The More the Merrier? On how many passengers should follow real-time crowding information (RTCI) during bus service disturbances

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SHORT SUMMARY

Regularity of public transport services can be substantially impeded by feedback loops between supply operations and demand flows. Amongst potential countermeasures, an interesting (yet unexplored) pertains to informing passengers in real-time about estimated travel times and on-board crowding levels of bus arrivals at the stops. In this study, we analyse whether providing such real-time crowding information (RTCI) can restore regular public transport performance, depending on passengers' voluntary responsiveness to the RTCI. We apply the simulation-based assignment model *BusMezzo* to the real-world model of a busy bus corridor in Warsaw (Poland). Findings from sensitivity analysis reveal that RTCI can bring the most tangible benefits in passengers' journey experience with the 50 – 75% RTCI penetration rate, while also contributing towards greater service regularity. Ubiquitous (100%) response to the RTCI seems also advantageous for the PT supply and demand performance, although with a certain risk of rebound in overcrowding effects.

Keywords: public transport; overcrowding; bus bunching; real-time crowding information; RTCI.

1. INTRODUCTION

Public transport (PT) service quality is profoundly shaped by the reliability (stability) of supply operations and demand flows. However, demand-supply interactions are also characterized by feedback effects that are prominent especially in congested, urban areas. Variations in passenger volumes and service movements influence each other, implying that even a single, isolated event can suddenly spiral into a major network disruption. A notable example is illustrated by the ***bus bunching*** effect, i.e. the feedback loop between fluctuations in service headways, dwell times and passenger volumes. The bus bunching effect becomes self-reinforcing (and eventually uncontrollable) after exceeding stability criteria (Newell and Potts, 1964), resulting in major service delays, travel time unreliability, system overcrowding and operational inefficiency.

This inherent variability of PT system calls for development of proper and effective tools, strategies and interventions. These have been hitherto more explored on the supply side, comprising a wide set of holding control strategies, overtaking, stop-skipping (expressing), short-turning, robust slack-time planning policies etc. (see e.g. (Cats et al, 2011; Delgado et al, 2012; Leffler et al, 2017; Laskaris et al, 2019; Gkiotsalitis and van Berkum, 2020); and therein cited sources). On the demand side, individual studies have investigated the effects of (no-)boarding policies, i.e. restricting the passengers from boarding the overcrowded and delayed buses, and/or queue-swapping behaviour (e.g. (Wu et al, 2017; Sun and Schmoecker, 2018; Saw and Chew, 2020)). Their objective is to avert the knock-on impact of excessive passenger loads upon the bunching feedback loop and deteriorating network performance.

However, while exposing certain benefits of anti-bunching strategies, studies acknowledge that they are also intertwined with additional costs incurred by passengers and/or operators, being *imposed upon* the current network operations. Especially, the demand-side policies are seldom implemented because of their limited acceptability amongst PT service users and providers. Little remains known, on the other hand, about policies aimed at *inciting voluntarily* a more co-operative travel behaviour – and simultaneously, yielding an enhanced system performance. Such prospective solution emerges in the (increasingly feasible) **real-time crowding information (RTCI)** (Delgado et al, 2012; Schmoecker et al, 2016; Wu et al, 2017; Drabicki et al, 2021(a,b); Wang et al, 2021). By coupling the (historical and/or real-time) data on estimated arrival times with on-board loads of PT vehicles (Figure 1), the RTCI system can help passengers make more informed decisions, with a much greater awareness of actual service conditions. In context of the bunching effect, the RTCI provision at bus stops may encourage the so-called willingness to wait to reduce overcrowding. This may lead to potential gains both for passengers (travel utility) and operators (system performance) – which have not been yet thoroughly explored in the state-of-the-art.

Our objective is to address the above-mentioned research gap with a sensitivity analysis of the impacts of the RTCI on trip (departure) loads and its provision during bus service disturbances. We apply the simulation-based, dynamic PT assignment model *BusMezzo* to analyse the RTCI influence upon passengers' boarding decisions and network performance. A series of simulations on a PT network model of one of the busiest bus services in the Warsaw city (Poland) illustrate the ramifications of RTCI provision under various service variability scenarios for passengers' travel experience and service operations. Results indicate the improvements achievable under variable demand responsiveness, especially with rising RTCI penetration rate and choice sensitivity. Outputs of this work aim to contribute towards improved understanding of the prospective RTCI benefits (and shortcomings) in alleviating the bunching effect. An in-depth elaboration on these implications will follow in the final stage of our study.

Figure 1: Conceptual scheme of the RTCI system – a bus-stop display with information on (estimated) crowding levels and waiting times of the next bus arrivals.

