Dynamics and Processes in Operations Control Centers in Urban Public Transport: Potentials for Improvement

Frederik R. Bachmann, Lars Briem, Fritz Busch, and Peter Vortisch

***Abstract*— Disruptions in public transport operations occur every day. Thus, providing a reliable system is a challenge for operations and planning. This paper gives insights into the dynamics and processes of operations control centers in public transport to reveal potentials for further improvement in reliability. Therefore, directors were interviewed, dispatchers observed, and operations documentation was studied. It has become obvious that the process of dispatching has four different types of call signals (assault, accident, missing replacement, and wish-to-talk) corresponding to different kinds of incidents. The drivers use those call signals to contact the operations control center and initialize different procedures of communication between the dispatchers, drivers, and other involved parties. As the communication is mostly conducted via phone or radio, several improvements are possible, such as training in communications and increased use of information technology in operations. In planning tools, the handling of incidents is marginally supported. As all kinds of incidents can affect the service, they should be represented in planning tools to design more reliable public transport systems. However, they do not need to be represented in full detail. Verbal communication could mostly be reduced to single decisions. Accidents, for example, influence the operation by delayed vehicles and blocked ways. The findings of this work allow a better understanding of operations control centers and reveal their potentials for improvement.**

***Index Terms*— Disruptions, incident management, operations and management, public transportation.**

I. Introduction

THE current debate on the accelerating climate change and its consequences reveals that a huge reduction of greenhouse gas emissions is necessary to curb the impact of the change. Transportation plays a major role in this [1]. The carbon footprint of transportation can either be reduced by cutting down the vehicle distance traveled or by a switch to more environmentally friendly means of transport. Politically, cutting down the distances traveled is currently not in sight but a switch to more environmentally friendly means of transport is.

For short distances, walking or cycling are the most auspicious alternatives. For longer distances, shared mobility with public transport (PT) as the main mode is the most promising option. Therefore, it plays a crucial role in reducing mankind's carbon footprint [1]. From travel demand research, we know that a mode shift can be realized by impeding other modes of transport or by providing a better PT service [2, pp. 309-332]. For PT, this means that the more frequent and reliable the service, the more attractive it is.

From the passengers' point of view, reliability is simply the difference between the planned arrival time before departure and the actual arrival time. If the difference is small, the reliability is high. In PT, there are two aspects that let operations diverge from planning: fluctuations and disruptions. Fluctuations of travel times happen during normal operations due to traffic conditions and passengers' boarding and alighting. Service disruptions, such as delays and cancellations, are caused by various types of incidents.

To improve reliability, we can search for possible optimizations in operations and planning. In operations, the operations control center (OCC) is the facility that monitors fluctuations and handles incidents. It has the responsibility to first keep operations running and second provide a reliable system for the passengers. In planning, the reliability of a timetable can only be measured by taking real fluctuations, incidents, and the reactions of an OCC into account.

The reliability of PT can be improved in operations and planning. In both areas, it is crucial to understand the dynamics and processes within PT OCCs as accurately as possible. Dynamics in PT mean the interactions between different involved parties during incident handling. Thus, the goal of this paper is to bridge the gap between research and practice in this field of transport.

II. Literature Review

As mentioned earlier, OCCs are responsible to keep operations running and to provide a reliable system. Briem *et al.* [3] point out that in most OCCs this is done manually by human dispatchers. The authors conducted an interview study with dispatchers of one OCC in Germany to understand the dispatcher's view on the processes. They categorize information given by dispatchers into the main categories: influences and limitations, described dispatching procedures, and other topics besides disruption management. The study reveals several internal and external factors and

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limitations, such as legal constraints or constraints due to the presence of passengers. Further, characteristics of disruptions and dispatching measures themselves also influence the possibilities of a dispatcher. They also mention that communication to various parties is a major part of a dispatcher's job. They conclude that interviews with dispatchers are an appropriate method to analyze general processes in OCCs. However, it's beneficial, if the interview is as soon as possible after the experienced incident to improve the level of detail of the described incident. Shorter periods or interviews during such situations would substantially improve the results.

The scope of action of dispatchers has widely been increased by operational tools such as the one described by [4], [5]. Refs. [4], [6] show in case studies of one, respectively three lines how real-time vehicle information improves the reliability of a line. They also mention a couple of challenges on a system-wide implementation. Those challenges have been tackled in the past few years. Thus, dispatchers of today have quite more possibilities of providing a reliable system. Nevertheless, the major part of a dispatcher's job still is the communication with PT drivers, external emergency forces, and internal staff to maintain operations as well as providing passengers with a reliable transport.

Carrel *et al.* [7] shows how important service delivery is. Based on extended visits to one control center, they point out that during the dispatching process, many inherent factors influence the reliability of the system. Further, they provide an overview of influencing factors for the dispatching process, which dispatchers have to consider during their daily work. El-Geneidy *et al.* [8] take another approach. Instead of visiting an OCC, they analyze data from an automatic vehicular locator (AVL) system. They present a methodology to estimate the reliability of a system using its AVL data. The literature about dispatching in operations shows that it is quite a complex task and further research is necessary, like analysing a whole PT system or comparing different systems employed in different cities or/and countries.

Besides the operations, the planning process could also improve reliability during incidents. If planning tools support the evaluation of timetables to real scenarios covering fluctuations, disruptions, and the OCCs' response to these, planners could create more robust timetables or provide dispatchers with more options for dispositive measures. Thus, the reliability of a timetable could and should be measured during the planning process. Possible measures are either static or dynamic. Static measures focus on the supply side of a system while dynamic ones combine demand and supply. Static measures typically require less information and are therefore easier to calculate. Refs. [9], [10] describe various static indicators calculated on the timetable allowing a fast comparison of the reliability of various timetables, e.g. link vulnerability.

Dynamic measures combine demand and supply and are typically simulation-based. Therefore, they need more information, such as the arrival time of passengers at stops [11] or the overall demand. The combination of randomly arriving passengers and a delayed PT vehicle can cause bus bunching as an ever-increasing number of passengers is waiting at the follow-up stop. This problem is widely known [12]. Strathman *et al.* [13] give an overview of the literature about solutions for bus bunching issues which could be implemented in operations and planning tools.

Neumann and Nagel [14] analyze bus bunching and different strategies to solve it on a single line using MATSim. The authors integrate an optimization algorithm to depart busses bunched by passengers and individual traffic evenly. Cats *et al.* [15] describe a similar study using the tool BusMezzo. They simulate different holding strategies for busses letting them also depart evenly. Afterward, they test them with a real bus line, [16] take a similar approach. They combine four strategies for five bus lines in a city of China to find the optimal combinations of strategies. A literature review about such measures is given by [17]. These studies measure and reduce the fluctuations and variability in travel times during normal operations.

As those tools can be considered as state-of-the-art planning tools, they only support fluctuations and variations in travel times up to a certain level. Most of the studies have been conducted with a single line.

In contrast, disruptions or the inherent factors of dispatching are hardly supported by planning tools. The main issue thereby is the variety of disruptions and reactions in OCCs. The considerations of those are necessary to show similar effects in simulations as in reality. To introduce such effects into planning, a better understanding of the processes and dynamics in OCCs is necessary. In most OCCs work is done by human dispatchers, who are at most supported by optimization algorithms, which still play a minor role in OCCs. The use of optimization algorithms in planning tools, as often done in research, could mislead towards too optimistic evaluations. To measure realistic reliability in the course of disruptions, one must represent the behavior of human dispatchers in planning tools as well.

Refs. [4], [7] give first insights into the incident handling in PT OCCs. While [7] describes the overall process of incident management in PT quite well but focusses on metro operations, [4] focuses on the technological enhancements in bus operations. However, in operations and planning further insights into the dynamics and processes of OCCs could help to improve the understanding of a PT system. This helps to improve its reliability as the process of dispatching offers potential for enhancements. Therefore, the goal of this paper is to give further insight into the dynamics and processes of PT OCCs based on the research done by [3], [4] and [7]; in particular by filling the gaps in research which we identify as 1) only single OCCs have been visited, 2) only one aspect of operations control has been addressed, 3) only one or few lines have been analyzed using planning tools, and 4) optimization algorithms have been used in planning tools which stand in contrast to human dispatchers as shown by [3]–[8].

III. Methodology

As shown in the previous chapter, only a few studies exist, which deal with this topic. Therefore, it is difficult to derive a common procedure for this research area from the literature. Because of this, we have used several ways to collect data. First, we conducted interviews with either a director or trainer of each of the visited OCCs. Second, we observed dispatchers during their work. Third, we studied

documentation of the OCCs. This way, the dispatching process is being illuminated from different perspectives.

A. Interviews With OCC Directors and Trainers

The objective of the interviews with OCC directors and trainers was to survey the planned scheduling process from the perspective of the supervisors. We conducted the interviews with the help of a questionnaire. The questionnaire follows the methodology described by [18] and is divided into several sections.

In the first section, the procedure of the OCC in case of an incident is discussed gradually. Special attention has been paid to the used equipment (tools and software), communication between the dispatchers, and the distribution of work among the dispatchers.

Then the term incident is defined. For the definition, the necessity of the available information is relevant, where this information comes from and how reliable it is. At the end of this section, the communication channels with the driver, as well as the duration between the occurrence of the incident and the arrival of the information in the OCC, are discussed.

