Visual Analytics Approach to User-Controlled Evacuation Scheduling

Gennady Andrienko, Natalia Andrienko, Ulrich Bartling

Fraunhofer Institute IAIS (Intelligent Analysis and Information Systems), Germany

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

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 [1].

In this paper, we consider the problem of planning the evacuation of people from a disaster-affected area, which often needs to be solved in time-critical conditions. An efficient tool capable of automated generation of evacuation plans can save precious time and, as a consequence, people's lives and health. Algorithms for transportation scheduling are devised in the area of Operations Research (generic methods need to be adapted to the specifics of the evacuation problem). However, such an algorithm cannot account for all relevant information and criteria, especially for what is specific to the geographic area of the disaster and its neighborhood. One reason is that some types of information, such as spatial and spatio-temporal relationships and semantics of spatial objects and locations, cannot be adequately encoded (yet) in a computer-interpretable form. Besides, an attempt to encode all relevant local information would take too much time, which would nullify the value of the automated tool.

A solution is to involve a human expert in the process of planning. The idea is that the automated tool produces a "draft" schedule. The expert (henceforth called "planner") evaluates this schedule, identifies parts needing improvement, and directs the further work of the automatic tool for revising the schedule.

Our goal has been to design and implement a tool or a combination of tools that would allow a planner to efficiently assess the acceptability of a schedule, detect possible problems, understand their reasons, and find appropriate ways to solve or alleviate them. The complex structure of the information to be analyzed necessitates the use of several coordinated displays. The size of the data (hundreds of transportation orders) demands computational analysis and summarization of information.

The objective of this paper is to demonstrate a problem-oriented design of visual analytics tools for schedule examination and improvement. The discussion of the schedule generation algorithm requires a dedicated paper, which we plan to write soon. Here, we only describe the inputs and outputs (section 3). In section 4, we present our analysis of the problem and the design considerations derived from it. Thereby, we substantiate our choice of visual and computational tools. It should be noted that inventing highly innovative and original visualization and interaction techniques has not been our goal. On the opposite, we intentionally strived to apply common techniques, expectedly familiar to the user. The rationale is to decrease the time required for the planner to recognize the meaning of a display and learn how to use it.

Section 5 is intended to demonstrate that the choice of the techniques is adequate to the purpose. We do not describe any of the techniques in detail since the techniques per se are not the focus of the paper. Instead, we show how they may help the user to detect problems in a schedule and investigate into possible reasons.

Prior to the presentation of our work, we briefly review the related literature.

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.

The problem of transportation scheduling is considered in the area of Operations Research, where it is ascribed to a generic class of Vehicle Routing Problems [2]. For this class of optimization problems, deterministic mathematical techniques do not work sufficiently well while heuristic methods, such as Genetic Algorithms [3], offer a powerful alternative [4,5,6]. As we have noted, the problem usually cannot be solved fully automatically and requires the involvement of a human analyst with his/her domain expertise and knowledge of the geographic area. Existing software systems for automated transportation planning typically

Schloss Birlinghoven; 53754 Sankt Augustin; Germany
http://www.ais.fraunhofer.de/and

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include visualizations to presents the results of schedule computation and optimization to the user and allow the user to modify the schedule [7,8,9,10]. 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 [7]. Sometimes, planned shipments and vehicle moves are also represented on a map as directed lines (vectors) connecting source and destination locations [9]. 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 [8,10]. In this chart, diagonal lines represent movements of vehicles from place to place and horizontal lines or bars indicate their staying in 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 [11], the authors present a solution based on the micro/macro display concept advocated by E.Tufte [12]: 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 used for the visualization of data concerning planned transportation of injured and sick people to medical treatment facilities. Tiny symbols representing individual patients are positioned according to the planned departure times or readiness times while 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. Another approach is representing data in an aggregated way. In [13], temporal, geographic and categorical aggregations are used to visualize data about multiple events distributed in space and time. These ideas can be adapted to the visualization of transportation orders taking into account the differences in the data structure.