2. METHODOLOGY

To examine the effects of RTCI during bus bunching, we will utilize the microscopic, simulation-based PT assignment model *BusMezzo* (Cats, 2011). The *BusMezzo* model has been demonstrated in a number of studies to capture the wider impacts of passenger overcrowding, demand-supply feedback performance and real-time information provision (e.g. (Cats et al, 2011; Cats and Jenelius, 2014; Cats et al., 2016; Drabicki et al., 2021(a,b))). The *BusMezzo* framework reproduces the network performance in a dynamic, sequential (event-based) manner. Crucially, this allows to reflect that the passengers may instantaneously reconsider their travel actions in response to unravelling network conditions and the obtained real-time information.

In this study, we apply the *BusMezzo* model extension whose proof-of-concept was demonstrated in (Drabicki et al, 2021a). The impact of RTCI on passengers' instantaneous departure choices at stops and the resultant network effects can be essentially described in the 3 following stages:

1. **Recording the RTCI**. Each time when the bus vehicle departs from a given (upstream) stop, the information on its current passenger load is instantaneously recorded. This value is compared against the vehicle capacity and categorized on a 1-to-4 crowding information scale. The resultant RTCI value is then stored by the ITS system.

2. **Generating and disseminating the RTCI**. Each time when the bus vehicle departs from an upstream stop, its newly recorded RTCI value is transmitted outright to all the downstream stops. This RTCI value is thus disseminated among passengers at these stops (via electronic displays, journey planner apps etc.).

3. **Utilising the RTCI**. Each time when the passenger evaluates a boarding decision (i.e., when a bus vehicle has arrived) at the downstream stop, (s)he acquires the current RTCI on the next 2 bus departures. The passenger evaluates then boarding decision based on the information on crowding levels of the next 2 bus trips, plus the waiting time required for the second departure. This probabilistic boarding decision process can result with 2 possible outcomes: boarding the first bus now – vs. – waiting and boarding the second bus later. (To avoid erroneous, 'infinite' deferrals of boarding, we assume that such RTCI-based decision may occur only once for a given passenger.)

The above summarized framework reproduces the RTCI impact on passengers' boarding choices, which might become especially prominent once passengers waiting at a stop are informed of lower crowding conditions on-board the later (second) bus arrival.

In this study, we apply the model to examine the consequences of such travel behaviour during bus service irregularities. The principal aim of simulation experiments is to analyse the effects of RTCI provision in the event of bus bunching. To this end, we define a set of scenarios and perform multiple simulations, comparing essentially the output between the *RTCI* vs. *no RTCI* cases. In simulation scenarios, we examine the influence of different demand-side settings. Firstly, these relate to the information penetration rate, i.e. share of passengers who follow the RTCI in their travel decisions – spanning between: 0% / 25% / 50% / 75% / 100%. Secondly, we investigate the impact of variable choice sensitivity parameter, considering *low* / *mid / high* sensitivity conditions. (Whereby *lower* sensitivity tends towards a stochastic choice model, while *higher* sensitivity translates into a deterministic choice model.) A set of demand- and supply-related metrics help us then to evaluate the RTCI impact on travel experience and service performance in our bus network.

3. RESULTS AND DISCUSSION

Case study. Simulation analysis is performed on a bus line model, which represents a real-world bus corridor in the capital city of Warsaw (Poland) (Figure 2). The case study concerned is a major east-west express bus service no. 523, connecting highly-populated suburbs with the central Warsaw area and a number of busy urban PT interchanges. This is a high-demand bus route, routinely prone to overcrowding and operational uncertainty. Buses run approx. every 5 minutes in the peak hour and total ride time equals ca. 60 minutes.

Figure 2: Bus line model used in our simulations – Warsaw case study.

Preliminary results (presented in tables and captions) illustrate the potential consequences of providing RTCI once bus bunching emerges in the case-study network. The baseline comparison – i.e. between scenarios with full (100%) vs. no (0%) RTCI availability - already results in a number of interesting observations. RTCI-induced boarding decisions lead to more uniform distribution of on-board passenger loads, with lower risk of high overcrowding conditions, and conversely – higher seating probability (even in the peak-hour conditions) (Figure 3). Hence, passengers can benefit from better on-board comfort experience, as they are more likely to travel in a moderately crowded bus, especially along the busiest bus line segment. From the operators' perspective, this implies more efficient capacity utilization, as individual bus loads oscillate within much narrower range, closer to the average value. Overall travel utility can be thus improved by ca. 7% (in relation to the *no RTCI* scenario), and importantly – these benefits are observable at a vast majority of bus stops in our case-study network. However, the exact scale of attainable outcomes and their positive (or sometimes negative) impacts differ depending on scenario settings.

