system and establish response behaviours aimed at either building the capacity to withstand the disruption or recover as quickly as possible after an impact</td>
</tr>
<tr>
<td>Holling, 1973</td>
<td>Ecology</td>
<td>The ability of a system to absorb changes and still persist</td>
</tr>
<tr>
<td>Pimm, 1984</td>
<td>Ecology</td>
<td>The speed of (or time for) a system’s return to equilibrium</td>
</tr>
</tbody>
</table>

3. RESILIENCE IN TRANSPORTATION NETWORKS

Definitions of the resilience of a transportation network have been given under various contexts, though all relate to the function of a network in facilitating accessibility and mobility. A sample of definitions present in literature is provided in Table 2.
Table 2: Summary of Resilience Definitions in Transportation Specific Contexts

<table>
<thead>
<tr>
<th>Source</th>
<th>Proposed Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battelle, 2007</td>
<td>A characteristic that enables the system to compensate for losses and allows the system to function even when infrastructure is damaged or destroyed</td>
</tr>
<tr>
<td>Freckleton et al., 2012</td>
<td>The ability of a transportation network to absorb disruptive events gracefully and return itself to a level of service equal to or greater than the pre-disruption level of service within a reasonable time frame</td>
</tr>
<tr>
<td>Urena Serulle et al., 2011</td>
<td>The ability of a system to maintain its demonstrated level of service or to restore itself to that level of service in a specified time frame</td>
</tr>
<tr>
<td>Litman, 2012</td>
<td>The ability of a system to accommodate variable and unexpected conditions without catastrophic failure</td>
</tr>
</tbody>
</table>

3.1 Transit Resilience in Existing Systems

In practice, strategies for enhancing the resilience of a transit system are often applied in conjunction with those intended to enhance the sustainability of a system. Resilience strategies are often presented as related to, or even interchangeable with, strategies for supporting environmental sustainability and climate change preparedness (Davoudi et al. 2012, Stumpp 2013). In planning, few transit agencies possess comprehensive resilience plans or policy documents which explicitly outline an agency’s approach to considering and improving system resilience. Many agencies regularly apply strategies that increase a system’s resilience; however, most strategies are applied singly and not as part of an adopted comprehensive resilience-building approach. Furthermore, the implementation of these strategies tends often to be ad-hoc, as reactive actions. Instituting a bus bridging scheme following closure of subway services is an example of one such ad-hoc strategy.

3.2 Reliability and Resilience

Parallel to growing interest in transit resilience is a growing interest in service reliability. Given the understanding that improvements in service running time and running time variability increases rider satisfaction levels (Boyle 2006, Hensher et al. 2003, Hollander 2003), many have investigated the development of metrics and methods for measuring transit reliability and benchmarking best practices for enhancing service reliability. Many such studies have focused on the use of Automatic Passenger Counter (APC) and Automatic Vehicle Location (AVL) data to measure on-time performance and schedule adherence of transit service (Hammerle 2005, Camus et al. 2006, Carrasco 2011, Cevallos et al. 2011, Diab et al. 2013, Gittens et al. 2015). APC and AVL systems offer quality real-time information that can inform service planning and provide more reliable service (Hammerle 2005). Service delivery quality has also been measured using elapsed travel time collected by Automated Fare Collection (AFC) (Chan 2007). Overall, reliability metrics provide a robust measure for transit operation, especially from the operator’s perspective, but fall short of explicitly capturing the concept of transit resilience; further, they are typically stop- or line-specific and lack the representation of network-wide performance.

Evidently, a gap exists in the understanding of transit resilience. Considerable efforts are needed to establish the value of applying the concept of transit resilience in practice to proactively improve transit systems. This study helps define the key attributes of transit resilience through an expert survey, enriching the overall understanding of transit resilience.

4. CONSULTATION APPROACH

This study designed and conducted an expert survey for capturing the attitudes and opinions of experts in the public transit and transportation planning industry. Expert surveys are often characterized by their use of open-ended questions in obtaining attitudinal information. The questionnaire for this study was designed to be open-ended, so that attitudes towards resilience could be captured and, consequently, differences in attitude between groups also indirectly captured. A summary of the questions that were included in the survey questionnaire is presented in Table 3. Survey responses were accepted for a period of four weeks in March 2014 following distribution of the survey to initial respondents.
An online questionnaire was used to collect responses. A non-probability sampling technique, snowball sampling, was used against a sampling frame based on four expert groups: academia, consulting, governmental transportation/planning agency and transit company. The rationale for defining the expert groups was related to the role of an individual in the transportation industry. Individuals from a list of academic institutions, consulting firms, transit agencies, and governmental planning agencies were contacted as initial respondents and invited to nominate other potential respondents from their contact networks.

