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Investigating the Impact of Public Transport Service Disruptions upon Passenger Travel Behaviour—Results from Krakow City

Arkadiusz Adam Drabicki [1,*], Md Faqhrul Islam [2] and Andrzej Szarata [1]

[1] Department of Transportation Systems, Cracow University of Technology, 31-155 Kraków, Poland; aszarata@pk.edu.pl
[2] Transport Research Institute, Edinburgh Napier University, Edinburgh EH10 5DT, UK; faqhrul.islam@gmail.com
* Correspondence: adrabicki@pk.edu.pl

Abstract: Public transport (PT) service disruptions are common and unexpected events which often result in major impediment to passengers' typical travel routines. However, attitudes and behavioural responses to unexpected PT disruptions are still not fully understood in state-of-the-art research. The objective of this study is to examine how PT users adapt their travel choices and what travel information sources they utilize once they encounter sudden PT service disruptions. To this end, we conduct a passenger survey among PT users in the city of Kraków (Poland), consisting of a series of stated- and revealed-preference questions. Results show that passengers' reported choices during past PT disruptions mostly involve adjusting the current PT travel routine, exposing a certain bias with their stated choices (which tend to overestimate the probability of modal shifts). Factors influencing travel behaviour shifts include frequency and recency of PT disruption experience, as well as propensity to arrive on-time. With regards to travel information sources, staff announcement and personal experience play an important role in recognizing the emerging disruption, but real-time information (RTI) sources are the most useful in planning the onward journey afterwards. Based on these, we highlight the implications for future RTI policy during PT service disruptions; in particular, the provision of a reliable time estimate until normal service conditions are resumed. Such RTI content could foster passengers' tendency to use PT services in uncertain conditions, especially as their stated wait time tolerance often matches the actual duration of PT disruptions.

Keywords: public transport; travel behaviour; service disruption; real-time information; RTI

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1. Introduction

Reliability (robustness) of public transport (PT) services is an important factor, shaping general passenger attitudes towards PT systems, and consequently affecting passengers' travel choices. Disruptions in PT services may cause various shift patterns in passengers' travelling strategies, depending on a wide range of aspects. This is especially the case for sudden (unexpected) service disruptions, which pose great journey disturbance and inconvenience. These invoke instantaneous shifts in the passengers' current travelling strategies and lead them to undertake much less-familiar travel options. Under such circumstances, availability of reliable travel information becomes even more crucial to the decision-making process, with the increasingly ubiquitous real-time information (RTI) sources offering a greater chance to minimise the resultant disturbance. Moreover, repeated experience of recurrent service disruptions may induce long-term shifts in typical trip patterns, including the risk of permanent modal shifts from PT systems. Understanding passengers' attitudes and responses to sudden PT disruptions is thus of paramount importance for defining such information and management strategies that will ultimately improve travel experience in uncertain PT service conditions.

1.1. Literature Review

Behavioural responses to both private and public transport travel disruptions are commonly acknowledged in research sources [1–3]. These comprise: adjusting the usual travel routine (i.e., route shifts or temporal shifts), switching to alternative transport modes, satisfying trip purposes at other destinations, consolidating trips (e.g., trip-chaining routines), changing the trip frequency, and cancelling the trip activity. The most common reactions comprise spatial and temporal shifts in existing trip patterns (i.e., change of travel route and travel time) [4], with remaining types of responses typically much smaller in magnitude, and depending on each individual case. As noted by monitoring studies [5], the majority of PT users regularly experience travel service disruptions and develop counteracting strategies. A summary of six city-wide surveys [2] reveals that ca. 10% of travellers encounter disruptions each week as part of their usual travel routine; ca. 50% are affected at least once a month. Experience of travel disruptions induces both short-term and long-term shifts in travel behaviour, which can be difficult to distinguish in practical observations [1] but might be substantially different from each other. Initial reactions tend to be exaggerated, especially in the event of sudden and unplanned service disruptions, after which the scale of trip pattern shifts decreases—a so-called settle-down effect [6]. Meanwhile, accumulated travel experience might facilitate other, permanent (and perhaps initially unforeseen) changes in travel behaviour.

Evidence summarised from multiple case studies [1] reveals the causes of various sudden, unplanned disruption causes and their impact on travel choices. Following a 1966 New York City public transport strike, 50% of travellers cancelled their trips on the first day—a figure which went down to 10% in following weeks, but in the longer run, the PT patronage only decreased by ca. 3%. However, for the 1986 Orange County strike, this figure was almost equal to 20%. After the 1994 earthquake in the Los Angeles area—another type of sudden disruption—31% of commuters changed their travel route and 30% of them adjusted their travel time. In comparison, other reactions were observed in much smaller magnitude, such as only a 6% rate of mode shift. Notably, the long-term propensity to change travel modes can be inhibited by the tolerable margin of increased travel time due to disruption—even as much as 10–20 min of extra delay before eventually switching from private to public transport. The scale of trip destination and trip cancelation changes is usually found to be lower, especially for more resilient commuting and business trips, affecting no more than 2–6% of total trips (excluding exceptional circumstances—explained below). For non-work trips, these rates are more variable, depending on trip motivation (e.g., shopping, leisure, health) and may reach up to 10–30% [2].

