Design and Evaluation of a Visual Query Interface for Maritime Route Planning

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Abstract

Efficient route planning is crucial in seafaring, where navigating requires consideration of various factors such as environmental conditions, vessel capabilities, safety, and arrival time constraints. While timely arrival is key to energy efficiency, prevailing strategy is getting near the destination as quickly as possible, anchoring or drifting until arrival conditions are met. Focusing on design factors for implementing arrival time (re)negotiation in onboard route (re)planning, we developed and tested two visual query interfaces for identifying arrival time windows under multiple constraints. Our first insights from this ongoing study are relevant for route planning in multi-objective optimization scenarios beyond the maritime context: *(1) Stop dumbing it down*—Query interfaces should not conceal too much of the inherent complexity. *(2) Hitting the sweet spot of controllability* is not (so much) a case of individual preferences. *(3) Be realistic*—Critical design challenges emerge only with a realistic or plausible fictitious scenario.

CCS Concepts

• **Human-centered computing → Visualization application domains**; **Empirical studies in interaction design**.

Keywords

route planning, arrival windows, query interface, interactive visualization, interaction design

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1 Introduction

Efficient route planning is crucial in seafaring, where navigating through vast waters requires meticulous consideration of various factors such as weather, currents, tides, or further environmental conditions, vessel capabilities, and most importantly, arrival time windows. Arrival time windows refer to the specific time intervals within which a vessel must—or only can—reach its destination. Identifying, communicating about, and meeting these windows is often imperative for ensuring smooth operations, meeting contractual obligations, and optimizing resource utilization.

In this paper, we present our design research endeavors towards developing an intuitive and efficient solution to address this challenge. To this end, we designed two distinct visual query interface (VQI) components for identifying arrival time windows under environmental constraints and evaluated a high-fidelity prototype with prospected users. The results of this explorative focus study, which included questionnaires on acceptance [17], intuitiveness [12], and usability [4], as well as interviews and thinking-aloud data, gives pointers for design considerations in route planning tools targeted at multi-objective optimization scenarios in the professional context.

2 Background / Related Work

In tramp shipping (e.g., tankers, dry bulk vessels operating without fixed schedules), current practices often involve getting close to the destination quickly and then anchoring or drifting until final approach, leading to high emissions both during travel and at anchor [10]. While the motivation for this is an area of research in itself, the realization of arriving at just the right time combined with short-term operational measures for emissions reduction, such as speed optimization (i.e., slow steaming) [3], complicate arrival time calculations in dynamic conditions. The optimization goal hence becomes “Don’t go faster than necessary—and mind all constraints”, and optimizing for energy efficiency throughout the whole sea transport requires careful consideration of environmental conditions not only during passage, but also in the target area (e.g., tides, lock and port operation times, booked port arrival windows). These cross-influencing conditions are often susceptible to uncertainties and difficult to visualize and account for. Furthermore, captains bring in vast experience and implicit/tacit knowledge to consider, requiring an approach of decision support rather than decision automation, because “Not the fastest route is always best”[1]—replace “fastest” with *shortest*, *safest*, *most fuel-efficient* etc. As such, incorporating multiple arrival time windows into route planning poses a significant challenge, particularly in terms of user interface design. Traditional route planning systems primarily focus on single arrival time scenarios, overlooking the complexities associated with multiple possible windows and further constraints. Existing solutions often require cumbersome manual inputs, repetitive runs, and manual note-taking on possible solutions, leading to inefficiencies and potential errors. Query previews and similar techniques have previously demonstrated significant contributions in the field of information retrieval, such as in the area of e.g., data exploration systems [7, 15], and query space visualization [8]. We aim to apply similar principles here to maritime commercial shipping route planning, where complex, multi-factor route optimization currently requires a multi-tool, multi-step process. Seafarers are constantly juggling safety concerns, high workload, fatigue and conflicting orders from stakeholders [21], therefore we need a system which fits into the working reality of seafarers. One method to ensure such fitness could be the use of intuitiveness (for a cursory overview, see [12]). Intuitive use has been applied as a measure in HCI in emerging technologies (e.g., [2, 9]) to ensure technology adaptation, ease of use and successful transfer of embodied knowledge, among others. Furthermore, by applying intuitiveness as a design strategy for just-in-time-arrival, we offer benefits for other domains as well, e.g., aviation, railway and multi-modal transport, up to battery-electric vehicle route/charging planning. Recognizing this gap, the objective of the current research was to examine the effect of interface design on a novel user interface component specifically tailored for the seamless input of multiple arrival time windows in seaborne transportation route planning.

