Interactive Human-Guided Optimization for Logistics Planning

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Abstract

Logistics planning is an important problem in industry, where goods have to be parceled appropriately to meet delivery dates or reduce shipping costs. This optimization problem is classically solved offline using standard algorithms and focused heuristics, e.g. bin packing or route planning. However, in practical work environments, constraints may change flexibly and it is often not clear what an optimal solution looks like. Further, logistics planning consists of multiple steps that often are handled by different human employees in different departments. In this paper we propose an interactive approach using human-guided optimization, where solution spaces can be *interactively* explored, manipulated, and constrained at runtime. Based on an analysis of the problem of multi-step logistics planning, we present a system that supports users in solving this optimization problem, and we report first evaluation results obtained in the first two iterations of a user-centered design process.

1 Introduction

A common problem in industry is the organization and scheduling of the transport of goods to customers or processing companies. Often, a delivery consists of numerous parts that can be parceled and portioned in different ways (e.g. in pallets, trucks, ships, etc.). This is a complicated optimization problem where solutions have to fulfill various constraints like meeting delivery dates, minimizing shipping costs, or complying with allowed ways of packaging goods. Standard algorithms can be used for different parts of this optimization process (e.g. bin packing, route planning) and this problem has been analyzed theoretically as 2D/3D loading capacitated vehicle routing problem (Iori & Martello 2010).

In practical work environments, however, things are more complicated and a specific optimization algorithm often is too rigid. Constraints often change flexibly, e.g. when custom tailored goods with variable size and weight have to be handled, and it is often not clear what an optimal solution looks like. In some cases, maximum usage of packing volume is considered optimal while avoidance of mixing different orders might be optimal in other cases.

Often, these constraints are imposed at different stages of the logistics planning process, by human employees with long-standing expertise working in different departments.

In this paper, we analyze such a multi-step logistics planning process as practically implemented in a mid-size company (~400 employees). Our goal is to provide a system that supports this optimization process. Our approach is to enable an *interactive human-guided* optimization, where solution spaces can be interactively explored, manipulated, and constrained at runtime by human operators. In the next section, we review related work. We then analyze and frame the optimization problem. Finally, we describe our ongoing design and development process by laying out the concept of our approach, describing first iterations of our user-centered design process.

2 Related Work

Research has led to a plethora of algorithms and heuristics that provide approximate or (near) exact solutions to optimization problems like bin and strip packing (Lodi et al. 2002, Jylänki 2010) or the well-known traveling salesman problem (Rego et al. 2011). While there still is a growing demand in industry for automated solutions to single optimization problems, recently, combinations of several optimization problems gain increased interest, as they bear high potential for savings (Hasle & Kloster 2007). Iori and Martello (2010) provide a systematic view to combinations of routing and loading problems, called Capacitated Vehicle Routing Problem. Concerning applicability to real-world applications, they state that due to additional constraints not captured by theoretical models practical application of such theoretical analyzed problems is limited.

It has been demonstrated that interactive approaches to optimization problems are able to surpass mere computer-based solutions (Anderson, et al. 2000, Klau et al. 2002, Klau et al. 2002, Klau et al. 2009), since additional knowledge of human experts can be used to further optimize a solution. An advantage of such interactive approaches is that the generated solution is better understandable and more trustworthy to the user if taken into the loop. Based on the Human-Guided Search paradigm, Klau et al. (2002) developed a platform, called HuGS, that visualizes optimization processes and enables users to actively guide the optimization by constraining and exploring the search space. The idea is that a human user is able to select sub solutions among alternatives produced by an algorithm, taking additional constraints into account that are not implemented in the algorithm. While the authors state that a so called Optimization Table allows for several users to interact with the system, no additional information is given on how this type of interaction looks like in an actual application. Lesh et al. (2005) extend the HuGS platform to the domain of packing problems and make three types of actions available for human guidance (Klau et al. 2009): (1) manual selection of the next move, (2) invocation, monitoring, and halting the search process, and (3) reverting to a previous solution. Kopfer and Schönberger (2002) suggest a framework for interactive problem solving with focus on vehicle routing and scheduling problems in. Their basic idea is to enable a human operator to guide the optimization process by activating and deactivating constraints of the underlying problem. While the authors analyze requirements of interactivity for such a framework and provide an interactive tabu search-based approach, their account remains theoretical.