Following this general definition of incidents, the next two sections deal with common and rare incidents. The interviewee is asked to name specific incidents and their frequency. In addition, the interviewee describes the decision-making process, possible actions as well as the duration from the notification of the incident to the first dispositive action. In the following section, we return to the general handling of incidents. It is discussed which information about the state of the network is available and how it is used.

The next section deals with the post-processing of incidents. The interviewee is asked how frequently and infrequently occurring incidents are documented beyond the legal requirements and which conclusions are drawn for the future work or the next timetable.

After the incident section, the next step is to look at the dispatchers' scope of action. The possibilities of the dispatchers at different times of day, at different locations, or during different system states (peak and off-peak hours) are in focus here. As ensuring connections is a hard constraint for dispatchers, its role is clarified.

According to [19], many general disposition measures are defined. These are adapted accordingly in the transport companies on their network. The next step is to ask whether dispatching measures are to be structured or categorized, for example in a catalog of measures. If such a catalog exists, the content and its usage is inquired. Finally, the usage of replacement vehicles and a shift to other modes is discussed.

When using external vehicles or shifting to other modes of transport, the communication with the operators of those modes plays a major role. For this reason, the next section deals with the communication between different operators within the same PT system and the communication with passengers. Finding out about what information is passed on to the passengers as well as what kind of information the dispatchers would like to add is the core goal of the questions about communication.

Based on the information the dispatchers require, suggestions in general will be discussed in the following section. This includes both the current way of working as well as additional information that could help them to enhance their work. At the end of the interview, the initial training and further education of the dispatchers is discussed.

B. Observation of Dispatchers on Site

The general process, as discussed with directors or trainers in the interview sessions, is one part. However, dispatchers must adapt the process to the current situation because every incident has its individual characteristics. Therefore, the observation of dispatchers provides insights into details of their actual work. The focus here is on the processes, scope of action, and decisions of the dispatchers. The deviations from the general process are of special interest because the adaptations reveal important differences between various disruption situations.

We chose the morning or evening peak hours as the observation period. Experience has shown that there is a higher chance for incidents to occur in these periods due to the higher passenger and traffic demand. During our observations, we were able to experience and document various small and large incidents.

The observations were conducted in the OCCs. We had the opportunity to sit directly next to the dispatchers and experience the dynamics and processes in OCCs closely. This allowed us to also observe the entire communication with the other parties involved, e.g. PT drivers, ground staff, or emergency forces, but also between the dispatchers themselves. With increasing traffic, the dispatchers were more and more challenged to keep operations in line and to manage the incidents. Due to the immediate vicinity, first conclusions could be drawn by observing the dispatchers at work. When the situation allowed to ask questions, the conclusions were clarified in cooperation with the dispatchers. In idle times, questions of the interview could be directed to the dispatchers. This revealed another view of the general process of dispatching. Some of the interview questions were thus connected to real situations which were already seen during observation.

C. Documentation of Dispatching Processes

Finally, the documentation about OCCs, such as dispatchers' manuals, has been studied. These are compared with the processes extracted by the interviews and observations, to ensure the correctness of drawn conclusions. OCCs use the documentation to train their dispatchers. During incident handling however, dispatchers rely on their training and experiences, as descisions need to be made immediately and adequately without delay. There is no time to consult the documentation.

IV. RESULTS

We conducted our research in OCCs of five cities of different size in Germany and Singapore. Our research took place in OCCs for buses and trams. In the OCCs we visited, four to about 30 dispatchers must coordinate about 150 to 3000 vehicles during peak hours. Depending on the size of the PT system, a single dispatcher must coordinate dedicated lines, or all dispatchers work together on all lines. In the latter case, the first available dispatcher takes an incoming driver's call.

A. Incident Management in Public Transport

The dispatchers working in the OCCs are the main "actors" of incident management in PT. They monitor the service and act whenever there is a derivation from the timetable. There are several kinds of dispatchers covering different areas of operations control. The dispatchers who do most of the monitoring and coordinative tasks are called general dispatchers in the following. They use intermodal transport control systems (ITCS) such as the one described by [4] to monitor the service. In modern PT systems, every vehicle is equipped with a global positioning system (GPS) and an onboard computer [5], [15], [20], providing for the complete timetable. The computer automatically notifies the driver if the actual arrival times at stops differ from the timetable. Most importantly, the computer includes a communication device to the OCC. Whenever a driver encounters an incident or needs assistance, he/she sends a call signal to the OCC. In most cases, a general dispatcher answers the call. Whenever a second general dispatcher is available, he/she assists the colleague who took the call, if necessary. In addition, the general dispatcher is supported by transport wardens, who are sent out to assist troubled drivers and collect details of an incident on-site. The step-by-step procedure between general dispatchers and the other parties involved is shown in Fig. 1.

Another dispatcher type is the human resources (HR) dispatcher. This type of dispatcher manages the staff. Depending on the size of a fleet, there are a lot of drivers, shifts, and vehicles which need to be coordinated, especially if drivers unexpectedly cannot take up or continue their shifts. These dispatchers are always in contact with the depots, especially if PT vehicles are reported as failing. Depending on the size of a depot or the level of its automation, there is an additional depot dispatcher who manages the depot. With the ongoing automation of the depots, employing a dedicated depot dispatcher becomes more and more redundant.

For communication with the PT users, most OCCs have an extra passenger information (PI) dispatcher. The main task of this dispatcher is to deliver relevant information to PT users. This is crucial when changes to the service occur, for instance, in case of an incident. The passengers need information about delayed, canceled, or rerouted services. To meet these demands, the PI dispatcher puts the information on the operator's website, smartphone apps, social media, and on PI displays in PT vehicles and at stops. In some cases, speaker announcements are also being used for information dissemination. Depending on the size of an OCC, one person fulfills one or several of these dispatcher roles or several persons cover the same role.

Most of the communication in an incident situation between the dispatcher and a driver starts with a call signal by the driver. There are four different types of call signals (Fig. 2): assault call, accident call, missing replacement call, and wish-to-talk call. The priority decreases from the first to the last mentioned. Due to the signal, the dispatcher answering the call already has an idea of what kind of situation is present.

All calls are answered by a general dispatcher except the missing replacement call, which is answered by the HR dispatcher. Whenever colleagues are available, they assist the answering dispatcher, if necessary. After a call has been ended and the incident is dissolved, the dispatcher documents the case in a reporting system. For future references, the dispatcher, driver, line, run, a description of the situation, and the taken measures are recorded.

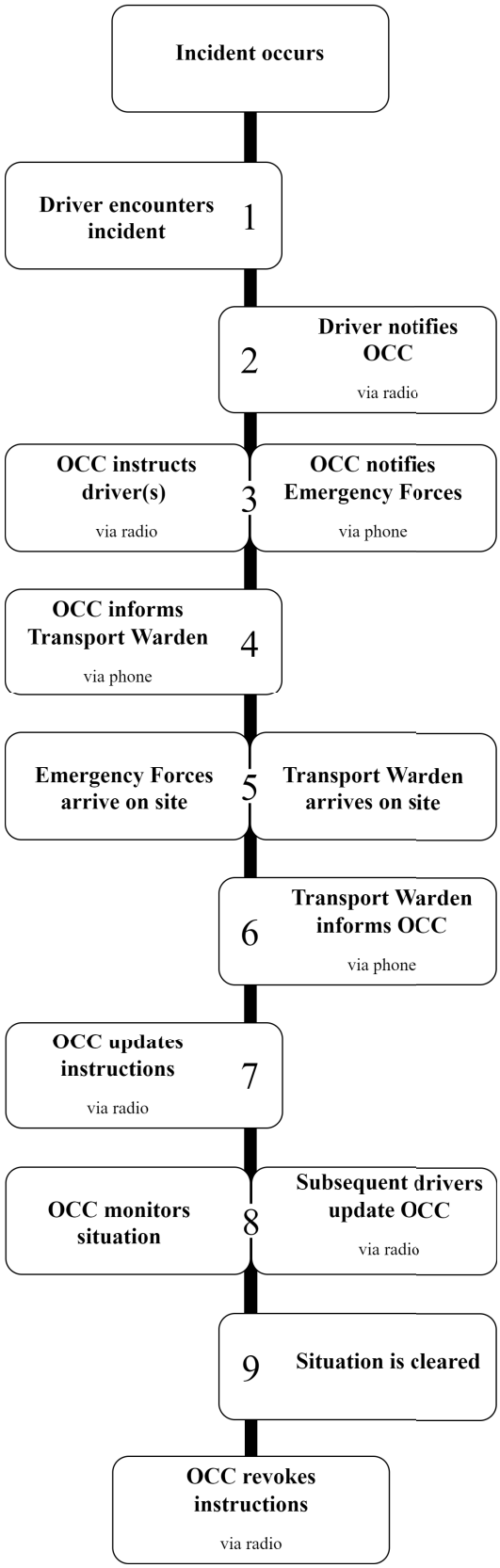

Fig. 1. Step-by-step reactions of an OCC to an incident.