3 System / Demonstrator

In all test conditions, the mockup, a high-fidelity *Figma* prototype [5] comprised a display of environmental factors alongside suggested arrival time windows, providing the following functionality: (1) (De)Selection, deletion and modification of time windows, (2) Prototypical modification (length) of time windows, and (3) Interaction leading to the definition of a new, additional time window (not fully implemented). Information display was enhanced by (4) visual hints indicating unmet mandatory conditions (e.g., water level too low for ship to arrive safely). The mockup was situated in a frame suggesting being midway into a multi-step route-planning wizard, in a thematic sub group titled *Eco Goals*. The design frame was that of the *MariData* DSS [13] running on a tablet (see fig. 1 and 2). The conditions differed in the visual display of the relevant external factors (e.g., tides, ship lock states) and the interaction leading to the selection/deselection/modification of an arrival time window: The *A*-condition (*Graph*), displayed environmental factors as a line graph, and allowed for arbitrary time window marking via a touch/click-and-drag interaction, allowing for a very direct manipulation (see fig. 1). Unmet conditions in selected time frames would be additionally hinted at through callouts, reading a warning message and the relevant parameters. The *B*-condition (*Bar*), displayed an interactive bar chart, where each bar signified the magnitude and duration of the environmental condition (see fig. 2): The height of the bar corresponded to the water depth, the width to a time interval belonging to this metric. An open lock would display a full-height bar with the width corresponding to the duration of this state. Here, clicking/tapping each bar would toggle the *selected* state. As the bars overlaid each other (i.e., the ship lock bar covered multiple tide bars), tapping a wider bar toggled all corresponding narrower bars within its dimensions. Individual items could then be toggled off again, to allow for a quick selection/exception management. Here, unmet conditions in selected time frames (i.e., bars) would be tinted and additionaly hinted at through callouts, reading a warning message.

The high information density and amount of functionality aimed to mirror the complexity of factors to be considered in this professional context (in contrast to the archetypal “startpoint–endpoint [+ departure/arrival time]” consumer street navigation query interface): *i.a.*, 1) environmental factors (e.g., tides, currents), 2) target area logistical constraints (e.g., ship lock operational states, availability of pilotage, mandatory channel pilot station operation times, berth time slots), 3) operational constraints. In other contexts, these constraints could also be found: E.g., multi-modal transport dependencies in logistics, traffic density or regulatory aspects allowing only certain operational times, contract-based requirements etc. The pre-selection of these two variants in the design process preceding the study aimed to maximize plurality in mode of information display and interaction on a number of typical devices (tablets, laptops, fixed terminals), while keeping information display familiar (enough) to key variables’ presentations (in this case, tide graphs). The modes of interaction seeked to represent two extreme ends of interaction: *Tap/Click-and-Drag to select*, and *Toggle on/off*.

4 User Study

4.1 Pre-Study Questionnaire and Introduction

$N = 6$ seafarers were recruited for this focused in-depth remote expert evaluation study, comprising individuals with expertise in Marine Engineering, Maritime Transport, Nautical Sciences, and Logistics. Recruitment was focused on (prospective) graduates, associates and staff of a nautical school. Prior to the study, participants completed a questionnaire gathering demographic information such as educational background, and professional experience in the maritime industry ($M = 0.58$ years, $SD = 0.49$). Additionally, participants were asked about the (approximate) total number of planned routes ($M = 35$ times, $SD = 35.78$, $min = 5$, $max = 100$) , and their familiarity with route planning tools. Finally, participants filled out a questionnaire to gauge their disposition towards technology interaction in general (ATI [6]; $M = 4.69$, $SD = 0.37$). Compared to the general public, which is expected to be around 3.61 [6, p461], this is an

[1] Participant 4, see section 5.1

Figure 1: Design Variant *A*, dubbed *Graph*

Figure 2: Design Variant *B*, dubbed *Bar* / *Toggle*

indicator for high affinity for technology interaction within this study sample.

