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Field Operation Processes for Electrical Networks

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1 Introduction

Natural phenomena such as wind, storms and snow loads create recurring outages in the power distribution grid. Major disturbances in the grid can paralyze vital functions of the society already in a couple of hours. In addition the outages have an impact on the distribution system operator (DSO)'s financial performance via regulatory outage costs.

There are different types of typical fault situations, but the most severe are the major disturbances often created by large-scale weather phenomena such as winter storms. There's no universal definition of a major electrical network disturbance, but as an example, a Finnish DSO defines it as a fault situation where more than 15 000 customers experience outages and the geographical impact is at least regional (Pylkkänen 2015).

Especially after the tightening of the regulatory framework following the major storms in Finland during the early 2010's, the DSOs are increasingly incentivized to operate efficiently during major disturbances. Therefore a large part of the requirements for the operative processes and tools supporting them are defined by the demands of these extreme situations.

Situation awareness has been used as the conceptual framework for the analysis of human decision making in complex situations (Endsley 1995, Nofi 2000). In (Pylkkänen 2015) it has been applied to the operative processes of a DSO during major electrical network disturbances and to derive overall requirements for supporting information system development.

Here we continue to refine the requirements specifically from the point of view of field operations and related mobile software support. The analysis has been carried out by looking at main operative issues related to field work (especially as related to major disturbances), defining a set of key requirements and related software features together with a DSO and analyzing the suitability of mobile application technology alternatives with some early prototyping.

2 Team Situation Awareness

The central goals of field operation processes and the related mobile information systems can be framed in terms of maintaining an optimal shared state of situation awareness for the whole cross-organizational, distributed team working on the network disturbance. In (Endsley 1995), the team situation awareness is described as a combination of the knowledge states of the individual members as illustrated below.

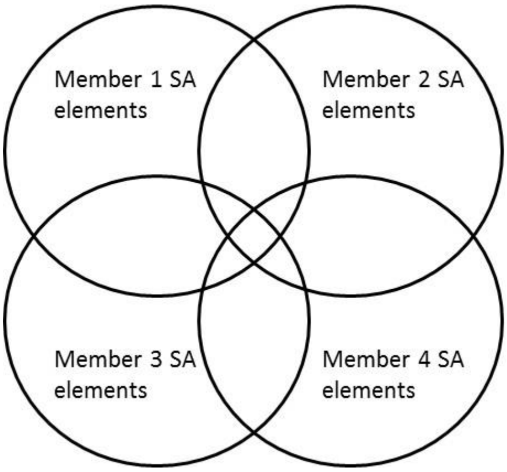

Figure 1. Shared SA (Endsley 1995)

The overall team situational awareness can be conceived as the degree to which every team member possesses the SA required for his/her responsibilities. An interesting implication is that maximizing the information available for individual team members does not necessarily lead to optimal team SA. In fact, a study (Mosier and Chidester 1991) found that better-performing teams actually communicated less than poorer-performing ones.

3 Current state in field operations

3.1 Field operations in fault situations

In most normal fault situations the resources of the regular DSO organization and its contractors are sufficient to manage and execute the repair operations. During major network disturbances a separate predefined and trained organization with specific roles is set up to deal with the situation. This often means that additional personnel is needed for various tasks within and outside the DSO (Pylkkänen 2015).

The field operation resources need to be scaled up in major disturbance situations. During and after major storms with a large number of network faults and challenging conditions additional network technicians may need to be recruited from contractors outside the DSO’s own network area. As a result, the field work is often distributed to a diverse set of teams from the DSO, its regular contractors and outside help. These teams can move and work fairly independently within the network area.

The field teams need to be prepared and available for a fast and flexible deployment. In the fault situations the main tasks in the field are related to

- locating and isolating the outage with guidance from the operative center,

- performing the repair works and
- restoring the electricity in the network.

In some cases additional work is needed afterwards to remove temporary fixes and to finalize the repairs.

In the case of a wide and long-lasting fault situation the management of various field resources becomes increasingly complex. The availability of materials, equipment and suitably skilled personnel has to be taken care of while observing the regulations related to field personnel working and resting hours.

3.2 Issues and problems of team situation awareness

(Pylkkänen 2015) documents a long list of process and support system development needs for the general situation awareness during a major network disturbance. Here we elaborate further those related to the shared SA of the DSO operative center and the field teams.