In sum, to the best of our knowledge, existing approaches regard optimization problems as an isolated task that can be solved automatically, like the aforementioned routing and loading problem, or allow for some guidance by a single human operator. However, there is no solution to the problem of multi-step logistics planning, as encountered in real companies (as described in the next section) and involving different kinds of users in different stages of the optimization process. In the remainder of this paper we follow a user-centered design process towards such a solution by describing the results of a requirement analysis, a concept generation/refinement, and first prototyping and user evaluation steps.

3 Analysis of a Multi-Step Logistics Planning Problem

In the present work, we focus on multi-step logistics planning, a special instance of what we refer to as multi-step optimization problems. Such problems are solved in practical work flows where it is not possible to consider a certain task an isolated step. Tasks that are further down the stream depend on earlier steps and might fail if certain requirements are not met by previous steps. To assess the steps necessary in a typical work flow of logistics planning and to identify typical problems, we conducted initial interviews with staff of the dispatching and the warehouse department of a mid-sized company that builds and delivers custom-tailored windows and doors. Visiting the warehouse and following the shipping process, we got an image of the whole logistics chain, from planning to packing. The work flow extracted from these interviews looks as follows (see Figure 1):

Planning Stage

- *PL1* As a first step, orders have to be grouped according to shipping regions.
- *PL2* Based on the estimated packaging volume (amount of packing material and available number of delivery vehicles), orders have to be grouped to form a specific tour and a sequence for delivery has to be determined.

Packing Stage

- *PA1* Positions of a tour are packed onto special containers.
- *PA2* Containers are loaded into vehicles for delivery.

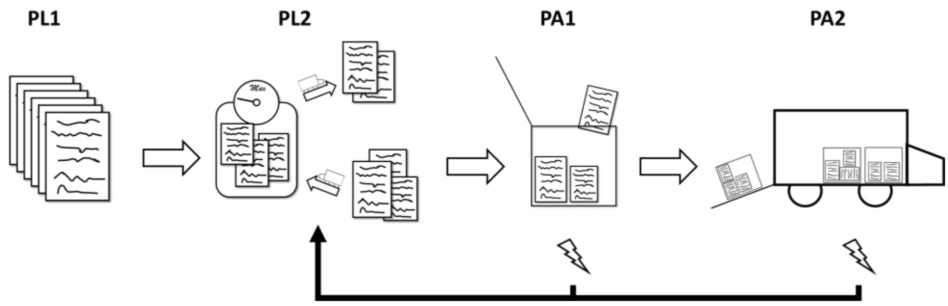

Figure 1: Steps occurring in the logistics planning process of an actual mid-sized company. (PL1) Orders have to be grouped according to shipping regions. (PL2) Orders have to be grouped to form a specific tour, based on estimated volume. (PA1) Goods have to be packed, and (PA2) loaded for delivery. If a step fails, planning has to start over (arrow at the bottom).

The final step *PA2* can only be accomplished, if specific constraints are met. Most of these constraints arise from planning step *PL2* (e.g. delivery sequence) and packing step *PA1* (affordances of different goods, e.g. some goods cannot be fixed on top of each other because of the delivery sequence or their material). Further constraints stem from the vehicles available in step *PA2*, e.g. maximum number and size of containers that can be loaded. If the estimated packaging volume in *PL2* is off, it is not possible to meet the requirements in steps *PA1* and *PA2*. Then, orders cannot be delivered in time: either some of the goods have to be scheduled for later delivery, or the whole planning process has to be restarted leading to delays for all orders. Hence, an accurate estimate of packaging volume in step *PL2* is crucial for the success of the whole logistics process. It became clear that whatever steps were left out during planning had to be solved eventually by warehouse staff. While they are instructed by the dispatching department what orders and components to pack, no details of how to pack them are provided. So, over the years the packers gained valuable experience in on-the-fly truck loading. A major issue arises from the fact that hardly any information that could be used to improve the planning process is fed back to the dispatchers if the packing process cannot be accomplished. But knowledge of constraints of all packing steps is needed for a good estimate. However, this knowledge is distributed among different employees and currently it is not possible to integrate members of different departments in the planning process.

3.1 Personas

To broadly analyze the context and the requirements our solution would have to meet, we arranged several meetings with employees of the company. During the (unstructured) interviews we identified two main user groups that will work with our system: dispatching and warehouse staff. To be able to address the specific requirements of these users during the development of our prototype, personas were compiled representing characteristic user features. In this stage we mainly focused on identifying the user type, tasks and goals, current company solutions, the information they need, how the information should be presented, and on the physical user environment.