4.2 Procedure

Prior to the interview on current practice and subsequent task execution, participants were introduced to the prospected use case and motivation by drawing a future scenario implying the mutual desirability of arrival time window optimization. Participants were then interviewed considering best practices by [19] to understand their current practices and methodologies in route planning, focusing on how they incorporate (multiple possible) arrival time windows into their planning process and gain insights into existing challenges, workflows, and tools, and prompt context-awareness for the experiment. As recommended by [17], *Technology Acceptance* data was gathered not only *after* presenting each design variant, but also *before*, after having been given key characteristics of a prototypical solution in form of a textual description. Participants were presented with two design variants (*A* and *B*) of the proposed UI component for inputting multiple arrival time windows (the order of presentation was counterbalanced to mitigate order effects): 1) *Task Scenario Briefing and Objective:* Participants were briefed on a specific route planning scenario and provided with a set of objectives to accomplish using the designated design variant. They were instructed to think aloud (TA), following best practice as defined by [18] during the task execution, verbalizing their thoughts, actions, and perceptions; 2) *Task Execution using Mockup:* During task execution, participants spent up to ten minutes in the scenario, sharing their screen with concurrent TA. In the course of this experiment, the experimenter was muted with camera off, and the participant's screen and audio were recorded; 3) *Post-Scenario Questionnaire:* Following each task scenario, participants completed a questionnaire assessing their experience with the respective design variant. The questionnaire included items related to usability (*SUS* [4]), *Intuitive Interaction* [16], and *Technology Acceptance* [17]; 4) *Post-Scenario Interview:* Finally, participants were asked to do an additional, retrospective thinking-aloud, following the recommendations for hybrid TA [1, 18]. Framed in a semi-structured interview [19], this provided room for additional feedback on the experience, sharing of anecdotal details, and further inquiry, e.g. verification of observations. After completing all of the task scenarios, participants engaged in a final, semi-structured interview to provide comparative feedback on their experiences with both design variants. This qualitative discussion allowed participants to elaborate on their preferences, challenges encountered, and suggestions for improvement. Additional themes were their perception of the proposed UI component's potential impact on their workflow, clarity of instructions, and overall satisfaction. In total, participants spent 60–120 minutes in the study.

4.3 Data Analysis

Survey data was analyzed with the help of a proprietary *R* script [11], enabling 1) data processing according to each scale author's guidelines, 2) visual analysis of value distribution, and 3) participant-(i.e., row-)based grouping and mean/standard deviation calculation (see table 1). Initial interview, in-task thinking-aloud, post-task, and final interview data were analyzed as follows: We first reviewed recordings and notes, entering observations into a table with data points categorized by type (e.g., think-aloud, interview, observation), preliminary codes, and associated *a priori* themes. This was done separately for each task scenario/interview. For the initial interview, the themes were related to the interview questions (challenges, parameters, procedures, tools) and further differentiated into categories (e.g., constraints, decision factors, optimization parameters). For task-related data, initial themes related to usability problems (*success*, *misinterpretation*, *functionality used*/*ignored*/*missed*, *difficulty*). For the final interview, a similar table was created with different themes (preference, feedback, rationale, idea). During coding, the codes and themes were consolidated both during data entry and after all entries were complete. The initial themes remained mostly stable: Only for task-related data, "success" and "misinterpretation" were merged with "functionality-used" and "difficulty", respectively. A few themes were added, to capture general feedback beyond functionality issues.

		Usefulness		**Satisfying**		**Effortlessness**		**Gut Feeling**		**SUS**	
P.	**Exp.**	Graph	Bar	Graph	Bar	Graph	Bar	Graph	Bar	Graph	Bar
P1	50	1.00 (0.35)	0.88 (0.48)	1.30 (0.45)	1.63 (0.48)	2.40 (0.89)	5.20 (0.84)	6.00 (0.00)	3.00 (0.82)	36	72
P2	10	1.50 (0.00)	1.38 (0.25)	1.10 (0.22)	0.75 (0.29)	5.40 (0.55)	3.60 (1.14)	2.75 (0.50)	4.25 (1.71)	68	56
P3	100	1.80 (0.27)	1.75 (0.29)	1.40 (0.22)	1.25 (0.29)	4.20 (2.28)	5.60 (0.89)	3.25 (1.89)	5.00 (0.82)	68	62
P4	15	1.20 (0.27)	1.00 (0.41)	1.60 (0.42)	1.63 (0.25)	6.80 (0.45)	5.60 (1.52)	1.50 (0.58)	2.75 (1.50)	34	76
P5	5	1.70 (0.45)	1.75 (0.29)	1.20 (0.27)	1.38 (0.25)	2.80 (0.84)	6.20 (0.45)	3.50 (1.00)	2.50 (0.58)	86	74
P6	30	1.50 (0.35)	1.25 (0.29)	1.60 (0.42)	1.63 (0.25)	5.80 (0.45)	4.20 (1.48)	5.00 (2.16)	2.50 (0.58)	76	54
		Scale range -2–2; $0 < x \leq 2$ *attributed positively*				*Scale range 1–7;* $4 < x \leq 7$ *attributed positively*				*Range 0–100*	

Table 1: Planning experience (no. of planned routes), *Acceptance* subscales (*Usefulness* and *Satisfying*), selected *INTUI* subscales (*Effortlessness* and *Gut Feeling*), and *SUS* for the two conditions. Except for experience and *SUS*, values are in the format “Mean (SD)”.