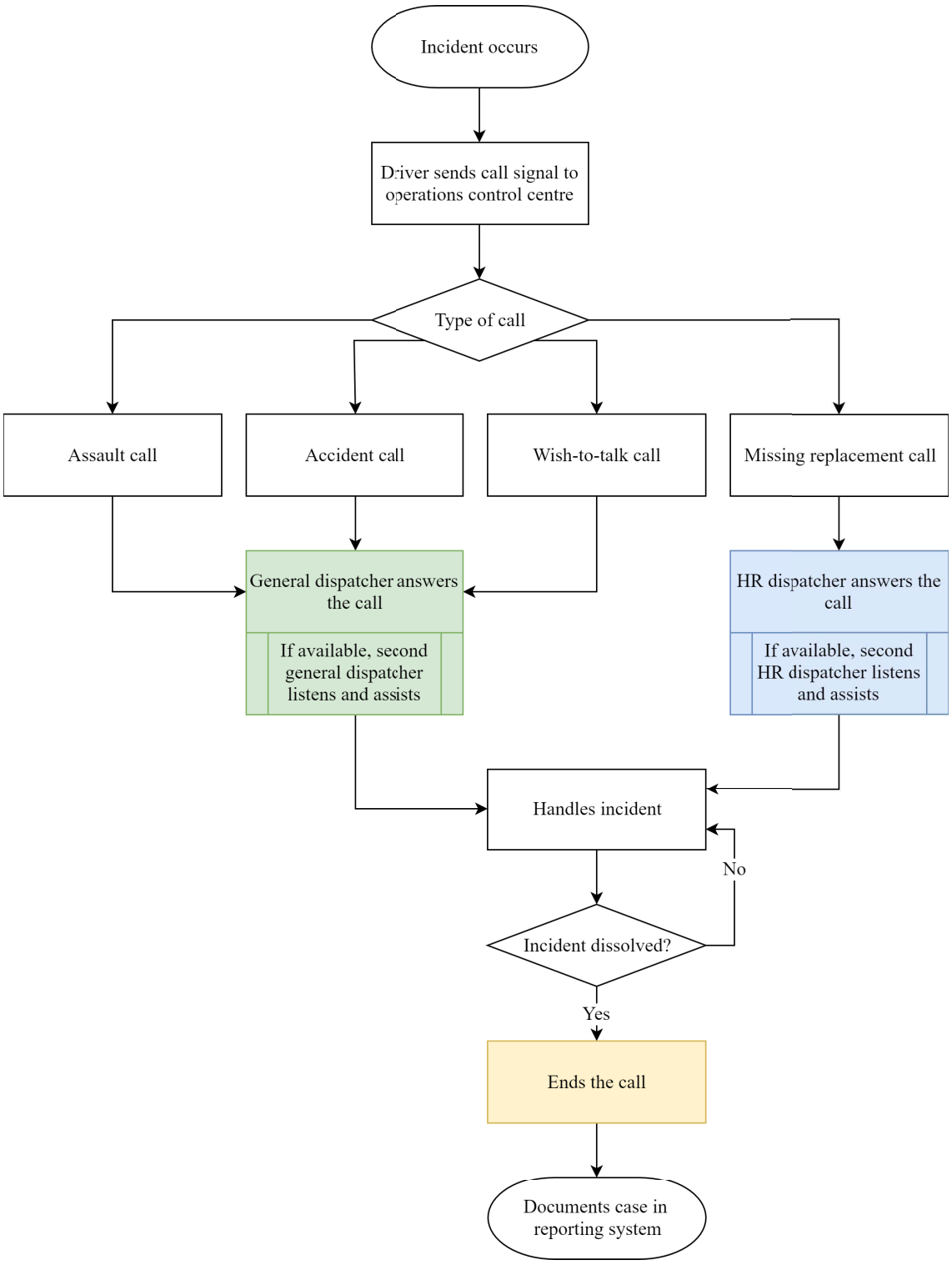

Fig. 2. Types of call signals from driver to OCC.

After a dispatcher has assessed an occurred incident, he/she takes measures to dissolve the incident as well as returning the service to normal operations. Therefore, several measures are at hand. In addition to measures such as calling an ambulance, the police, or a towing service to dissolve the incident, the dispatcher uses operational measures to readjust the service back to the schedule. Typical measures are holding, stop/section skipping, deadheading, short turning, line splitting, rerouting PT vehicles or lines, deployment of standby busses, deployment of external vehicles, or establishing a rail replacement service. For a more comprehensive and detailed description of operational measures, we refer to [2, pp. 595-612], [19], [21].

This paper does not focus on the measures themselves but the dynamics and processes taking place in OCCs and how dispatchers handle incidents. Therefore, the following chapters

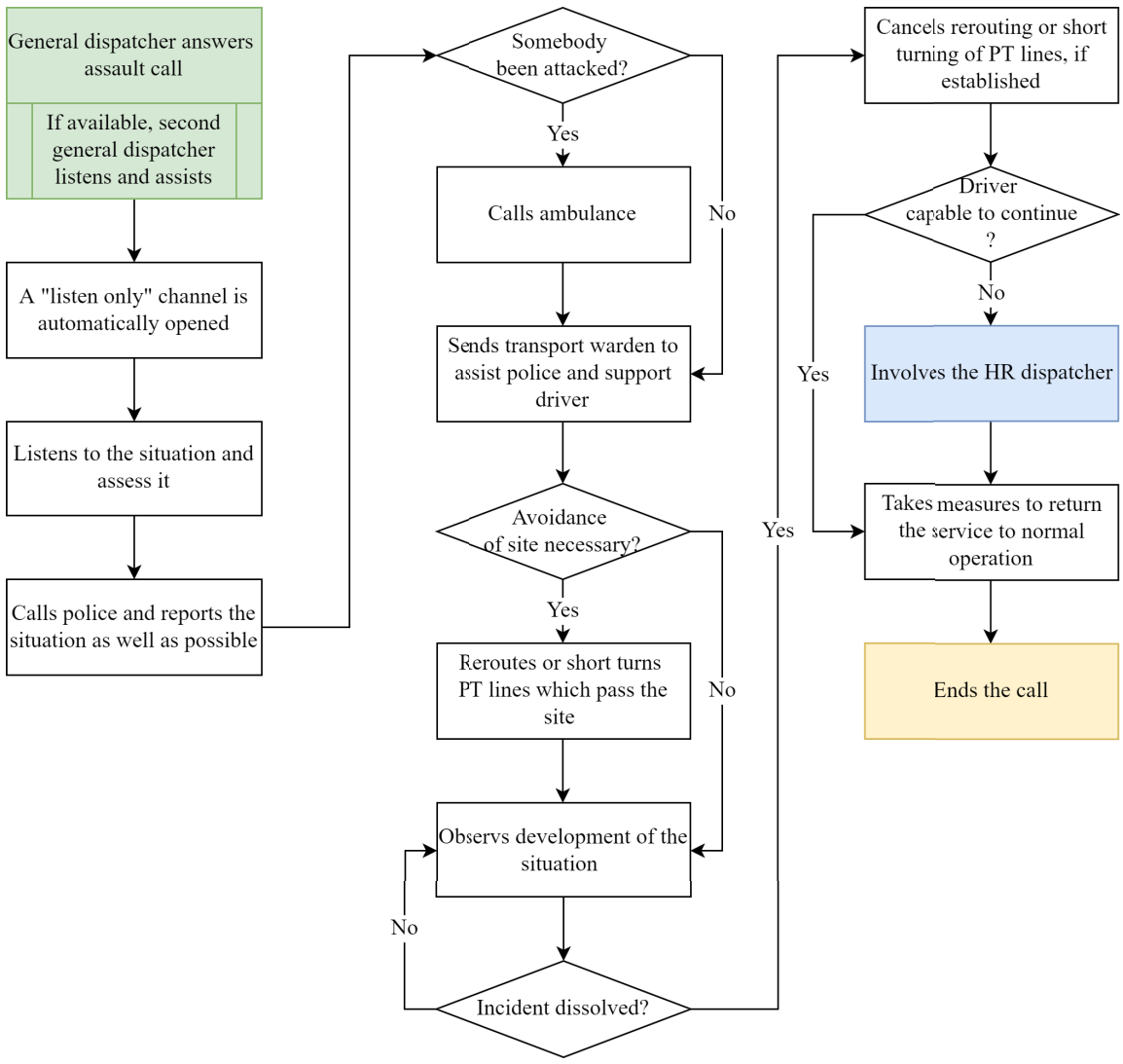

Fig. 3. Assault call.

describe in detail the procedures for the four call signals mentioned.

B. Assault Call

The assault call (Fig. 3) is used when a person assaults a driver or passenger. Since this kind of situation has the potential to escalate and the safety of the driver and passengers might be at risk, this call has the highest priority. When the dispatcher answers the call, it automatically opens a ”listen-only” channel to the dispatcher so he/she can hear anything that is happening on the PT vehicle. The dispatcher’s first task now is to call the police and report to them the situation as precisely as possible. The quicker and better informed the police arrive at the scene, the higher the chance that the situation can be dissolved quickly without anyone getting hurt.

If the dispatcher hears anything that suggests a physical attack on the driver or passenger, the dispatcher calls an ambulance. As a second step, the dispatcher sends a transport warden to the PT vehicle to assist the police but, more importantly, to support the driver. These assault situations cannot just physically harm a driver but also burden him/her psychologically. The transport warden assesses the situation and updates the dispatcher about the situation. It is also essential to consider whether the driver needs a replacement or not, depending on the driver’s physical and psychological state. If a replacement is needed, the general dispatcher involves the HR dispatcher. It goes without saying that the general dispatcher stays with the case until the police de-escalate the situation and take care of the assaulter.

