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Potentials of Context-Aware Travel Support during Unplanned Public Transport Disturbances

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Abstract: Travel support for public transport today usually takes no or little account of the traveler's personal needs and current context. Thereby, travelers are often suggested irrelevant travel plans, which may force them to search for information from other sources. In particular, this is a problem during unplanned disturbances. By incorporating the traveler's context information into the travel support, travelers could be provided with individually tailored information. This would especially benefit travelers who find it more difficult than others to navigate the public transport system. Furthermore, it might raise the accessibility and general attractiveness of public transport. This paper contributes with an understanding of how information about the traveler's context can enhance the support provided by travel planners, in the case of disturbances in public transport. In particular, the paper includes a high-level analysis of how and in which situations context information can be useful. The analysis shows how information about the traveler's context can improve travel planners, as well as highlights some risks in relation to some identified scenarios. Several technologies for retrieving information about the physical context of the traveler are also identified. The study is based on a literature review, a workshop, and interviews with domain experts.

Keywords: public transport; disturbances; travel support; travel planner; sustainability; context awareness

1. Introduction

In most public transport systems (PTSs) today, travel planners (i.e., applications providing traveling itinerary suggestions) play an important role in delivering vital information about available routes and traffic disturbances to the travelers. Of the most essential functions of a travel planner, disturbance information and alternative routing are often rated as very important by the users [1,2]. Moreover, a high degree of individuality of this information is preferred over an overview of all disturbance information [2]. However, the support for these preferences in the travel planners available on the market today is relatively poor [3,4]. In many cases, they provide no information about alternative routes at all, and the disturbance information only describes the delay of the different travel links included in the initial route, without regard to the traveler's personal needs and current context. Thereby, there is a risk of travelers having to use their travel planners in other ways than intended or search for other sources of information, in order to get the information most relevant for them. For instance, they might need to search for travel options for each of the travel links separately, in order to find a complete route that is feasible (or has a high feasibility rate), given the disturbances. We believe that taking the current context of the traveler, including the personal needs (e.g., being onboard a specific vehicle and in a great hurry to catch a flight), into account when the traveler has to replan the journey because of disturbances would enable better travel support for the user. In particular, with traveler context information, travel planners could offer individually adapted information services providing travelers with comprehensive and personalized disturbance information, including alternative routing, from a single information service. This would benefit all travelers, but particularly travelers who find it more difficult than others to navigate the PTS and search for information during disturbances; for instance, children, disabled people, elderly, tourists, and other travelers new to the surroundings. Moreover, emerging technologies within, for instance, the Internet of Things (IoT) and machine learning, open up new possibilities to collect information about the traveler context. These technologies could be used to develop a context-aware travel planner that enhances accessibility of the transport network. As a consequence, the general attractiveness of public transport might increase, which in turn may have positive effects on sustainability in terms of reduced use of private cars.

Context-aware travel support has been previously studied by the research community, especially within the area of micro-navigation. Micro-navigation commonly refers to fine-grained contextual guidance along a journey [5,6], often including alerts for entering the wrong bus or missing an alighting. The interests in micro-navigation can partly be attributed to the increasing availability to local network connectivity, which opens up for travel assistants with micro-navigation capabilities based on the current location of the traveler. Handte et al. report from a trial in Madrid, in which an IoT-enabled navigation system for urban bus riders was deployed [6]. On the basis of WiFi communication connecting bus travelers' mobile devices with the buses, the system was capable of detecting which bus a traveler was currently on and presenting replanning options, for instance, if the traveler was still on a bus he/she should have left, or if a traveler had entered the wrong bus. Additionally, by monitoring the wireless signals from mobile phones, the system was capable of recognizing and predicting passenger crowds. Thus, less crowded routes could be suggested. Though micro-navigation assistants may be useful for inexperienced travelers, they do not fully satisfy the travelers' information needs that emerge during a journey. For instance, the initial conditions might change during the journey, either for personal reasons or non-personal reasons, for example, because of public transport disturbances, forcing the traveler to replan the journey. This replanning should be based on the new conditions, the current location of the traveler (e.g., on-board a specific vehicle or at a station), and any special needs or preferences of the traveler. Thus, a more dynamic and personalized assistant or travel planner, with extended context-aware capabilities, is needed.

Only a few of the travel planners available on the market today offer information about alternative routes in case of disturbances; however, without taking context information into account (other than current position). One of the more advanced travel planners is the German railways travel planner (DB), which is able to calculate new, alternative routes based on the current traffic situation [3]. Recently, Transdev released a new travel planner, Res med Pia, which provides improved prognosis calculations and alternative routes [7]. Within research, a few examples of travel planners providing alternative travel routes also exist, for example, Transitr and DB Cairo [8,9]. Transitr predicts the shortest path between any two points in a transit network using real-time information from Global Positioning System (GPS) equipped vehicles [8]. DB Cairo suggests alternative routes considering different means of transport and the current passenger position [9].

Another relatively rare feature in the current travel planners is personalized information provision (beyond origin, destination, and time of travel) [3]. Zhang et al. propose a framework for developing a personalized multimodal traveler information system, which is capable of providing user-tailored travel advice, monitoring persons' activity schedules, and incrementally learning user preferences from their response patterns [10]. A few travel planners with less advanced personalization functionalities also exist, such as ENOSIS and WISETRIP, which provide notifications and alerts about future stages of the trip and relevant delays/cancellations [11,12]. García et al. have developed a travel assistant providing on route-related information to bus passengers, such as estimated time of arrival to the next stop of the route or the traveler destination [13]. The system utilizes the vehicle infrastructure (positioning system, local network, and operations control system) and information from Bluetooth devices installed in vehicles and stations, and at bus stops. These travel planners with personalization capabilities usually do not take dynamic changes of the traffic, caused by disturbances, into account.

In summary, we have failed to find previous studies on travel planners capable of providing personalized information, as well as suggestions for alternative routes, that adapt to the new conditions that arise during traffic disturbances. We believe that such travel planners are necessary to enable efficient and true support during disturbances, especially for travelers who find it more difficult than others to navigate the PTS.