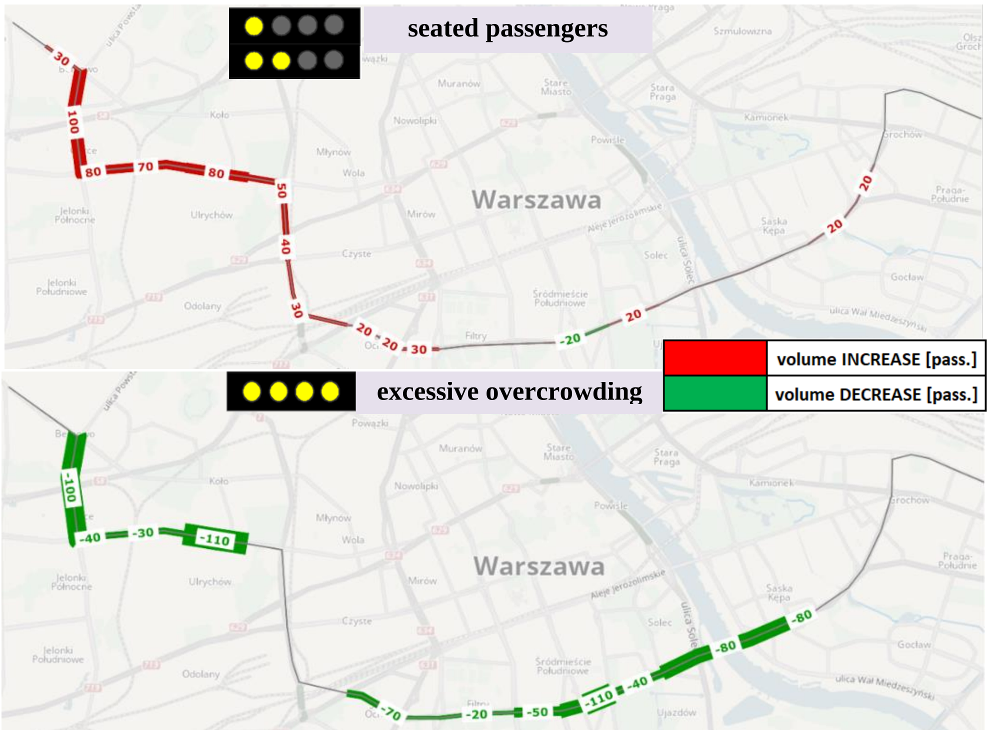

Figure 3: Sample results – RTCI impact on the on-board travel experience – passenger load changes vs. the *no RTCI* scenario.

Further simulation analyses underline the influence of variable RTCI penetration (response) rate against the bunching disturbances. In our case-study scenarios, an increasing share of passengers adhering to the RTCI induces enhanced journey and service conditions, particularly up to approx. 50 – 75% of total network flows. Improvements are evident across a wide range of journey experience parameters, including the in-vehicle and waiting travel utility, and particularly – the negative effects of on-board overcrowding and denied boardings. The latter can decrease by 30 – 60% in global terms and diminish altogether in specific parts of the bus network. However, ubiquitous (100%) response rate to the RTCI may induce a certain rebound in the overcrowding effects (Figure 4). Nevertheless, in addition to demand-side consequences, higher RTCI penetration rates also result in lower bus headway irregularities (Figure 5). Hence, the propagation of bus bunching effect becomes then effectively suppressed in the downstream network.

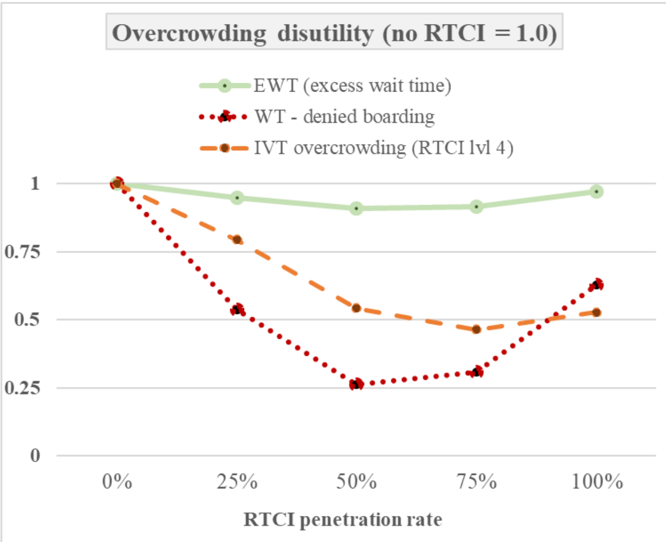

Figure 4: Sample results – impact of the variable RTCI penetration rate on passengers' experience of the PT overcrowding effects.