While the police are focusing on the de-escalation of the situation, the dispatcher must examine the impact on other vehicles passing the site of the incident. In extreme cases, it is necessary to reroute or short turn following vehicles of the according lines. After the dissolution of the assault situation, when the driver is capable of continuing the service or was replaced by a colleague, the dispatcher takes actions to readjust the affected service to its schedule.

Such assault situations can cause severe delays depending on how long it takes to de-escalate them as well as on the type of the disrupted service. In bus operation, for example, it might only lead to the blockage of one-stop, the location of which can easily be shifted temporarily forward or backward.

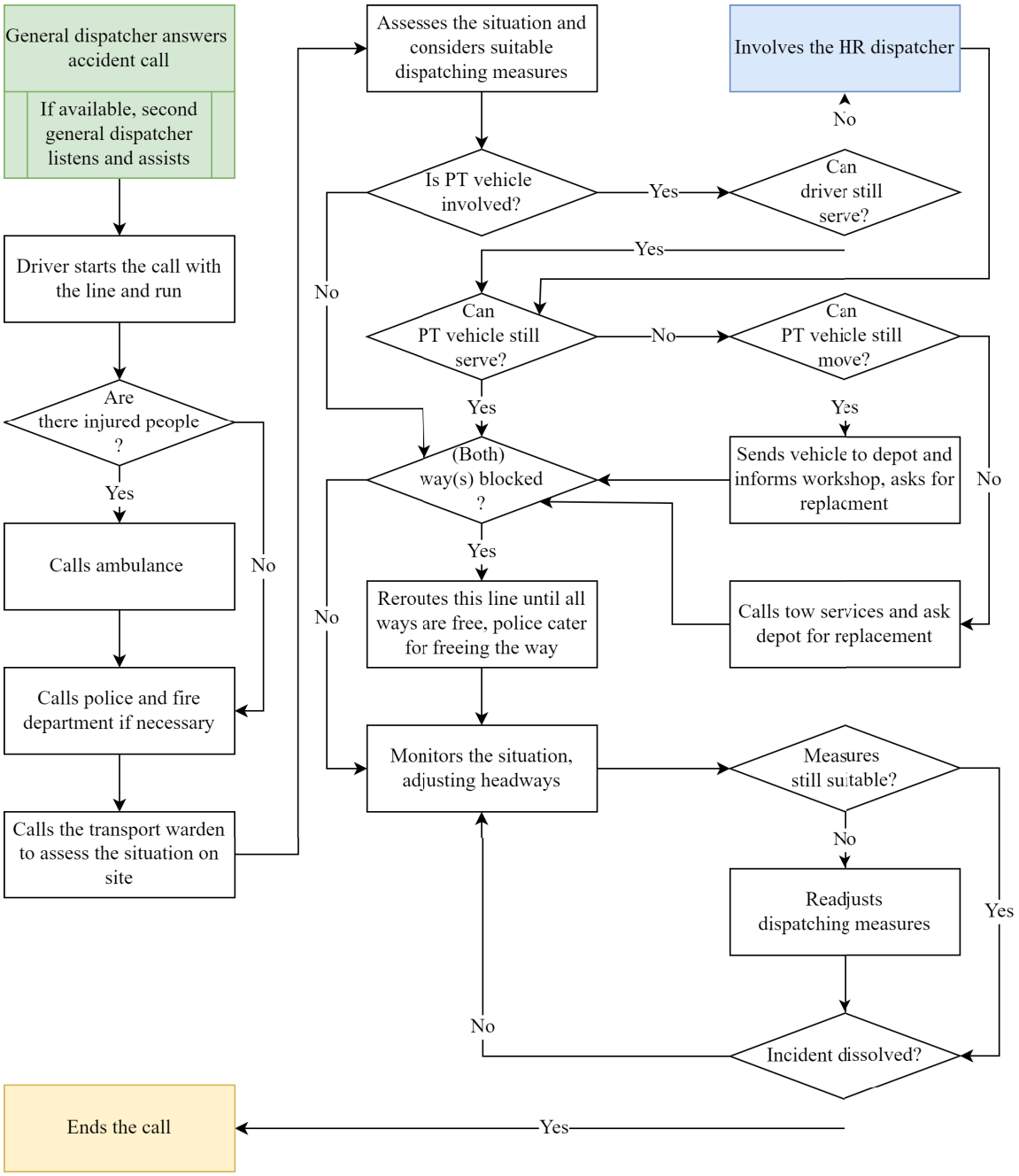

Fig. 4. Accident call.

Following buses can still serve the stop and the impact on travelers is rather low. In rail-bound services, such as trams, an assault situation can have a more severe impact on the PT service and thereby the PT users. E.g., the affected train blocks the track and following trains are not able to pass it or even worse, the section might be single-tracked. In these cases, it takes time to return the service to normal operations and the delays of travelers are rather severe.

C. Accident Call

Accidents can easily cause injured people who need to be taken care of immediately. Therefore, the dispatcher asks first about the number of injured people to call ambulances accordingly (Fig. 4). The dispatcher also calls the police and fire department if necessary. In case of a very severe accident or a situation that is hard to assess, the dispatcher sends out a transport warden. The transport warden supports the driver and observes the situation on-site, to support the dispatcher assessing the situation more detailed. He/she also communicates with the emergency forces on-site to help to dissolve the accident and its impact on the PT service as fast as possible.

Now; the question how strongly the PT vehicle is involved in the accident and how severely the service is disturbed must be answered. In case a PT vehicle is involved, it is first checked whether the driver is still capable of doing his/her duty. If not,

an HR dispatcher is involved to find a replacement. In case the driver is still capable of serving, the focus of the dispatcher moves onto the PT vehicle and its suitability for service. If not, one must clarify whether it is still roadworthy or not. If it is, the driver or the replacement driver drives it into the depot and the dispatcher informs the depot staff accordingly. If this is not the case, a towing service is ordered by the dispatcher to free the road from the PT vehicle. This kind of situation makes it very clear that it is not only a dispatcher's job to monitor the PT service and make sure that it is on schedule but also to manage a variety of situations and challenges.

No matter if a PT vehicle is directly involved in the accident, the dispatcher asks the driver or transport warden about the impact on any PT lines which might be affected by the accident. In the case of rail-bound services, it is crucial to find out if the track section involved in the accident is blocked and whether it is single- or double-tracked. If a tram is involved and damaged, it is also important to know whether the accident happened close to a side-track onto which it can quickly be moved.

These cases are easier in bus operations due to the flexibility of busses, which can simply pass most accidents or take a parallel side road. Nevertheless, during our observations, we experienced several incidents in which a road blockage forced even busses to wait for the dissolution of the incident. In case of a blocked single-tracked tram section, the dispatcher tries to reroute the tram line if the network provides for according options. If this is not feasible, it is examined at which stops a split of the line is possible, meaning the line is short turned on both sides of the accident. Depending on the severity and the expected duration of the accident, the dispatcher will establish a rail replacement service [22].

In case the way is blocked for a bus line, it is usually rerouted. This is only reasonable if an appropriate alternative route exists. Here, it is crucial that the detour does not cause too much delay and that as few stops as possible are skipped. The travelers who are waiting at such skipped stops need to be informed accordingly. The PI dispatcher broadcasts such information on the aforementioned channels.

Most accidents block just a part of the road, and bus services can still pass the accident site and continue their trip with a short delay. In any case, the dispatcher instructs all drivers of the affected PT lines to report to him/her the current state of the accident and the road blockage. In case of rerouting, the drivers report to the dispatcher at the last stop before the beginning of the alternative route to check if the rerouting is still on and whether the alternative route has been changed or not. Once a driver reports the dissolution of the blockage, the rerouting, if it has been established before, is canceled and the dispatcher takes measures to readjust the service to the timetable.

D. Missing Replacement Call

The missing replacement call is the only call that is not answered by a general dispatcher but by an HR dispatcher (Fig. 5). Most calls start with the driver naming his/her line, direction, and location, so the dispatcher has a better understanding of the situation and can open the according information in the staff management system. Since this call is initiated by a missing replacement call request of the driver, the nature of the situation is already clear. The dispatcher then asks about the stop at which the driver is supposed to end his/her shift and hands over the PT vehicle to a colleague.

When an HR dispatcher answers a missing replacement call, he/she can check the staff management system for the missing driver, whom he/she calls immediately to find out if the driver is indeed missing or just too late for the shift. If the driver is just delayed, there is nothing more to do for the dispatcher besides arranging a new location for the handover if the delay is too large for the PT vehicle to wait.

The situation gets a lot more complicated if the replacement driver is indeed missing. By law, PT drivers are only allowed to drive a certain amount of time per day in total and in one piece. Therefore, the dispatcher asks the driver how much driving time he/she has left. If there is enough time left to finish the current run, the driver will do so. The dispatcher now has time to look for an alternative replacement driver to take over.

In case there is not enough driving time left, the dispatcher checks for a standby driver with a standby bus who can take over the run immediately. If this isn't possible either and there is no alternate driver, the dispatcher asks the driver on the call to continue the run as long as possible until he/she lets the passengers alight the vehicle at the last possible stop before he/she moves into the depot. If the dispatcher is able to organize a replacement driver before the next run starts, the handover is arranged accordingly. Otherwise, the dispatcher tries to get a PT vehicle with a driver from another PT line with low demand for the disturbed line to arrange at least a minimum service coverage. This is mainly done in road bound PT services, due to their flexibility. Afterwards, the dispatcher ensures that the service can return to normal operations with the start of the next shift by calling the according driver.