This paper contributes with an understanding of how information about the traveler's context can enhance the support provided by travel planners, in the case of disturbances in public transport. In particular, the paper includes a high-level analysis of how, and in which situations, context information can be useful. It also addresses the potential of different types of context information, as well as possible risks. Our findings can hence support both the aspects of designing new travel support as well as the understanding of the usefulness of different information types that today often are underutilized for this purpose, such as real-time public transport vehicle position.

The study is structured as follows. In Section 3, we propose a framework for travel support during unplanned public transport disturbances. By focusing on the fundamental decision options available to the traveler in the case of disturbances, we identify the traveler's information needs and the corresponding travel support tasks required. In Section 4, we list a number of different context information types that can improve travel support, based on the results from interviews and a workshop. These context information types are then mapped to the identified travel support task requirements, providing an overview of which context information types are needed to fulfil different travel support tasks. Furthermore, we specify a few concrete scenarios in which context-aware travel support has the potential to make a difference during unplanned public transport disturbance. In these scenarios, we assess the potential requirements (including the information needed) and risks with the travel support suggested. Section 4 ends with an investigation of which technologies can be used to retrieve relevant context information, with a focus on the traveler's physical context. Finally, the results are discussed and concluded in Section 5.

The study is based on a literature review, a workshop, and interviews with domain experts. The workshop and interviews were conducted with Swedish participants only; hence, the results are primarily valid for the Swedish context. However, because the Swedish PTS and travel support is similar to other countries, especially within Europe, the results may be relevant for other contexts as well. Furthermore, the study only focuses on context-aware travel support during unplanned public transport disturbances, that is, travel support for situations not related to unplanned disturbances, have not been considered. Neither does this study investigate micro-navigation services, such as support for locating a train-replacement bus stop, an uncrowded train carriage, or a bike rental, even though they might be beneficial to the user during unplanned disturbances.

2. Methodology

As mentioned in the previous section, the framework proposed in this paper identifies the traveler's information needs and corresponding travel support required, based on the fundamental decisions available to the traveler during public transport disturbances. The set of fundamental decisions available to the traveler was initially defined as a hypothesis, developed from experiences gained from previous work [4]. The workshop and interviews described below indirectly validated this hypothesis as sound, in the sense that no inadequacies or additional decision options were detected. On the basis of the set of fundamental decisions available to the traveler, in combination with basic decision-making steps suggested by the literature, the traveler's information needs and the corresponding required travel support were identified. Finally, the framework also describes the concept of context-awareness and, in particular, what we include in the concept from the perspective of context-aware travel support during unplanned disturbances in public transport. This part of the framework is based on a literature review.

In order to gather information about the current status and plans for the future of the travel planners available in Sweden, we conducted interviews with two different representatives for local authorities responsible for public transport; one from the southern part of Sweden (Skånetrafiken), and one from the capital of Sweden (SLL Trafikförvaltningen). At Skånetrafiken, we interviewed the responsible manager of the travel planner, and at SLL Trafikförvaltningen, we interviewed three managers responsible for traffic information, disturbance information, and passenger services. The travel planners offered by these local authorities cover the two most crowded and public-transport-intensive areas in Sweden. After the interviews, the respondents verified our written documentation of their answers. All questions and answers from the interviews are presented in Appendix A. The objectives of the interviews were to investigate the travel planner services offered today, in terms of alternative route suggestions and personalized traveler context-based information, as well as the transport actors' plans ahead. The objectives were also to investigate the actors' views on potential benefits and risks with offering alternative route suggestions and personalized traveler context-based information.

The interviews were preceded by an empirical study of the information provided by different travel planners. This study included three travel planners provided by three local authorities in the most populated and public transport intensive regions in Sweden: Skånetrafiken, SL (owned by SLL), and Västtrafik (responsible for public transport in the western Sweden). In order to investigate the information provided, we conducted travel searches in each of the respective travel planners during unplanned disturbances. The results from this study were used as input when formulating the interview questions (see Appendix A).

We also conducted a workshop involving five public transport domain experts (one PhD student; two senior researchers; one senior consultant; and the director of K2, Sweden's national center for research and education on public transport). The aim of this workshop was to identify and validate different scenarios in which traveler context information has the potential to improve travel support, as well as relevant context information types. All questions and answers from the workshop are presented in Appendix B.

Thus, the interviews and workshop mainly gave answers to the following questions:

(1) Which services do the considered travel planners offer, in terms of alternative route suggestions and personalized traveler context-based information?
(2) What are the potential benefits and risks with offering alternative route suggestions and personalized traveler context-based information?
(3) In which situations (scenarios) can the support provided by travel planners be improved, based on traveler context information?
(4) Which context information types would be needed to improve the travel planner in these scenarios?

On the basis of the answers to the above questions, in particular to question 4, we identified a number of context information types that could be used to improve the travel support in different situations, in comparison with the support offered today. By analyzing the travel support task requirements originating from the traveler's information needs, together with the identified context information types, we mapped the context information types to the different travel support tasks (i.e., the context information types needed to fulfil each of travel support task requirements were identified). Further, a comparison between the answers to question 1 and the answers to questions 2 and 3 revealed the potentials and risks with adding different types of services based on traveler context information to the currently offered services. It also revealed potential services and situations in which they may be of use for the traveler. These results were used to specify a few concrete scenarios in which context-aware travel support may be of benefit to the user. We employed a narrative analysis of the results from the interviews and workshop in the work with the scenarios and thematic content analysis to identify the context information types.

Finally, we performed an investigation of which technologies can be used to retrieve relevant context information, based on a literature study.

In addition to the above, the results from the interviews and, to some extent, the results from the workshop also contributed to the problem description presented in the introduction.

3. Travel Support Framework

As described above, the results presented in the following subsections are based on experiences gained from previous work, the workshop and the interviews, basic decision-making steps suggested by literature, and a literature review.

