

Visual Analytics Approach to User-Controlled Evacuation Scheduling

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ABSTRACT

Application of the ideas of visual analytics is a promising approach to supporting decision making, in particular, where the problems have geographic (or spatial) and temporal aspects. Visual analytics may be especially helpful in time-critical applications, which pose hard challenges to decision support. We have designed a suite of tools to support transportation-planning tasks such as emergency evacuation of people from a disaster-affected area. The suite combines a tool for automated scheduling based on a genetic algorithm with visual analytics techniques allowing the user to evaluate tool results and direct its work. A transportation schedule, which is generated by the tool, is a complex construct involving geographical space, time, and heterogeneous objects (people and vehicles) with states and positions varying in time. We apply task-analytical approach to design techniques that could effectively support a human planner in the analysis of this complex information.

CR Categories and Subject Descriptors: H.1.2 [User/Machine Systems]: Human information processing – Visual Analytics; I.6.9 [Visualization]: information visualization.

Additional Keywords: Geovisualization, transportation planning, vehicle scheduling, task-centered design, coordinated multiple views.

1 INTRODUCTION

In managing time-critical problem situations, automation of generic tasks can be of great service. Thus, an efficient software tool for scheduling the evacuation of people from a disaster-affected area can save precious time and, as a consequence, people's lives and health. However, an automatically generated schedule cannot be blindly accepted for implementation but must be reviewed and evaluated by a person responsible for planning the evacuation (called 'planner' or 'evacuation planner' henceforth). Our goal has been to design and implement a tool or a combination of tools that would allow a planner to assess as quickly as possible the acceptability of a schedule and, in case of detecting a need for improvement, direct the further work of the automatic scheduler. We consider this as an opportune application for visual analytics techniques, in line with the ideas of the emerging research area of Geovisual Analytics for Spatial Decision Support [1]. Our arguments are presented below.

An evacuation (or, more generally, transportation) schedule is a collection of transportation orders assigned to available vehicles, where a transportation order specifies one trip of a vehicle: source and destination locations, start and end times, and people (more generally, items) to be delivered. In an emergency evacuation, it is typically necessary to schedule the transportation of people from multiple sources (original locations) to multiple destinations. The number of people to evacuate may be quite large. An evacuation planner does not deal with each person individually and even does

not have data at the level of individuals but only data about the (estimated) number of people in each location. The task is to assign groups of people to suitable destinations, find appropriate vehicles to deliver them, and set the times for the trips of the vehicles. There may be diverse categories of people such as general public, disabled people, and critically sick or injured persons. These categories need to be handled differently, which includes the selection of proper destinations and proper types of vehicles as well as proper timing of the transportation.

A schedule for the transportation of a large number of people from multiple source locations to multiple destinations is inevitably large, i.e. consists of very many orders. In our experiments, we used input data with 14 sources containing in total 4692 people of 6 different categories, 105 vehicles of 7 different types, and 25 destinations. For these data, a meta-heuristic scheduling tool based on a genetic algorithm produces transportation schedules with about 400 orders (the number of orders may vary as there are many possible variants of dividing the total number of people in a location into groups fitting in the available vehicles). An evacuation planner usually has no time for a detailed inspection of all orders. However, it is hardly possible to summarize the properties of a schedule in a few numeric or qualitative indicators permitting a sound assessment of its appropriateness, as a schedule is a complex construct involving geographical space, time, and heterogeneous objects (people and vehicles) with states and positions varying in time. Hence, to gain an insight into characteristics of a schedule, the planner needs a properly designed visual representation of its relevant aspects.

Because of the size and complexity of the information to be reviewed, the design of the visual representation needs to adhere to the 'Visual Analytics Mantra' put forward by D.Keim [2]: Analyze First - Show the Important - Zoom, Filter and Analyze Further - Details on Demand. This means that the visualization should expose the most important features and hide details while keeping them accessible on demand. This can be achieved by means of computational pre-processing of the data ('Analyze First'). With this principle in mind, we have designed a suite of visual analytics techniques for supporting schedule evaluation and made a prototype implementation.

The remainder of the paper is structured as follows. After reviewing the related work, we briefly describe the entire system for evacuation planning support, which includes an automated scheduling tool based on a genetic algorithm, procedures for computational analysis of tool outputs, and interactive visual techniques for schedule assessment. Then, we present our analysis of the task of supporting schedule evaluation and the design requirements resulting from the analysis. After that, we introduce the visual analytics tool created to meet these requirements. We demonstrate the work of the tool on several examples of automatically generated schedules. At the end, we present our ideas concerning the future development of the tool towards an interactive visual interface allowing the user not only to evaluate but also to direct the work of the automatic scheduler.

2 RELATED WORK

The research agenda of Geovisual Analytics for Spatial Decision Support [1] sets the support to time-critical decision

making as one of the priority directions. It also points to the need to find appropriate ways to visualize and analyze complex spatio-temporal constructs, such as scenarios and action plans.

Various computational methods have been developed to deal with the complexity of real-world decision making problems. In particular, the problem of generating adequate transportation schedules is considered in the area of Operations Research, where it is ascribed to a generic class of Vehicle Routing Problems [3]. For this class of optimization problems, deterministic mathematical techniques do not work sufficiently well while heuristic methods, such as Genetic Algorithms [4], offer a powerful alternative [5,6,7]. However, the problem usually cannot be solved fully automatically as not all aspects of it can be adequately encoded for computer processing. Only a human analyst on the basis of his/her domain expertise and knowledge of the geographic area can ultimately judge the quality of a plan. For this purpose, the analyst needs the plan and the related information appropriately presented.