These behavioural responses induced by travel disruptions differ in type and magnitude depending on a wide range of factors, related to trip characteristics, travel experience, individual (socio-demographic) characteristics, local conditions, etc. In principle, changes in travel behaviour occur once a stimulus caused by service disruption exceeds a sufficient threshold—i.e., a certain tipping point of travel behaviour stability is achieved [7]. This stimulus can relate either to an isolated, high-impact disruption, or a series of low-impact disruptions which becomes frequent enough to spur changes in individual's travel patterns [8]. Travel shifts are more likely to occur with increased trip length [2] or time [9], as travellers are initially reluctant to rearrange their shorter-range trips. Among factors shaping individual's strategies, past travel experience is of seemingly high relevance [1], as it influences the traveller's perceptions and the resultant choice context. In this context, it should be noted that attitudes towards public transport are biased by negative travel experience and past worst-case situations [10]. Consequently, prior experience of service reliability in PT is relatively more important than in the case of private transport.

The importance of travel habits plays out especially in conjunction with another vital aspect, namely, familiarity with transport network [1]. Travellers who feel more familiar with their environment tend to remain more stable in their travel choices, or as formulated by [11]—reluctant to 'upset an ordered and well-understood routine'. Additionally, different underlying causes of travel disruptions lead to substantially variable adjustments

in trip patterns, e.g., when comparing between the impact of natural catastrophes, mass events and technical failures [1]. Data provided by [2] indicates a cancelation rate for business and commuting trips of 6% for flooding-induced disruptions, but a rate of ca. 40% due to adverse winter weather conditions. These responses of PT users vary depending on the PT mode which they use: rail passengers tend to be more 'forgiving' towards service disruptions than bus passengers [12].

Finally, access to travel information is an important factor shaping passengers' decisions —especially in the event of sudden, unplanned service disruptions. Accurate, timely and relevant information allows travellers to tackle the feeling of being somewhat disconnected in first place and make more informed choices. UK surveys of bus passengers [5] outline the contents of information which are desirable during travel disruptions: cause (reason) of the on-going disruption, estimated impact on journey time, an idea of the scale of the problem, and possible travel alternatives. In terms of dissemination sources, a wide range of available sources are utilised to consult travel information. According to passenger surveys, the most popular source of information is electronic RTI displays at stops [5,13]—since they provide information relevant for current choice context, and their recurrently-updating nature is in itself reassuring [14]. Traditional sources of information (printed schedules), as well as interaction with staff (or the driver), with other travellers, or even relatives are also popular among travellers. Other modern-day sources, such as mobile apps and on-line planners are also increasingly widespread, though they are sometimes biased by unsatisfactory experience of past reliability and incur higher cognitive costs [9].

RTI provision is of vital importance; even though it does not always improve journey experience, it does reinforce the travellers' confidence (reassurance) in unusual circumstances [15]. Even under regular service conditions, passengers can experience certain frustration [16] associated with travel uncertainty, which will be even more important during disruptions. The consulted information may not therefore induce travel shifts in case of minor and short-lived service disruptions, as the propensity to change travel choices will only emerge beyond a certain disruption delay threshold. A survey in London [9] found that the majority of PT travellers would change their travel plans in the case of a 20-min disruption delay. Acquisition of RTI during disruptions was found to be influenced by issues such as prior travel experience, travel choice context, past experience of RTI reliability, and trip purpose [9,15]. It is also observable that on-time travel information is especially crucial in the recovery phase of disruption, once travellers seek for preventive measures to mitigate the disruption effects and recover their journey [8]. In general, RTI access induces different decision-making strategies among PT users [17] and increases the responsiveness in their choices to actual travel conditions. This has been demonstrated in simulation models [18,19] which observe additional passengers' travel benefits with access to RTI (as compared to "non-RTI" passengers), especially once disruptions occur. Experience of relevant and purposeful travel information thus contributes to an improved perception of the RTI system, and higher compliance with RTI content in future travel decisions [13].

1.2. Objectives and Contribution

Despite substantial advancements in recent works, certain gaps have not yet been thoroughly addressed in state-of-the-art research. We argue that further investigation is required to achieve a complete understanding of travel behaviour shifts and travel information usage during sudden PT service disruptions. This pertains to, among others, influence of travel experience upon ensuing strategies, consistency between passengers' attitudes and responses (i.e., stated vs. actual choices), as well as potentially different shifts in instantaneous vs. long-term travel patterns. Another aspect not yet fully explored concerns the utility of available travel information sources, either for recognizing the PT disruption itself and/or planning the onward PT journey afterwards. A further research

question relates to whether passengers' decision-making processes in the face of sudden PT disruptions can be supported with an improved RTI provision policy.

With this study, we aim to address these gaps and contribute with comparable and enriching results to the state-of-the-art research. To this end, we conduct a series of stated- and revealed-preference surveys (SP/RP) among urban PT users in the city of Krakow (Poland). Its objective is to inspect the impact of sudden service disruptions—defined as short, unexpected service suspensions due to service failures, vehicle incidents, track obstructions, etc.—on passengers' ensuing travel strategies. We investigate the passengers' past (historical) experience of service disruptions, their output travel choices and shift patterns in travel choices with respect to relevant factors—such as: prior travel experience, trip purpose (i.e., time-criticality) and general socio-demographic characteristics. Moreover, we analyse the utilization of various travel information sources and their relevance for ensuing travel decisions, as well as preferences towards RTI content in the event of sudden service disruptions.