3 SCHEDULER OUTPUT AND RELEVANT SOURCE DATA

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.

The problem of evacuation planning differs from standard vehicle scheduling problems solved in business applications, where an input for a scheduling algorithm usually consists of transportation requests (incomplete transportation orders) specifying the types and numbers of items to be delivered and their sources and destinations. The task of an algorithm is to associate each request with an appropriate vehicle and a time interval when this vehicle will fulfill the delivery.

In evacuation planning, the input information includes (1) the places where there are people to evacuate, (2) the numbers and categories of these people, (3) the latest allowed departure times per place and category; (4) possible destinations, i.e. safe places to which people can be moved, and their capacities, by people categories. The user has no time for the formulation of transportation requests. According to the specifics of the problem, we have devised a specialized scheduling algorithm (by adapting the Breeder Genetic Algorithm described in [5]), which, in addition to the standard functionality, is able to divide the total number of people in a location into groups fitting in available vehicles and choose an appropriate destination for each group. Similarly to other scheduling algorithms, our algorithm also requires the following data:

- 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.

It should be noted that defining the routes of the vehicles is not the task of the scheduler but can be done by one of the existing routing tools, which can also provide the estimated travel times for the time matrix.

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 with 14 source locations containing in total 4692 people of 6 different categories, 105 vehicles of 7 different types, and 25 destinations, we could have quite good schedules already after one minute of running the tool. The tool stops either when further optimization does not significantly improve the solution or the specified time limit is reached, whatever comes first. 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.

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. However, a schedule for the transportation of a large number of people from multiple source locations to multiple destinations is inevitably large. Thus, in our experiments, the number of orders in the automatically produced schedules varied around 400 (the variation results from the non-deterministic character of the algorithm). An evacuation planner usually has no time for a detailed inspection of all orders; hence, a different approach is required.

Besides being more time-critical, the emergency evacuation problem is also more complex than typical business transportation problems. The additional complexities, which have been noted in the previous section, do not only affect the scheduling algorithm but also complicate the planner's work on schedule evaluation and increase the amount and diversity of information to be analyzed (thus, the planner additionally needs to assess the choice of the destinations and vehicles).

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 (effectiveness problems):
   - 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.

These problems clearly differ in importance. Thus, under time-critical conditions, the planner would not spend time for building a perfectly rational plan but rather use any feasible plan that attains the goal. The tool(s) need to be designed so that the presence or absence of effectiveness and feasibility problems could be immediately visible and, in case of presence of such problems, the reasons were also immediately seen or easy to find out. The planner should also be able to spot and explore rationality problems when time permits but immediate detection is not so much required.

According to the design of the scheduling algorithm, effectiveness problems can only arise due to resource deficiency. Hence, it is reasonable to construct the visualization so that it simultaneously exposes the presence or absence of effectiveness problems and shows the availability and use of resources, specifically, vehicles and destination locations. The display of resource use can also demonstrate the absence of overuse of resources (it is guaranteed by the algorithm but nevertheless needs to be shown to the planner).

The potential feasibility problems with multiple vehicles coming to the same place at the same time are place-dependent. Thus, there will be no problem in such a place as a shopping centre or industrial enterprise having a big parking lot. In such a place, simultaneous arrival of multiple vehicles may be advantageous rather than problematic. Therefore, it is unreasonable to preclude such situations completely through algorithm design. On the other hand, it is hardly possible to supply all relevant location-related knowledge to the automatic scheduler in advance for taking it into account in schedule building; besides, there is no time for this in an emergency situation. It is therefore necessary to design the visualization so that the human planner could easily detect potentially problematic situations and involve his/her domain knowledge to decide whether the problems really exist.

Because of the time pressure and the size of the data, the planner needs summarized information. 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. A useful general guideline is given in the Visual Analytics Mantra put forward by D.Keim [14]: the data are computationally processed ('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'). As may be seen from Fig.1, our approach corresponds to this principle.