3.2.1 Distributed situation awareness

The main problems in forming an optimal shared view of a fault situation can be seen in relation to two main causes:

1. Insufficiently formed and organized total view at the DSO operative center
2. Lack of tools for efficient communication between the operative center and the field teams

Currently a centralized information system facilitating the creation and sharing of situation awareness does not typically exist. Often the most complete overall picture of the situation is maintained in the distribution management system (DMS) of the network operator. Lot of information relevant for the total situation awareness (including total fault quantities, repair progress, available resources and overall cost) is outside the system and needs to be collected, maintained and reported manually in various tools. The reports are time-consuming to update and communicate and often lag behind the real-time events. There are no sufficient high-level visualization tools to support and share situation awareness.

The DMS collects and provides a lot of detailed information that is essential in the coordination of fault repair. However, the intensive flow of detailed data often makes finding the essential information difficult. This means that assigning priorities to repair task execution is very hard and depends on the local knowledge of the fault coordinator (Pylkkänen 2015).

Even if a coherent picture of the overall situation existed, the problem of sharing it efficiently with the field teams would remain. In the case of the Finnish DSO the only overall view available is the public fault map service. However, it only provides basic outage information. According to the field service contractors interviewed for (Pylkkänen 2015), a more detailed view on the progress of the repair work with some estimates of the scale and duration of the disturbance would be useful. For the individual field teams most interesting information would be the remaining work in their area of responsibility. For teams working in an unfamiliar area as part of a major disturbance organization the lack of basic local knowledge about the network and overall circumstances can slow down the repair work.

3.2.2 Utilization of data from the field

To maximize the speed of fault repair it is essential for the fault coordinator to know as much as possible about the faults before assigning them to teams. A lot of relevant information about the individual faults and general conditions in the field is distributed across the field teams. They often have detailed understanding of the scale of the damages to the network in their area, exact fault locations and causes and the equipment needed for the repair work. Even more importantly, the teams assigned to faults have the most accurate estimate of the time required for the repair.

The field information contributes essentially to the overall shared situation awareness. The critical fault data is part of the status maintained in the central DMS, but as direct access to the system is very rarely available in the field, the information has to be passed to the already busy fault coordinator through phone calls. In practice this means that only the most urgent information will be immediately recorded in the system. Even the information most relevant to the external situation awareness, the estimated repair time, is in many cases maintained on the basis of insufficient field data (Pylkkänen 2015).

3.2.3 Prioritization and task communication

For optimal economic and social outcomes it is important to assign the available field resources to repair the network faults in the right priority order. The main criteria for fault prioritization at the operative center are based on the Electricity Market Act of Finland. DMS support exists for automatic prioritization of outages based on customer interruption costs, direct compensation, high priority customers and the supply continuity criteria.

Even if the overall priorities for fault repair are clear, managing the field resources to execute the repair work present another challenge. During major disturbances hundreds of technicians can be deployed across the network area simultaneously, employed by several contractor companies responsible for fault repair within their respective areas.

In the case of the Finnish DSO some status information (working, resting, available) for the field technicians is updated manually in a group call system to maintain an overall resource view. It does not, however, provide a mapping to the contractor areas, which makes it hard to form an overall picture of the resource assignment.

Within the individual areas the visualization of the team locations combined with up-to-date fault and outage information would facilitate the management of repair work. Knowledge of free workgroups near unattended faults could be utilized to avoid non-optimal routing and unproductive time.

Task communication between the fault coordinator and the field teams happens most often by telephone. The synchronous nature of phone communication creates a bottleneck for the flow of information, as in a situation with multiple faults the coordinator is tied to a single call at a time. The calls from field teams can end up in a queue. All this delays the task assignments and the overall repair work (Pylkkänen 2015).

4 Field operation processes and tasks

The analysis above suggests several straightforward ways to support the creation and maintenance of shared situation awareness in network fault situations with mobile software tools. For our next steps we took the approach of first focusing on a limited set of key tasks in field operations. These tasks were identified in collaboration with a DSO as the ones with the largest immediate potential for overall performance gains.

As discussed in section 3.1, the field tasks in a fault situation are typically related to the outage management sub-processes of locating and limiting faults, fault repair and electricity restoration. In addition, some work is often needed afterwards to finalize and document the network status. In this context, the following tasks and corresponding features were selected to be evaluated and tested with a software prototype.