Yet, in case there is a standby driver with a bus available to jump in and replace the calling driver, they meet along the run and switch vehicles on site. The calling driver can then use the standby bus to move into the depot and end his/her shift, while the standby driver ends the run. In the meantime, the dispatcher tries to organize an alternate replacement driver to take over at the terminal to do the subsequent run. If no driver is available, the standby driver takes over for as long as there is no alternate replacement or his/her legal driving time or shift ends.

During that time, the standby driver is not available for other situations, which can increase the severity of following incidents and lowers the PT system's resilience. In this case, again, the dispatcher ensures that the service can return to normal operations during the next shift of this line. If there is indeed an alternate replacement driver available, he/she takes over the vehicle at the terminal from the standby driver, who then can return to his/her standby post with the original standby bus.

E. Wish-to-Talk Call

The last category of calls is the wish-to-talk call (Fig. 6 – 8) which has the lowest priority. It is also the most versatile call, as it is used for every situation not covered by the previous three types of calls, including situations where actually no incident occurred. Thereby, it is first checked whether the current situation is indeed an incident or not (Fig. 6). If not, the dispatcher asks for the reason for the call and tries to help

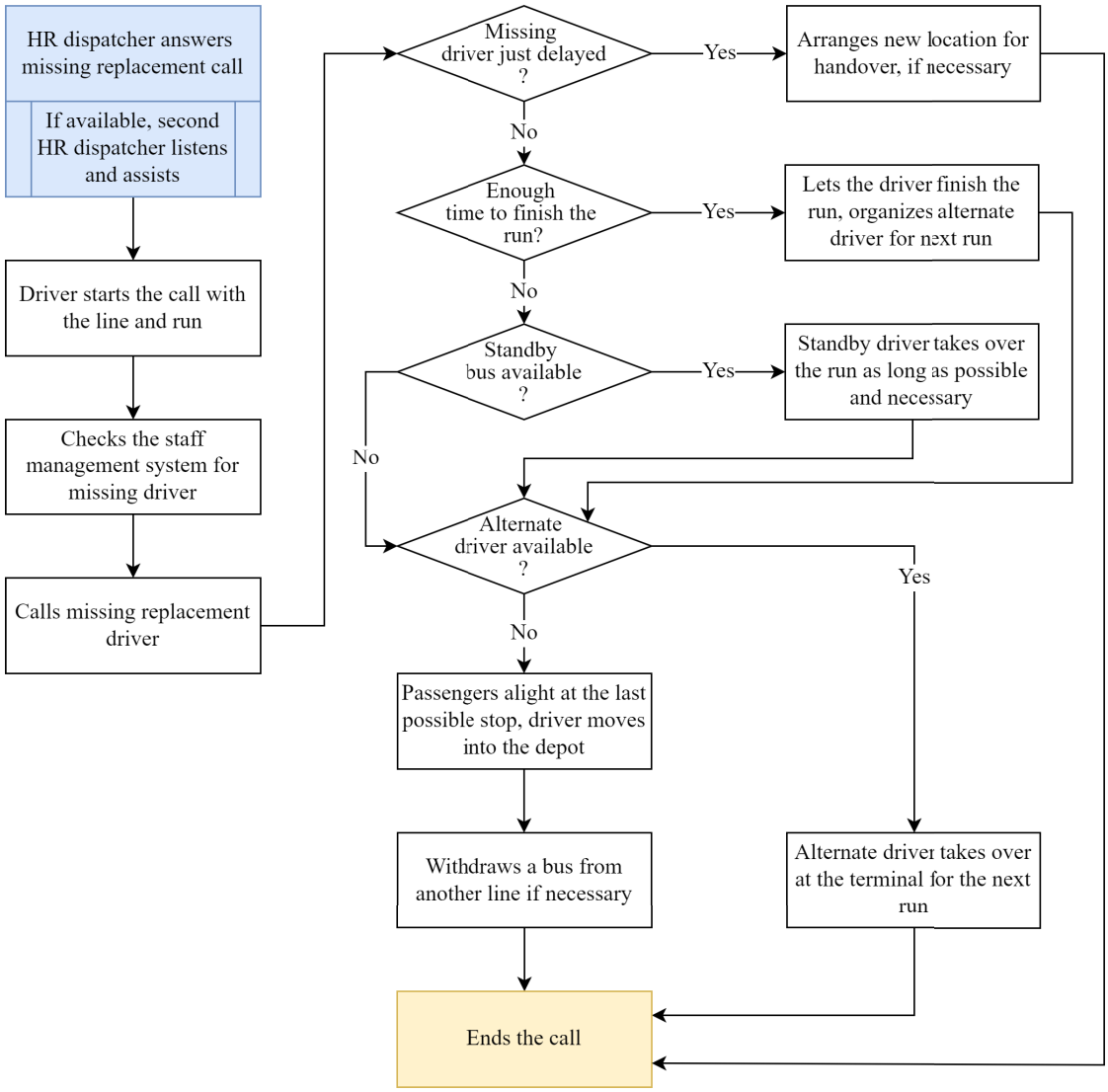

Fig. 5. Missing replacement call.

the driver accordingly. In many cases, the driver just needs certain information. Sometimes it is merely used to report a situation, as dispatchers document every call in the reporting system.

If an incident has occurred, it is to be differentiated between four kinds of issues, namely: personal, delay, technical, or traffic-related issues.

1) Personal Issues: Personal issues are incidents in which the driver him-/herself has an issue with the potential to disturb the PT service, e.g. a health issue (Fig. 7). First, it is to be asked whether a replacement is needed to hand over the call to the HR dispatcher. After clarifying the replacement question, the next question arising is if a break is needed. Often it is enough to point out that the driver has sufficient time to take a break between the current and the next run. In case the driver needs a break straight away, the dispatcher tries to fit the break into the schedule. If this is not possible and the reason for the break is urgent, the dispatcher checks whether it is possible to send a standby bus to take the run over. In these situations, the drivers sometimes switch roles: The standby driver takes the rest of the issued driver's shift or finishes it when this shift is about to end. Then, the standby driver returns to his/her standby post to wait for the next deployment. If this is not an option either and the driver still does not want a replacement, the dispatcher tries to help the driver as well as possible and afterward ends the call.

2) Delay Issues: Another kind of issue covered by the wish-to-talk call are delays. Through AVL, the OCC and the drivers are notified about the current delay. The system informs them by a color code whether a run is on time, ahead of its timetable, slightly delayed or strongly delayed. Normally, the dispatcher notices when a run builds up a delay and calls the driver. The other way around also happens when the dispatcher is preoccupied due to other occurred incidents. Especially smoking drivers or drivers at shift ends are sensitive to delays and ensure their break or shift end is on time, even if this means to drive faster or ask for the possibility of deadheading.

Deadheading is a dispositive measure in which a driver asks all passengers to alight at the next stop and drives with an empty PT vehicle to the terminal, skipping all intermediate stops to ensure in-time deployment for the next run. When all runs of a certain line are delayed, the dispatcher discards the