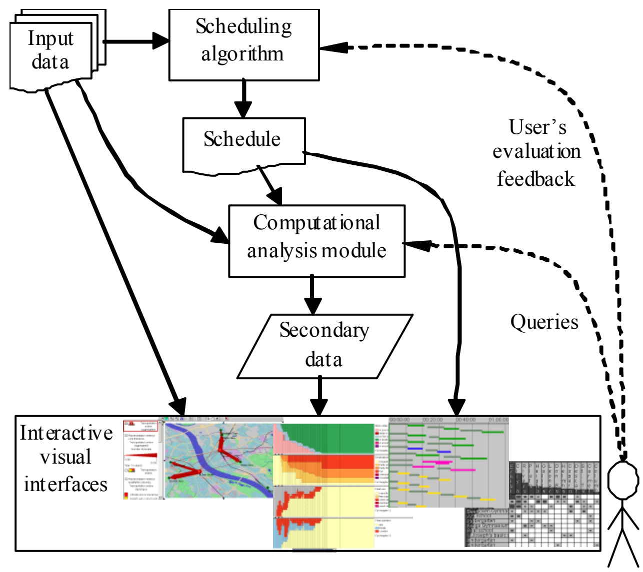

Figure 1. The architecture and information flows of the evacuation planning support system.

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.

What should be done when the planner is not satisfied with some part of the schedule? Manual correction of individual transportation orders is time-consuming and therefore not appropriate in emergency situations. A good approach is to utilize the scheduling algorithm not only for the generation of schedules but also for improving them. It should be borne in mind that a specially designed objective function directs the algorithm towards generating effective, feasible, and rational schedules. If the algorithm has been stopped early in the optimization process, allowing additional computation time may in some cases be sufficient for making the schedule acceptable. It is reasonable to apply additional optimization only to the part of the schedule that requires improvement. For this purpose, the algorithm is devised in such a way that some transportation orders may be marked as fixed (non-modifiable); the further optimization is then applied only to the remaining orders. The corresponding user interface should enable the planner to divide the set of orders into fixed and modifiable without the need to view and mark individual orders. The following division criteria are appropriate:

- people category: the user selects one or more categories, and the system fixes the respective orders including the empty trips of vehicles to the source locations of these people;
- time: the user selects a time moment, and the system fixes the orders that will have been fulfilled before it or will be under execution at this time moment;
- source location: the user selects a subset of source locations, and the system fixes the orders for in- and outgoing trips.

However, the helpfulness of additional optimization is quite limited: it can eliminate or decrease delays in a schedule (when the transportation resources permit) and improve its rationality. As noted earlier, effectiveness problems mostly arise in case of insufficient resources. Thus, the only possible reason for some people being not evacuated is the lack of suitable destinations and/or vehicles or insufficient capacity of the destinations. The same applies to the use of improper places and/or vehicles (there is a parameter determining whether the algorithm is allowed to use unsuitable destinations and vehicles when suitable ones are lacking). Insufficient transportation resources cause delays that cannot be eliminated through optimization. Such problems require the planner to undertake certain actions or make decisions such as:

- seek additional resources (meanwhile, the acceptable subset of the schedule may be taken for execution);
- set priorities between people groups according to their categories and/or source locations and permit delays for less prioritized groups;
- conclude that the problems (in particular, delays) are not critical and the schedule may be accepted.

As we have discussed, simultaneous presence of multiple vehicles in the same place may or may not be a problem. If the planner detects an undesirable coincidence in a particular place, he/she should be able to shift some of the transportation orders forward in time, mark them as fixed and let the scheduling algorithm appropriately modify the further orders assigned to the same vehicles. If these modifications introduce delays, the planner may require the algorithm to optimize the subset of the schedule comprising the orders that start after the latest shifted order.