Existing software systems for automated transportation planning typically include visualizations to present the results of schedule computation and optimization to the user and allow the user to modify the schedule [8,9,10,11]. Commonly used types of display are table and Gantt chart (a horizontal bar chart representing the duration of tasks against the progression of time). As these displays do not contain geographic information, they are often combined with maps showing the geographic locations involved [8]. Sometimes, planned shipments and vehicle moves are also represented on a map as directed lines (vectors) connecting source and destination locations [10]. A disadvantage is that the spatial and temporal aspects of a schedule are shown separately, and it is not easy for the user to establish links between them. To alleviate this problem, the user is offered a chart where the horizontal dimension represents time and the vertical dimension provides positions for the names of the locations [9,11]. In this chart, diagonal lines represent movements of vehicles from place to place and horizontal lines or bars indicate their staying at a location. Movements of several vehicles are shown by lines differing in color.

A shortcoming of these approaches to schedule visualization is their lack of scalability. Thus, a table or Gantt chart representing hundreds of orders can hardly facilitate schedule analysis, and a map with hundreds of overlapping and intersecting vectors is completely unreadable.

In [12], the authors present a solution based on the micro/macro display concept advocated by E.Tufte [13]. The main idea is that the macro features (overall shape) of a graph capture dispersion and trend information about the entire data set while micro encoding represents individual data items. This idea has been applied to the visualization of data concerning planned transportation of injured and sick people to medical treatment facilities. The display described in [12] consists of many tiny symbols each representing a single patient. The horizontal position of a symbol corresponds to the planned departure time of the patient or to the readiness time if the transportation of this patient has not been scheduled yet. The color and shape of a symbol can encode attributes of the patient. The symbols for scheduled and unscheduled patients are stacked on two sides of the time axis. In the result, the macro features of the display show the total number of the patients and the distribution of the planned vs. unplanned patients over time. This visualization, however, does not present information about the transportation means (vehicles), source and destination locations, and durations of the trips. It does not seem that the micro/macro display concept can be straightforwardly applied also to these types of information.

3 THE SYSTEM FOR EVACUATION PLANNING SUPPORT

The visual analytics techniques, which are in the focus of this paper, work in the context of a larger system for evacuation planning support. The architecture of the system is presented in Figure 1.

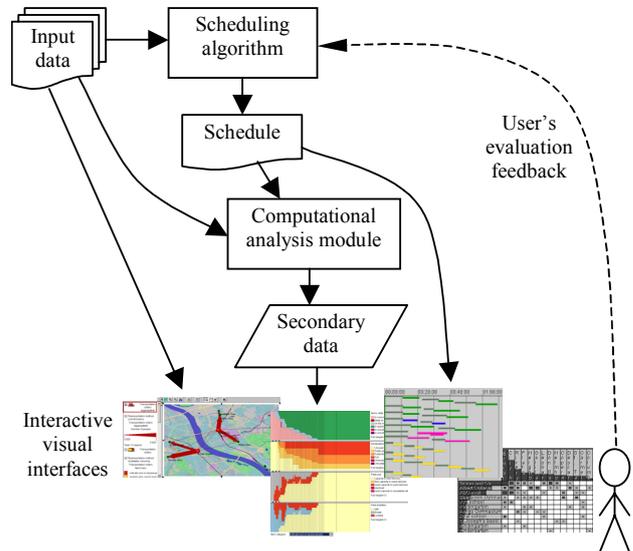


Figure 1. The architecture and information flows of the evacuation planning support system.

A Breeder Genetic Algorithm [6] is used for the automatic generation of feasible evacuation schedules. A schedule is a set of *transportation orders*, where an order is a structure defining a trip of a vehicle. It includes the identifier of the vehicle, the identifiers and names of the locations where the trip starts and ends, the category and number of items to be transported, and the start and end times of the trip. Among the possible types of items, there is a null item. It is needed to describe a trip of a vehicle with no load, which can occur, in particular, when returning to the scene of the disaster after delivering some group of people to a safe place.

At a certain degree of abstraction, the work of the algorithm can be viewed as follows. Originally, there is a set of so-called “transportation requests”, or under-specified transportation orders, where some fields contain preset data while others are empty. For instance, a request may specify a source location, an item class, and the latest allowed departure time. The scheduling tool fills in the remaining fields, in this case, a destination location, a departure time, and a vehicle identifier. Note that, in contrast to standard vehicle scheduling problems, it is sufficient that only a source (or destination) location is specified in the input. It is the task of the scheduler to determine the most appropriate destination (source) location. Furthermore, the scheduler is able to unite multiple transportation requests into a single order for transporting multiple items by a single vehicle, taking into account its capacity.

It should not be thought, however, that it is the task of the user to prepare the transportation requests for all individuals that need to be evacuated. The user needs to specify the places where there are people to evacuate, the numbers and categories of these people, and the latest allowed departure times per place and category. On this basis, transportation requests are generated automatically. Additionally, the following data are required:

- Possible destinations, i.e. safe places to which people can be moved, and their capacities, by people categories.
- Fleet description, which defines the types of vehicles and the initial distribution of available vehicles over the various

locations. For each vehicle type, the capacity is specified, separately for each category of people it can be used for.