Our objective is to provide a valuable contribution to the developing stream of research on travel behaviour in public transport systems. The results of this study provide an evidence-based insight into stated and reported travel decisions due to sudden PT service disruptions. In particular, we observe the influence of passengers' recency of 'travel memory' and highlight potential discrepancies between their stated attitudes vs. actual behaviour. Moreover, our research investigation aims to underline how the RTI provision policy can be enhanced to mitigate the negative impacts of PT disruptions, by providing information that could meet passengers' expectations, and thus improve PT travel experience in such circumstances.

The remainder of this paper is organized as follows. Section 2 presents the methodology of our research investigation, including passenger survey design and data collection. Section 3 reports detailed results from the combined SP/RP passenger survey. We conclude with Section 4, which summarises the main findings of our study, discusses their research and practical implications and indicates fields for follow-up research.

2. Materials and Methods

2.1. Case Study—Public Transport (PT) System in Krakow

Surveys were conducted in the city of Krakow, the second-largest Polish city with ca. 750,000 inhabitants. The city PT system consists primarily of bus and tram services with ca. 130 permanent bus and tram routes operating on a typical weekday. As of March 2017, the RTI system was in operation in the form of electronic display signs (i.e., platform-level RTI) mounted at ca. 99% of tram stops in the city, providing passengers with information on estimated waiting times until the next tram departures. At the time, the RTI system in Krakow city was in its early development stages, and so far, its coverage has been extended only to the tram network; bus services are not yet included. Nevertheless, electronic RTI displays at tram stops are a popular source of real-time travel information for city PT users, and apart from remaining waiting times they also display notifications in case of both sudden service disruptions, as well as planned (long-term) line suspensions. However, the content of the displayed information is usually confined to a mere notification (report) of the on-going disruption, its location, and current diversion routes of affected tram services, without any time estimations or advisory travel information.

2.2. Data on Registered PT Service Disruptions

Although the city PT system has undergone substantial improvements in recent years, it still remains vulnerable to sudden service disruptions. As part of this study, we analysed data records obtained from the city transport management authority (ZIKiT Kraków), which covered all the notified service suspensions in the core part of the PT system in Krakow city (i.e., coverage of the full tram network and the majority of bus networks). The datasets were collected over a 6-month period between August 2015 and January 2016. It should be noted that such a time horizon was chosen on the grounds of data

availability and representability. (Soon afterwards, a series of major investment works in the Krakow tram network has started, which significantly influenced the 2016–2017 data on PT disruptions' and thus undermined the overall data representativeness.) The obtained sample was carefully inspected to ensure that it yields a valid and characteristic picture of typical PT disruption events in the case-study PT system:

- A total of 577 unplanned service suspension events were registered for the 6-month analysis period, which gives a monthly average of 97 suspension events.
- The vast majority of service suspension events were short-term in their duration (Figure 1): 52% of suspensions took no longer than 15 min, and just 22% of them were longer than 30 min. Note that this only includes the time duration of suspension itself, excluding the subsequent service recovery period.
- No significant differences were observed in terms of temporal distribution. Disruption events tend to occur at fairly similar frequencies both throughout the daytime (with 78% of them taking place between 6 a.m. and 6 p.m.) and across the consecutive months (82 to 108 events registered per month).

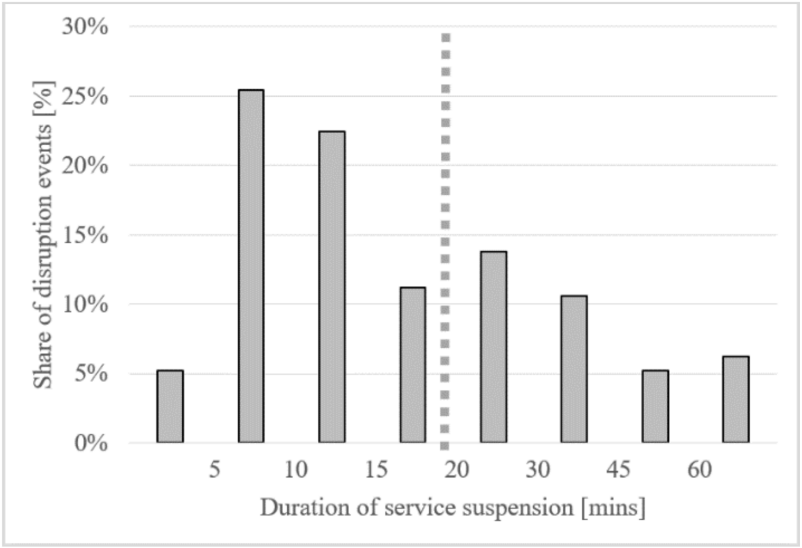

Figure 1. Share of registered service disruption events, depending on the suspension duration, in the PT system in Krakow (source: ZIKiT Kraków).