Besides the possibility of correction, it is also necessary that the scheduling algorithm could adjust the schedule to changes in the situation such as appearance of additional people to be evacuated, deviations of the real travel times from the estimated ones, some resources becoming unavailable or new resources being added. For this purpose, the planner can apply the time-based division for marking the past and currently executed orders as fixed. Then, after appropriate changes of the input data, the planner re-runs the algorithm to obtain an adapted version of the schedule.

In the next section, we present the visual and computational techniques we have chosen on the basis of the task analysis and demonstrate their use for schedule assessment.

5 VISUALLY SUPPORTED SCHEDULE ASSESSMENT

5.1 Overview of the schedule progress

When the scheduling algorithm stops its work, the resulting schedule and the corresponding input data are immediately loaded in the system for schedule exploration and assessment, which comprises computational and visualization modules. The initial computational analysis and subsequent visualization of its results (Fig.2) 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.

The visualization 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 correspond to one and the same time moment. The whole schedule execution time is divided into unequal intervals where the breaks are 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.

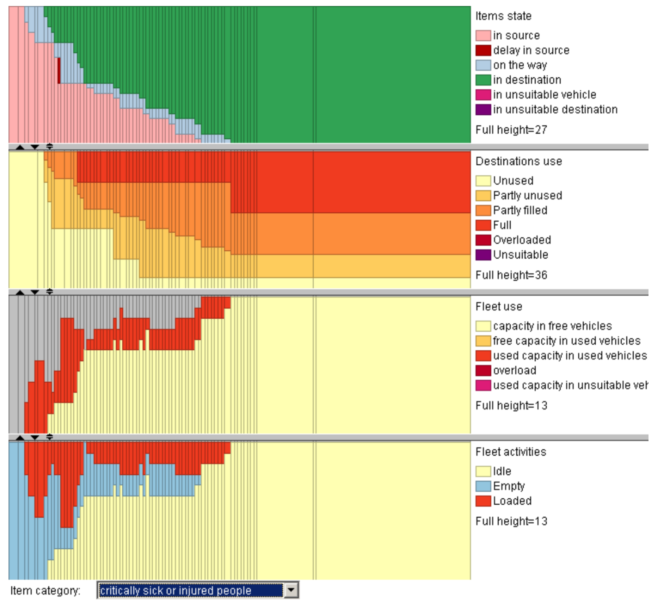

Figure 2. The summary display of the transportation progress presents the part of the schedule relevant to the evacuation of the critically sick and injured people.

The upper section shows for each time interval how many people are in 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. The full height of the bars represents the total number of people, which is shown in the legend on the right. The remaining panels are constructed in a similar way. 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 display is able to present the transportation progress either for all people or for any single category selected by the user. In the latter case, the display shows only the information relevant to the selected category: 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. Thus, Fig.2 shows the transportation progress for the category ‘critically sick or injured people’.

The colors for the display have been chosen in such a way that more prominent colors signify problems. Thus, dark red segments in the upper panel represent groups of people staying in their source locations after the time limits having been exceeded. 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 are exposed on the display.

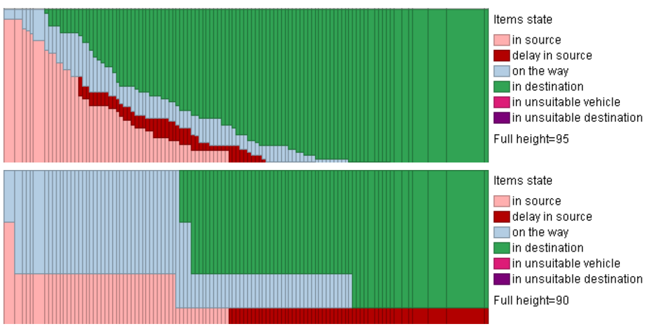

Figure 3. Top: long delays appear as red segments occurring in multiple consecutive bars. Bottom: when some people are not delivered, the display contains a red stripe stretching to its right margin.