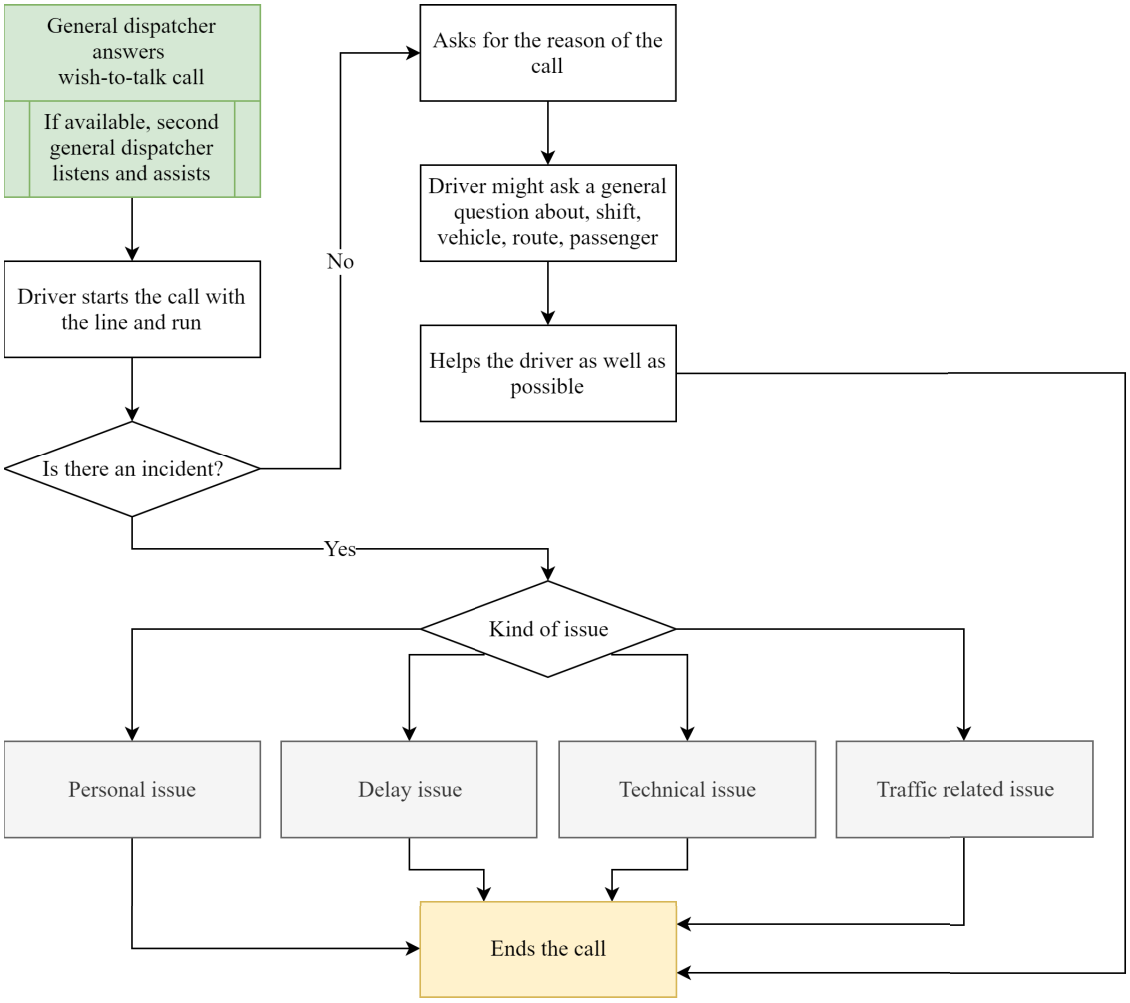

Fig. 6. Wish-to-talk call–Kind of issue.

timetable but tries to keep the scheduled headway. If all runs of a certain line are delayed by the scheduled headway of the line, the line is on time again from the passengers' perspective and only the first delayed run is perceived as delayed.

If only one run is strongly delayed, measures are considered, or the driver is told to continue the run. Depending on the delay and position, the driver may be told to call again at a certain stop for a reassessment. If the delay is already severe, it is checked if the following run is catching up and causing bus bunching. If not, the driver is told to continue and call again as aforementioned. If the following run is catching up, the occupancy of the vehicle is checked by either calling the driver or checking the automatic passenger counting system, if available. Drivers carrying many passengers in their vehicle are told to continue the run and call again at a later stop. If there are just a few passengers, the driver is told to let the passengers alight at the next stop to take the following vehicle and to short turn or to deadhead. This enables the driver to reduce the delay. Since this means a high level of inconvenience to the passengers, it is only considered if the delay is bigger than the time the next run starts.

3) Technical Issues: The third category refers to technical issues (Fig. 8) of the PT vehicle or the infrastructure. Issues of the infrastructure cannot be solved through measures taken by the OCC. Therefore, the dispatcher sends out ground staff to investigate and ideally solve the issue quickly. The driver can often solve issues of the vehicle. Hence, the dispatcher first supports the driver with a remote diagnosis and advice on possible solutions. This is only feasible with minor issues such as malfunctioning doors where sometimes simple "driver's tricks" can solve the problem. In case the issue is solved, the call is ended. Otherwise, the dispatcher sends the transport warden to solve the issue. If this is necessary, it is always checked whether the vehicle itself needs to be replaced. Depending on the broken part of the vehicle, the issue takes longer, or the vehicle must be sent to the depot. In such cases, a replacement vehicle is dispatched, if available. A broken-down vehicle can cause additional issues when it is blocking the way; this is especially true for a broken tram.

4) Traffic-Related Issues: The last category of issues covered by the wish-to-talk call concerns traffic-related issues. Traffic accidents are not the only traffic-related situations, which can disrupt PT operations. Nonetheless, it is first confirmed if it is an accident, which means it is then handled as such. In some cases, a driver sends the wrong call signal because he/she is burdened by a traffic accident situation or he/she is not sure if the accident is severe enough to justify an accident call that has a higher priority than the wish-to-talk

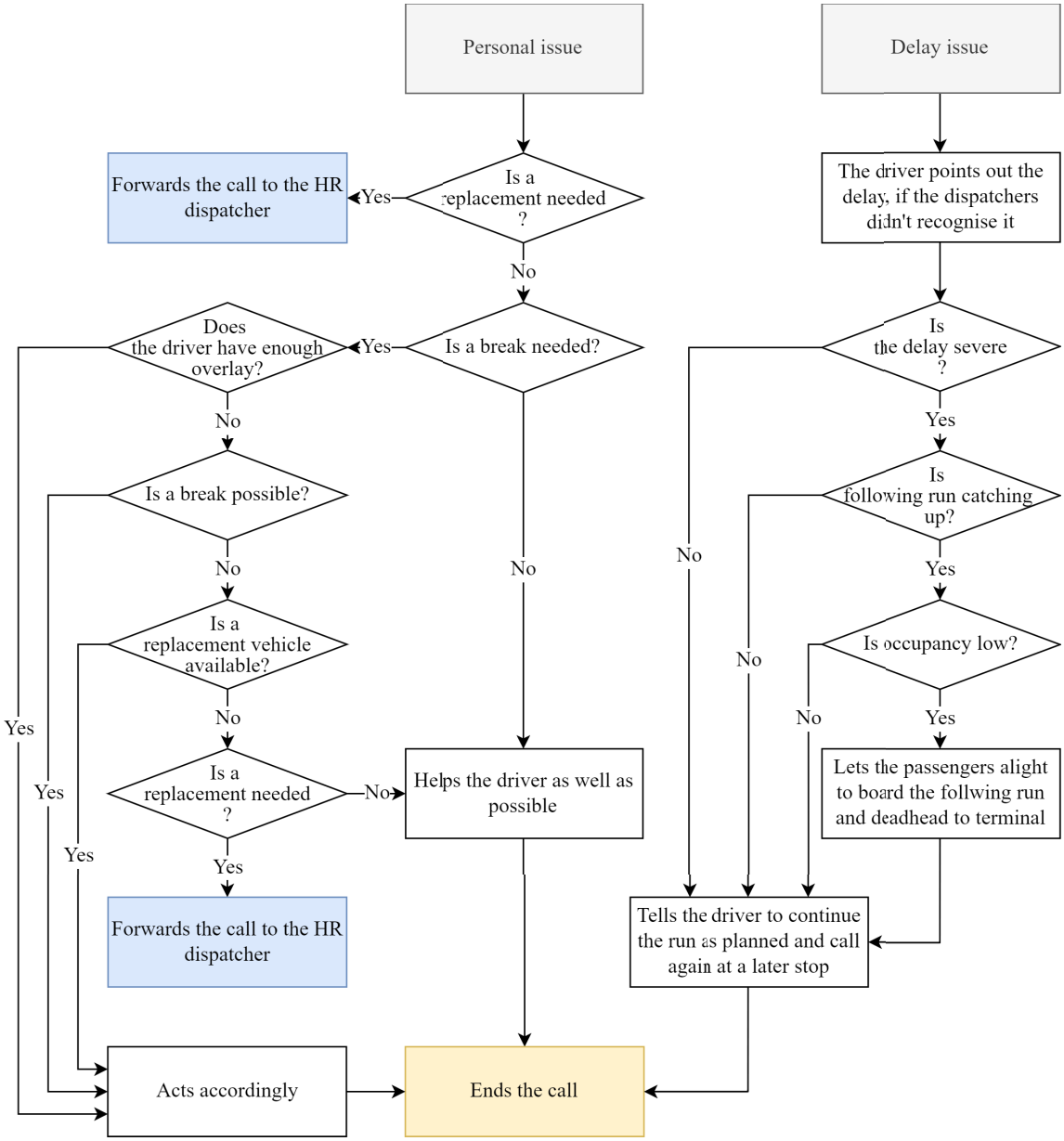

Fig. 7. Wish-to-talk call–Personal and delay issue.

call. Even if traffic accidents are not the only traffic-related situations that can disrupt the PT operations, it is always necessary to make sure that the incident is surely not caused by an accident. In most cases, the traffic-related issues are not an accident situation but traffic congestion, parking offenses, or police deployments that block the way in one or even both directions.

Whenever a tram track is blocked, the situation is more challenging. If the way is blocked and the situation seems to last for a longer time, the dispatcher tries to temporarily reroute the affected PT line. In bus operations, this is rather easy. The decision if the line is rerouted depends on the available detours and the estimated duration of the incident. In tram operations, the drivers are often told to first wait in front of the last track switch before the incident site and then call again to reassess the situation for each tram individually. Depending on the situation, the dispatcher might also split the line apart and establish a bus bridging service. Again, the dispatcher monitors such a situation by telling all drivers to inform the OCC when passing the incident site. In such severe cases, a transport warden is sent to the site. Once a blockage dissolves and traffic runs again freely, the dispatcher cancels all taken measures and tells all drivers of the according line to continue the service as scheduled.

Especially this call makes it obvious how comprehensive and versatile the job of dispatchers is and how much responsibility lies on them. They are the backbone of the incident management of PT services.