The most relevant decision for which travel support may be of assistance during unplanned disturbances in public transport concerns whether or not to change the original travel plan. We define the original travel plan as the plan for moving from a point A to a point B; the travel time; and the travel legs of the planned route (including public transport, biking, walking, etc.), including departure and arrival times. Further, we define public transport disturbance as something affecting public transport in a way that has an effect on travel plans (otherwise, they are not relevant for our study). Public transport disturbances typically involve delayed departure and arrival times, but they could involve changes influencing the comfort or accessibility, in comparison with the original travel plan. Finally, we view a cancelled departure as a departure delayed to next available departure time.

3.1. Fundamental Decisions

When the traveler receives information about a disturbance, he/she has to decide whether to change the original travel plan. However, not changing the original travel plan still implies that the journey is affected in some way, typically with at least a delayed arrival to planned point B or other significant changes, such as reduced comfort. Below, we list the fundamental decision options that exist for a traveler before starting the journey or in the middle of a journey, during public transport disturbances.

Identified fundamental decision options:

- Stick to the original travel plan (but with delays or other changes in, for example, comfort or accessibility, as consequences)
- Choose another travel plan with the same final destination, being different from the original plan with respect to, for instance, the following:
    - Departure time, that is, bringing forward or postponing the departure time of the next travel leg (more than the delayed original travel plan suggests)
    - Travelling path, for example, involving the following:
        - Change of route within the PTS (with potential implications on departure/arrival times)
        - Change of entry or exit point of the PTS (with potential implications on departure/arrival times)
    - Travelling means, that is, replacing public transport with other means of travel, for the entire or part of the journey/remaining journey (with potential implications on departure/arrival times and use of private car/bikes)
- Choose not to travel
- Choose to travel to another final destination

3.2. Fundamental Information Needed for the Decisions

In order to be able to select the most appropriate alternative of the decision options identified in the previous section, the traveler needs some fundamental information. Below, we suggest a structure of the information that ideally should be available to the traveler in this decision process.

Identified information demands:

(a) The need to make a decision (e.g., a disturbance does affect my travel plan)
(b) The possible (relevant) decisions that can be made in this situation, that is, the options at hand
(c) The estimated consequences of the different possible decisions, with respect to the following:

    i. Estimated time (both departure and arrival times) of the route
    ii. Travelling costs (including, for example, reimbursements or additional ticket fees)
    iii. Comfort and related implications (where comfort should be broadly interpreted, so as to include, for example, crowdedness, changing points in unfamiliar surroundings, walking distances, environmental impact, and social status)
    iv. Personal effects of not traveling, travelling to another final destination, or arriving/departing at a different time (e.g., missing a work meeting)

(d) The probabilities of the estimated consequences (e.g., probabilities of different estimated arrival times, of different estimated travelling costs, of available seats, or of missing a work meeting)
(e) The traveler's own preferences regarding the consequences of the different options, which, together with the corresponding probabilities, can be used to prioritize the possible decisions

Ideally, a traveler should also consider possibilities to switch from one travel plan to another, at a later stage (e.g., going to the bus stop and see if the buss appears within 20 min, and if it does not, replan to go home).

Some information about the consequences of different travel plan decisions, and corresponding probabilities, can be provided by the PTS, such as estimated arrival/departure times, PTS ticket fees, reimbursements, and crowdedness. Other information must be provided by other sources, such as costs related to personal car or taxi use, as well as implications related to changing points in unfamiliar surroundings, not traveling, travelling to another final destination, or arriving/departing at a different time. These types of information might instead be provided by, for instance, the traveler him-/herself or personal self-learning digital assistants [14] in combination with external databases.

3.3. Travel Support Task Requirements

Given the fundamental decisions and corresponding information demands identified above, we suggest that travel support can be of assistance to the traveler by performing one or more of the tasks below:

I. Notify the traveler when there is a need to make a decision
II. Suggest multiple different (new) travel plans
III. Provide estimated consequences of the different travel plans from the traveler's perspective, potentially including probabilities of the different consequences
IV. Rank the travel plans, including suggesting the best choice

These tasks are aligned with the decision-making steps suggested by Katie Carpen (https://www.snhu.edu/about-us/newsroom/2018/03/decision-making-process?utm_source=YouTube&utm_medium=socialmedia&utm_campaign=YTchannel_EndScreen&utm_content=MPM-1206-content-article-vid-7-steps-decision&snhu_segment=ol), which also include information gathering, action taking, and reviewing (or assessment of the taken decision). However, in our work, we leave out the steps of choosing an alternative, action taking, and after- following review of the results. Further, we view the information gathering as a part of each of the above tasks instead of as a separate step.

Please note that a task higher up in the list above has to be performed before (or simultaneously with) a task lower down in the list, by the travel support. Furthermore, the first three tasks in the list (I–III) can be mapped to the first four information entities in the previous list (a–d), that is, these travel support tasks provide the information needed by the traveler to make an informed decision about what to do in the case of disturbances. The last task in the list above more or less makes this decision on behalf of the traveler. Thus, the travel support suggests an alternative that the traveler may or may not follow, partly depending on the travelers' trust in the capabilities of the travel support to make the best choices for him/her.

The travel support does not necessarily have to be responsible for all tasks (I–IV), but some may be performed by the traveler or external resources. In particular, some parts of task III and task IV may have to be performed by the traveler because of personal circumstances. In order to provide travel support that reduces the number of tasks that have to be performed by the traveler, we suggest the use of a context-aware travel support, in the form of a travel planner. In fact, a context-aware travel planner has the potential to improve the support of all of the above tasks, by, for example, notifying the traveler when relevant, suggest only relevant new travel plans, computing consequences that apply for the context, and ranking them according to the context. In other words, a context-aware travel planner may be of use for the traveler in all decision steps during unplanned public transport disturbances.

It is outside the scope of this paper to explore and suggest different design options of how a traveler could be presented with information to be able to make informed decisions associated with the above tasks.