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 Finding reasons for delays

In our example scenario of schedule assessment, the planner looks first of all at the planned transportation of the critically sick or injured people (Fig.2). The planner detects the one-minute delay but decides that it is not very critical and accepts this part of the schedule for implementation. Then the planner focuses on the other people categories one by one. The display demonstrates the absence of delays, undelivered people, and improper use of resources for all categories except “prisoners”, for which a long delay is exposed (Fig.4). Through mouse-over querying, the user learns that the delay involves 10 persons whose transportation will begin in 1 hour 34 minutes after the evacuation start whereas the time limit is 1 hour. With the vehicle use charts, the planner finds that 5 suitable vehicles with the total capacity of 50 persons will be free after 50 minutes of the schedule execution and some of them even a few minutes earlier. Could the delay be eliminated or reduced by utilizing some of these vehicles? This depends on where they will be located after completing their orders. To find this out, the planner clicks on the corresponding bar segment in the vehicle activities chart (bottom). This operation highlights the locations on a map.

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

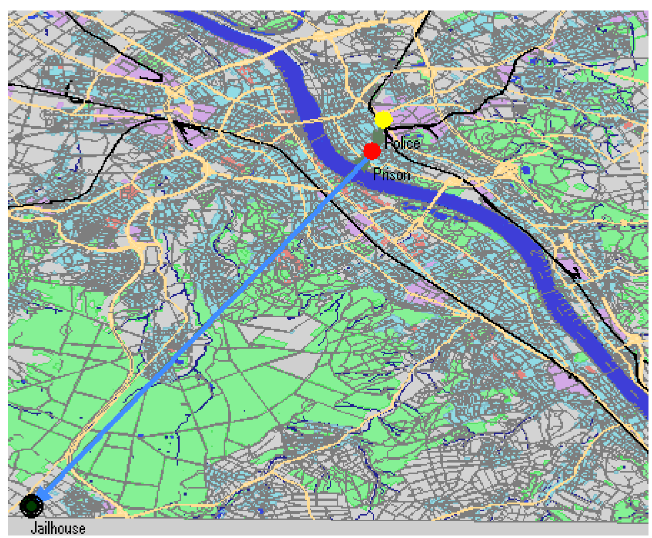

Figure 5. The map highlights the location of the vehicles suitable for transporting prisoners at the moment when these vehicles become free.

The resulting map (Fig. 5) shows that all 5 vehicles will be in one and the same location called “Jailhouse”. Note that the information on the map has been automatically filtered to show only the information relevant to the selected category ‘prisoners’. 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).

From the map, the planner notices that there is only one suitable destination for the prisoners, which is very distant from the source location. All free vehicles will be situated at the destination. Would they be able to get to the source location before the time limit is exceeded? To check this, the planner looks at a Gantt chart display (this type of display is commonly used in planning). As all other displays, the Gantt chart (Fig.6) has been filtered according to the currently selected people category. The light blue bars represent the trips where prisoners are transported and the greenish bars represent trips without load. The chart shows that a trip from the source to destination or back takes about 47 minutes. Hence, there is no way to avoid or reduce the delay: no vehicle can get from the destination to the source earlier than the vehicle that finally takes the remaining prisoners (the corresponding transportation order is highlighted in white color).

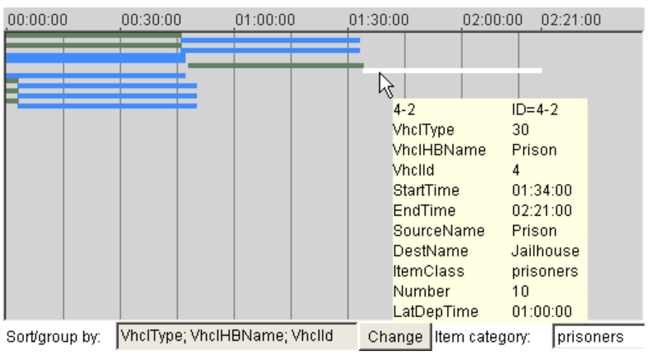

Figure 6. The Gantt chart display shows how the transportation of the prisoners is scheduled.