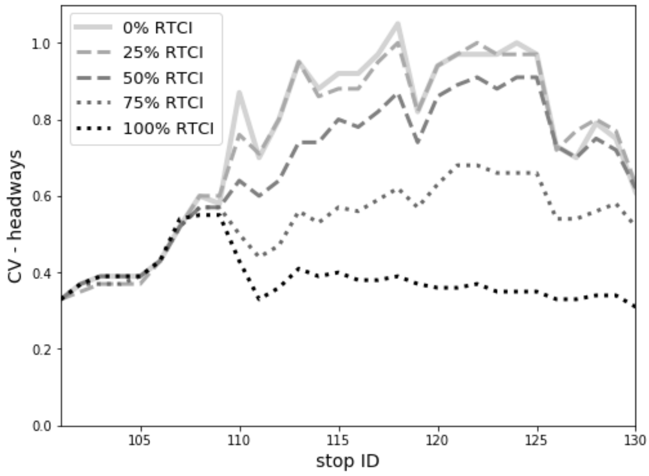

Figure 5: Sample results – impact of the variable RTCI penetration rate upon service headway variability along the bus route.

In another set of simulations, the impacts of RTCI are investigated for various levels of choice sensitivity (of passengers' boarding decisions). A summary of the results (Table 1) indicates that

RTCI benefits are more exposed with 'higher' (i.e. more *deterministic*) choice sensitivity. These are particularly attributable to improved on-board travel conditions, as waiting times tend concurrently to increase, yet not sufficiently to mitigate the overall travel utility gains. Simultaneously, such findings suggest limited RTCI effectiveness in more *stochastic* choice behaviour conditions.

Table 1: Sample results – impact of the variable RTCI choice sensitivity upon passenger travel experience – changes vs. the *no RTCI* scenario.

Utility changes with RTCI: choice sensitivity:	**Waiting time disutility**	**In-vehicle travel time disutility**	**Total travel time disutility**
low	+ 3.8%	- 2.0%	- 0.2%
mid	- 1.3%	- 7.7%	- 5.8%
high	+ 5.5%	- 22.3%	- 10.9%

4. CONCLUSIONS

The main contribution of this study pertains to the sensitivity analysis of real-time crowding information (RTCI) provision to public transport (PT) passengers affected by the bus bunching disturbances. We adopt the microscopic, event-based *BusMezzo* modelling framework that simulates the consecutive stages of generating, disseminating and utilizing the RTCI, and the wide spectrum of resultant demand and supply phenomena in the PT network. Simulations on a real-world model of a busy bus corridor in Warsaw, reveal the plausible upsides (and downsides) of RTCI influence on boarding decisions under different demand settings, which may result both from travel behaviour and network coverage aspects – i.e., variable penetration rate and choice sensitivity among passengers.

Preliminary findings show that passengers with RTCI access can improve their own travel experience and mitigate the overcrowding impacts, while also inducing supply-side benefits (e.g. lower headway variations). An advantageous consequence of the widespread RTCI availability is the stimulation of co-operative travel behaviour among passengers, as *individual* decisions ultimately yield *global* (network-wide) improvements. We observe that substantial travel experience improvements are attainable once more than 50% of passengers follow the RTCI in their boarding decisions during the emerging PT service irregularities. These benefits are also sustained, albeit to a lower extent, with ubiquitous (100%) response rate to the RTCI. Meanwhile, higher choice sensitivity - implying more deterministic decisions – points towards greater efficacy of RTCI provision in mitigating service irregularity. This observation should be verified, though, in follow-up studies to examine whether system over-responsiveness to the RTCI can bring counterproductive results in certain conditions. Future research should also prioritise the real-world data validation of the actual RTCI effects to support their practical implementation in PT networks.

Implications from this study highlight the prospective role of RTCI systems in future PT networks, underlining their impact on travel behaviour and network-wide consequences. These can be especially helpful in the aftermath of the negative COVID-19 pandemic impacts upon PT systems. Rising concerns regarding the PT crowding levels and social distancing requirements can be adequately addressed with the provision of reliable and trustworthy RTCI information. Finally, findings of this study indicate the prospective application of future RTCI systems as a travel demand management tool targeting the common bus bunching problem in PT networks.

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