Jürgen W, 39 years, works in the *dispatching department* of company X. The main tool for his daily work is standard logistics software, where three dimensional data of goods and containers is translated into numerical values and provided through spreadsheets. Jürgen therefore has necessarily learned to think in abstract ways of the underlying problem. The combination of different software solutions providing different kinds of information constantly forces him to switch back and forth between different views. Since the software he uses does not support estimations of packing volumes, most of his decisions rely on his experience and gut instinct, often leaving him with an unpleasant feeling.

Hans S., 55 years, works in the *warehouse department*. Most of the day he is busy gathering goods and tucking them onto containers. A list of the goods that comprise a tour is provided on a central computer terminal, that he uses as seldom as possible. Hans has to figure out how to arrange them efficiently on his own since no detailed instructions are provided. As a long time employee of company X he looks back on solid experience of solving complex packing problems on the fly. He almost intuitively knows which goods can be fixed together on a container and which goods pose problems.

4 LogiPro: A Tool for Multi-Step Logistics Planning

The idea of our approach is to enable an optimization process in a stepwise fashion, which can be interactively guided. To this end, we want to provide both a tailored algorithm that solves the optimization problem at hand, and an embedding of this algorithm in a tool that allows users at different work places to inspect the current state of the solution process and to add information relevant to the specific task. As a first measure, we focused on the planning stage (steps *PL1* and *PL2*) of the multi-step logistics problem under consideration and on users from the dispatching department (*persona Jürgen W.*).

In line with existing approaches to interactive human-guided optimization (Klau et al. 2009), we employ a visual representation of the search space as a starting point. However, during requirement analysis it became clear that a lot of additional information is necessary for a user to judge the quality of a given (sub) solution. For instance, weight or material of components influence the acceptability of a certain configuration. While such attributes could be integrated in a visual representation, e.g. by color coding or specific icons, there is a risk of overwhelming the user with too much information (Oviatt 2006). Therefore, we opted for a combination of visual representations including only the most relevant information (width, height, depth, and order membership) and standard spreadsheet-based views, where additional information like material or weight of components is provided and can be highlighted. To enable a user to interactively guide the optimization we adopt the basic actions described in Lesh et al. (2005) and Klau et al. (2009). Further, we chose a simple means of changing multiple parameters and constraints at once to allow for quick browsing through the solution space. Central to our approach is the ability for different users to add and manipulate constraints that are used by the underlying algorithm. Therefore, in line with Lodi et al. (2002), constraints can be added, enabled, and disabled at runtime. This allows to incorporate knowledge of different users in the solution process of the optimization problem.

4.1 First Prototype: Features

To fit into the specific workflow used by persona Jürgen W., two basic tasks were identified that our system has to support: 1. Exploration of orders that have to be shipped and 2. planning of needed containers for a certain tour. An intermediate step, where an optimal route for a tour is calculated, is performed using a third-party software. Thus, we implemented two separate views to explore all or subsets of orders to be processed by dispatchers (Figure 2). The exploration view consists of two spreadsheets containing orders and associated positions of components, and a 2D/3D display of a suggested packing for the currently selected order (Figure 2, bottom left). For this view, the use case is to get an overview of all orders that have to be shipped and to easily identify critical orders, e.g., containing heavy-weight components. The second planning view allows for interactively exploring and manipulating the solution space for combinations of selected orders (Figure 2, bottom right). Again a combination of a spreadsheet-based presentation and a 2D/3D view is used. Two ways of parameterizing the underlying algorithm were provided: a simple slider-based view and a detailed configuration pane. Predefined configurations are associated to the different positions of the slider. If the user drags the handle of the slider, the algorithm is triggered with the corresponding configuration and the 2D/3D view is updated in real-time accordingly. For greater in-depth control, the configuration pane allows for tweaking all aspects of the algorithm, like heuristics, constraints, and constraint parameters. Furthermore, the user is able to open a detailed view of a single container and add/remove/reposition objects by direct manipulation using drag'n'drop mouse gestures.

