The Impact of Visualizing Uncertainty on Train Trip Selection

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Abstract

Train trip planning means deciding on one of several travel connections. Possible train delays lead to uncertainties in the schedule connections and may influence the planning decisions. Although several designs for the visualization of the available train trips exist, it is still unclear how these designs and the visualization of delay uncertainty influence the decision making. We let 86 people decide ten times on different train trips using one of four designs, (not) visualizing delay uncertainty and with(out) temporal constraints. The results show that planning decisions depend on whether the design is visual or textual and on the availability of trip uncertainty visualization. In case of a temporal constraint, non-critical train connections are preferred.

CCS Concepts

•***Human-centered computing*** → *Information visualization; User studies; Empirical studies in visualization;*

1. Introduction

While planning a train trip, the traveler must choose one of several train connections which differ in attributes like the travel duration, the arrival time, and the number of transfers. The travelers' decision on the train connection may be influenced by these attributes as well as a potential arrival deadline, e.g., an appointment determines latest accepted arrival while when traveling for leisure or holiday, one may accept longer travel. Furthermore, train delays may affect the travel, e.g., "critical" delays in one train trip may cause missing subsequent trains, thus, require to take a later connecting train which also arrives later. As train delays are uncertain when planning they may also influence the travelers' decisions, e.g., the traveler may favor the connection which most likely will arrive on time despite expected delays. Many designs for travel schedules and trip planning exist (e.g., [PGSF16, KKHM16, WBFvL17]). However, most of them show trip information without uncertainty. It is known that believed as well as displayed uncertainty can influence a decision [Tve03,GS06] and people employ different decision strategies for uncertainty visualization [TWSM15]. Nevertheless, it is still an open research question, how the design of train trips and the display of delay uncertainty influences the decision for a train connection.

We conducted a study in which 86 participants used one of four train trip designs to decide in ten situations which train trip to take. Thereby we address how the train trip selections differ depending on (1) the availability of delay uncertainty in the visualization, (2) the design of connection display (the design of delay probabilities and whether the train trips are visualized or presented as text), and (3) the arrival time constraint (the existence of a deadline).

2. Train Trip Designs

We displayed the decision situations (cf. Sec. 3) with one of four (between-subject study design) state-of-the-art train trip designs (cf. Fig. 1). We can evaluate the decision results as all of these designs were found to be comprehensible [WBFvL17].

Two designs show trips with delays: with $\boldsymbol{D_{cum}}$ and $\boldsymbol{D_{noncum}}$, trains are visualized as blue bars positioned on the timeline in the background. Transfers within one connection are visualized as grey dashed lines. These designs include expected train delays, which visually postpone the scheduled arrival of the trains, and alternative train connections in case of critical delays, i.e., when connecting trains might be missed. The delay probabilities are visualized by the color's saturation in two variants: D_{cum} (cf. Fig. 1a) visualizes cumulative delay probability distributions to answer what the probability of the train being delayed by at least (or up to) x minutes is. This is useful for retrieving the probability of catching the consecutive train or being on time for an appointment. D_{noncum} (cf. Fig. 1b) shows the probability of delayed arrival times.

The two designs showing trip connections without uncertainty are commonly used in Germany: $\boldsymbol{D_{vis}}$ (cf. Fig. 1c), derived from *Öffi* [Oef], visualizes the trips similar to vertical Gantt charts [Gan13] whereby different means of transportation are colored differently. $\boldsymbol{D_{text}}$ (cf. Fig. 1d), derived from the online travel information system of Germany's largest railway operator *Deutsche Bahn* [Bah], utilizes solely text.

3. Decision Situations

Each decision situation is a combination of 1) two available train connections and 2) a time constraint. The train connections differ in common decision parameters [WBFvL17]: the arrival/departure time, travel duration, number and duration of transfers, delay probabilities, and alternative connections (cf. Table 1). The travel options are anonymized to mitigate the use of travel experience. The time constraints represent common situations [WBFvL17]: (**C1**) no arrival deadline (e.g., as for a leisure travel), and (**C2**) latest ac-

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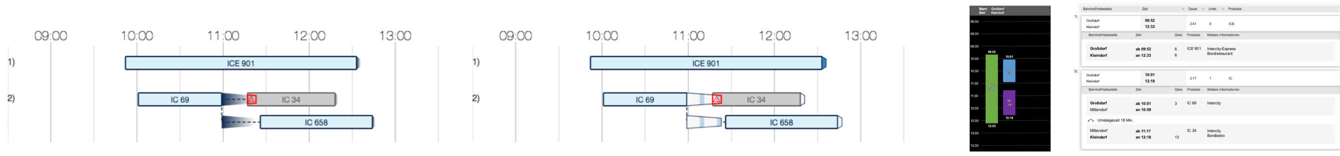

(a) D_{cum} **(b)** D_{noncum} **(c)** D_{vis} **(d)** D_{text}

Figure 1: *Train trips TO3 as presented by the four train trip designs D (cf. Sec. 2; D_{cum}/D_{noncum} with cumulative/non-cumulative delays and alternative connecting trains, trains as vertical bars D_{vis}, and textual display D_{text}).*

cepted arrival at 1pm due to an important appointment. For each decision situation, the participants chose: ○ *Train trip 1*, ○ *Train trip 2*, ○ *For me, both trips are of equal value*, ○ *I can not decide based on this depiction, because: [text input]*, or ○ *I don't know*. All visualizations of the study are given in the Annex.