To solve the problem, the planner needs to find an additional suitable vehicle located not far from the prison or an additional (temporary) destination out of the danger zone. The planner may also decide that the delay is not very dangerous and may be accepted.

5.3 Checking the feasibility

Although the overuse of resources is normally excluded by the scheduling algorithm, the computational module of the schedule assessment support system and the transportation progress summary display are nevertheless designed so as to detect and expose the cases of overuse (which may potentially occur if there are errors in the scheduler). The legends of the destination and vehicle use charts (the second and third panels in Figs.2 and 4) include items for overload of destination places and vehicles, respectively. The absence of the corresponding colors in the charts indicates that overloads do not occur.

As discussed in section 4, situations when multiple vehicles come to the same place at the same time are not always problematic but may be also beneficial. Therefore, each situation needs to be examined separately by a human expert with the involvement of local knowledge or information from external sources. To detect potentially problematic situations, the expert needs a display presenting the numbers of vehicles in individual locations or the numbers of trips to individual locations. One possibility is to show this information on a map. Thus, the numbers of vehicles may be represented by bar charts with the bars corresponding to time intervals. The numbers of trips may be represented by proportional widths of vectors connecting pairs of locations. A serious drawback of both approaches is that the diagrams or vector symbols greatly overlap, which makes the display illegible. A three-dimensional display (perspective view) where the third dimension represents time is unlikely to eliminate the problem since there are many trips occurring simultaneously. Besides, such a display may be hard to understand and use.

After considering these and other options, we finally chose to use the permutable matrix display (Fig.7) technique introduced by Bertin [15]. As demonstrated in [16], this is an effective tool for the exploration of interactions and movements between spatial locations. The rows and columns of the matrix correspond to the sources and destinations, respectively. In Fig.7, they are ordered according to the numbers of trips from/to the corresponding locations. The user can choose another ordering method from several predefined variants. The symbols in the cells and the shading of the captions of the rows and columns can encode different aggregated characteristics, depending on the user's choice. In Fig.7, the sizes (areas) of the rectangular symbols are proportional to the numbers of trips between the respective locations, and the sizes of the dark grey segments in the captions represent the total numbers of trips from/to the corresponding 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. These different modes enable multi-purpose use of the display. One of the purposes is detection of potential feasibility problems due to simultaneous arrival of multiple vehicles to the same place.

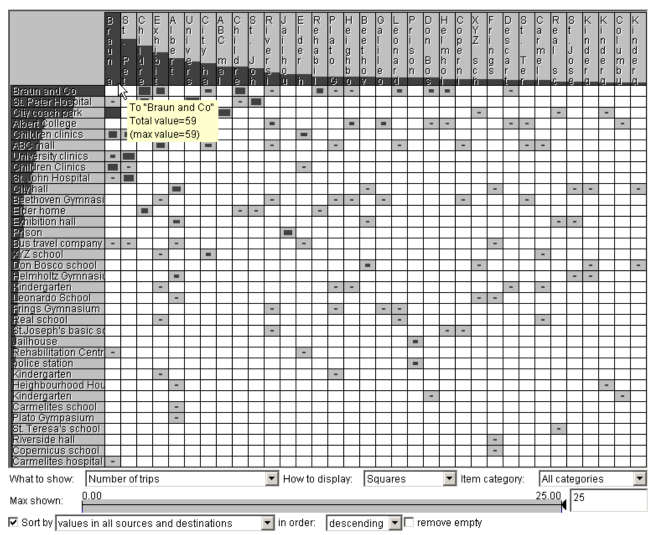

Figure 7. The permutable matrix shows the numbers of trips between pairs of locations.

