MULTI-CRITERIA OPTIMIZATION IN WORKFORCE MANAGEMENT

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INTRODUCTION

Using WFM Systems by utilities, software-based optimization becomes increasingly important [1]. Would an optimization tool provide tangible performance gains in workforce scheduling and dispatching? Which optimization method should be preferred under the constraints of electrical grids? How can automated optimization be used in practice, which process-related implications and which organizational consequences are crucial for its implementation and operation?

This paper shows the analysis of the application of optimization methods on the work force management in electrical grids, which means the structure of yearly work force orders, the dependencies of different activities in the grid, the possible interaction with outages as high priority works. Also, this document highlights the requirements and challenges in applying software optimization in scheduling and dispatching of work orders. Qualicision® and fuzzy logic concepts used to achieve multi-criteria optimization are described.

WFM WITHIN ENVIA NSG

Located in eastern Germany, enviaM is a large network operator providing electricity to over 1.4 million customers with a network covering 26,000 square kilometres. A volume of around 150,000 work orders each year is handled.

In 2005, enviaM's network service division, envia NSG, began using WFM tools for their workforce management needs. The dispatching, which is responsible for the scheduling and coordination of execution of all work orders involving network operations, has been separated.

In 2010 envia NSG, PSI and F/L/S started to create a software optimization solution for the dispatching centre resulting in a more effective processing of work orders.

The analysis has shown that the optimization of travel time to choose the nearest suitable service crew and the use of on-board navigation is an effective and sufficient method to handle fault clearance processes. Route optimization solutions offered by some manufacturers are suitable for scheduling multiple time-independent work orders within a day, such as metering orders.
The complexity of the network operation of utilities requires an optimization method that takes into account different conditions and goals, such as switching, appointments, keeping of maintenance cycles and safety requirements, e.g. the assignment of a second employee for live working.

BARRIERS FOR THE APPLICATION OF AUTOMATE OPTIMIZATION

One challenge with implementing software optimization is the need to address all processes in network operations including fault clearance, maintenance measures, and construction projects. Even though work orders for planned maintenance and clearing high priority faults cannot be processed automatically, these factors have a strong influence on optimization algorithms; both tasks are inherently different yet are carried out by the same in-field service crew. As such, it is imperative to model all different types of work orders in one single workforce management system (see Figure 1). envia NSG defined 78 different qualifications, 10 types of vehicles and 493 work order types.

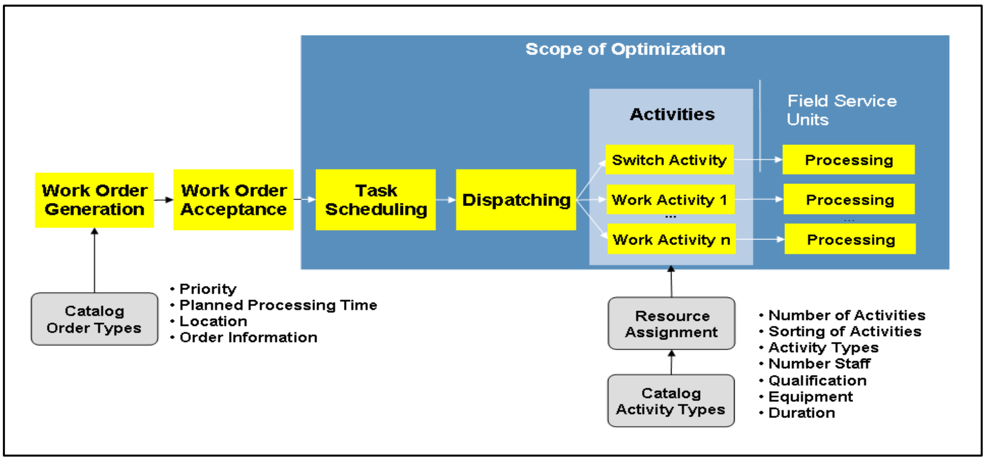

Figure 1 Optimization Scope in the Project

In order to create a strong foundation for software optimization, it is necessary to effectively use all relevant system element data, as well as data from both planned and unplanned work orders. It is also important to factor in parameters from the vehicles, necessary equipment, staff qualifications, personnel authorizations and the availability of service crew members

For technical and financial reasons, work orders must be processed and completed in a given time frame. Also, third party service providers are often utilized which affects scheduling and costs of planned work. Software optimization must consider these dynamic and complex influences.