Table 3: Questions included in the expert survey questionnaire

<table>
<thead>
<tr>
<th>Question</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>Where are you from? - Organisation</td>
</tr>
<tr>
<td>1b</td>
<td>Where are you from? - Occupation</td>
</tr>
<tr>
<td>1c</td>
<td>Where are you from? - City/Town</td>
</tr>
<tr>
<td>1d</td>
<td>Where are you from? - Country</td>
</tr>
<tr>
<td>2</td>
<td>Which of the following groups do you feel you belong to most? (Choice of ‘academia’, ‘consulting’, ‘governmental transportation/planning agency’ and ‘transit company’)</td>
</tr>
<tr>
<td>3</td>
<td>Are you familiar with the concept of resilience? (Choice of ‘not at all familiar’, ‘slightly familiar’, ‘somewhat familiar’, ‘moderately familiar’ and ‘extremely familiar’)</td>
</tr>
<tr>
<td>4</td>
<td>Through what experiences and sources have you become familiar with resilience?</td>
</tr>
<tr>
<td>5</td>
<td>Provide your description of resilience. Feel free to use examples, short phrases or related terms.</td>
</tr>
<tr>
<td>6</td>
<td>Rank how well the resilience descriptions below correspond with your own description of resilience. Rank 1 for most related to 6 for least related. (See Table 1 for presented descriptions)</td>
</tr>
<tr>
<td>7</td>
<td>Provide your description of transportation resilience. Feel free to use examples, short phrases or related terms.</td>
</tr>
<tr>
<td>8</td>
<td>Rank how these presented descriptions, from 1 for most related to 5 for least related, correspond with your own description of transportation resilience. (See Table 2 for presented descriptions)</td>
</tr>
<tr>
<td>9</td>
<td>Consider the infrastructure components of a transit system. Consider the range in complexity of infrastructure components associated with different types of transit service. Of these infrastructure components, which do you feel are most critical to the operation of a transit line or system?</td>
</tr>
<tr>
<td>10</td>
<td>List some infrastructure components which you feel can be easily enhanced with respect to resilience. Also list strategies which could be used to enhance the resilience of these components.</td>
</tr>
<tr>
<td>11</td>
<td>Consider the small to medium, daily or relatively frequently disruptions which affect a transit system. List below those which come to mind.</td>
</tr>
<tr>
<td>12</td>
<td>With respect to operational dimensions of a transit system, how do you feel the operational impacts of a disruption can be classified?</td>
</tr>
<tr>
<td>13</td>
<td>What are your experiences with transit resilience? As related to your role in your sector, what strategies for approaching and enhancing transit resilience have you come across?</td>
</tr>
<tr>
<td>14</td>
<td>From your experience, provide an example(s) of a time when you felt that the resilience, or lack of resilience, of a system influenced system operation.</td>
</tr>
<tr>
<td>15</td>
<td>As an individual in your sector, how do you regard the role of resilience planning in the design and improvement of future transit systems?</td>
</tr>
<tr>
<td>16</td>
<td>If you have any further questions regarding transit resilience and this study, or any general comments, please free to leave them in the box below. These suggestions will be helpful for future research purposes.</td>
</tr>
<tr>
<td>17</td>
<td>If you would like to receive a synthesis of the responses from all survey participants when it is available, please enter below the email address to which you would like it to be sent.</td>
</tr>
</tbody>
</table>

5. SURVEY RESULTS AND DISCUSSION

Responses were received over a period of four weeks in March 2014. A total of 106 survey responses were received, of which approximately half were considered complete. Since open-ended questions in expert surveys are intended to accurately capture a range of views and opinions, a systematic approach to interpreting survey responses was adopted. In our study, this approach enabled a complete analysis of all available data through consideration of both complete and partial responses.
5.1 Summary of Respondent Characteristics

The survey received responses from individuals from a range of organisations including both public and private organisations. The majority of reported occupations were related to the transportation and public transit industry. Respondents reported representing the following agencies and organisations:

- **Academia**
  - Monash University
  - TU Delft
  - University of Amsterdam
  - University of British Columbia
  - University of Catania
  - University of Illinois at Chicago
  - University of Toronto
  - University of Waterloo

- **Consulting**
  - Arup
  - HDR
  - IBI Group
  - Parsons Brinckerhoff
  - SNC-Lavalin
  - Urban Systems