Importantly, the above-presented data includes only those disruption events which were registered by the city PT management authorities. It does not account for a vast number of short-term disruptions which quite often go unnotified, yet often cause enough disturbance to the passengers. The exact scale of these unregistered (and often recurrent) disruptions events remains unknown; as anecdotal evidence shows, in many cases it can be at least as high as the number of officially registered events.

2.3. SP/RP Survey Setup and Design

To investigate the impact of recurrent PT service disruptions on passengers' travel behaviour in the city of Krakow, a combined stated- and revealed-preference (SP/RP) survey was designed. The survey questionnaire consists of 15 questions in total, and its average completion time ranged between 3 to 4 min. It was carried out on electronic portable devices at (randomly selected) main bus and tram stops in the central area of Krakow city. Final passenger surveys took place over a 3-month period. i.e., April–June 2017 and additionally in September 2017. A total sample of ca. 450 fully completed questionnaires was collected, which was then further analysed, and the main findings are reported in the sections below. Before the main passenger survey was designed, focus-group discussions and pilot surveys were carried out. Their purpose was to avoid confirmation bias [20], ob-

serve the passengers' understandability of general survey purpose, gather their ideas and observations, and reformulate the questionnaire content. The final survey questionnaire can be subdivided into a few general sections as follows:

- The first (RP-based) part of the questionnaire focuses on their historical experience of travel disruptions, trip circumstances, information sources and reported travel choices in the event of the most recent disruption. In the case when a passenger did not experience any disruption at all, this survey part is omitted.
- In the second (SP-based) part, passengers are asked to state their maximum (tolerable) time thresholds and ensuing travel decisions for two hypothetical situations, i.e., service suspension for two distinct trip purposes: a time-critical journey and a non-time critical journey (i.e., depending on the propensity to arrive on-time).
- The final part contains questions on the judgement of the existing RTI system quality in the city of Krakow and desirable future RTI content during service suspensions.

Survey data collection was carried out with the prior consent of each respondent, ensuring their full anonymity and privacy protection. No personal data was stored thereafter, and all ethical standards were duly observed during this investigation.

3. Results

In the following section, we summarise the results of our survey investigation and elaborate on findings from each part of the survey.

3.1. General Experience of PT Disruptions

Overall results show that majority of respondents do indeed experience sudden, unplanned disruptions in their PT trips in Krakow city. In total, 68% of the interviewed passengers recall having encountered sudden disruptions, and 23% report a frequent experience of service disruptions (i.e., once a week or more often). Interestingly, a closer inspection reveals a valid discrepancy in obtained answers, depending on the data collection period (Table 1). For surveys carried out in May and June, about 9% of travellers recall not having experienced the PT disruption at all; for September surveys, this rate surges up to 56%; meanwhile, the shares of those who encounter frequent disruptions are 39% and 7% respectively. This indicates that, although the question objective refers to the travellers' past, long-term record travel experience, their travel memory seems to be in particular influenced by the most recent events and travel incidents. Consequently, travellers interviewed in September exhibit much lower service disruptions right after summer holiday period, compared to those questioned in the midst of typical commuting season. It should be noted that share of PT commuters is constant in both samples, comprising over 90% of all respondents (Table 1). In addition to that, city PT system returns to its typical service pattern in September, and (as reported earlier from the city registry data) the incidence rate of PT disruptions is rather constant over consecutive months.

Table 1. Frequency of encountered PT service disruptions. Results distinguished depending on survey period.

	Total Sample	**Survey Period**	
		May/June '17	**September '17**
More than once a week	10%	21%	2%
Ca. once a week	13%	18%	5%
Less than once a week	45%	53%	37%
Never experienced yet	**32%**	**9%**	**56%**
Share of regular PT users (i.e., 2 + PT trips per week)	92%	91%	91%

3.2. Revealed Impact of Past PT Disruptions

We investigated travel choices revealed (reported) by travellers for their most recent experience of journey disruption (Table 2). The most typical shifts in trip patterns once PT disruptions had been encountered either involved changing the initial PT trip route (i.e., using an alternative bus or tram connection—39%), waiting until the PT service has arrived (29%), and completing the rest of trip by walking to the destination (27%). Otherwise, remaining options such as mode shifts (4%) and trip cancelations (2%) are much less popular. The Chi-Square tests yield statistical significance of reported travel choices with a number of travellers' sociodemographic factors. Notably, this pertains to the propensity among elderly PT users (aged 60 and over) to remain and wait at their stop (63%) in the event of disruption; they were much less likely to consider other re-routing options. We also observe a certain increase in modal shift probability towards walking among students (32%) and respondents aged 18–35 (31%), as well as towards private transport (i.e., car, taxi, ride-sharing) among those employed (7%) and aged 26–45 (7%). Moreover, choice patterns are seemingly correlated with the stated frequency of past disruption experience. Frequent exposure to travel disruptions leads to a smaller likelihood of changing current trip itinerary, with 45% of travellers likely to wait further at the stop. Regardless of that, hardly anyone considers shifting to private transport.

Table 2. Revealed travel choice response during the most recent PT service disruption.