4. Dependence on the Availability of Delay Uncertainty

The *Fisher's Exact Test* showed that the decisions on train trip selection significantly ($p < 0.001$) depend on the availability of delay uncertainty visualization in case of critical delays (i.e., the uncertainties may have an impact on the connecting trains or the time constraint; all decision situations except TO4). For the decision situations TO1–TO3 and TO5, we identified a clear preference for either of the two train trips. The participants favored the train trip with earlier arrival time (TO1, TO3, TO5), shorter travel duration (TO1), longer transfer duration (TO2), without critical transfers (TO3) with respect to the visualized delays or (without delay information) according to the schedule.

5. Dependence on the Design of Connection Display

According to the *Fisher's Exact Test* the peoples' decisions significantly ($p < 0.001$, $p < 0.05$) depend on the display design for all of the ten decision situations except TO4-C2, in which the majority of the participants avoided the train connection with shorter travel duration but two (non-critical) transfers.

Surprisingly, *Post hoc Fisher's Exact Test* shows significant differences for the two delay probability designs in case of train trips TO1 without arrival deadline (C1) – albeit they visualize the same delay data and both designs show the delay criticality, which is a dominating decision factor. This may be attributed to the delayed arrival of trip 1 after trip 2 appearing more likely with non-cumulative delay probabilities (D_{noncum}) than with cumulative delay probabilities (D_{cum}).

Post hoc Fisher's Exact Test unveils different decisions ($p < 0.05$) for train connection pair TO5 in case of no arrival deadline (C1): with textual display (D_{text}) there is clear choice for the equality of both trip options whereas with visual display (D_{vis}), the participants chose either trip 1, trip 2, or the equality of both trips. A potential reason could be that train attributes can be more transient when visualized opposed to text [Jar90].

6. Dependence on the Existence of an Arrival Deadline

McNemar test showed that the existence of an arrival deadline has a significant ($p < 0.05$) impact on the travelers' trip selection for TO1 with D_{cum} and for TO3 with D_{text}.

The decisions for TO1 differ only with cumulative but not with non-cumulative probabilities; possibly due to great delays appearing less probable with the cumulative design.

With an arrival deadline (C2), the participants preferred the train connection which arrives before the deadline (TO1) or earlier (T3) in the case of maximum expected delay. With D_{text} without uncertainty, the participants favored the connection without transfers in case of an arrival deadline. This (and results in Sec. 5 for D_{text}) may indicate the difference of time displayed as text or visually.

Surprisingly, for design D_{text} and train connections TO5, where the connections are equal in terms of the number of transfers and duration per transfer and the arrival time differs only slightly, one sees indecisiveness in case of no deadline but general preference for trip 1 in case of a deadline. This indicates a strong effect of only a slightly earlier arrival in case of a deadline.

7. Duration of Train Trip Selection

Our results indicate that the fastest decisions were made with the visual design without uncertainty (D_{vis}) and slowest with the text display (D_{text}). The duration of decision making with both visual designs with uncertainty (D_{cum}, D_{noncum}) was in between. The selection was faster in case of arrival deadline (C2). The preferred earlier arrival in the case of an arrival deadline may lead to fewer comparisons of other attributes than the arrival time, which leads to faster decisions. For very similar train trips (e.g., TO2, TO5), decision making took more time than for discriminant decision options.

8. Conclusions

We presented a study on the impact of visual representation of train trips, of showing train delay uncertainty as well as the existence of an arrival deadline for trip selection. All of these conditions showed significant impact on the selection task for at least one of the decision situations. More details are given in the Annex.

Online studies allow to attract a large number of diverse participants, but the participants' reliability may be limited and simple tasks as well as a low study duration are required [BLB*17]. Our results motivate a more detailed investigation. With more decision options (train trips) which attributes are varied systematically, we could include the impact of user preferences as well as the comparison with ground truth to derive a utility/risk-functions. To evaluate the causality of each of the single conditions and to eliminate confounding effects, a further evaluation could use one design for which only the amount of displayed information varies.

TO1	different, delay-depended travel duration and arrival
TO2	different, delay-depended transfer duration
TO3	no transfers vs. critical transfer with alternative connection
TO4	no transfers but earlier depature vs. two transfers
TO5	critical transfer of both resulting in slightly different arrival times

Table 1: *Brief description of the two train trips per TO1–TO5. A detailed description of the decision situations is given in the Annex.*

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