- Distance (time) matrix, which contains the estimated travel times between each pair of locations. The times can be automatically computed by a routing tool.

An important property of the algorithm is that a valid solution exists at any moment while the quality is progressively improved as the algorithm continues its work. In a case of emergency, the user does not need to wait until the algorithm finishes its work but can get a reasonably good (although not necessarily optimal) solution within affordable time limits. Thus, for our example data, we could have quite good schedules already after one minute of running the tool. Generally, genetic algorithms, like any other heuristic methods, do not guarantee arriving at an optimal solution. They do, however, produce near-optimum solutions when properly designed.

After a schedule is obtained, it is processed together with the source data in the computational analysis module, which produces specific secondary data suited to the purpose of visual analysis of the schedule. These data are presented to the user, who explores them by means of interactive visual interfaces and, when needed, directs the tool towards desirable improvements of the schedule.

4 PROBLEM ANALYSIS AND DESIGN CONSIDERATIONS

The visualizations discussed in Section 2 are designed to represent detailed information about individual transportation orders so that the user could review the orders and, if needed, modify some of them. In time-critical situations, there is no time for reviewing a schedule in detail. Still, the planner must be able to assess the appropriateness of the schedule since it is the human and not the computer who bears the responsibility for any decision taken. Hence, the planner needs a summarized representation of a schedule conveying all information necessary for the evaluation. However, the user should not be restricted to viewing only summarized information but all kinds of detailed information should be accessible on demand [2].

Besides the time pressure, the emergency evacuation problem has also other differences from the 'standard' transportation problems typical for business applications:

- Diverse categories of items (people) to be transported;
- Diverse types of vehicles, which differ in their suitability and capacity for different item categories;
- Diverse types of destinations, also differing in suitability;
- Necessity to choose right destinations (in business applications, it is usually known what and how many items need to be delivered where).

Owing to these specifics, the emergency evacuation problem is more complex than business transportation problems. This additional complexity affects not only the scheduling algorithm but also the process of schedule evaluation by the planner.

Essentially, evaluation of a schedule means finding answers to three questions:

1. Does it achieve the goal, i.e. are all people timely delivered to appropriate destination places by appropriate vehicles?
2. Is it feasible?
3. Is it rational?

In case of detecting problems such as undelivered people or late deliveries, they need to be explored in order to understand the reasons (e.g. deficient transportation resources) and find suitable corrective measures. Here is a list of possible problems:

1. Problems in attaining the goal:

- Undelivered people;
- Late deliveries with respect to the time constraints;
- Use of improper vehicles;
- Delivery to improper places.

2. Feasibility problems:

- Use of more resources than available, i.e. exceeding the capacities of the vehicles or destinations;
- Multiple vehicles loading or unloading simultaneously in the same place (there may be not enough space or not enough personnel for this).

3. Rationality problems:

- Time gaps between transportation orders when vehicles are idle;
- Distant trips that can be avoided by choosing other destinations;
- Low use of vehicle capacities;
- Unjustified use of very expensive vehicles.

As already said, the planner needs summarized information because of the time pressure and the size of the data (hundreds of transportation orders). However, highly summarized information such as the total number of undelivered people and total delay with respect to the time constraints may indicate the existence of problems but is insufficient for the exploration into their reasons. A degree of summarization adequate for both purposes is highly desirable. In this respect, it is productive to show the temporal progress of the transportation according to the schedule using data aggregated by small time intervals. This will allow the planner not only to note the existence of a problem (e.g. late delivery) but also the time when it occurs and immediately explore the status of the transportation resources and destinations around this time.

Another design consideration is that the planner should be able to focus on the parts of the schedule relevant to different people categories. One reason is simplification of the display and the information to be perceived from it. Another reason is that the planner can apply some priority order in reviewing the parts of the schedule, for instance, start with critically sick and injured people who need urgent help. Then, if the planner is satisfied with the scheduling for this category, he/she can launch the execution of this part even before the rest of the schedule is reviewed.

One more consideration is that preference should be given to common and easily understandable visualization and interaction techniques. This will decrease the time required for the planner to recognize the meaning of the display and learn how to use it.

It should be noted that such general considerations play a subordinate role in tool design while the primary design principle is orientation to the specific tasks the tool is intended to support. In our case, this is answering the specific schedule assessment questions and detecting the specific types of problems and their reasons. In the design, we have also adhered to the Visual Analytics Mantra [2]: the data are computationally preprocessed ('Analyze First') to provide an overview and expose problems ('Show the Important'), which may be examined through querying and further computations and visualizations ('Zoom, Filter and Analyze Further') while the original data are always accessible ('Details on Demand'). The results of the design and prototype implementation are presented in the next section.

In the example considered in this paper, all resources (vehicles and destinations) are supposed to be available from the moment of the evacuation start, and all groups of people subject to the evacuation are known in advance. However, the scheduling algorithm and the visual analytics tools are also able to handle dynamic situations when additional people may appear, new resources found, some resources become unavailable, and estimated travel times modified.

5 A VISUAL ANALYTICS TOOL FOR SCHEDULE ASSESSMENT

5.1 Schedule progress summary display

Figure 2 demonstrates a summary display of the progress of the transportation over time. In order to build this display, the output

of the scheduling tool has been computationally analyzed taking into account the input data about the people to evacuate and available resources (vehicles and destinations). The computational analysis and subsequent visualization are designed so as to reveal major problems, specifically, undelivered people, delays, and use of unsuitable vehicles and destinations, or to demonstrate the absence of these problems.