3.4. Context Awareness

The concepts of context and context awareness are widely used in research literature. However, there are different opinions of the meaning of the word "context". Some definitions of context focus on the aspect of the user, whereas others focus on the aspect of the application [15]. For instance, Franklin and Flaschbart regard context as the situation in which a person's action occurs [16]. Ward et al., on the other hand, view context as the state of an application's surroundings [17]. In this paper, we focus on the situation of the traveler, and which information about this situation can be perceived by the travel planner and used to improve the travel support. Therefore, we base our study on the following definition of context, provided by Abowd et al. (which has been widely accepted by the research community [18]): "Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves" [15]. In our case, the traveler is the entity. In order to determine which pieces of information are relevant to the interaction between the user and the application (i.e., which pieces of information can be used by the travel planner to improve support), we have investigated the decision mechanisms applied by travelers during unplanned public transport disturbances, and used these to identify the required travel support tasks and corresponding information needs.

Abowd et al. have identified location, identity, time, and activity as, in practice, more important types of context than others [15]. Although we also recognize these types of context as crucial, we additionally regard user (traveler) preferences as important to our work. These preferences may be relatively static [18], for example, aversion to crowdedness, or dynamically changing, for example, tolerance for delays (depending on time and purpose of the travel). Furthermore, some of the preferences may have to be specified manually by the user, whereas others could be derived from historical behavior possibly in combination with machine learning techniques.

4. Results and Analysis

The fundamental decision options for a traveler during public transport disturbances, listed in Section 3.1, include the decision of not travelling (cancel journey) and the decision of travelling to another final destination. However, in the forthcoming results and analysis section, these two options have been regarded as out of scope, and have thus been excluded. Instead, the paper focuses on how a context-aware travel planner can be used to support the user in the decision-making process related to the two remaining decision options, that is, to keep the original travel plan or to choose another travel plan with the same final destination. The reason for this focus is that we believe these types of decisions can be supported by the next generation of travel planners, considering the services provided by the travel planners available on the market today. Support for the decision of not travelling and the decision of travelling to another final destination, on the other hand, can be realized in subsequent steps, as these decisions require a much deeper understanding of the traveler's personal context and preferences. However, our focus does include context-aware travel planners that are able to provide the traveler with enough information relevant for taking own initiatives to look for other alternatives as well—for example, not travelling and travelling to another final destination.

The results presented in the following subsections are based on the results from the interviews and workshop. The raw data from these interviews and the workshop (answering the questions posed in Section 3) are presented in Appendices A and B.

4.1. Context Information

The interviews and workshop resulted in a number of context information types that could be used by a travel planner to improve travel support during unplanned disturbances in public transport (see below). Some of these context information types are related to the context of the individual traveler, whereas others are related to the context of the PTS and fellow travelers.

Context information related to the traveler:

- Intended travel plan
    - Origin
    - Travel legs, including departure and arrival times
    - Final destination
- Entitled travel service level (standard or right to access priority, etc.)
- Current location of the traveler (not only the traveler's GPS position, as it is rather meaningless unless other relevant objects also are accurately positioned by GPS)
    - Knowing which zone/area the traveler is currently in
    - Knowing the relative distance to a particular public transport stop (e.g., being at or close to a station)
    - Knowing which public transport vehicle the traveler currently is on
- Special needs/requirements of the traveler (influencing exchange times, lift needs, etc.)
- Access to (and acceptability of) other transport means, in addition to public transport (e.g., bicycle or private car)
- Access to travel guidance, for example, micro-navigation (This context information type has not been identified by the interviews and workshop, but through analysis of previous research studies.)
- Experiences of changing connection in the areas/PTS specified by the travel plan
- Preferences of the traveler (for ranking alternatives)
    - Level of "hurry"/tolerance for delays (could be given by the purpose of the travel)

    - Risk aversion towards different delay magnitudes—weighting between one travelling alternative that might be more time-efficient, but have a higher level of uncertainty regarding the predicted arrival time, than another alternative with longer travel time, but with less uncertainty in estimated arrival time.
    - Aversion to crowdedness/inability to travel in crowded vehicles
    - Unwillingness to change connections in new areas/PTSs
    - Willingness to pay for alternatives, in relation to changes in estimated time of arrival to the destination (also dependent on reimbursement levels)
    - Preference to use different means of accessible travel means (e.g., prefer biking instead of taking the bus to the train station)
    - Other personal preferences (e.g., want to have long exchange time to feel comfortable, want to walk if nice weather, environmental impact concern)

- Historical behavior including choices made when travelling, which can be viewed as an estimation of the context information above

Context information related to the PTS:

- Updated departure and arrival times of all travel legs included in different possible travel plans (prognoses)
- Estimated probabilities of all travel legs included in different possible travel plans (e.g., additional delays)
- Travelling costs of all travel legs included in different possible travel plans (ticket costs and conditions for reimbursements)
- Comfort and related implications of all travel legs included in different possible travel plans, for instance, the following:
    - Expected crowdedness in vehicles and at platforms
    - Quality of service (availability of meals and first class)
- Imprecise disturbance information (e.g., delays on busses in an area)
- Externalities to the transport system, for instance, the following:
    - Weather information
    - General travel demand deviations (e.g., special events and holidays)

4.2. Context Information for Travel Support Tasks

By analyzing the travel support task requirements (Section 3.3) originating from the traveler's information needs (Section 3.2), together with the identified context information types (Section 4.1), we have created a mapping of which context information types are needed to fulfil the different travel support tasks. This mapping includes the context information types at least required, context information types that may improve the quality of the support, and the required travel support functionality, for each of the travel support tasks.

I. Notify the traveler when there is a need to make a decision

Required context information:

- Current location of the traveler: knowing which zone/area the traveler currently is in
- Imprecise disturbance information (e.g., delays on busses in an area)

With this information, the travel support would only provide very rudimentary support of notification.

Context information for quality improvement:

- Intended travel plan (to identify if any travel legs of the travel plan are affected) or historical behavior (e.g., to deduct approximate likely travel plan)
- Current location of the traveler: more precise than simply knowing which zone/area the traveler currently is in
- Special needs/requirements of the traveler

By extending with this information, the travel support can become more useful by notifying the user, or start the subsequent tasks below, only when it is needed.