- **Governmental transportation/planning agency**
  - City of Kelowna
  - City of Kelowna & Central Okanagan Partnership
  - City of Ottawa
  - City of Surrey
  - City of Toronto
  - Metrolinx
  - Ministère des Transports du Québec
  - Ministry of Transportation, Ontario
  - Region of Peel
  - Regulatory Agency (Fortaleza)
  - Town of New Tecumseth Engineering Department

- **Transit company**
  - BART
  - CITSO (Quebec)
  - Durham Region Transit
  - Greater Sudbury Transit
  - Metro Transit (Halifax)
  - St. Albert Transit
  - Transport for London

The geographic distribution of responses was broad with responses from individuals in 35 cities over 12 countries received; these cities and their transit systems range drastically in size. A greater share of Canadian responses was observed, which can be partly attributed to the bias associated with using a primarily Canadian sample frame for contacting respondents. The target population for the survey was comprised of four expert groups. The majority of respondents - almost 45% - identified themselves as belonging to the consulting industry. Approximately 29% of respondents reported belonging to the academia group, about 18% reported belonging to a government agency and 8% reported belonging to a transit agency or company.

Most respondents identified themselves as being somewhat or moderately familiar with the concept of resilience. Given that the conducted survey was intended to be an expert survey, such a distribution of familiarity is appropriate. The majority of respondents reported gaining familiarity with resilience through at least one education and academic experience, one work experience or a combination of both education and work. Around 31% of respondents reported becoming familiar with resilience through education and academic experiences only. Similarly, about 20% of respondents reported gaining familiarity with resilience through work experiences only.

5.2 Definitions of Transportation Resilience

Respondents were requested to present descriptions of definitions of transportation resilience. The descriptions can be classified in to 11 categories:

- Adaptability
- Mitigation of impact
- Preparedness
- Reliability
- Return to equilibrium
- Robustness
- Ability to learn
- Capacity to respond
The ability of a system to maintain function while disrupted was mentioned most often by respondents, with approximately one-quarter of respondents relating continued provision of service to transportation resilience. About 18% of respondents included descriptions of a transportation system’s ability to recover and restore function in their definitions of transportation resilience. About 16% of respondents characterised transportation resilience as a form of system adaptability, while 11% of respondents described the robustness of a transportation system as related to the resilience of a transportation system.

5.3 Resilience of Transit Infrastructure and System Assets

Respondents were instructed to identify infrastructure components most critical to the operation of a transit line or system. Infrastructure associated with transit right-of-way and its maintenance and with the fleet of a system were most frequently identified as most critical to the operation of a transit line. Almost a sixth of responses discussed aspects of transit right-of-way, while about 14% of responses included mention of system rolling stock. These two components were considered necessary at a bare minimum to operate a transit service, even if at a degraded level of service, assuming staff and adequate power (for electric rail systems) are available. Other identified components such as information systems, signals, communication, and controls act as support systems to these ‘central’ components and help in improving the level of service of the system, incrementally, after a disruptive event.

5.3.1 Critical Transit Infrastructure Assets

Right-of-way (ROW) infrastructure broadly refers to any physical infrastructure required for provision of transit service along a route. Respondents often referred to the availability of tracks, roads, tunnels, bridges, and other pieces of general transportation infrastructure when describing the critical nature of ROW infrastructure. Most respondents agreed that infrastructure supporting the right-of-way for transit is a critical component to maintain operation of a transit service, especially for rail-based exclusive ROW transit systems. Buses have more flexibility in route planning and therefore are less susceptible to non-availability of regular routes due to closures.

Fleet refers to the availability of functioning transit vehicles, including rolling stock and buses. Redundancy in fleet, including streetcars, trains and especially buses, is considered important to maintain the operation of a transit system. Even if buses in mixed traffic provide a potentially lower level of service when replacing suspended rapid transit operations, their inherent flexibility during route planning and immediate dispatch renders them an attractive option. Fleet yards like train sheds and bus depots store large number of transit vehicles. Therefore, ‘events’ that incapacitate the ability of these centres to dispatch vehicles could significantly affect system-wide transit service operations. Specifically for surface transit routes, bus priority and bus only lanes were considered important to expedite movement in a congested environment due to a disruptive event on the transit network.