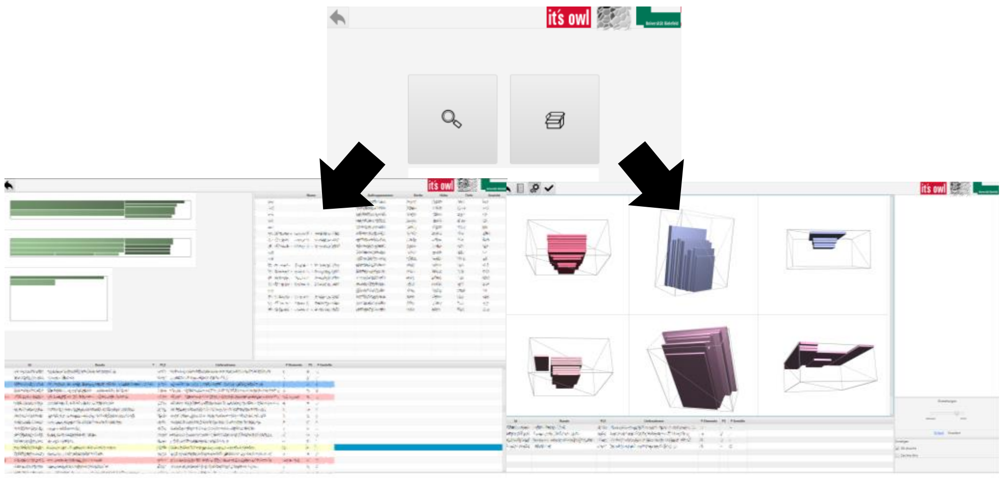

Figure 2: The two major planning tasks identified during analysis of the company's workflow are strictly seperated into two different views – an explortation view (bottom, left) and a planning view (bottom, right) – within the first prototype.

As optimization algorithm, we implemented a bin packing algorithm (rotations of objects are not considered so far) with different Guillotine-based split heuristics as described by Jylänki (2010). In addition, two different placement rules, bottom left and bottom center, as well as possibilities to sort elements in a preprocessing step, e.g. by increasing/decreasing width, have been added. The latter is considered to improve overall quality of generated solutions (Lesh et al., 2005, Jylänki 2010) and may depend on certain attributes like material or weight. Constraints are modeled in an object-oriented manner and evaluated at different steps in our algorithm. Similar to what is suggested by Kopfer and Schönberger (2002), this allows for flexible addition and removal of constraints to influence the ongoing search.

4.2 First Prototype: Evaluation

We scheduled a focus group to evaluate our first fully functional prototype, thus ensuring the identification of major usability issues and basing the next step of our development process on user feedback. The session was conducted by two moderators. Three prospective users participated: two employees from the dispatching department (1 female, 48 years; 1 male, 45 years) and one member of the warehouse department (male, 61 years). The latter would work with a modified version tailored to his different needs not considered at this phase of the project, but was nevertheless included for feedback and familiarization purposes. The two dispatchers were seated adjacently, each in front of a 22-inch monitor, while the warehouse employee did not actively work with the prototype. Both were provided with an individual system and a sample dataset of actual logistic use cases. We first showed a brief tutorial of the prototype and explained all parts. Next, they explored the prototype, trying to work on typical tasks. A combination of thinking-aloud and communication between both employees was encouraged, thereby enabling them to develop a shared understanding. When an issue was encountered, both dispatchers discussed suggestions for improvement. All remarks were noted by the moderators. Subsequently, both dispatchers had to fill in a questionnaire comprising a German version[1] of the SUS inventory (Brooke 1996).

Roughly two results emerged from the results of this first evaluation. First, the dispatchers quickly felt that the visualization supported their work flow significantly, providing them with novel options to effect solutions. They also reported that usability (for this specific user group) could benefit from a stronger integration of the functions that are distributed among the two views in the prototype. Second, the packer, overlooking the exploration, seemed hesitant to accept the system. For one thing, he struggled with the novel presentation of familiar information and saw issues, e.g. because the visualization was missing specific product details. Remarks about a somewhat cumbersome usability of the first prototype were supported by the analysis of the SUS questionnaire revealing usability issues with a score of 68.75 (borderline).

[1] Taken from: https://blog.seibert-media.net/blog/2011/04/11/usablility-analysen-system-usability-scale-sus/

4.3 Second Prototype: Features

As the results of the first evaluation suggested, the strict separation of the tasks was not accepted by the user group represented by persona Jürgen W. The participants could not imagine to integrate the two separate tasks into their workflow. Therefore, in our second prototype we arranged the tasks in a sequential manner and thereby resemble their actual workflow more closely (see Figure 3). In addition, we introduced a possibility to define tours to be used in the intermediate step described above to further foster the integration into the existing workflow. To allow for a more transparent configuration of the underlying algorithm, the slider-based view was merged with the detailed configuration pane. This way it is more apparent how different slider positions affect the algorithm.