Because workforce management is not only an important information technology topic, the coordination of the network operator's organization and the objectives to be reached by implementing optimization is imperative. The results from software optimization may be rejected if contradictions exist between the organization structure and the formulated goals.

To obtain usable results, it is necessary to process all work order data by the software optimization as early as possible. Inspections, repair work and construction projects can be planned for periods of months and sometimes up to a year. Introducing unplanned work orders for fault clearance may affect already scheduled work orders for maintenance. Creating an efficient schedule with planned maintenance work orders and short-term work orders while minimizing the down-time of personnel is a difficult but necessary task.

In order to achieve positive optimization results for automated order scheduling each individual work order must be analyzed. As well, operational processes must be adapted to reflect the information from this analysis. For example, in-field travel time and planned supply interruptions can be minimized when work orders for the same network elements are grouped together.

The optimal completion of work orders is not only required, but the pre-dispatching to available in-field service crews is essential.

- Example 1: The work load of service units in certain situations will conflict with the minimization of individual work-order costs in regards to the service unit's qualifications and resources.
- Example 2: The occurrence of faults and short-term appointments conflicts with long-term optimization which aims to minimize rescheduling of work orders.

Generally speaking, the multi-criterial nature of the optimization problem is caused by the multi-source structure of the optimization goals and restrictions: There are goals and restrictions implied by the structure of the work orders and their activities. There are optimization goals stemming from both the dispatching and the service crews. There are goals describing the degree of matching between the particular tasks and the qualification profiles of the service crews. There are work schedule goals which reflect the time oriented sequences to be considered. Furthermore, all these different types of goals are embedded into optimization goals which reflect the routing aspects of the travel activities of the service crews, their initial current positions, the distances between the positions and the respective travel time. All the mentioned goals interact in different way and to an uncertain extend depending not only on the nature of the goals itself but also on the point of time they are considered and evaluated. Additionally, the decision and optimization alternatives are non-continuous: A particular service crew can be attached to a particular work order at a particular position in the network at a particular point of time. This means that the optimization problem to be solved is combinatorial by nature. Both the fact that the interactions between the goals are uncertain and the situation that the interactions have to be coordinated with routing optimization goals that are defined upon a combinatorial amount of optimization alternatives imply that the optimization problem is NP complete [2]. Therefore, an efficient optimization algorithm that means a non-exponential algorithm on the one hand is expected to be a heuristic one. On the other hand such an algorithm has to reflect both the uncertainty of the interaction of the goals itself and their interaction with routing and travel requirements. To meet all these requirements the described optimization model is integrated into the WFM solution (see Figure 2).