	Total Sample	**Frequency of Experienced PT Disruptions**		
		More Often	**Ca. Once a Week**	**Less Often**
Wait at the stop	29%	45%	29%	26%
Use an alternative PT route	39%	26%	39%	41%
Walk down to destination	27%	25%	20%	29%
Shift to private transport	4%	1%	8%	4%
Resign from travelling	2%	2%	3%	1%

Chi-square results: $x^2 = 21.74$, $p = 0.041$.

3.3. Long-Term Travel Behaviour Shifts Due to PT Disruptions

In the next stage of our survey, we ask travellers to report the long-term changes they made in trip patterns as a consequence of PT disruptions' experience, using a 1-to-5 Likert scale (where: 1—never, 5—always). The results presented in Figure 2 indicate that 77% of travellers acknowledge having made such long-term travel routine adjustments. Similar to previous questions, shifting to private transport seems to be the least likely option: 17% did so at least sometimes and only 4% did so on a regular basis (i.e., often or always). The remaining alternatives—changes in current PT route (different origin departure time, different alighting stop) or choosing an alternative PT route—exhibit much higher popularity, with respective figures ranging around 40–50% (at least sometimes) and 15–20% (on regular basis). Statistical tests reveal that travellers who frequently experience disruptions are more inclined towards changing their alighting stop (43%—at least sometimes) and especially towards adjusting their departure time from origin (52%—at least sometimes, 30%—on regular basis). Concurrently, shifting to an alternative PT route on a long-term basis is a popular option regardless of disruptions' experience frequency.

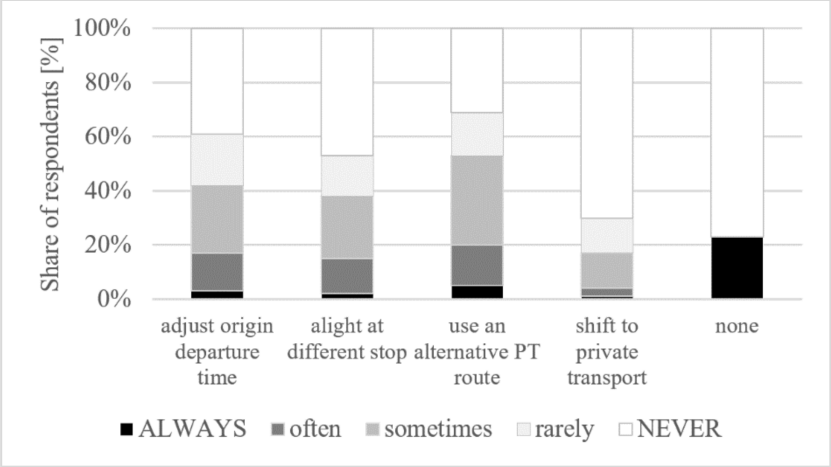

Figure 2. Reported long-term travel behaviour changes due to PT disruptions.

3.4. Stated Travel Choices during PT Disruptions

We then move to the next stage of our survey, where we ask travellers to report their preferred (stated) travel action in two hypothetical cases, assuming they have an exact information on remaining time of disruption duration. We distinguish here two scenarios depending on propensity to arrive on time: ***time-critical trips***—e.g., to work or study place (need to arrive on-time), vs. ***non-time-critical trips***—e.g., shopping or leisure purposes (need not be in a hurry). Respondents are asked to provide maximum acceptable waiting times and ensuing travel actions beyond this time limit for their typical PT trip context (to the workplace, shopping mall, etc.). As expected, resultant time tolerance thresholds are much lower for time-critical trips, with the vast majority of respondents (80%) reluctant to wait longer than 10 min (Figure 3). In contrast, for non-time-critical trips, results show that for a 10-min disruption just 35% of travellers would already consider taking alternative travel action.

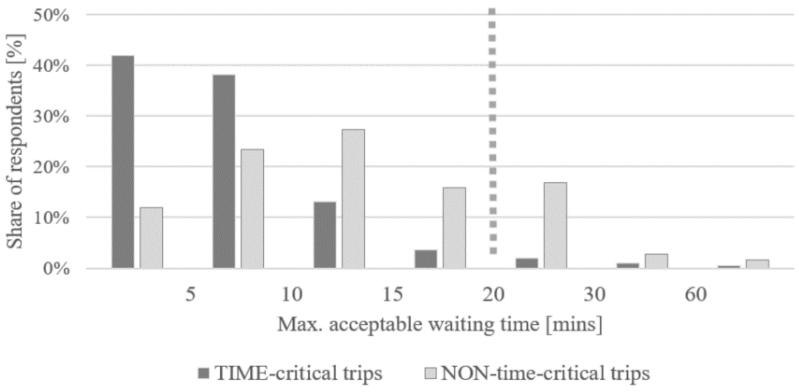

Figure 3. Stated max. acceptable waiting time before considering alternative travel action. Results are distinguished with respect to the propensity to arrive on-time (i.e., trip time-criticality).