4.4 Second Prototype: Evaluation

Two employees of the dispatching department (1 female, 46 years; 1 male, 45 years) participated. As in the first evaluation, both were provided an individual copy of the system and actual logistic data. However, this time the participants were spatially separated so that they could test the system without interacting with each other. Both were asked to complete a total of ten tasks, ranging from basics like opening a certain dataset to more complex tasks like planning a tour given some constraints. We used a combination of the thinking-aloud method and the SUS questionnaire to assess usability of the prototype. In advance, a brief introduction to the new prototype was given and initial questions were clarified.

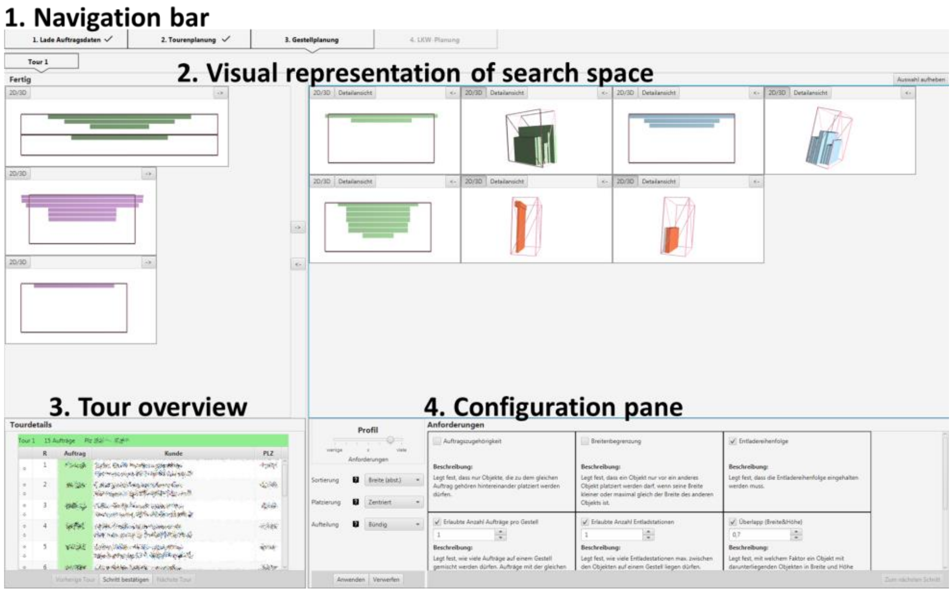

Figure 3: In the second prototype the exploration task (not shown) and planning task (depicted) are arranged in a sequential manner (navigation bar at the top, 1.) to more closely resemble the dispatching staffs' workflow. The visual representation of the search space (2.) is accompanied by a spreadsheet-based overview of the current tour (3.) and can be modified using controls provided by a configuration pane (4.).

Both the comments obtained using the thinking-aloud method and the score of the SUS questionnaire (81.25, good) indicate that major usability issues present in the first prototype were resolved. For example, the possibility to compile different orders into tours was recognized to fit well into the overall workflow. During the evaluation, the participants used the slider to create initial configurations that were then refined using the more detailed controls suggesting that the participants were able to establish a mental connection between these features. However, both participants used quite different approaches to tackle the tasks and preferred different ways of achieving a solution (e.g. use of slider vs. use of in-depth configuration options). Therefore, an approach that would be able to learn such preferences and adapt the user interface accordingly, could further improve the usability of our system.

5 Summary and Next Steps

In this paper we presented an approach to interactive human-guided optimization for the example of multi-step logistics planning as encountered in an actual company. Based on an analysis of the logistics process, we devised a concept for interactive guidance of the optimization process towards a solution that meets various, flexibly explored constraints. The results gained with a first prototype implementation, both in terms of user feedback as well as the technically realizable optimization process, were promising. Based on the user feedback we refined our concept and prototype, i.e. provided a more guided stepwise workflow. The evaluation of our second prototype showed that the user-centered design approach helped to achieve a significant improvement over the first prototype, as revealed by the SUS questionnaire.

A basic tenet of our approach, the next step will be to enable multiple users with different expertise to interact with the system (although not simultaneously). This entails incorporation of steps PA1 and PA2 of the packing stage to enable persona Hans S. to interact with the system. Here, design of an appropriate user interface for inspecting and affecting solutions poses the main challenge. We are confident that in result our system will not only achieve important steps to enabling intelligent systems that allow for interactive optimization, but also bridge the gap between theoretical algorithmic solutions and the actual requirements in a real-life application scenario.

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