The infrastructure required to provide adequate and timely information from the transit agency to the users of the transit system about current/future planned/unplanned disruptions on the transit system and the subsequent impacts on schedule and travel time, was identified as another critical component to operate a resilient transit service. In the event of a service disruption, availability of real time information display/announcements and guidelines on alternate travel options help mitigate the impact of the disruption, and increases the comfort of transit users. The infrastructure required to communicate within the transit agency, from the control centre to dispatch, and transit operators, was considered another critical component to facilitate a quick and organized response to disruptions. It is crucial for the development of alternative routes, and it also enables efficient dissemination of ‘information’ to transit users. It helps reinforce the confidence of transit users in the agency that the disruption is being readily addressed.

Stations, including rail and bus stations and especially ‘nodal’ stations at the intersection of two or more transit service lines, were identified as a significant component in providing transit service as well. Disruptions at busy interchange stations during peak travel periods, for instance, can have trickle down effects on operations for multiple transit lines thereby increasing the range of transit users affected by delays.

Maintenance of a system command centre that leads, directs and monitors the mitigation measures implemented in the event of disruption was considered crucial to ensure the integrity of control systems/centre to facilitate efficient
execution of the disruption management strategy adopted. Control systems refer to systems that monitor the operation of the overall transit system. Although signals can be characterised as part of the ROW infrastructure, they were frequently identified as a separate item of critical infrastructure. Signalling systems, especially the interlocking system for rails, were considered important to maintain an acceptable service for rail systems.

5.4 Spectrum of Disruptive Events

Respondents were asked to provide examples of small to medium, daily or relatively frequent disruptions. In interpreting responses provided, it is unclear whether respondents listed all disruptions, including those perceived as large, severe disruptions, or only those perceived as small to medium, and more frequently occurring, as instructed. Based on responses received the disruptions are classified into the following categories:

- Passenger-related
- Failure of infrastructure
- Congestion delay
- Weather-related
- Accidents
- Construction
- Signals
- Power
- Demand surge
- Other disruptions

Passenger-related disruptions were largely characterised as involving security and passenger safety concerns. Examples of such events include at-track injury, driver/employee assaults and other medical or police emergencies. Events associated with failure of infrastructure were those related to failure and malfunction of vehicles and rolling stock, track and signalling components, power systems, fare and payment systems, and passenger information systems. Congestion delay-related events were those associated with both expected and unexpected demand conditions. For instance, congestion during peak periods and congestion generated by demand surges due to incidents and special events were cited as examples of disruptive events. Weather-related disruptions included extreme storms and natural disasters, as well as less severe, yet disruptive, seasonal weather conditions. Disruptions caused by accidents referred to those associated with traffic incidents involving transit vehicles, and those not directly involving transit vehicles but influencing traffic conditions that impact transit operation. As a source of disruption, construction referred to both transit-related and other construction work, and road repairs which affect travel conditions. Failure or malfunction of signals, both track and road traffic signals, was cited as a disruptive event. Similarly, the failure and malfunction of power systems was cited as a disruption. Events associated with unexpected increases in demand, due to special events or incidents, were also identified as disruptive.

5.5 Strategies for Enhancing Transit Resilience

Based on the responses of survey respondents, strategies for enhancement of transit resilience are classified into the following categories:

- System Level Planning
  - Monitoring procedures for system performance and regular reviews of system vulnerabilities
  - System expansion to increase system capacity and add system redundancies
  - Application of modelling and forecasting in developing a better understanding of system vulnerabilities
  - Support of initiatives for establishing and supporting multimodal transportation networks and improving connections between transit and active transportation networks
  - Transit network designs which reduce vulnerability by minimising convergence of multiple transit lines or systems at a single point or node

- Operational Level Planning
  - Regular and proactive maintenance of fleet and ROW infrastructure
• Establishing transit priority schemes (priority lanes, queue jump lanes, signal priority)
• Establishing exclusive transit ROW or adding greater elements of ROW separation
• Provision of passenger information and real-time information
• Use and transfer of information within a transit system, specifically between operators and control centre
• Security presence for passenger safety and perception of increased passenger safety

• Emergency Standards
  • Emergency preparedness measures and protocols
  • Established protocols for implementation of operational ‘bandage’ and ad-hoc solutions (short-turning, bus-bridging, and active rerouting of services) following disruptions
  • Established protocols for weatherproofing pieces of transit infrastructure
  • Employee training for protocol during and following disruptive events

The most mentioned resilience enhancement strategy, included in almost 18% of responses, was the provision of system redundancy. The next most cited strategies were provision of passenger information and prioritization of passenger communication, provision of system flexibility, establishment and maintenance of transit ROW, mentioned by 10%, 8% and 7% of respondents, respectively. Respondents reported that the infrastructure needed to provide user information (17% of responses), maintain right-of-way (12%) and the fleet / rolling stock (14%) can be most easily enhanced with regards to resilience. Other enhancements recommended include improvements to network to provide alternate travel options, having sufficient redundant sources of power, better signalling and communication systems, management of transit staff, and bus/train station infrastructure.