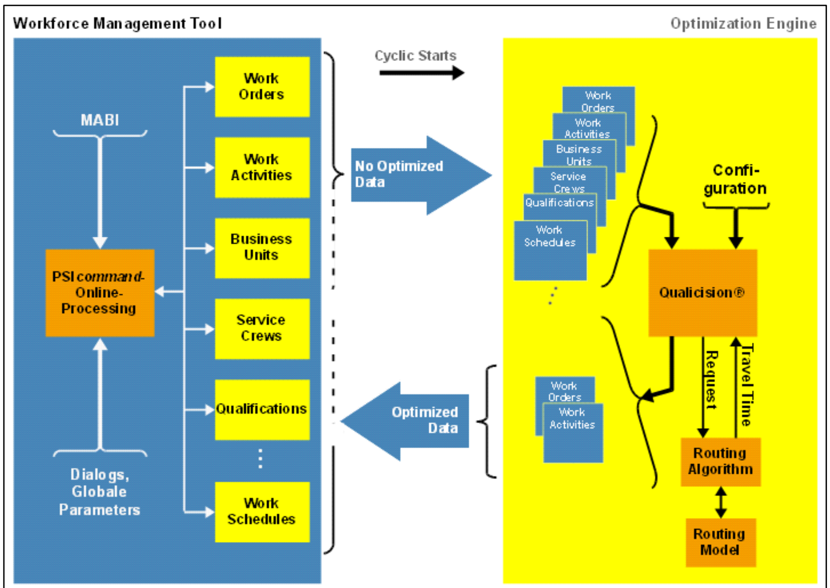

Figure 2 Principle of Optimization

THE QUALICISION® TECHNOLOGY

At the core the optimization is a model of interactions between optimization goals. It is based on extended fuzzy relations that, in contrast to traditional fuzzy relations [3], are from the input data point of view defined upon the interval [-1,1] instead of [0,1]. Formally, it is done by the concept of the positive and the negative impact sets (see Figure 3).

These extended fuzzy relations allow for better reasoning between the pros and cons of decision alternatives while also factoring in important optimization goals. In contrast to this, traditional fuzzy relations in decision analysis [4] only allow for reasoning of pros; as such they are not able to explicitly model conflicts between optimization goals.

The interactions between goals are a crucial factor in creating an adequate model of the search process being part of the optimization algorithm because they reflect the way the goals depend upon each other and reflect the situation dependent pros and cons of the decision alternatives with respect to the goals. Together with information about goal priorities, the types of interaction between goals are the basic search guideline in the optimization process and help to navigate in the optimization space.

For example, it is beneficial to conjunctively aggregate optimization alternatives in search subspaces which support cooperative goals. Independent goals may be aggregated in a disjunctive way. If goals compete with each other, then these goals must use exclusively disjunctive search subspaces. In the sequent it is shown how the different types of interaction between the optimization goals imply their aggregation.

TYPES OF INTERACTION IMPLY THE WAY OF AGGREGATION

With the assumption that cooperative goals imply conjunctive aggregation and conflicting goals rather lead to exclusive disjunctive aggregation, is easy to accept from an intuitive point of view.

The fact that the types of interaction between optimization goals are defined as fuzzy relations based on both positive and negative impacts of alternatives on the goals provides information about the confluence and competition between the goals: The negative impact functions reflect the negative aspects of the decision alternatives with respect to each goal. Compared with other approaches, the negative impact functions represent additional information which enables non-presence of cooperation between two goals to be distinguished from an effective competition between them.

Figure 3 shows two different representative situations which on positive and negative impact of goals will be distinguished appropriately only if, besides the positive impact, (S) the negative impact (D) of decision alternatives (index 1 and 2) on goals is also represented.

If these goals were represented only by the positive impact of alternatives on these goals, situation A and situation B in the figure could not be distinguished and a disjunctive aggregation would be recommended in both cases.