#	Field task	Description	Software features
1	Finding a fault-related item	Locating a network element, operative item (such as trouble call, outage or point of interest) or a customer point on the map	Network and address search
2	Finding faults with AMR alarms	Locating a fault based on AMR alarms associated with a connection point or transformer substation	AMR query creation, AMR query results on the map
3	Finding faults with trouble calls	Locating a fault by related customer trouble calls	Active trouble calls on the map
4	Finding faults with field notes	Locating a fault exactly by a previously created field note	Points of interest on the map
5	Finding a work zone for an outage	Locating the existing work zones for a network outage	Outages on the map, work zones for an outage

6	Finding a customer point related to an LV switch	Finding out the customer point that is connected to a specific switch in a LV distribution cabinet for fault isolation	Connection/switch highlighting for a LV distribution cabinet
7	LV switch operations	Changing the status of an LV switch in the field to isolate a fault	LV switch change
8	Updating ETOR for an outage	Updating the estimated repair time for a network outage or a work zone in the field	Outage/work zone attribute updates
9	Updating a trouble call	Updating the status of a trouble call in the field after repair	Trouble call updates
10	Documenting a fault location	Adding a field note to document the exact location of a fault related to an outage	Point of interest creation
11	Location sharing and viewing	Viewing the locations of work groups in the field (with additional attribute data) to streamline task assignment	Location sharing/viewing

Table 1. Field tasks and related software features

A full software prototype implementation and systematic user testing are subjects for future work. For this study, we quickly iterated the general approach by implementing the first features (roughly supporting tasks 1-6 in the table above) and analyzed the results qualitatively in collaboration with the DSO.

5 General demands for field operation software

Based on the selected field tasks and software features, we implemented an initial prototype. The implementation consists of a few web services built around a Trimble NIS/DMS data model and a web front-end for HTML5 clients.

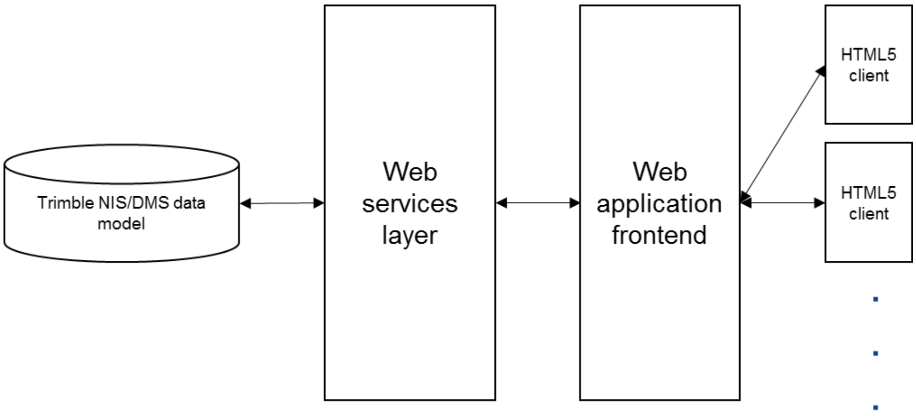

Figure 2. Prototype architecture

The initial prototype was tested internally to understand the usability and performance implications of the selected approach. It was also trialed by a small group of experts from the collaborating DSO. They provided qualitative feedback on the general compatibility of the approach with their particular field processes. These early results are summarized below as general demands for the final solution.

5.1 Software availability and deployment

As discussed in chapter 3, during a major network disturbance a large number of field teams need to be deployed quickly. The teams may be employed by a diverse set of local and possibly non-local contractor companies. The deployment may need to take place outside office hours and during holidays and ideally requires minimal involvement from DSO personnel.

The members of the diverse field teams can have access to various types of mobile devices to run operations support software, either as company or personal devices. In particular, it is hard to guarantee the availability of any given operating system or device version. Therefore the mobile field operations support system should be accessible as widely as possible across the different mobile ecosystems and device form factors.

In practice the most straightforward way to satisfy this requirement is to rely on web technologies for the mobile client software. It can be argued that modern mobile browsers support sufficiently rich client capabilities to support field operations as discussed above. Our early prototyping work seems to support this claim.