In terms of ensuing travel action afterwards, choosing an alternative PT route is the most favourable option, with a rather uniform popularity rate in both scenarios (57–58%). Variability in results is exposed for other travel options, as shown in Table 3—with higher probability of potentially shifting to private transport for time-critical trips, walking down to destination for non-time-critical trips, and additionally—a potential 7% trip cancelation rate in the latter case. It should be emphasised though that these figures refer to passengers' stated-preference (SP) travel actions for hypothetical disruption scenarios. Validating these results against the revealed-preference (RP) choices for previous (past) disruption cases, reported also in Table 3, underlines an interesting discrepancy arising between SP vs. RP

results. The most popular travel behaviour pattern pertains to using an alternative PT route, regardless of the time-criticality of trip. Its share is revealed to be similar to that of passengers' stated preferences (54% in RP choices vs. 58% in SP choices). However, important differences are traceable for remaining travel options: in contrast to stated results, walking is revealed to be much more popular (37% in RP choices). Likewise, the actual tendency to use private transport (i.e., car, taxi, ride-sharing) is over-exaggerated (6% in SP choices), as is the trip cancelation rate (ca. 2% in SP choices). These findings thus underpin a certain bias in passengers' answers to hypothetical stated-choice scenarios when contrasted with the actual choices that they reported for recent disruption.

Table 3. SP vs. RP travel choices due to PT disruption. Comparison between stated (potential scenario) vs. revealed (past experience) choices.

	Stated Choices Potential Trips		**Revealed Choices Past Trips**			
Need to arrive on-time?	yes	no	yes	no	yes	no
Wait at the stop	(n/a)		(excl. waiting):		25%	35%
Use an alternative PT route	58%	57%	54%	54%	40%	35%
Walk down to destination	22%	34%	38%	36%	29%	23%
Shift to private transport	19%	2%	5%	7%	3%	5%
Resign from travelling	~0%	7%	3%	1%	2%	1%

3.5. Travel Information during PT Disruptions

In the final part of our survey, we investigate impact of travel information sources and content during sudden PT disruptions. Firstly, we analyse which information sources are helpful in recognising past PT service disruptions. The results in Table 4 show that the highest (34%) share of respondents admit to having recognised the on-going disruption by themselves (i.e., without the need to consult other information sources). This is followed by 26% of travellers who became aware of the disruption by observing electronic RTI displays at stops. Traditional information sources are also found helpful in recognising service disruptions, i.e., driver or PT staff announcement (20%), and reactions of other passengers (13%). Moreover, a relevant correlation with the experienced disruption frequency (Table 4) is observable. Those who are used to frequent PT disruptions (more than once a week) are more likely to recognise them by themselves (52%), and less reliant on other sources such as RTI displays or passengers' reactions (i.e., collective behaviour).

Table 4. Revealed recognition source of the most recent PT service disruption.

	Total Sample	**Frequency of Experienced PT Disruptions**		
		More Often	**Ca. Once a Week**	**Less Often**
Driver or PT staff	20%	15%	12%	24%
Other passengers	13%	4%	17%	13%
Internet, social media	7%	9%	10%	6%
RTI displays at stops	26%	20%	20%	30%
Just notice them myself	34%	52%	41%	27%

Chi-square results: $x^2 = 20.25$, $p = 0.027$.

However, it is the dynamic and RTI devices which are the most frequently consulted travel information sources once service disruptions occur (Figure 4). Initially of little use in recognising of PT disruptions, smartphone apps (and on-line resources) become a popular means for the ensuing trip planning purposes—having been consulted at least sometimes by 75% of travellers, and by ca. 50% of them on regular basis (i.e., often or always). Similar figures are reported for electronic RTI displays at stops, which are the second most popular travel information source. On the other hand, social media alerts and feeds (e.g., local PT Facebook page) were yet utilised by a limited share of travellers (just 15% did so regularly).

This can be attributed to low awareness of social media travel alerts at the time of this research.

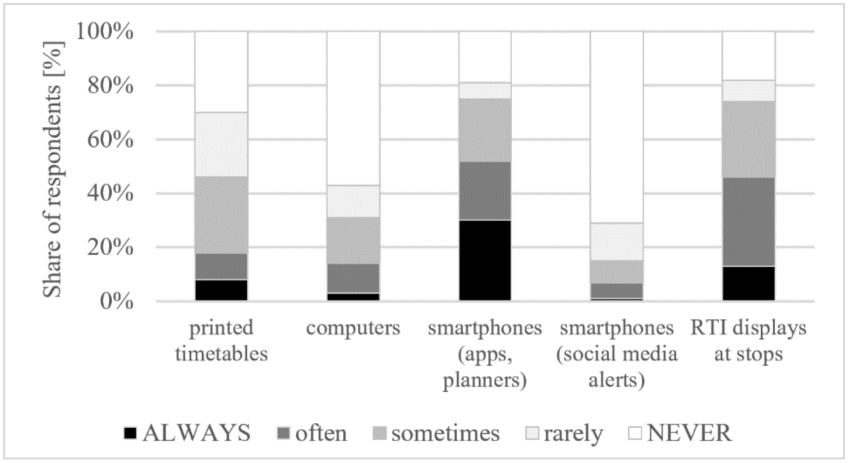

Figure 4. Consulted travel information sources during the PT service disruptions.