Required travel support functionality:

- Identification of whether the traveler should be notified of the potential need of making a decision.

II. Suggest multiple different (new) travel plans

Required context information:

- Intended travel plan: final destination and arrival time
- Current location of the traveler: more precise than simply knowing which zone/area the traveler currently is in
- Updated departure and arrival times of all travel legs included in different possible travel plans

This information would allow the travel support to suggest new travel plans, more or less as the travel planners available today do, but in this case, with updated timetable information. It may provide the traveler with a number of plans that are not feasible or desirable.

Context information for quality improvement:

- Current location of the traveler: knowing which public transport vehicle the traveler currently is on (e.g., on a moving vehicle)
- Special needs/requirements of the traveler
- Entitled travel service level
- Access to (and acceptability of) other transport means, in addition to public transport

The extension by this information would allow the travel support to suggest only the feasible travel plans.

Required travel support functionality:

- The computation of new travel plans based on the context information at hand included updated timetables.

III. Provide estimated consequences of the different travel plans from the traveler’s perspective, including probabilities of the different consequences

Required context information:

- Possible travel plans from II

This information would allow the travel support to provide information of estimated arrival times for the different travel plans, which probably is the most important information. Obviously, some of the travel plans may not be feasible if insufficient context information was available and used in II.

Context information for quality improvement:

- Travelling costs of all travel legs included in different possible travel plans
- Comfort and related implications of all travel legs included in different possible travel plans
- Externalities to the transport system (e.g., weather information)
- Estimated probabilities of all travel legs included in different possible travel plans

This addition of information would allow the travel support to provide the traveler with richer information about the different suggested travel options.

Required travel support functionality:

- The computation of the relevant implications for the traveler, associated with the different options from III.

IV. Rank the travel plans, including suggesting the best choice

Required context information:

- Possible travel plans and their estimated arrival times (from III)
- Intended travel plan: arrival time (according to original travel plan)

This would allow the travel planner to provide the most basic ranking according to arrival times.

Context information for quality improvement:

- Preferences of the traveler (for ranking alternatives) or historical behavior (e.g., to deduct approximate preferred travel plan)
- Additional output from III: costs, comfort implications, and probabilities of travel plans (with respect to additional delays)

This would allow the travel planner to provide a more relevant ranking of the travel plans from III. Information about probabilities of travel plans could be given especially in terms of potential additional delays. Here, alternatives to one-dimensional ranking could be relevant to consider, as well as interactive approaches for supporting the traveler to find the most desirable alternative.

Required travel support functionality:

- Ranking of different travel plans according to different features of the plans and preferences.

4.3. Scenarios

In this section, we highlight a few scenarios identified as relevant in the workshop. For each scenario, we present a description as well as identified potentials, requirements, and risks. The descriptions both illustrate the situations and specify the particular decision support the traveler should receive.

4.3.1. Scenario 1: To Commence the Travel; New Route Needed

Description: A traveler's travel plan is affected significantly by a disturbance. The traveler has not started the first travel leg of the travel plan or is waiting for the next travel leg. The traveler should get suggestions of updated travel plans, in terms of both departure times and route, potentially involving new means of transports (e.g., bicycling or taxis).

Potentials: This scenario obviously covers many situations as it is reasonable to assume that a large number of travelers affected by a disturbance may not have commenced the first/next leg of the travel plan. The scenario assumes that there are alternative routes that can be considered, which may not be the case in all situations, though.

Requirements: This scenario requires information about the traveler's travel plan and updated timetable information of the PTS. To be fully useful, information about the traveler's preferences and access to different travel means would at least also be needed.

Risks: The traveler may be advised to choose travel options that turn out to be bad in some way; both with respect to uncertainties in travel times of suggested travel routes and with respect to potentially missing context information about the traveler (e.g., access to different travel means). Another concern is the privacy issue connected to the traveler having to reveal his/her travel plan and preferences, in order to get good suggestion of a new travel plan.

4.3.2. Scenario 2: Onboard a Train; New Route Needed

Description: A traveler is on a train and has just been informed that the train is significantly delayed. The traveler's destination stop is not one of the stops of the current train, that is, the journey involves several travel legs. There are other realistic options for reaching the destination stop with public transport. In particular, the traveler can get off the train at another location than originally planned and travel along an alternative route. This option should be suggested to the traveler.

Potentials: Obviously, a rather common type of disturbance scenario is that the train a traveler is currently on is delayed. However, Scenario 2 only applies for situations in which alternative routes do exist, that is, primarily in areas with relatively high density of public transport networks (alternatives for travelling between places that may be differently affected by disturbances exist). The number of cases/situations in which this can make a great difference for the travelers may be limited. However, the workshop results showed that travelers tend to use travel planners and other sources of information to find alternative travel plans during disturbances (even though such alternative may not exit). Hence, a travel planner providing this type of support has the potential to significantly reduce the efforts spent by these travelers on this task.

Requirements: This scenario requires information about the traveler's travel plan and which train the traveler is currently on, which may be obtained by the following means:

- Mapping GPS positions between train and traveler's smartphone
- Mapping the identity of the vehicle with the one identified by the traveler's phone (e.g., by identity of beacon installed onboard)
- Manual provision by the traveler

This also requires updated timetable information of the PTS and the ability to compute new routes/travel plans given this information. It is important to note that it is not enough to have a travel support that only highlights affected legs of the travel plan—it needs to actually provide suggestions of new routes, given updated timetables.

Risks: The traveler may be advised to choose travel options that turn out to be worse in some way than the original plan. For instance, the traveler may be even more delayed or experience worse discomfort. The latter may derive from too many travelers, with respect to capacity constraints, choosing the same travel option. Another risk is that the traveler probably has to reveal his/her location (e.g., GPS position or identity of the vehicle he/she is onboard). Solutions to completely avoid this may include a substantial amount of data (e.g., updated timetable data) having to be downloaded to the traveler's local travel planer client.