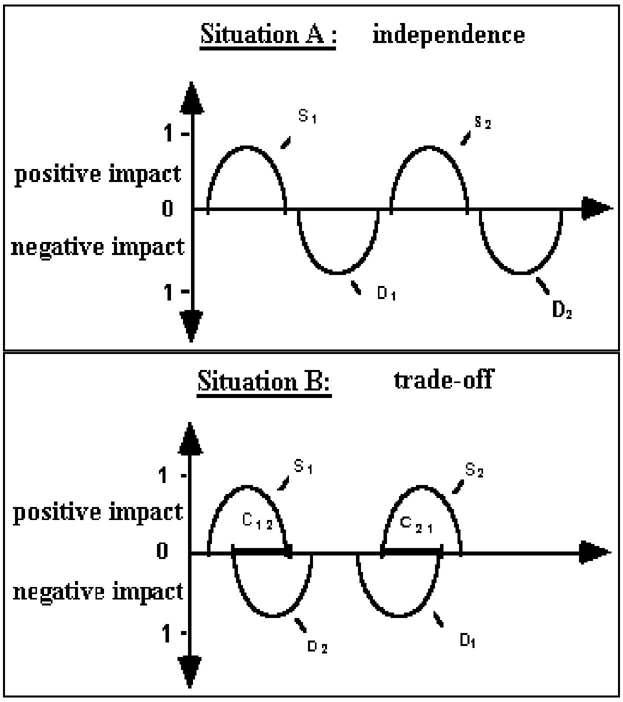

Figure 3 Distinguishing independence and trade-off based

However, in situation B a decision set $S_1 \cup S_2$ would not be appropriate because of the conflicts indicated by C_{12} and C_{21} (see Fig.3, Situation B). In this situation the set $(S_1 / D_2) \cup (S_2 / D_1)$ could be recommended in the situation that the priorities of both goals are similar (where S_x / D_Y is defined as the difference between the sets S_x and D_Y, that means $S_x / D_Y = S_x \cap \overline{D}_y$, where S_x and D_Y are fuzzy sets). If one of the two goals, for instance goal g_1 is significantly more important than the other one, the appropriate decision set would be S_1. The aggregation used in that case had not to be a disjunction, but an exclusive disjunction between S_1 and S_2 with emphasis on S_1.

The information about the interaction between goals in connection with goal priorities is used in order to apply interaction dependent search policies which describe the way of aggregation for each type of interaction.

For conflicting goals g_1 and g_2, for instance, the following search policy which deduces the appropriate decision set is given:
if (g_1 is in trade-off to g_2) and (g_1 is significantly more important than g_2) then S_1

Another policy for conflicting goals is the following:
if (g_1 is in trade-off to g_2) and (g_1 is insignificantly more important than g_2) then S_1 / D_2

In this way for every pair of goals g_i and g_j, $i,j \in \{1,2\}$ subsets of the optimization space called decision sets are calculated. The results of the policies are called local decision sets. For each pair of goals there is a local decision set $D_{Li,j.}$

Note that both policies use priority information which in case of a conflictive interaction between goals is substantial for a correctly estimated decision.

The used search decision model presented above accurately mimics human made decisions. People naturally concentrate on which goals are positively or negatively affected by different alternatives. Furthermore, they evaluate this information in order to understand how the goals interact with each other and prioritize individual goals. In the sense that this decision making approach presented explicitly refers to the interaction between goals, the used model is much closer to the human way of decision making than other mathematical methods.

However, when people make decisions they are limited in their ability to evaluate properly when the number of goals increases. Normally a person cannot consider more than ten different goals at the one time. When the number of goals increases, the likelihood also increases that important information to make informed decisions is overlooked or forgotten. Workforce management systems must consider significantly more goals as well as deliver results much faster than a single person is able to. In contrast to this, the concept of the used model is able to manage considerably more goals, each with different characteristics. At the same time, the ability to calculate the interactions is maintained even as the number of goals increases.

Several real-world applications based on the proposed model are used in industry and finance; they have proven the relevance and capabilities of multi-criteria optimization [5], [6], [7]. In these applications more than one hundred of goals are considered in parallel.

PROJECT RESULTS

As one result of a fully detailed specification of process, organization and data, the optimization task was split up into two part tasks (modes): The scheduling of work orders (long term) and the pre-dispatching of work orders to service crews (short term). For both modes 14 goals (see Table 1 and 2) with 21 conditions for a system-based optimization function have been specified.

Daily cyclic optimization runs can be parameterized for different areas, organizations and the defined modes, so that the work load is assigned only to service crews which belong to the responsible organizations.
Several tools are introduced to verify the optimization results and to give transparency to the dispatcher. The dispatcher may use a Gantt chart for the interpretation and possible changes of optimization results.