5 Results and Discussion

5.1 Multiple distinct arrival time windows—A realistic scenario?

All participants agreed that arrival time (RTA[2]) optimization plays a big role, although there were mixed opinions on the possibility and negotiability of more than one RTA: e.g., berthing slots, channel passages and pilots are booked weeks in advance and can hardly be changed due to financial/logistical factors. Undisputed was the role of environmental conditions (e.g., tide, currents, ship locks, traffic) in this process. Still, even for these critical factors, current tools available hardly allow for multi-objective optimization[3], let alone variation. In addition, practitioners reported critical waypoints (WPT) often coming from (captain’s) experience with route, ship, and expected conditions, further narrowing down optimization corridors. To summarize, with these influences on planning procedures (*i.a.*, RTA fixed, WPTs by experience, impracticability of tools), “It becomes quite labor intensive very quickly [. . .]. If you had a support system [. . .], changing variables, making suggestions for optimal route, [. . .] it would open up more opportunities for deciding parties [master of vessel / s/o in back office]” (P1). As a consequence of these over-defined queries, a more suitable tool design affords a design approach ignoring certain constraints (e.g., fixed/single, narrow RTA window), aiming at a tool supporting query formulation and visualizations of alternatives and (non-)negotiable parameters.

5.2 How complex may a time window identification interface component get?

Bridge ecosystems are characterized by multiple, redundant instruments and displays, with task-dependent rearrangement of screen contents. Current meta-tasks in route planning involve managing complexity in 1) factors influencing a decision, 2) tools and 3) stakeholder perspectives (cf. [20]). Being accommodated to this might explain, why none of the participants commented on the complexity of the information display, despite below-average ratings in *Gut Feeling* (see table 1). Another explanation can be found in the contents of the semantic differentials in *Gut Feeling*, where e.g., “I consciously performed one step after another” (= 1) is contrasted with “I performed unconsciously, without reflecting on the individual steps” (= 7): Due to its inherent complexity, route planning in shipping is likely not perceived as an unconscious, non-analytical process. Still, some features were ignored, e.g., manual entry of time slot ($n = 4$; in both conditions), and brought up as missing in the interviews, indicating a design problem. Regarding complexity in interaction, changing the section length (functionality only in *Graph* condition) led to difficulties in interaction ($n = 5$), which can be attributed to the prototyping technology used. Still, this feature was generally appreciated—in the other condition, this functionality was even missed ($n = 3$). The information display overall was lauded—esp. environmental constraints in relation to arrival time: These were reportedly normally either a) spread over multiple devices/sources, b) affording mental work to relate data in tabular form to travel data, or c) only metrics for one point in time instead of timeline visualizations.

5.3 Hitting the sweet spot of controllability

Multiple perspectives on granularity and controllability were identified in the interview data: a) Uniform width and length of time slots in *Bar* condition was seen problematic ($n = 3$)—here, b) unrestrained input (as in *Graph* condition) was generally preferred ($n = 4$), and c) some P. missed a zoom functionality on the timeline ($n = 3$). *Bar* input was generally mentioned as easier to use ($n = 4$)—P5 even apprehended motor difficulties regarding touch-and-drag operations due to vibration—but nearly all ($n = 5$) missed the accuracy and freedom of the *Graph* input at the same time. As in both conditions timeline data display was coupled directly to the mode of interaction, P. acted ambivalent about their preference ($n = 3$), although, when asked directly, mostly gave a single preference ($n = 5$). While most ($n = 4$; rest: 1 indifferent, 1 preferred *Bar*) preferred the tide display as a continuous curve, only P3 mentioned also the interaction to be best suited for multi-modal input on board (e.g., tablet, laptop, terminal).

[2] *RTA* here denotes a required/requested time of arrival, as a result of contractual obligations, negotiation, or environmental constraints.
[3] While some vendors claim to assist in “multi-objective optimization”[14], diversification in routes, times and strategies still has to be done manually.

6 Conclusion

The first results of this ongoing study are relevant for route planning in multi-objective optimization scenarios, even beyond the maritime context: Arrival time window identification in the context of multiple constraints affords more elaborate kinds of query interfaces, considering 1) Routing interfaces should not conceal too much of the inherent complexity, 2) Controllability is not a case of individual preferences, 3) Critical design challenges only unravel if you commit to a plausible scenario. Refocusing the discussion from motivational factors to an exploration of design factors to be considered when trying to implement arrival time (re)negotiation in onboard (en-route) route (re)planning settings, we developed and tested two distinct UIs for identifying arrival time windows under immutable constraints. While just-in-time arrival is key to energy efficiency and emission reduction in many domains, and efficient route (re)planning is crucial, this study was situated in the context of maritime shipping, where navigating through vast waters requires meticulous consideration of various factors such as weather and further environmental conditions, vessel capabilities, and most importantly, arrival time constraints, in ways currently not well supported in commonplace bridge systems.

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