4.3.3. Scenario 3: Before Boarding—Earlier Departure, Same Route

Description: A traveler is located relatively close to the point of departure of the traveler's first/next travel leg. Some time remains to the planned departure. The traveler should receive information about anticipated delays in the PTS that may affect the travel plan. Furthermore, the traveler should be advised to take an earlier connection, because of these anticipated delays. Thereby, the risk of missing a planned connection at the next interchange points is reduced. Even if the traveler would have had no upcoming interchanges, he/she should still be advised to take the earlier connection, in order to avoid reaching the destination later than planned.

Potentials: This type of support is particularly relevant when disturbances have not yet reached full effect, enabling the traveler to avoid the corresponding problems. It may also be relevant in situations in which the exact effects of the disturbances (and new departure times) are uncertain/imprecise. For instance, if weather conditions affect the traffic or there is an unplanned need to close one out of two tracks on a train stretch.

Requirements: This scenario requires information about the travel plan and "closeness" to the first (next) departure. The closeness could, for instance, be assessed by combining the GPS position of the traveler and the departure position of next travel leg.

Risks: The recommendation may be given too often, making the service annoying. This scenario presumes that an assessment of whether the delay will influence the traveler and in that case how, is difficult to achieve. Therefore, the risk of giving the recommendation too often primarily depends on the particular implementation. Also depending on implementation, the traveler has to reveal his/her location area, causing the same negative privacy implication as above.

4.3.4. Scenario 4: Before Boarding—Later Departure, Same Route

Description: A traveler is about to commence the first travel leg of his/her journey according to a plan. There is a disturbance in public transport that will affect the travel plan. There are no possibilities to take earlier connections that avoid the disturbance. Because of this disturbance, the traveler should be advised to take a later connection with no anticipated delays. Thereby, the risk of having to spend a larger amount of time travelling is reduced. Instead, the traveler could potentially make better use of the time before starting the journey.

Potentials: This travel support has relatively low potential, as there might be rather limited opportunities for the traveler to make use of the time when waiting for departure, in particular, if this information is late. However, if the traveler has established his/her travel plan early, the potential benefit may increase for the traveler.

Requirements: This scenario requires information about the travel plan and "closeness" to the first (next) departure. The closeness could, for instance, be assessed by combining the GPS position of the traveler and the departure position of next travel leg. Updated timetable information is also needed.

Risks: An obvious risk is that delays that influence the initial travel plan also end up affecting the new travel plan (with delayed departure as a result). This type of support requires early and complete information about travel plans, which may induce a risk of negative privacy implications.

4.4. Technologies for Retrieving Context Information

The context information, corresponding travel support tasks, and scenarios presented in the previous sections can partly be seen as a high-level specification of the information requirements for enhancing travel support by means of a context-aware travel planner. As a complement to this, we also investigated how the information required can be retrieved, through a literature review. The primary aim of this investigation is to show that it is possible to obtain this type of information. The investigation was restricted to the two location subtypes: knowing the relative distance to a particular public transport stop (e.g., being at or close to a station) and knowing on which public transport vehicle the traveler currently is. The reason for focusing on these context information subtypes is that these can be seen as essential for the first step towards context-aware travel planners. Furthermore, the literature review is focused on solutions where the traveler application can collect the context information itself, possibly with complementing information from external sources. Solutions relying solely on data from external systems (e.g., ticketing systems collecting travel information via scanned tickets) have not been included. Thereby, the personal information privacy issues may be reduced.

Many of the travel planners used today enable the user to search for travel routes originating from their current position. In these cases, the systems typically determine the traveler's current position by means of GPS and search for the nearest public transport stop. Because of the limited access to traveler context information, they are unable to provide services adjusted to, for instance, travelers that are onboard a moving vehicle. Thus, more information is needed. One of the simplest solutions for obtaining more information is to let the traveler manually register the context. For instance, Deutsche Bahn launched a ticketing system in 2011, in which the traveler checked into and out of a journey using the smartphone's GPS, by taking a photo of a local Quick Response (QR) barcode identifying the station, by letting the smartphone read a local Near-field communication (NFC) tag identifying the station, or by typing in the station identification number by hand [19]. Finžgar and Trebar present a similar solution [20]. Further, Stelzer et al. suggest that travelers insert information about time, destination, and route in an app, in order to be able to receive disturbance notifications and reroute recommendations from the transport company [21]. This suggestion may be realized by simply relying on the information inserted by the traveler into the travel planner.

Another solution for obtaining more information about the traveler context may be to combine the current traveler's position with real-time positioning data on the transport system. For instance, Stenneth et al. have studied how the bus that the traveler is currently riding on can be identified, based on the GPS sensor on a traveler's mobile device and knowledge of the underlying transportation network, in the form of real time bus locations, as well as spatial rail and spatial bus stop information [22]. However, these data may not be sufficient, especially in areas with a high public transport density, as positioning systems usually are not precise enough to enable a clear distinction between two passengers sitting on different vehicles, but only a few meters from each other or between a passenger on a vehicle and a traveler standing right outside.

Yet another solution has been proposed by Handte et al. [6]. In their solution, a background process running in a navigation app on the traveler's smartphone continuously tries to establish WiFi connections to surrounding buses. If the traveler leaves the bus, the signal quality drops. Thus, the change in WiFi connectivity is used, in combination with rescan triggers and timeouts, to detect on which bus the traveler is riding. One solution related to this might be to detect the current vehicle based on local beacons, for instance, using Bluetooth to communicate, installed inside the vehicles. This may provide higher accuracy as beacons usually have a shorter range. However, these types of solutions may involve the same problems with identifying the correct physical context in areas with high public transport density as solutions based on GPS positioning.

In summary, there are several solutions for retrieving information about the traveler context. Some require more sophisticated technology, whereas others require more activity from the user. Further, there may be issues with precision. Although the literature shows several examples of how this type of information can be retrieved, there are very few studies on how to make use of this information in a way that is beneficial to the individual traveler. In particular, there is a lack of studies utilizing information about which particular vehicle the traveler is currently on, in this respect.