As for the quick and flexible deployment, we found that it is essential to decouple the field team provisioning from the administrative processes of the DSO as much as possible in order to prevent the DSO personnel becoming the bottleneck here. One way to ensure this is to separate the user accounts and access rights of the field support solution from the DSO internal systems, so that the bulk of the work for creation of new user accounts can be distributed and delegated to the contractors themselves. This is fairly straightforward to achieve when considering the sharing of information from the fault coordination center towards the field teams. However, as discussed above, for the maintenance of the shared situation awareness it is essential to include various data from the field teams in the overall picture, implying the need to provide write-type access rights for the teams. To ensure the consistency and traceability of the field data updates to the internal systems of the DSO (such as DMS), some kind of centralized control is required for these.

As an example, the figure below describes a process for creating user accounts and assigning read/write rights that is compliant with these requirements.

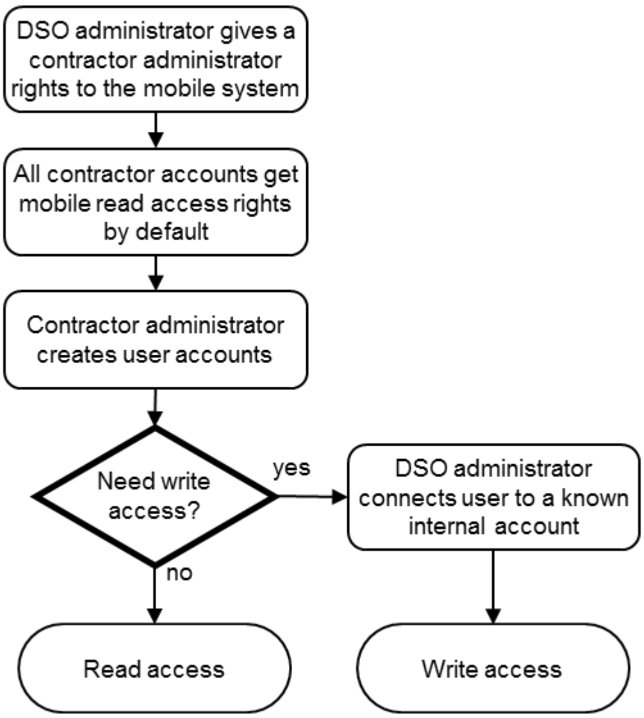

Figure 3. Account and access right creation (example)

With a separate user account space for the field support software, the DSO can simply grant administration rights to an administrator role in the contractor company. The contractor administrator can then independently create accounts with read access rights within the company. Traceable write access rights are created by connecting the user account to a known, existing DSO internal system account by the DSO administrator.

5.2 Network and operative state sharing

The basic elements of the overall situation that needs to be shared with the field teams are related to the network context:

- where are the network lines and other objects,
- what is the network connectivity status,
- what is the overall fault situation (in a given area),

- who (else) is working in the area and where?

For optimizing the situation awareness of a field team member, the information presentation (together with the software interactions) needs to be designed to enable focusing on the essentials of a given field task and to avoid information overload. We selected two mechanisms to achieve these goals:

1. Make the network and other data layers shown on the main UI view (background map) intuitively selectable, so that only relevant parts of the total information is visible in any situation. Examples: create selectable layers for different levels in the network hierarchy (HV, MV, LV), connectivity status, outage and fault information and location of field teams.
2. Optimize the information further in terms of the background map zoom level so that only information related to a particular viewing level is visible. Examples: on a regional level, show only contractor areas, high voltage network and substations; on a street level, show only low voltage network with connectivity status and customer connection points.

Many of the network faults caused by natural phenomena in Finland occur in rural areas where overhead lines are common in the network. Although mobile data network coverage in Finland is generally at a very high level, it is in these rural regions that the network data capacity may occasionally be low or missing. In addition, during major disturbances parts of the telecommunication network can suffer from outages. Therefore it is essential to guarantee at least the basic usability of the mobile operations support system even when offline.

Modern web browsers in the HTML5 era support fairly powerful storage APIs, including Web Storage, Web SQL, IndexedDB and Filesystem API (www.html5rocks.com) that in principle provide sufficient support for downloading and using map and network data offline. However, as the exact storage capabilities vary between browsers and mobile devices, close attention needs to be paid to optimizing the number of downloadable data layers and map zoom levels together with a maximum area size. To ensure the best possible user experience it can be worthwhile to also limit the selection of supported browsers.

Native runtime environments of mobile devices offer richer capabilities for independent offline work. However, reaching the same level of device compatibility as with a HTML5-based solution with a set of native applications would require significantly more development and maintenance work. This approach would also create the extra task of application downloading in the often already hectic deployment phase. Besides, based on our initial prototyping, the most critical offline limitations seem to be related to the size of the downloaded asset compared with the available offline storage and download speed, regardless of the implementation technology.