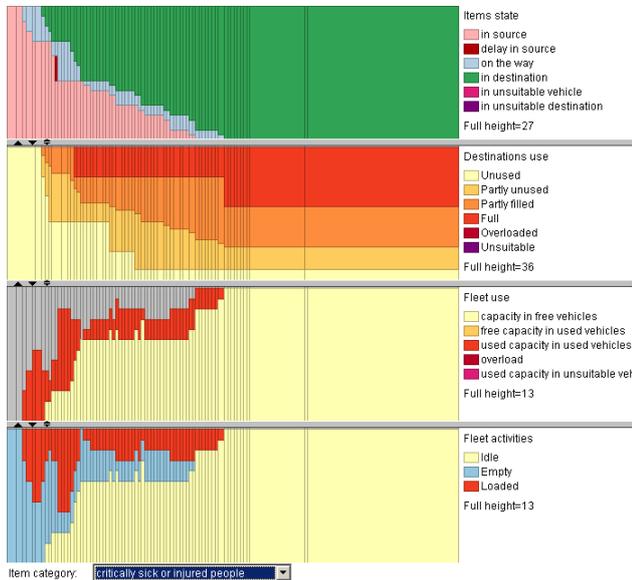


Figure 2. The summary display of the transportation progress presents the part of the schedule relevant to the evacuation of the critically sick and injured people.

The schedule progress display consists of four sections. The horizontal dimension in each section represents the time of the schedule execution. The sections are aligned so that the same horizontal positions in all of them correspond to one and the same time moment. The whole schedule execution time is divided into unequal intervals with the breaks being the moments when changes occur, i.e. some transportation orders are started or finished. For these intervals, each display section contains segmented bars of corresponding widths, which encode various aggregated data.

The upper section represents the evacuation progress in terms of the states of the people. For each time interval, the tool computes how many people are in each of the following states:

- stay in their source locations while the time limits (latest allowed departure times) are not yet exceeded;
- stay in the source locations after the time limits have been exceeded;
- are on the way to designated destinations in suitable vehicles;
- are transported in unsuitable vehicles;
- are in suitable destinations;
- are in unsuitable destinations.

The bars corresponding to the time intervals are divided into colored segments proportionally to these numbers, and the full height of the bars corresponds to the total number of people, which is shown in the legend on the right. The schedule presented in Figure 2 is quite good; there is only a small delay (1 minute long). Figure 3 demonstrates how longer delays and undelivered people may be exposed on the display (for this purpose, we have taken an under-optimized schedule variant from an early stage of the work of the scheduling tool).

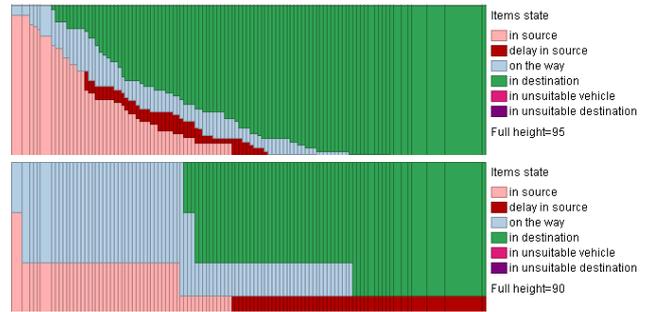


Figure 3. Top: long delays appear as red segments occurring in multiple consecutive bars. Bottom: when some people are not delivered, the display contains a red stripe stretching to its right margin.

All other sections are built similarly to the first one. The second section shows the dynamics of using the capacities in the destinations. The bar segments represent fully used capacities, used capacities in partly filled destinations, remaining free capacities in these destinations, and free capacities in the destinations that are not used at all. Potentially, the chart can also show overloads, i.e. destinations receiving more people than their capacities permit, and used capacities in unsuitable destinations. The full height of the bars shows the total capacity of all destinations, i.e. how many people they can accommodate. It is shown in the legend and can be easily compared with the total number of people to be evacuated. The third section shows the used and unused capacities in the vehicles, similarly to the capacities in the destinations. Grey-colored segments correspond to the capacities in the vehicles moving without load from their home locations or from destinations to the sources. The full height of the bars corresponds to the total capacity of all vehicles. The fourth (bottom) section shows how many vehicles are idle, moving without load, and moving with load. The full height of the bars corresponds to the number of available vehicles.

The user (evacuation planner) may choose one of the people categories, and the schedule progress summary display will show only the information relevant to this category. This means that the people status chart represents only people of this category, the destination use chart includes only capacities in the destinations suitable for this category plus, possibly, used capacities in unsuitable destinations, and the other two sections contain information about the vehicles suitable for this category or used for it. In Figure 2, the display shows information relevant to the category ‘critically sick or injured people’.

When the schedule progress summary display exposes a problem, the reasons are often clear from the same display. Thus, some people may be undelivered or delivered to unsuitable destinations because of the lack of capacity in suitable destinations. This will be easily detectable on the destination use display: either it will be empty, which means that no suitable destinations exist at all, or it will show that all suitable destinations are full at the end. The investigation into the reasons for delays or the use of unsuitable vehicles is, however, less straightforward and requires involving additional displays.