Finally, we turn our attention to the RTI system in the city of Krakow and expectations towards the future information provision policy during disruptions. In general, when asked to provide an assessment on a 1-to-5 Likert scale (1—poor, 5—excellent), current RTI reliability is reported on average equal to 3.9, and the RTI usefulness—equal to 4.5. Such results indicate a potential field for improving the perceived RTI accuracy and users' preference to obtain a more reliable (and extended) RTI content, especially during variable and disrupted travel conditions. This can be complemented by our next findings, i.e., future desirable RTI content during PT disruptions (Figure 5). Travellers are in particular interested in obtaining an accurate estimate of remaining time until normal conditions are resumed. Other information options, including real-time advice on alternative travel routes and cause of the on-going disruption, are also positively viewed, albeit evidently less important for survey respondents.

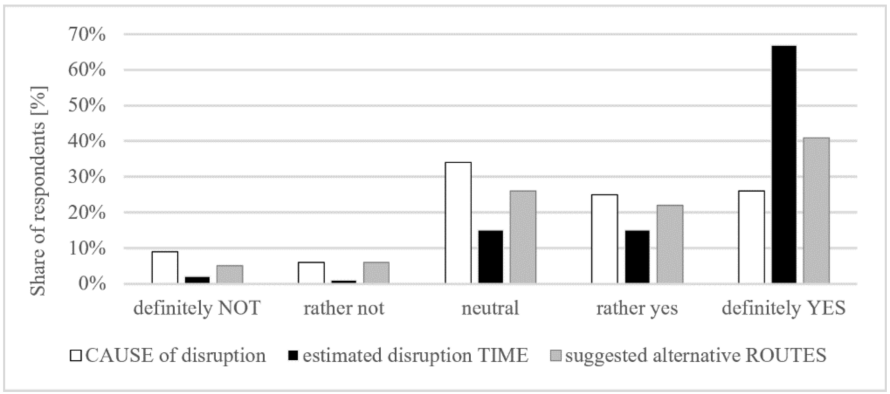

Figure 5. Preference towards future RTI content in the event of disruptions.

4. Discussion

The study presents results from combined stated- and revealed-preference (SP/RP) survey conducted among urban public transport (PT) users in the city of Krakow (Poland). The main objective was to investigate the impact of sudden PT disruptions upon resultant changes in passengers' travel behaviour. The secondary objective was to establish travel information sources and content relevant during sudden service disruptions.

The principal contribution of this study lies within an improved, evidence-based understanding of how passengers' travel behaviour is affected by experience of sudden PT service disruptions. Detailed results of our investigation (described in the previous section)

shed more light on what adjustments in travel decisions may occur either in case of a single, sudden PT disruption, as well as a long-term consequence of repeated PT disruption experience. We examine the passengers' stated attitudes and waiting time tolerance and indicate how they match the actual (real-world) travel behaviour and duration of PT suspension events. As a secondary contribution, we investigate the popularity of travel information sources during the PT disruptions. Finally, as shown in the subsection below, we utilize our findings to indicate what travel information content should be particularly provided in real time to passengers in the event of such PT service disruptions.

The main findings of our study can be summarised as follows:

- Majority of surveyed PT users (68%) recall having experienced sudden, unplanned service disruptions in their PT trips and 23% of them report such experience on a frequent basis (at least once a week). Importantly, we observe that recency of experienced PT disruptions has significant influence upon passengers' travel memory. Only 9% of passengers interviewed in the midst of a typical commuting season (May–June), recall not having experienced any disruption before. However, the same survey conducted just after holiday break (September) yields a corresponding rate of 56% respondents. This is all the more remarkable, given that registered PT disruptions exhibit similar characteristics (frequency and duration) across consecutive months, and both samples are controlled against the steady share of regular PT users.
- Travel choices revealed by passengers during the latest (most recent) PT disruption primarily involve using an alternative PT (bus or tram) route (39% of travellers), followed by waiting at the stop (29%), walking towards the destination (27%), shifting to private transport (4%) and resigning from travelling (2%). Passengers more accustomed to frequent experience of PT disruptions are less likely to change their current PT travel routine and instead tend to wait further at the current stop.
- Furthermore, 77% of respondents admit to having made long-term adjustments in their travel behaviour as a consequence of recurrent disruption experience. These mostly involve using an alternative PT route or adjusting current PT trip itinerary, by changing the origin departure time or an alighting stop (40–50% of travellers). In contrast, increased frequency of car usage is reported only by ca. 20% of respondents.
- In the hypothetical (SP) disruption scenarios, trip time-criticality stands out as a major factor, influencing the stated choices and maximum acceptable wait time at the current PT stop before taking further action. For time-critical trips (e.g., work, study), only 7% of travellers would accept a max. waiting time longer than 15 min—whereas for non-time-critical trips (e.g., shopping, leisure) this rate increases to 37%.
- Our findings also expose relevant differences between passengers' preferred vs. actual choices during PT disruptions. Stated preferences (SP) vary with time-criticality, with higher propensity to use private transport for time-critical trips (19%), and to resign from travelling for non-time-critical trips (7%). Corresponding rates in the revealed preferences (RP), meanwhile, are equal to ca. 6% and 2% respectively, suggesting that SP answers overestimate the probability of modal shifts and trip cancellations. In contrast, RP answers exhibit uniform patterns regardless of trip time-criticality. Revealed travel choices primarily involve taking an alternative PT route (55%) or walking to a destination (38%—remarkably, also for time-critical trips).
- The main information sources which help travellers to recognise the emerging PT service disruptions are travellers' own observations (34%), and electronic RTI displays at stops (20%), followed by PT staff announcements or observations of other passengers. At the time of this research, on-line and internet resources were the least popular means of recognising the PT disruption. However, smartphone apps and RTI displays are the principal (most consulted) travel information sources for planning an onward journey once the PT disruption takes place, even despite limited information content utility.