5. Discussion and Conclusions

This paper has shown how information about the traveler's context can be used to enhance the support provided by travel planners. In particular, it specifies what types of context information are relevant and which travel planner tasks they support. Furthermore, the paper has shown that several concrete scenarios can be identified, where context-aware travel planners would provide useful travel support during unplanned disturbances, for instance, by suggesting alternative travel routes that are not displayed by the travel planners available on the market today. The potentials, requirements, and risks associated with the travel support suggested in these scenarios have also been identified. In particular, risks connected to traveler privacy and uncertainties of the PTS have been identified. Finally, the paper has shown that there are several technologies proposed in literature that may be used for retrieving information about the two traveler context information subtypes: knowing the relative distance to a particular public transport stop (e.g., being at or close to a station) and knowing on which public transport vehicle the traveler currently is. In summary, this paper has provided support for the analysis and development of context-aware travel planners by addressing the information and tasks that need to be performed during unplanned disturbances. In relation to previous research, the paper contributes with knowledge of how travel planners and micro navigators can be enhanced using information about the traveler's context. Thereby, the travel support provided can be more personalized, and can include individually adapted suggestions for alternative routes, taking the real-time effects of public transport disturbances into account. These results might be used to increase the attractiveness of public transportation, with increased sustainability as a result.

When comparing the support provided by public transport travel planners with the support provided by road navigators, which can be seen as a type of travel planner for car travelling, one may find the road navigators more advanced during unplanned traffic disturbances, in terms of suggesting alternative routes. Traditionally, transport providers have treated public transport travelers as a relatively homogenous group. Consequently, all travelers are often offered the same services during unplanned disturbances. For instance, when the rail traffic breaks down, all travelers are directed to the same train-replacement buses, irrespective of, for instance, individual level of hurry or disabilities. Instead, information about alternative transport services based on individual needs should be provided. For instance, travelers in a great hurry could be advised to take a taxi and travelers with disabilities should only get route suggestions that fulfil the disability needs. There are several advantages with increasing the personalization of the support provided by the public transport travel planners. Some of the greatest advantages concern the potentially increased availability and trust in the PTS, as well as sense of personal control. However, there are risks with moving in this direction as well. For instance, public transport actors express a concern regarding the high level of uncertainty of some of the traffic prognoses generated today and unpredictable capacity problems induced by travelers' replanning decisions. In order to reduce the effects of uncertain prognoses, we suggest combining them with probability measures, enabling the travelers to make their own choices. However, the unpredictability of capacity needs might increase with a more personalized, context-aware travel planner. In the current PTS, there are already problems with predicting the capacity needs during unplanned disturbances. We believe that, despite increased predictability, a context-aware travel planner may, on the contrary, decrease problems related to capacity needs. If the travelers make different decisions depending on personal context, there will be a natural load balance between different means of transport, which will spread out the need for added capacity. Thereby, the possibilities to practically meet these needs will be higher. This may compensate for the negative effects of more unpredictable capacity needs.

The transport operators also highlight that collecting context information about the traveler may violate data protection and privacy legislations. However, a context-aware travel planner does not necessarily imply giving up personal data to the transport operator. Depending on implementation, the data may just as well be collected, stored, and used by the travel planner user client only, that is, the travel planner client application may collect information about the user context and the PTS in order to provide personalized travel support directly to the traveler. Our investigation of which technologies may be used for collecting traveler context information indicates that this latter approach is feasible. Thus, when designing a context-aware travel planner, it is necessary to decide which information should be collected and/or stored in operator systems or in user-controlled systems, respectively. These choices have an impact on both the risks and the potentials with the travel planner system. However, they also have an impact on other potential application areas of the collected traveler context information. In particular, if information about travelers' route requirements were collected and stored in transport operator systems, it could also be used in disturbance management, for instance, to calculate train replacement bus capacities needed during a disturbance and to direct the different buses to different stops based on actual transport demand (using real-time public transport scheduling). A data collection controlled by the transport operator would also open up alternative ways to collect the data, for instance, by means of social media analysis or automatic passenger counting. These advantages should, however, not be used as an argument to compromise with the privacy concerns.

In order to keep the necessary user interaction with the travel planner to a minimum, machine learning focused on the user behavior and context should be a central part of a context-aware travel planner. In particular, machine learning techniques could be applied to generate information about user preferences, as suggested in Section 3. This information would be most useful to the travel planner for the last of the identified travel support tasks, that is, "Rank the travel plans, including suggesting the best choice". Our preliminary literature studies indicate that this an unexploited area that needs further studies.

This study is based on a literature review, a workshop, and interviews with domain experts. In addition to being domain experts, all respondents are users of the PTS. Thereby, their input represents the aspects of the users as well. However, this input might be slightly influenced by the respondents' extended knowledge about public transport. Furthermore, the data sampling set can be regarded as relatively limited, from the user perspective. Thus, further studies are needed to fully cover the aspects of the users.

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Appendix A

This section shows the questions and answers from the semi-structured interviews.

What support do the travel planner offer today in terms of updated route or alternative route suggestions, taking the new traffic conditions into account during unplanned disturbances? What are the plans ahead?

- One of the interviewed actors does not provide any alternative route suggestions. Instead, the travelers are usually directed to train replacement buses during disturbances. The other interviewed actor provides alternative route suggestions, if all processes have been followed.
- One of the interviewed actors uses a travel planner search engine that does not support real-time data. This means that all search results are based on fixed timetables, with added real-time data, that is, the travel planner shows all delays, but there are no possibilities to search for a complete journey that takes delays of individual travel legs into account. There are plans to exchange the search engine for one that supports real-time data. The other interviewed actor provides real-time data.
- The prognoses provided to the travelers today are too uncertain. The prognoses within rail transports are usually generated and updated manually by the Swedish transport administration, when there is time for it. There are plans to implement automated prognosis generation based on GPS. Within bus transports, prognosis generation has already been automated.

What are the potential benefits and risks with providing updated route or alternative route suggestions, taking the new traffic conditions into account during unplanned disturbances?