5.2 Examining the use of vehicles

Figure 4 shows the schedule progress summary for the people category ‘prisoners’. The upper section exposes a long delay with transporting a group of prisoners (through mouse-over querying of the display, the user may learn that the group consists of 10 persons, the time limit is exceeded by 1 hour from the schedule start, but the transportation of these people starts only in 1 hour 34 minutes). The lower two displays show that 5 suitable vehicles

with the total capacity of 50 persons become free after 50 minutes of the schedule execution; moreover, some of these vehicles become free even a few minutes earlier. It is hard to understand why none of these vehicles can be used to transport the remaining 10 prisoners unless the locations of these vehicles are considered.

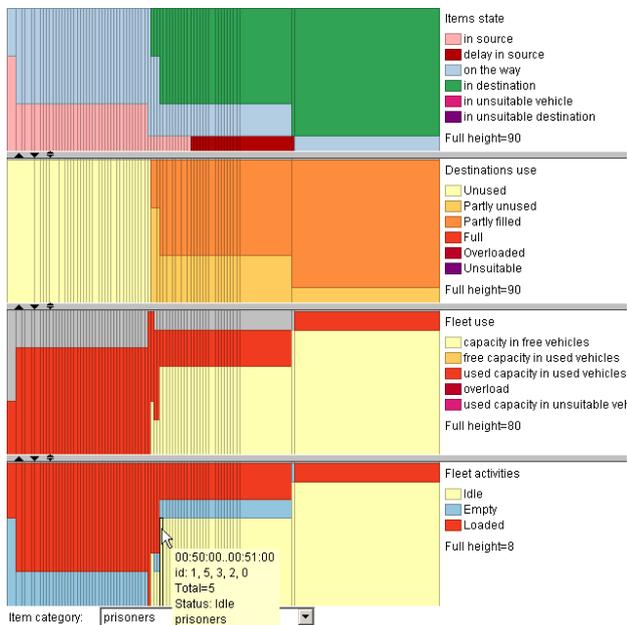


Figure 4. The progress summary display with the category 'prisoners' being currently selected.

To find out where the free vehicles are located, the user clicks on the corresponding bar segment in the vehicle activities chart (bottom). In the result, the locations are highlighted on a map. The map in Figure 5 shows that all 5 free vehicles suitable for transporting prisoners are in one and the same location called "Jailhouse". Note that the information on the map has been automatically filtered according to the selection of the category 'prisoners': the map shows only the source and destination locations and vehicle moves relevant to the selected category. The locations are marked by colored circles where red is used for people sources, green for destinations, and yellow for other locations involved, such as home locations of the vehicles. The moves of the vehicles are shown as directed lines (vectors).

It becomes clear from looking at the map that the free vehicles are rather far from 'Prison', the source location of the prisoners; evidently, it takes much time to get from 'Jailhouse' to 'Prison'. Besides, it can be seen that 'Jailhouse' is the only suitable destination for the prisoners. Since this destination is very distant, it appears that the available fleet of suitable vehicles does not permit the delay to be avoided.

The fleet may be additionally examined using a table view display of the available vehicles, where only vehicles suitable for the currently selected category of people are shown (Figure 6). Note that the table view reacts to clicking on a bar segment in the vehicle activities chart by highlighting the rows of the corresponding vehicles.

The Gantt chart view, which is demonstrated in Figure 7, shows how the trips of the available vehicles are scheduled. As all other displays, the Gantt chart has been filtered according to the currently selected category. The light blue bars in Figure 6 correspond to the trips where prisoners are transported, and the greenish bars correspond to empty trips. The chart shows that, indeed, a trip from 'Prison' to 'Jailhouse' (or back) takes about 47

minutes, and that there is no way to avoid or reduce the delay since no vehicle can get from 'Jailhouse' back to 'Prison' earlier than the vehicle that finally takes the remaining prisoners (the corresponding transportation order is highlighted in white color).

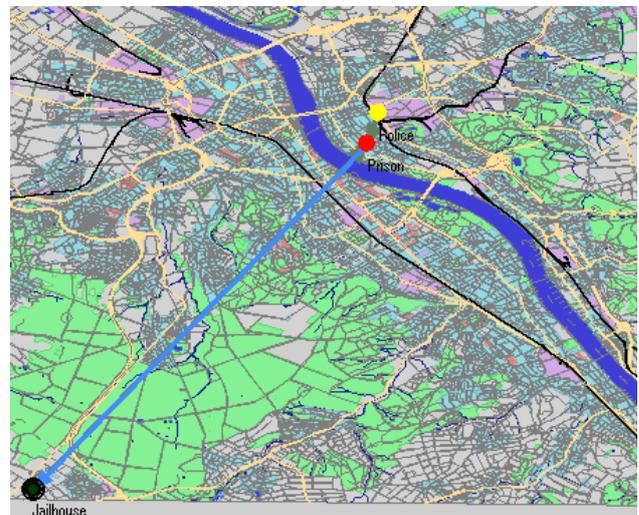


Figure 5. The map highlights the location of the vehicles suitable for transporting prisoners at the moment when these vehicles become free.

VhclType	Vehicle type description	VhclHBName	Capacity, item category=prisoners
0	30 police van	police station	10
2	30 police van	police station	10
1	30 police van	police station	10
3	30 police van	Prison	10
5	30 police van	Prison	10
4	30 police van	Prison	10
104	30 police van	Jailhouse	10
103	30 police van	Jailhouse	10

Figure 6. The table view displays static information about the vehicles suitable for transporting prisoners.