Even during the phase of analysis and specification the opportunities for a better understanding of the total process occurred, e.g.:

- The earlier the generation of work orders, the higher is the potential for optimization. It is important to have as much work orders as possible for the actual year in a big pool.
- The structure of the business units of which the operation is to be optimized, was analyzed. In theory the higher the number of work orders, the higher the number of units to be dispatched and the larger the period of optimization, the better results would be achieved. In practice uncertainties, such as weather, external influences must be regarded as well.
- It is crucial to structure the process of maintenance with respect to the requirements on specific qualifications and equipment. For example, special know how about maintenance of protection or maintenance of high voltage switchgear can systematically be distinguished from ordinary switching and maintenance in medium and low voltage grids. On the other hand the decision of having a large amount of different qualifications may mislead the optimization to a non optimal way.

The restructuring of the processes according to the described findings is an important mile stone for the development and appliance of a system-based optimization.

The next step is to adjust the weights of the goals and conditions so that an optimal outcome can be obtained. The project participants expect a significant rise in efficiency due to the reduction of travel time and the better use of down-time between appointments, while documenting better quality work and having broader acceptance by dispatching staff and service crews.

Goals	Description
Minimizing the distance in the work orders within a day.	Work orders are grouped so that a geographical focus is found primarily near to already manually terminated work orders.
Maximizing the work load of the organization	The planed work capacity of the organization is calculated. The work orders are scheduled to utilize a given percentage of the work capacity. For consideration of urgent fault clearance activities the percentage decreases within the optimization period to secure enough capacity and to avoid unnecessary changing even in the distance future.
Minimizing multiple trips to one network element or area	Work orders are grouped to process different types of work orders on the same network element the same time so that multiple trips and switching can be avoided.
Preferring selected work order types	Because of seasonal or organizational reasons it can be necessary to process selected types of work order with higher priority. E.g. measures for protection of birds should be processed before autumn.
Grouping similar types of orders to different network elements	To spread the service crews evenly in all areas of the supply area a concentration of similar work orders in only one region has to be avoided where possible. This goal helps to shorten the travel time in case of short term fault clearance.
Smooth distribution of orders in the optimization horizon	Peaks of work orders can be costly because of the use of third party service provider. Dents may lead to non efficient operation.
Minimizing rescheduling of already scheduled work orders	Frequent changing in scheduling is not accepted by the dispatchers. If work orders have to be scheduled with a higher priority than already scheduled work orders, the number of changes should be minimal.
Finishing of inspections in an district	Inspections of components in low voltage grids have to be processed within a cycle of six years. For commercial and operative reasons all inspections in a district should be processed as close as possible but within a year.
Avoiding the exceeding of the processing horizon	A timeframe for processing is given for each work order. If possible, this timeframe should be used. Sometimes a slight exceedence may be tolerated.

Table 1 Goals of scheduling work orders (long term)

CONCLUSION

The integration of automated optimization within the WFM tool delivers substantial performance and quality benefits when managing workforce operations. The used model provides optimization that can take any number of criteria into account. Because of its multi-criteria decision making, it is capable of determining operational goals through intelligent registration and analysis of every event in the network allowing work orders to be better matched to personnel with the appropriate qualifications and education level. Following all these considerations it should be mentioned, that not the system, but people and the safety of work form the heart of the efficient work force management.

Even while specifying the relevant optimization goals and conditions within the project conflicts in current processes are discovered and can be changed for a more effective workforce management.

Goals	Description
Minimizing the distance in the work orders of a service crew within a day	To avoid traveling time and costs work orders are grouped with geographical focus for each service crew. For the calculation of travel time a routing algorithm is used.
Maximizing the work load of the service crew	The available work capacity of the service crews should be used as much as possible. Extra work and reduced hours may be permitted in specified limits with respect to the weekly working hours.
Smooth dispatching of work orders to all available crews in the optimization horizon	Great differences in planned working hours will not be accepted by the crew members.
Closing the gaps between appointments with non terminated work orders	Between two appointments time may be left for additional work orders which can be processed by the service crew. It is the task to find the right work orders considering all given restrictions.
Minimizing the utilization of resources and qualifications	To reduce costs and to give more satisfaction to the service crew work orders should be processed by crews with adequate qualification. Over-qualification should be avoided.

Table 2 Goals of pre-dispatching work orders (short term)

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