5.5.1 Industry-based Commonalities in Familiarity with Resilience Enhancement Strategies

To investigate commonalities in industry experience with resilience enhancement strategies, responses listing familiarity with a specific enhancement strategy were cross-classified by reported role in industry (academia, consulting, governmental transportation and planning agency and transit company). As presented in Figure 1, knowledge of enhancement strategies related to information provision is shared by individuals in academia, consulting and governmental planning. Recognition of the relationship between providing system redundancies and increasing resilience is common in academia, consulting and governmental planning. Based on the responses received, it appears that individuals representing governmental transportation and planning agencies may be more familiar with operational strategies for enhancing resilience than individuals in academia and consulting; enhancement strategies related to conducting regular emergency preparedness drills and facilitating employee training were reported only by those at a governmental agency. Classification of enhancement strategies by a role in a transit company is not included in Figure 1, as the survey did not receive a sufficient number of responses from individuals belonging to the ‘transit company’ group.

<table>
<thead>
<tr>
<th>Resilience Enhancement Strategy</th>
<th>Role in Transit Industry</th>
<th>Academia</th>
<th>Consulting</th>
<th>Governmental transportation &amp; planning agency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information Provision</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real time travel information</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Passenger communication</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Operational Fixes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emergency preparedness drills</td>
<td>×</td>
<td>×</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Employee training</td>
<td>×</td>
<td>×</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Maintenance and monitoring procedures</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Schedule flexibility</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Operational ‘bandages’</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Transit ROW and transit priority schemes</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Weatherproofing/flood proofing initiatives</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Redundancy</td>
<td>✓</td>
<td>✓</td>
<td>×</td>
<td></td>
</tr>
</tbody>
</table>

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5.6 Relevance of Resilience in Future Transit Systems

Respondents were instructed to provide a personal anecdote about service disruptions or system deficiencies, as an indirect approach to identifying examples of system vulnerabilities and to establishing contexts in which resilience is especially needed. Reported service disruptions or system deficiencies can be generalized as related to the following conditions:

- Systems with aging infrastructure
- Systems which are large and complex
- Service suspension of higher-order systems
- During maintenance/system upgrades
- Demand surges on transit
- Lack of information
- Lack of passenger communication
- Staffing/shift problems
- ROW obstruction and/or delays due to congestion, incidents or construction
- Vehicle failure
- Extreme weather conditions

The responses received were broadly classified as related to the condition of and context surrounding a specific transit system and as related to the occurrence of a specific disruption. A system with aging infrastructure or a system which is particularly large and complex exists can be considered to exist, given surrounding context, in a state of elevated vulnerability. A system is also in a state of disruption if it experiences a demand surge or staffing problems.

Respondents were also asked to comment on their perception of the relevance of resilience in planning and operating future transit systems. The majority of respondents reported regarding the role of resilience planning as important or critical, indirectly indicating interest in considering resilience implications in planning and design. There appears to be little difference in this sentiment with respect to sector. Individuals from all four expert groups reported similar sentiments for the significance of resilience in transit systems.

6. CONCLUSIONS

This paper presented a survey-based approach to elicit expert attitudes and opinions on aspects of transit resilience, allowing the establishment of a baseline summary of knowledge related to defining transit resilience, and developing high level strategies to enhance transit resilience. Survey findings indicate a common industry interest in the implications of enhancing resilience, and a shared regard of resilience as not just a relevant topic of consideration in planning, operating and designing future transit systems, but a critical subject of focus. Transit ROW, system fleet and the provision of information to users are identified by most respondents as being infrastructure components most critical to maintaining transit operation and most easily enhanced with respect to resilience. By indirect extension, transit ROW, system fleet and user information systems or protocols represent infrastructure components which are of particular significance in developing transit resilience enhancement strategies.

Further research on the relationship between transit resilience and the size or complexity of a transit system would serve as an appropriate complement to this investigation. Further attempts related to eliciting the opinions and expertise of individuals associated with transit agencies specifically would serve to supplement current findings. Finally, a more quantitative, model-based exploration of the relationship between system resilience and the occurrence of a disruption should be conducted. It is the authors’ hope that the expert knowledge collected in this study supports future investigation into the integration of resilience-sensitive approaches to transit operation and planning by researchers and practitioners alike.
ACKNOWLEDGEMENT

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