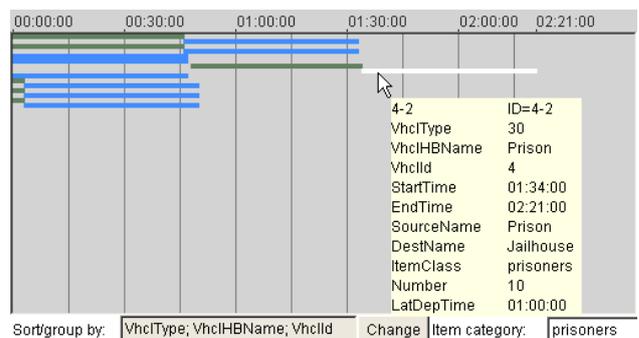


Figure 7. The Gantt chart display shows how the transportation of the prisoners is scheduled.

Like the map and table view, the Gantt chart display is also linked with the schedule summary display through brushing: clicking on a segment corresponding to moving vehicles (loaded or empty) highlights the corresponding transportation orders in the Gantt chart (Figure 8). Simultaneously, the vectors indicating these moves are highlighted on the map, if the map layer containing these vectors is currently active. Note that different colors (black as in Figure 8 and white as in Figure 7) are used for durable highlighting induced by clicking and for transient mouse-over highlighting.

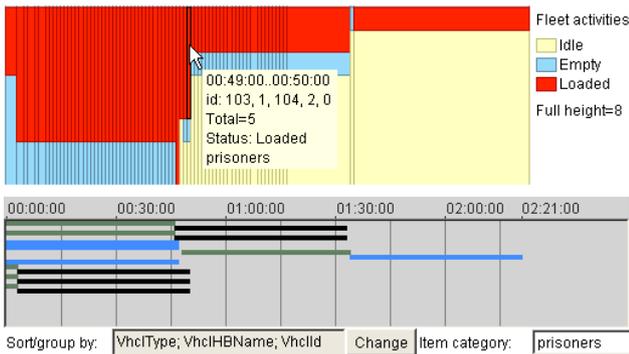


Figure 8. Brushing between the vehicle activities chart and the Gantt chart.

Hence, the investigation has shown that the delay in the transportation of the prisoners cannot be avoided by a better utilization of the available resources. The decision maker will need either to find an additional vehicle located not far from the prison, or an additional (temporary) destination out of the danger zone, or to decide that the delay is not very dangerous and may be accepted.

5.3 Investigating the choice of destinations

The visualization and interaction techniques described thus far allow the planner to assess the potential of the schedule for attaining the goal and certain aspects of its feasibility and rationality:

- Whether the capacities of the available resources are not exceeded;
- Whether there are time gaps in vehicle use (i.e. vehicles are idle and then used again);
- Whether vehicle capacities are significantly under-loaded.

In our example data, there is no information about the costs of using different types of vehicles. In case of availability of this information, it could be visualized on a segmented bar chart with the bars divided according to the numbers of vehicles of different types and the segments colored according to the costs of these types. This would allow the user to see whether expensive vehicles are used without a real need for this.

However, these visualizations are not well suitable for the investigation of the choice of the destinations, i.e. whether closer destinations are preferred to more remote ones. It is also difficult to check whether there are cases when many vehicles simultaneously come to the same destination. Furthermore, the planner may wish to check whether people from the same source location are not excessively spread between multiple destinations.

When the number of source and destination locations is small, a map display can provide an adequate support for the exploration of the distribution of people among the destinations. Thus, the map in Figure 9 presents summarized transportation orders relevant to the evacuation of critically sick and injured people. People from two source locations, which are marked by red circles, are transported to five destinations out of seven suitable locations; the suitable locations being marked by green circles. The total number of people delivered from a source to a destination is encoded in the thickness of the arrow symbol drawn between these locations. Thin lines correspond to empty trips. Figure 9 demonstrates a good choice of the destinations: people are transported to the nearest suitable places while two more distant locations remain unused. However, with increasing the number of locations and trips between them, the map display loses its effectiveness (Figure 10).

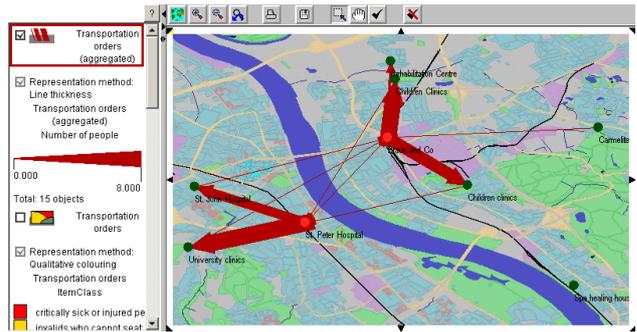


Figure 9. The map view shows aggregated transportations of critically sick and injured people.

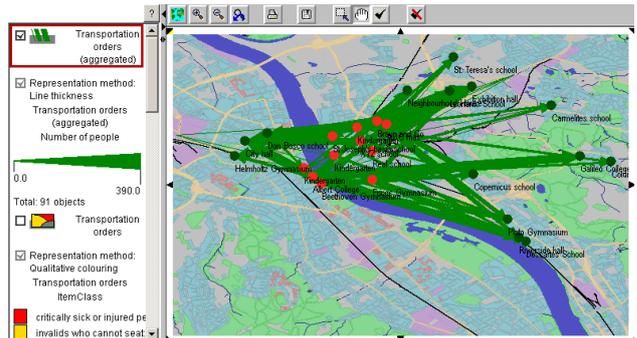


Figure 10. The map view shows aggregated transportations of general people.