- If only real-time information about departure and arrival times is provided to the traveler, how should reimbursements be handled? What is the offering and how should the time delay be calculated? This is an ongoing internal discussion topic.
- There are some risks related to directing too many travelers to an alternative route that does not have enough capacity. There are ongoing investigations of how to obtain vehicle occupancy.

On buses, they currently use automatic passenger counting (APC) to estimate the occupancy. However, not all vehicles are equipped with an APC system. Therefore, information about the vehicle occupancy is not provided to the traveler.
- There might be risks associated with directing many travelers to one specific platform, due to crowdedness.
- It would be great if we could offer push notifications that notify the traveler about a disturbance and advise the traveler what to do when there are disturbances in the area, for example, stay at home instead of travelling, without any preceding new searches from the traveler.
- There are plans to offer suggestions for routes without stairs, for travelers in wheel chairs, for travelers with walkers, and so on. This requires information about the current status of elevators.
- Travelers with cognitive impairments need great support during disturbances.
- We are currently working with historical data, not real-time data, during disturbances, that is, we have no real-time information about, for instance, the number of travelers in need of a train-replacement bus.

What support does the travel planner offer today in terms of personalized, traveler context-based information? What are the plans ahead?

- We are currently not working with information about the traveler's context, for instance, information about which vehicle the traveler is currently riding on and that he/she is expected to alight at a specific stop ahead. However, we believe it is necessary to start thinking about this.
- In practice, we are able to identify onboard travelers in real-time, as the conductor usually scans the tickets electronically. The ticket validation is performed online. However, if there is no network connection, the tickets are validated locally, based on the information contained in the tickets.
- We are investigating the possibilities to save a favorite journey in the travel planner.
- There are plans to add GPS to all vehicles.

What are the potential benefits and risks with personalized, traveler context-based information?

- There are difficulties (e.g., legal) related to personal data. The physical distance you are interested in might be relatively short, but it might still be sensitive. If you have continuous information about a person's position, it may be relatively easy to map the traveler to a vehicle.
- If a traveler is riding on a bus that is heavily delayed, it would be great if the traveler could only press a refresh button to get an updated travel route.
- A desired arrival time inserted in the travel planner might be very important for the traveler. Maybe the travel planner should take the level of importance into account.
- It would be great for us to get information about traveler context, for instance, when deciding on extended bus capacities, taxi capacity, and as decision support for dispatchers.
- An advanced travel planner needs to have a good mapping between the traveler and the vehicle, in order to avoid giving PTS-related advice to travelers not going by public transport, but, for instance, going by private car.
- We have introduced biking in the travel planner. This could be further developed to, for instance, advise the traveler to go by bike to a different stop than usual, because of disturbances.

Appendix B

This section displays the discussion points presented by the organizers at the beginning of the workshop, and the results from the workshop.

Appendix B.1. Discussion Points

Workshop: about context-aware travel support in case of disturbances in public transport

- To identify scenarios in which travel support can better support the traveler by context awareness (context information) in case of disturbances
- Approach: create new scenarios by thinking of the following:
  - Situations (involving disturbances in PT) in which you see a need for advice/support from a travel support tool that normally does not exist today—describe the scenario:
    - The situation
    - The support needed
  - What information (context information) would be needed for the travel support tool to achieve this

Appendix B.2. Workshop Results—Missing Information Concerning Context and Preferences

The most relevant factors affecting which transportation means and route are most suitable for a traveler during unplanned disturbances (according to the workshop results):

(1) Origin and destination of the traveler's journey if it has not yet started
(2) Current physical context of the traveler if the traveler's journey has already started

   a. If the traveler has arrived to the first/next stop of the journey earlier than expected (for instance, to a train station) and there are disturbances in the transport network, it might be safer for the traveler to select an earlier departure, in order not to miss the next connection. On the basis of the physical context of the traveler, these alternatives should be presented by the travel planner along with the regular alternatives, which usually focus on a minimizing travel time.
   b. If the traveler is currently onboard a vehicle that is being delayed, the traveler might want to get off at an earlier stop than originally planned, and travel by another route, for instance, in order to save time. These alternatives should be presented by the travel planner, based on the physical context of the traveler.

(3) Personal access to other transport means outside public transport, for example, bicycle or car
(4) How much of a hurry a traveler is in; for instance, if he/she is travelling to catch a flight or just to go shopping
(5) The level of uncertainty/risk connected to each travelling alternative in relation to the personal aim of the journey

   a. Each travelling alternative should be presented by the travel planner in combination with the level of uncertainty for each alternative.
   b. One travelling alternative might be more time-efficient, but have a higher level of uncertainty regarding the predicted arrival time, than another alternative. These less time-efficient (presuming the predicted timetable holds) alternatives should also be presented by the travel planner (along with the level of uncertainty for each alternative).

(6) The amount of personal experience of travelling in different areas; for instance, a tourist that is new to a country may prefer uncomplicated travelling routes without long walking distances, as this might feel safer
(7) Predicted or actual crowdedness in the transport system

   a. A traveler may have personal needs that cannot be fulfilled because of crowdedness. For instance, elderly or disabled people might not be able to travel standing and some travelers may bring baby strollers or walkers.
   b. A transport vehicle may be full and thereby no longer available for new boardings.

c. Disturbances and crowdedness might cause a lack of available taxis.

(8) Willingness to pay, which may or may not depend on how much of a hurry a traveler is in (as the personal price sensitivity may differ).
(9) Reimbursement level, that is, knowledge of the reimbursement level before selecting transportation means and route
(10) Possibilities of special treatment; for instance, disabled people or travelers in a great hurry (e.g., due to a flight) might have got/bought a special ticket giving them priority over others in case of disturbances, in terms of access to train replacement buses, and so on.
(11) Other personal preferences that affect the choice of transportation means and route also when there are no disturbances (e.g., I like to walk if the weather is fine)

Some of the factors above can be used for identifying available transport means and routes (Factors 1, 2, 3, and 5b). The other factors can be used to filter out unsuitable transport means and routes.

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