V. Discussion

The here presented investigation clearly reveals that the practice of incident management in PT is a vast and diverse topic and too complex to be presented completely in detail, as also shown by [3], [4], [7]. Therefore, the focus of this

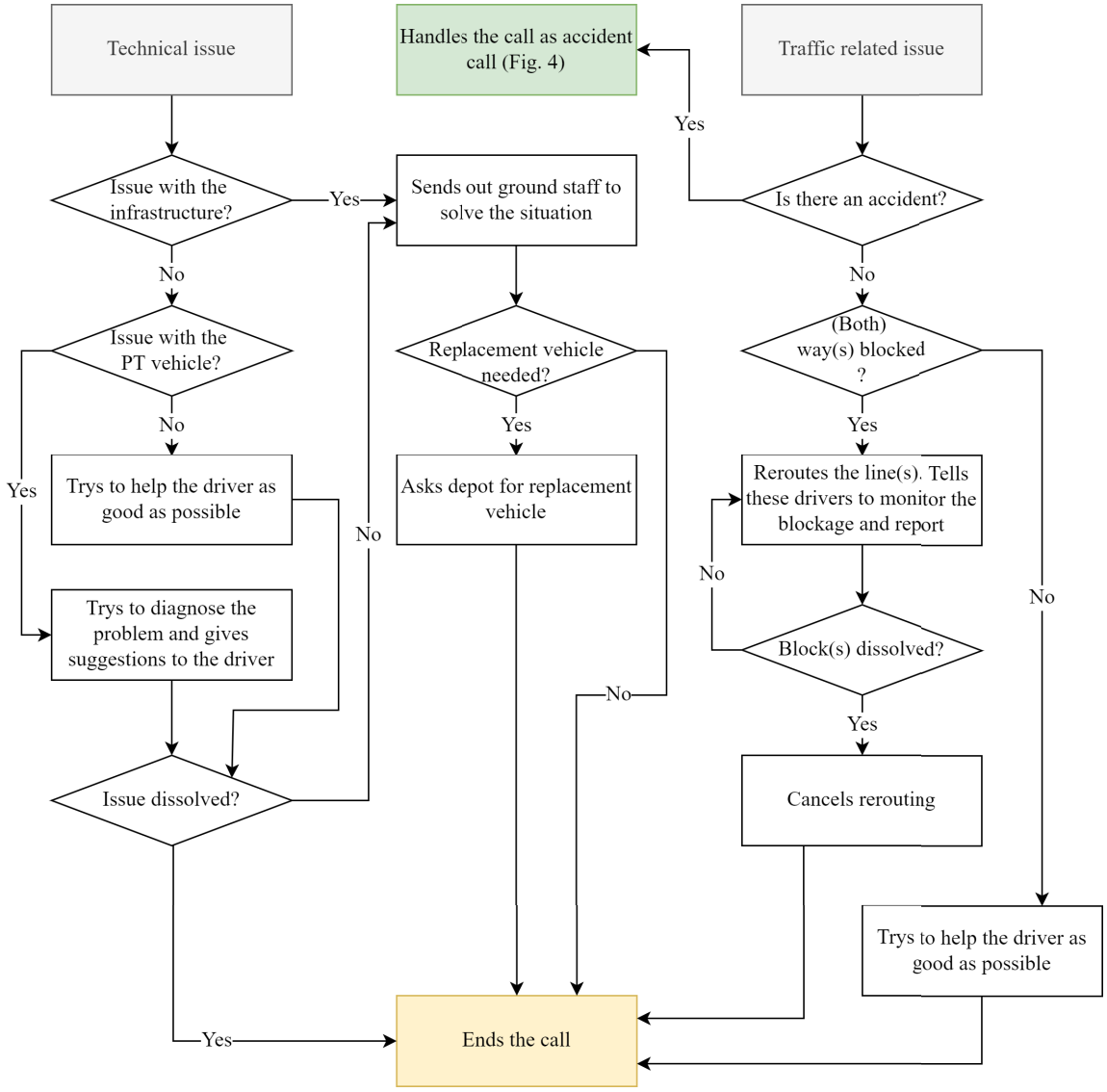

Fig. 8. Wish-to-talk call–Technical and traffic related issue.

study lies on the processes conducted by dispatchers during incidents and the dynamics in OCCs. This paper gives further insights into the practice of incident management.

Through the results, several aspects of incident management have been addressed and will be further discussed in this section, namely: Advantages and disadvantages of the used methodology, similarities and differences among the types of calls, similarities and differences between operations in Germany and Singapore, as well as potentials and recommendations.

A. Advantages and Disadvantages of the Used Methodology

As a first step, we conducted an interview with an OCC director or trainer of each visited OCC. The interviews catered for a general understanding of the daily processes of OCCs and the procedures after the occurrence of an incident in PT operations. As this insight helped a lot in understanding proceedings, the method of interviewing is highly recommendable when investigating the dynamics and processes in OCCs.

As a second step, we observed dispatchers during their work for several hours. Whereas the interviews gave a good understanding of the general procedures and approaches to incidents, the observations revealed details about the challenges which dispatchers face every day, for example, when deciding on how to react to a certain incident. Many factors influence dispatchers' reactions to an incident, namely: its location, its time of the day, which weekday, which type of transport, which type of incident, etc. Some of the processes were planned; others evolved through work conduct and work habits by experienced dispatchers. Since the observations always followed the interviews, we already had a good understanding of the operations of each particular OCC and it was possible to focus on details and differences between the reactions to various incidents.

Both the interviews and observations are the basis of the creation of common procedures, depicted in the presented flow charts (Fig. 2 – 8).

As a third step, the outcomes of observations and interviews were compared to manuals and other documentation provided by some of the visited OCCs. These supported the understanding as well as ensuring the correctness of the findings of the first two steps.

The here presented methodology worked well for the purpose of this research. The purpose was to gain a profound understanding of the practice of incident management in PT. However, it would have been an advantage to look at operational documentation, such as manuals and reports, describing the dispatching measures of the OCC, before conducting the interviews and observing the dispatchers. In that way, the questionnaire could have been further adjusted based on documentation, especially in terms of the order of questions. As we had no access to the documents beforehand, we dynamically changed the order of questions during the interview, according to the interview's development. The findings during the observations were clarified after the observations. Nevertheless, due to the preceding interviews, the general processes were already clear, and we could concentrate on specific situations and deviations from the general procedures during our observations of the dispatchers. We, therefore, recommend preparing such observations by taking interviews and/or studying documentation beforehand. The ideal order would be 1) study documentation, 2) carry out interviews and, 3) conduct observations.

As already pointed out by [7], the observations of the dispatchers give additional information on how they handle specific situations. These reveal a lot of insights and reasons for disruptions and according dispositive decisions, which are missing in the interviews with the OCC directors or the documentation. We can therefore support the hypotheses of [3], that interviews with dispatchers are an appropriate method to gain insights into incident management. However, the additional observations of dispatchers during their work are highly valuable to understand the dynamics and processes in OCCs in depth.

B. Similarities and Differences Among the Types of Calls

The procedures of dispatchers in PT OCCs are divided into four different calls according to the kind of incident or arisen situation. The general dispatchers answer all calls but the missing replacement call, which is the HR dispatcher's job, who solely focuses on staff management. This is in line with [7], who state that crew management is one of the most complex parts of a dispatcher's job.

As [7] already pointed out the existence of internal and external influencing factors, the four types of calls can also be categorized as external and internal matters. The missing replacement call and the wish-to-talk call handle mainly internal matters, which emerge on the operational side. However, the wish-to-talk call is more versatile since a variety of matters is handled through this call. This is due to the fact that this call signal does not clearly indicate the nature of the issue but is rather a collection of issues. Therefore, the call is further subdivided, namely: personal, technical, delay, and traffic-related issues.

The personal and technical issues are purely internal and handle problems of the driver, the vehicle, and the infrastructure. The delay issue is also an internal operational matter because it focuses on the reaction to delays rather than on the origin of the delay, which might have been caused by internal or external influences. Only the traffic-related issue is mainly an external issue that is used to report traffic congestions and other unusual traffic-related matters.

The remaining two types of calls, assault and accident, are mainly about external matters, meaning they occur because of external influences on the PT service. In the assault call, a person is harassing a driver or passenger and the accident call is about traffic accidents in which a PT vehicle is hindered by, involved in or even caused an accident. In the latter, it is arguable if it is an external matter.

Even though there are differences between all calls, they all start with a call signal sent by PT drivers and are followed by the drivers immediately naming their line route and location, unasked. The only exception here is the assault call, which automatically opens a one-way channel from the driver to the dispatcher, so the dispatcher can listen to what is going on in the vehicle. The dispatcher has to find out as much as possible about the present situation by merely listening to whatever the microphone in the PT vehicle picks up.

After the channel is open, the next step is to call emergency forces (e.g. police, ambulance, fire department) according to the situation. The same goes for the accident call after the line, route and location are clarified, the number of injured people is communicated, so this information can be given to the emergency forces. For both calls handling external matters, the first main task is to provide for necessary details needed by emergency forces and manage the situation with them. After the emergency forces have been informed, the necessity and availability of a replacement driver and/or vehicle is checked. Even though the causes might be very different, each type of situation can cause delays or even cancellations of services.

C. Similarities and Differences Between Operations in Germany and Singapore

With Germany and Singapore, OCCs of two very different countries in culture, size, and population density have been visited. It can therefore be expected that there are also differences in the PT operations. However, this was not the case for most situations. In all visited OCCs, surface operations have been monitored; all of them monitor bus operations; some also tram operations. Therefore, the characteristics of the PT service operations are very similar. Whenever PT drivers encounter an incident, they start the call by sending the dispatchers an according call signal.