As demonstrated in [14], a permutable matrix display technique introduced by Bertin [15] is an effective tool for the exploration of interactions and movements between spatial locations. In Figure 11, a permutable matrix shows aggregated data about the trips relevant to the transportation of general people. The rows and columns correspond to the sources and destinations, respectively. The symbols in the cells can encode several aggregated characteristics, depending on the user's choice.

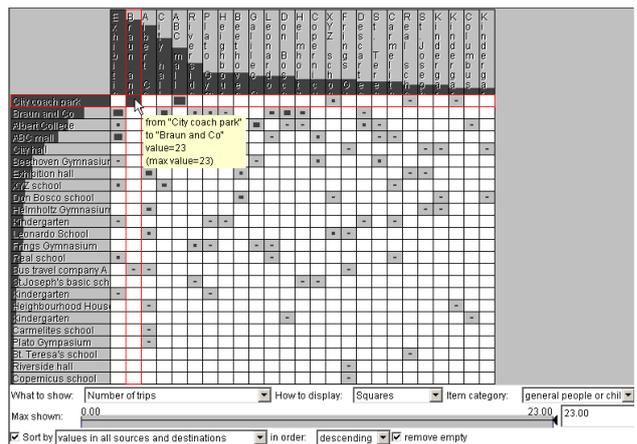


Figure 11. The permutable matrix shows the numbers of trips between pairs of locations.

In Figure 11, the sizes (areas) of the rectangular symbols are proportional to the numbers of trips between the respective locations. Other possibilities are: number of empty trips, number of non-empty trips, number of people, number of different vehicles, and special symbols encoding simultaneously the

number of transported people and the distance between the locations, as will be demonstrated later.

Using the movement matrix, the planner can see how people from each source location are distributed among the destinations: whether they are moved to one or a few destinations or to multiple destinations. Linking between the matrix and other displays gives additional investigation possibilities. Thus, Figure 11 shows that there are many trips (23) from 'City coach park' to 'Braun and Co'. In order to check whether all these trips are simultaneous or distributed in time, the planner clicks on the corresponding cell. As a result, the transportation orders for all these trips are highlighted in the Gantt chart (a fragment is visible in Figure 12) showing that they are supposed to start and end at the same time.

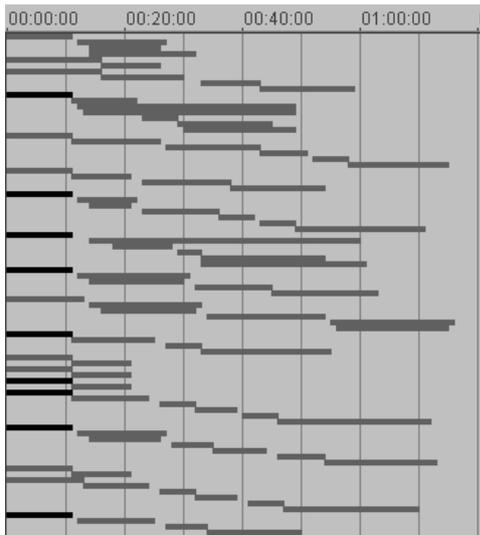


Figure 12. The Gantt chart (a fragment is shown) indicates that the trips from 'City coach park' to 'Braun and Co' take place simultaneously.

In this situation, the planner should involve his/her background knowledge and/or additional information to assess the feasibility of this plan, i.e. whether 23 buses can simultaneously (or almost simultaneously) leave the coach park and there will be enough space for them near 'Braun and Co' (for instance, the planner can phone to these two places). According to the imaginary scenario that was meant when preparing the example input data, 'Braun and Co' is a big chemical enterprise, which may have a parking lot sufficient for the 23 buses. While the buses are on the way to the plant, the workers can leave the buildings and come to the parking place. The quick arrival of many buses is an advantage: according to the scenario, the evacuation is caused by a fire and release of a toxic substance at 'Braun and Co', and the workers of this plant need to be evacuated among the first. However, in a different place, simultaneous arrival of many vehicles may be undesirable. It is hardly possible to supply all such location- and situation-dependent knowledge in advance to the automatic scheduler so that it could take it into account in schedule building; besides, there is no time for this in an emergency situation. It is more productive to enable a human planner to assess the output of the scheduler so that he/she could involve this knowledge.

Let us now demonstrate how the planner can assess the rationality of choosing the destinations in terms of the number of chosen locations and distances to them. Figure 13 shows the movement matrix in the mode of portraying the numbers of transported people and the distances to the destinations. The numbers of people are represented by the heights of the vertical lines and the distances by the lengths of the horizontal lines. The

lines make T-like shapes, which are present only in the cells corresponding to trips with people.

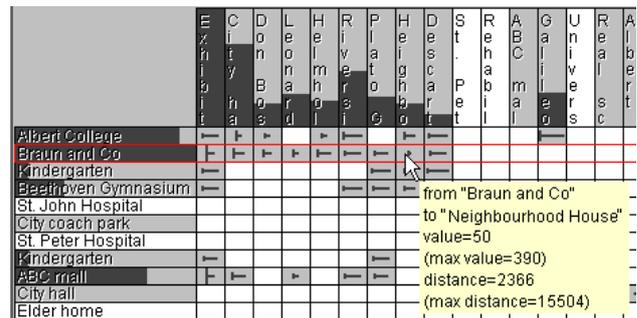


Figure 13. The matrix shows how many people and how far have been transported from each source.