5.3 Network data updates in the field

As discussed earlier, a significant part of the information essential for the overall situation awareness in a network fault situation is created locally on the field.

To optimally maintain the overall situation awareness, the common network status view should be directly updateable by the field teams using the mobile system to avoid the communication bottlenecks created by direct phone calls. However, it is also important to ensure that all the direct effects of the updates stay local so that concurrent updates by autonomous teams do not create inconsistent information (for example by switching status updates). Also, the updates should be traceable to individual users as described in section 4.1.

It is obvious that updated data is not uploaded and available for the overall situation view in offline conditions. To maximize the consistency of centrally available situational view, the mobile software should make uploads easy when it gets back online.

5.4 Resource management

Our analysis showed that the resource management process would ideally need wider support than outlined by our initial scope definition in chapter 4. The resource management functionality should first of all contribute to the shared situation awareness by collecting and sharing distributed status information. The key elements here are as follows:

- The amount and identities of available field teams should be known in real time both for the total network and separately for each contractor area. Optimally, the capabilities associated with the teams (such as professional skills and available tools) would also be known. This would enable matching the resources globally to the need in a best possible way.
- The statuses of the field teams or in some cases even individual technicians (free, assigned to a fault, working, resting etc.) should be available for the centralized view. This would refine the situation view and, when combined with network fault status, enable detailed planning and task assignment.
- As already defined in the initial scope, the locations of field resources should also be visible in real time at least on the team level. This would enable optimal assignment of field teams to faults in terms of travel time and costs.

Secondly, from the viewpoint of an individual field team, it is most important to have a reliable view of the work and resource status on its own network (contractor) area: how much work is left and where. In many cases the field teams have the best knowledge for the local optimization of task sequences and routing between the faults. Therefore, instead of strictly centralized task assignment, the support software system should allow for the teams to flexibly pick up available nearby work. This could be achieved for example by allowing tasks to be assigned more loosely to a work area or a group of teams.

A drawback of browser-based mobile applications is their limited capability for background processing and access to device resources. This is relevant for real-time location sharing, which is in this case possible only when the application is in active foreground use. This in turn may lead to situations where the team locations are not up-to-date enough for a reliable view of the situation.

This technical drawback can be alleviated by clearly timestamping the shared location data to indicate its probable validity. Without resorting to full native application development, it would also be possible to develop hybrid client software with some native capabilities (which would, however, again lose some deployment-related advantages of the generic HTML5 approach).

6 Conclusions

Efficient management of field operation processes and frictionless communication are vital for fast recovery from electric network disturbances and minimization of unwanted societal impacts.

We analyzed the outage-related field processes of a DSO and its contractors, especially in major disturbance situations within the conceptual framework of shared situation awareness. We continue the discussion started in (Pylkkänen 2015) towards more specific analysis of mobile field operations support software and have derived the most important overall system requirements. We also selected certain field operations tasks to be supported by a prototype mobile software system. We built an initial prototype implementation for the selected approach and carried out some limited testing together with the DSO.

Because of the dynamic nature of the major fault situations, the field operations support system needs to be deployable quickly to large numbers of teams with various backgrounds and mobile devices. To create and maintain shared situation awareness in this context it needs capabilities to share the overall situational view and keep it up-to-date with locally contributed information. All this needs to happen in a distributed manner without creating process bottlenecks associated with scarce DSO resources.

To enable efficient actions on the basis of shared situation awareness, also the fault repair task assignment must be free from point-to-point communication needs. Since the field teams have the best knowledge about their local conditions, they must be able to some extent independently optimize and document thseir workflow.

The user interface design for the mobile software has to support clean and simple views to the data relevant for the task at hand. The application has to support offline work in cases where data network is not available and effortless uploads afterwards.

In terms of fast deployment and wide compatibility it seems that a HTML5-based application running in a mobile browser environment offers the most benefits. The potential technical challenges relate at least to offline capabilities and real-time location sharing. However, our initial prototyping efforts support the view that the most relevant performance limitations may be unrelated to the client technology choice.

We plan to continue the work reported here by a more comprehensive implementation of the field operations support system and a systematic user study. Also, wider support for the overall field resource management process should be considered in the future.

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