In this respect, one of the observed differences is the lack of a missing replacement call signal in Singapore. The missing replacement call and the HR dispatcher were only to be found in Germany. This could be explained by differences in staff management and operations. In Singapore, driver's shifts start and end at terminals. In Germany, drivers are often on duty for as long as they are legally allowed to drive, and the handover happens during a run. In order to facilitate this replacement strategy, the driver taking over needs to be at a certain stop at a certain time, which makes the handover more complicated compared to the Singaporean way. This is a possible reason why there is an HR dispatcher in Germany but not in Singapore. What the HR dispatcher mainly does in these situations is to check the staff management system about available drivers to arrange for replacement drivers.

The largest differences in terms of taken dispositive measures, however, have been observed between road- and rail-bound services rather than between different OCCs, cities, or countries. This is mainly due to the restrictions that go

together with the special infrastructure of railways. Such restrictions on flexibility dictate the dispatchers to rather use short turnings than rerouting measures, for example.

In general, operations are done very similarly in the examined PT systems; logically, since the objectives and resources are comparable. The observed operations also fit the descriptions of [2, pp. 617-668], [4], [7]. This supports the assumption that the basis of PT operations and incident management is similar in PT systems with comparable objectives and resources. However, these investigations were all conducted in well-developed PT systems; more differences may appear in less-developed systems.

D. Potentials and Recommendations

Through this investigation, two areas with potentials for improvement have been identified, namely: operations and planning. The area operations can be further subdivided into communication and automation in this context.

1) Communication: The communication in OCCs can be improved in three ways: First, the internal communication between dispatchers and drivers could be improved. Incident situations can be very challenging for drivers and dispatchers. Consequently, the level of communication between these two parties can be challenging. The better the communication is, the better the dispositive measures and, therefore, the better the resilience of the PT system.

During our observations, we encountered several incidents during which dispositive measures were delayed or skipped due to misunderstandings between dispatchers and drivers. Disruptive situations such as incidents make communication more difficult and result very often in misunderstandings. Even though dispatchers have special training in communication, this investigation shows that further adjusted communication classes for drivers and dispatchers could improve incident management. This is especially relevant considering the demanding situations which they are confronted with during their daily duty. Good communications are crucial in today's incident management.

Another aspect here are language barriers. As operators very often have difficulties in finding enough drivers, they hire drivers from foreign countries whose command of the language spoken is not sufficient or even poor, thus causing even more misunderstandings between the drivers and dispatchers. This could either be solved by specific language training for the dispatchers and/or drivers, which would be rather demanding. Another thinkable solution could be to use the existing equipment as support. Modern PT vehicles are equipped with an onboard computer. These computers are used by the driver for routing, displaying the timetable, and sending call signals to the OCC. Possibly it could also be used to display translated subtitles of the conversations with the dispatchers to the driver. This could work only when the vehicle is standing still. In the reverse direction, the ITCS system could display translated subtitles to the dispatchers. Moreover, changes in route courses due to incidents are transmitted verbally via radio today. Such route changes could also be transmitted as navigational input onto to the display of the driver's onboard computers, such as in navigational systems for private cars. Before installing such an approach, legal issues must be clarified.

Second, external communication with emergency forces shows potential for enhancement. Especially during the two types of calls, which focus on external matters, namely the assault and accident call, emergency forces are mandatory. The flow of information about the location and severity of situations is transmitted via the dispatchers (Fig. 1). Here again, extended use of the onboard computers could be helpful. Taking, for example, the situation of an accident call, the question about the number of injured people could appear on the driver's on-board computer display with some answer options, directly after the driver sent out the accident call signal. Together with the number of injured people, the GPS location of the PT vehicle could directly be sent to the emergency forces to immediately dispatch ambulances.

Third, the communication between the OCC and the passengers could be improved. Based on this investigation, the PI includes real-time departure times and information about the occurrences of incidents, meaning their location and their effect on the PT system in terms of delays and cancellations of services. Moreover, this only happens when the changes are put into the ITCS by the general dispatcher, which still often happens manually since every incident has its individual characteristics in location, time, and possible dispositive measures. In most of the visited OCCs, there is an extra PI dispatcher who is responsible for informing the passengers accordingly. This dispatcher ensures that the PI is up to date and contains information about occurred incidents. If necessary, the PI dispatcher adds information on the operator's website, social media, PI displays at stops and in PT vehicles, on PT smartphone applications, and arranges for speaker announcements. By listening to the other dispatchers and their communication with the drivers and emergency forces, as well as monitoring the ITCS, the PI dispatchers gather the needed information. Based on the given information, the passengers are then expected to re-plan their PT trip if their original plan is influenced by an incident.

As suggested by [23] and [24], such passengers affected by an incident could be supported in such situations by providing them with route suggestions. In this way, they reach their destination with a minimum delay, whilst a secondary incident through overcrowding is avoided. With clear instructions, fewer passengers will probably get stuck at the incident site since they have been redirected beforehand. In addition, if it is clear which alternative routes are taken by affected passengers, it is also possible to reallocate PT vehicles accordingly, to optimize the dissolution of an incident and its negative effects.

2) Automation: Another topic in improving operations is the level of automation. The study at hand shows that only a few processes in OCCs are automated. This can be explained by the high level of complexity of the procedures in incident management and the intense involvement of verbal communication.

The dispatchers in OCCs do outstanding work to keep the PT service running and mitigate the negative effects of incidents on the PT service. However, as the results of this work show, some procedures follow a certain algorithm and could be automated. As mentioned before, the dispatcher is, among other tasks, responsible for delivering the information between the involved parties. Even though some information

is already digitally available and could thus be transferred directly to other parties, it is not done yet, e.g. the location of a PT vehicle that is involved in an incident. In case of an assault or accident call, emergency forces and transport wardens are always needed. Therefore, the request for those could be sent automatically together with the real-time location of the PT vehicle, which sent the call signal. Important initial information such as the number of injured people in case of an accident could be answered through a touch input via the drivers' on-board computer. As far as a transport warden or a standby driver is concerned, it would be possible to automatically check the nearest ground staff available and automatically send them a dispatching request, including the GPS location of the PT vehicle in trouble. The ground staff could then reply with a single touch at their onboard computer or an adequate smartphone application to accept the request. This is algorithmically comparable to ride-hailing platforms, such as Uber or Lyft, which match ride requests with nearby drivers. Such a system would reduce the number of calls dispatchers have to do during an incident and give them the time to concentrate on the dispositive measures. Thus, the dispatchers get more time to focus on the mitigation of the negative effects on the PT service, which improves the resilience of the PT system.

Another example for automation would be automated passenger information. As [25] show, the time between an incident and the PI is crucial. An automated toolchain could thus inform the passengers much faster and consistently.

3) Planning: Another area in which we identified potential improvements is the planning of timetables. To evaluate the robustness of timetables, not only incidents but incident management needs to be considered. This study shows incident management is highly dynamic. Simulation studies are capable of modeling the dynamic effects of incident management. The here presented results help to identify factors that are relevant for future simulative studies. Looking at the results, it becomes very clear that the availability of replacement and standby staff has a big influence on how severe a missing replacement, as well as assault, accident, and other situations, can become if there is no replacement or standby bus available. As already pointed out by [7], staff management is an important area of incident management in PT services.

The missing replacement call involves a lot of communication between the driver seeking a replacement, the HR dispatcher and potential replacement drivers. This is mainly done by phone calls, which can be cut down to two decisions in a simulation study: 1) is there a replacement available and 2) how long does it take for the replacement to be on-site? In case there is no replacement, the trip will be canceled; otherwise, the start time of the trip will be aligned with 2). In both cases, the location of the vehicle might influence other vehicles. It must therefore be represented in a simulation study, respectively.

The most important call for a simulation study is the accident call. It always results in a delayed vehicle, blocked way, or broken vehicle. Hence, it is necessary to represent accidents and the reactions to accidents. The most relevant aspects in such situations are the duration of the incident and the blocked lanes or tracks. The locations of the involved vehicles influence the possible options for dispatchers extremely; they must therefore be represented according to real situations.

Similar to the accident call is the assault call. The communication between the involved parties is irrelevant for a simulation study, but there might be blocked tracks or lanes. Therefore, the assault call behaves similarly to the accident call from a simulation point of view. In cases of delays due to accidents or assault calls, the passengers will be informed about the current situation. This can and must be represented to enable passengers in the simulation study to react adequately to the incident.

Consequently, one of the next steps to be made is to integrate the here presented processes into a simulation tool. The tool could then be used by planners to evaluate the robustness of timetables considering real operations, as considered by [3].

VI. Conclusion and Outlook

Six OCCs in Germany and Singapore have been visited. OCC directors and trainers have been interviewed, dispatchers observed, and documentation studied.

The objective was to gain a profound understanding of the practice of incident management in PT. To improve a system, one must first understand it.

This work shows the high level of complexity of the practice of incident management in PT. Moreover, it reveals several potentials for improvement with according recommendations, especially in the areas of communication, automation and planning. These areas also show obvious gaps between practice and state-of-the-art research in PT incident management. In the past decades, communication and computation technologies developed enormously. Only in a few approaches, PT incident management already profited from these. Therefore, it is the authors' hope that this work brings practice and research interdisciplinarily a step closer together and caters for further innovations in PT incident management.

Moreover, the findings of this work will support the further development of the two aforementioned approaches of [3], [24] to improve PI and timetable planning and hence the reliability and attractiveness of PT.

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