It may be seen that the scheduling algorithm tends to spread people from one source among multiple destinations. This is not unconditionally bad or good; thus, since the trips from 'Braun and Co' are supposed to start at about the same time and people need to be moved as quickly as possible out of the danger zone, it is quite reasonable to transport them to multiple locations. However, the time constraints for 'Albert College' are not so tight, and moving people from there to eight different places, which are indicated in the first row of the matrix, may be undesirable.

The planner may also be not quite satisfied with the choice of the destinations from the perspective of the distances to them. Thus, it may be noted (Figure 13) that some people from 'Braun and Co' are moved at rather long distances and relatively few people are moved to closer sites like 'Neighbourhood House'. To have the geographic context, the planner clicks on 'Braun and Co' in the matrix. In response, the map display (Figure 14) represents aggregated data about the transportation of the general people from 'Braun and Co' by arrows with the widths proportional to the numbers of transported people, and their destinations are marked by black circles. The map also shows other destinations that are suitable for general people and have unused capacities. The capacities may be portrayed on the map, e.g. by means of graduated symbols.

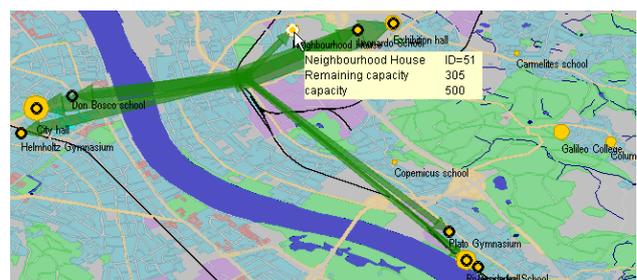


Figure 14. The map display portrays the geographic information corresponding to the second row of the matrix in Figure 13.

5.4 Schedule modification

As may be seen from the examples considered, the planner may be satisfied with some parts of a schedule but want other parts to be modified. Besides, the planner may detect a lack of resources and try to find additional resources, which will also require partial re-scheduling. A need for plan modification also arises when the situation changes while the evacuation is under way: new casualties appear, a road becomes impassable and a destination unreachable, a vehicle is damaged, or some routes take more time than initially estimated.

As with the initial scheduling, the planner may have too short time for modifying the schedule manually. Therefore, we develop the system towards mixed-initiative operation where the planner can fix a part of a schedule (i.e. a subset of the transportation orders) and let the automated tool re-plan the rest after modifying the input data and/or tool parameters and/or some transportation orders. Thus, in our example, the planner may decide that the transportation orders for the critically sick and injured people are good enough and can be taken for the execution. The planner may also decide that the scheduling of the transportation of the general people from 'Braun and Co' is reasonable (although not optimal) and can also be used since the time constraint for these people is very tight. These parts of the schedule are marked as fixed. Then, the planner finds an intermediate destination for a part of the prisoners and adds it to the input data. Besides, the planner modifies the parameters of the scheduling method, specifically, increases the relative importance of minimizing the distances to the chosen destinations. After that, the planner starts again the scheduling algorithm, which keeps the fixed transportation orders unchanged and re-schedules the rest.

If the situation changes while the schedule is being executed, the planner fixes the orders that have already started or are about to start. For this purpose, the planner specifies an appropriate time break, and the system automatically classifies the orders into fixed and modifiable. Then, the algorithm runs using the modified input data reflecting the changes in the situation.

An analogy exists between this mixed-initiative way of scheduling and interactive data mining [16] where a human analyst supervises the work of automatic tools for data analysis.

6 CONCLUSION

Real-world problems involving spatial and temporal data and information are often ill-defined and cannot be fully converted into a form suitable for automatic processing. However, the sizes and complexity of the problems call for computational methods, which are especially needed in time-critical applications. A sound approach is complementing the power and efficiency of computational methods with human's background knowledge, flexible thinking, and experience, which often involves intangible preferences and intuition. An effective way to provide material for human's analysis and reasoning and to enable human's guidance of the operation of computational tools is by means of visualization and interactive visual interfaces.

In this paper, we consider a specific type of problem, which often needs to be solved in time-critical conditions, and present an approach where human and computer cooperate in solving this problem. On the basis of task-oriented design, we have developed a suite of problem-specific tools, which include computational optimization and visual analytics techniques for analyzing results of computations and directing the work of the optimization algorithm. The complex structure of the information to be analyzed necessitates the use of several coordinated displays. An important design requirement has been to apply visualization and interaction techniques easily understandable (preferably, familiar) to the user rather than highly original and unusual. This paper demonstrates the potential of the visual analytics tools we have designed and implemented; however, user studies are required for testing their effectiveness. Unfortunately, real professionals are needed for this purpose rather than students or colleagues playing the role of emergency evacuation planners, but it is extremely difficult to find professionals that can participate in such experiments.

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support the response and rescue operations in case of large-scale disasters; more information is available at <http://www.oasis-fp6.org/>. Trials of the overall OASIS system with representative users from civil protection services (fire, police, and ambulance) will be conducted next year. These trials will give us a possibility to get feedback from relevant specialists concerning our work.

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