For this purpose, the planner looks at the shading of the column captions and notices that very many trips end at the place 'Braun and Co', which corresponds to the first column. To locate these trips in time, the planner uses the Gantt chart display. For convenience of the analysis, the lines in the Gantt chart may be grouped according to the trip destinations. Destination-based filtering makes the lines representing the trips to user-selected location(s) more prominent on the display than the other lines. Fig.8 (left) shows a fragment of the Gantt chart display presenting all trips to 'Braun and Co'. The lines are colored according to the types of the vehicles: blue represents ordinary ambulance cars, pink is used for ambulance cars with life support facilities, and yellow corresponds to buses. It is easily seen that many vehicles are supposed to come to the place simultaneously. Through mouse-over querying, the planner may see the exact times of the orders (Fig.8 right).

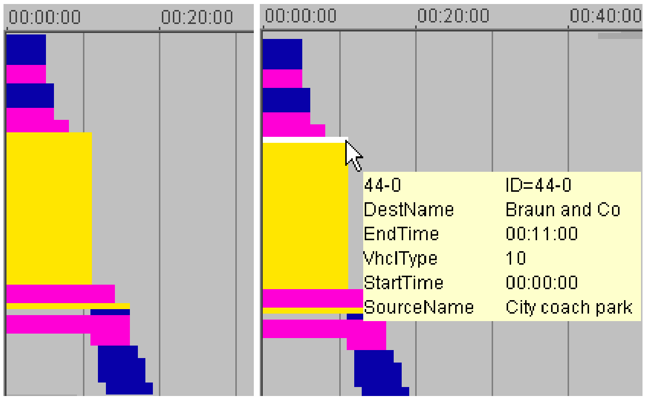

Figure 8. A fragment of the Gantt chart represents all trips with the destination 'Braun and Co'.

In this situation, the planner should involve his/her background knowledge and/or additional information to assess the feasibility of this plan. In our scenario, 'Braun and Co' is a big chemical enterprise, which has a big parking lot. The planner may know this or call to 'Braun and Co' to find this out. The size of the parking place is sufficient for the 23 buses that are supposed to come in 11 minutes after the evacuation start. 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. While the buses are on the way to the plant, the workers can leave the buildings and come to the parking place. However, it may be a problem that the buses come shortly after the arrival of the ambulance cars, which are supposed to take injured people. The mass movement of people to the buses may hinder the loading of the injured people in the ambulance cars and departure of the cars. Therefore, it may be reasonable to move the orders for the buses by a few minutes forward in time (while regarding the time limit of 20 minutes). This may be done by interacting with the Gantt chart display.

The planner also examines the other locations with many incoming trips and concludes that they do not pose feasibility problems: either the trips are spread over time or there is enough space for the vehicles.

5.4 Assessing the rationality

From the possible rationality problems, the under-use of vehicle capacities, if occurs, will be indicated in the fleet use chart (the third section of the display in Figs.2 and 4) by the presence of orange-colored bar segments. The fleet activities chart (bottom of Figs.2 and 4) is suitable for detecting time gaps in vehicle use. In a rational plan, the number of idle vehicles is minimal at the beginning and then monotonously increases as the number of undelivered people decreases. Hence, the height of the yellow bar segments representing idle vehicles should increase from left to right. An occasional decrease in height indicates that some vehicles will be idle for some time and then used again. Such cases may be noticed in Figs.2 and 4. However, the widths of the bars preceding the shorter segments show that the time gaps in vehicle use are very short. By means of mouse-over querying, the planner can learn the exact duration, which is 1-2 minutes.

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.

The planner should also be able to detect unreasonable choice of distant destinations. When the number of source and destination locations is small, a map display can provide an adequate support for this. 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 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 due to symbol overlapping. In such cases, the movement matrix (Fig.7) may be a better alternative.