The aim of our study is to deliver valuable insights that can enrich the state-of-the-art research on travel behaviour in modern-day PT networks. The findings of this study can

help better understand the attitudes, factors and outcomes in passengers' decision-making process in uncertain, disrupted PT travel conditions. In addition to research implications, the outputs of our investigation can be of practical relevance for PT policymakers, planners and operators. As such, they can support the design and implementation of new analytical models, travel information and management strategies, aimed at mitigating the negative effects of sudden PT service disruptions.

Implications and Recommendations for RTI Policy in Krakow

Conclusions from our study indicate a few possible means of improving the current RTI provision policy in Krakow during sudden service disruptions. Firstly, in terms of desirable future RTI content, there is a clear passenger preference towards obtaining an accurate time estimation of disruption duration. Such a feature is found to be rated as most important (useful) among other travel advice options. This can be further supported by the fact that, based on PT operator data, over 50% of recorded disruptions tend to last no longer than 10–15 min. Once compared against the SP results, this is a time threshold that can match the stated waiting time tolerance, especially for the vast majority of non-time-critical trips (Figure 6). Providing a reliable disruption time estimation could therefore reinforce passengers' tendency to stay on their current PT route, particularly for the vast majority of trips which are not time critical (i.e., leisure trips, trips with arrival time flexibility). This will also help them make more informed choices and substantially decrease the travel disutility associated with service uncertainty and unreliability, improving the overall perception of PT service quality.

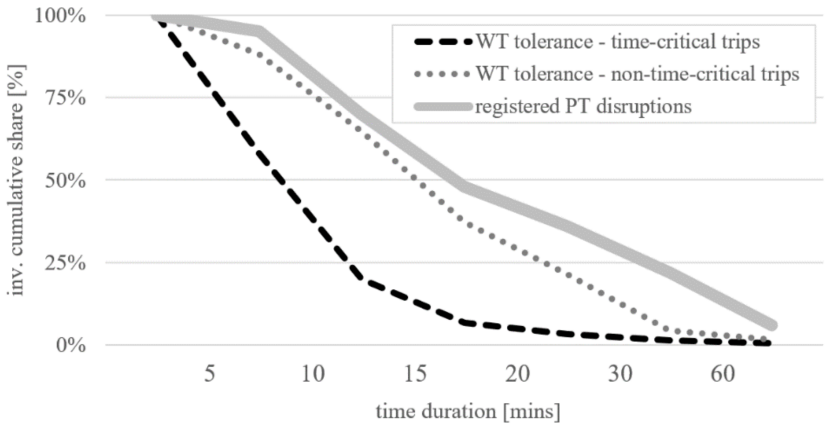

Figure 6. Results—revealed distribution of waiting time tolerance in the event of PT disruptions (acc. to surveyed passengers), plotted against the distribution of actual duration of PT suspension events (acc. to the PT operator's registry).

Secondly, another possible development relates to providing personalised RTI travel advice during disruptions, which would better match the individual travel preferences. Availability of the prescriptive O-D travel advice has prospective benefits for the majority of PT users, who exhibit constant travel (commuting) patterns even despite recurrent experience of service disruptions (Table 1). In this respect, customized, real-time O-D travel advice could decrease the uncertainty and cognitive effort associated with the urgent, unexpected trip re-planning process [9]. It should be noted that the awareness of RTI travel alerts and feeds was still relatively low among passengers (Figure 4) at the time of this research. Although RTI sources are already popular for en-route trip planning purposes—i.e., once the PT trip has already been disrupted—they are of more limited usefulness either in making pre-trip arrangements or recognising the on-going disruptions beforehand.

Thirdly, and as a final remark, passengers in general express a positive perception of present-state electronic RTI system in Krakow. RTI content is rated higher in terms of its usefulness than its reliability, which indicates a certain field for improving the RTI accuracy—especially crucial in terms of PT service irregularities and disruptions.

A certain limitation of this study can be attributed to the relative uniformity of the obtained sample: over 90% of respondents are regular PT users (commuters). Although surveys were conducted across multiple bus and tram stops in Krakow, on different weekdays and throughout the daytime, future surveys should take place also outside the central PT network and cover regional (suburban) trips as well. Additionally, follow-up surveys should be conducted in different urban and metropolitan areas to verify the potential influence of a wider range of aspects upon passengers' response to sudden PT disruptions such as transport network topology, demand levels, tariff policy, local specifications, etc. Further research will thus allow us to obtain more universal and transferable conclusions.

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