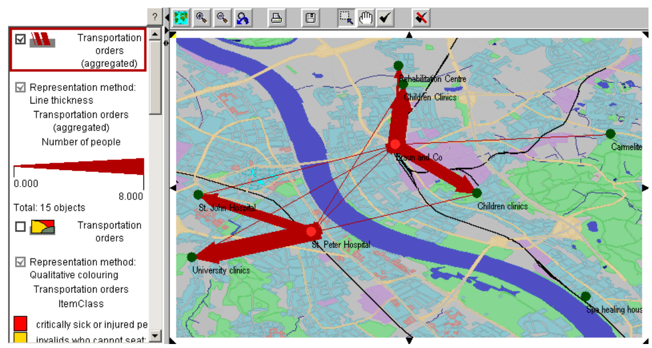

Figure 9. The map view shows aggregated transportations of critically sick and injured people.

Fig.10 shows the movement matrix in the mode of portraying the numbers of transported people and the distances to the destinations (the category 'general people' has been selected). 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. For additional convenience of analysis, the columns can be ordered according to distances from a selected source location. The symbols with long horizontal lines representing distant trips are easily detectable in the matrix. It is especially undesirable if they also have long vertical lines.

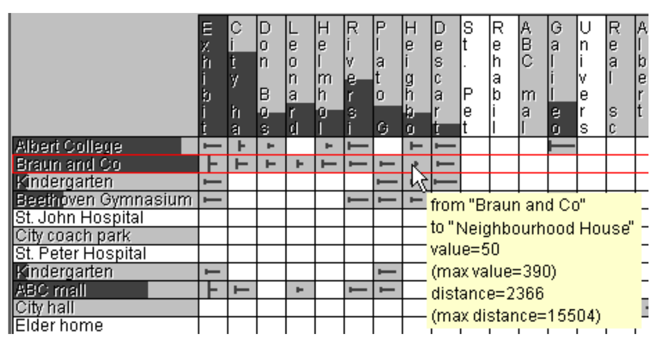

Figure 10. The matrix shows how many people and how far have been transported from each source.

In our case, the planner notes that some people from 'Braun and Co' are moved at rather long distances and relatively few people are moved to closer sites like 'Neighborhood House'. To have the geographic context, the planner clicks on 'Braun and Co' in the matrix. In response, the map display (Figure 11) 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.

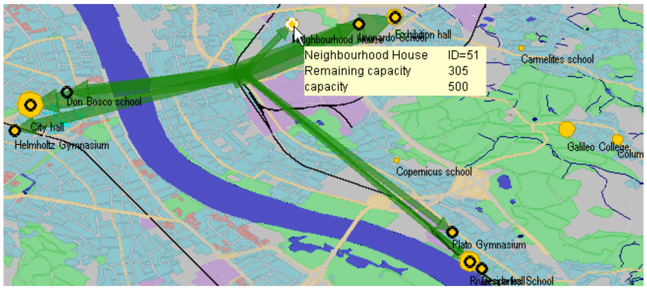

Figure 11. The map display portrays the geographic information corresponding to the second row of the matrix in Figure 10.

The planner concludes that the capacities in the destination places are not optimally used. If the time permits, the planner may require the algorithm to optimize the part of the schedule dealing with the transportation of general people either from all sources or only from ‘Braun and Co’. Since it is clear that there are more capacities in the destination places than really needed, the planner may safely remove the most distant places from the input of the algorithm.

6 Conclusion

This paper demonstrates a task-oriented design of visual analytics tools for assessment and improvement of evacuation schedules. The design bases on a detailed examination of the schedule assessment task taking into account the time-critical character of the situation in which it is accomplished. The size and complexity of the information to be reviewed and the need to analyze it in the shortest possible time call for a synergy of visual and computational methods as stated in the ‘Visual Analytics Mantra’ [14], which we have adhered in our design.

By an example scenario of schedule inspection, the paper shows how the tools we have designed help the user to detect various types of problems in a schedule, understand their reasons, and find appropriate corrective measures. Since the tools allow the user to detect all possible types of problems, which are listed in section 4, we may conclude that the design is adequate to the task; however, user studies are required for testing tool effectiveness. For this purpose, real professionals are needed rather than students or colleagues playing the role of emergency evacuation planners. Unfortunately, it is extremely difficult to find professionals that can participate in such experiments.

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