Organizational Factors of Robustness

Ivan Boissières
Institute for an Industrial Safety Culture
Ivan.Boissieres@icsi-eu.org

Eric Marsden
Institute for an Industrial Safety Culture
Eric.Marsden@icsi-eu.org

ABSTRACT

In complex socio-technical systems, robustness is achieved through interaction between the technical structure of the system and the social and organizational structure of the operators who run the system. While the need for human oversight of complex systems is widely recognized, the impact of organizational factors on the effectiveness of the oversight function is not well understood. We have studied the social interactions between supervision and maintenance operators of the largest French telecom operator, using techniques from the sociology of organizations. Detailed analysis of the social network formed by these operators has allowed us to identify a number of factors that contribute positively or negatively to the robustness of the system.

Keywords

Organizational robustness, dependability, social network, telecoms supervision

INTRODUCTION

A national telecommunications network is a complex socio-technical system composed of a dense network of technical elements, supervised and maintained by several hundreds of operators who work around the clock to ensure that the service functions correctly. The system is open, since it is connected to telecoms networks from other countries. Certain aspects of the service are safety-critical, since the network carries emergency calls. The telecommunications sector is undergoing rapid technological evolutions, with the introduction of new services and the increasing importance of mobile communications and data traffic. Despite the presence of technological change, the system is dependable, in that it continues to deliver correct service to its users in the presence of perturbations and faults. On a technical level, the system's dependability results from the use of redundancy: in the case of link failure, traffic can be rerouted over another link. Human operators play an important management role in ensuring the dependability of the system, firstly by detecting and diagnosing equipment faults (by analysing a stream of alarms that arrive in regional and national control rooms); in deciding on the most appropriate recovery actions (such as rerouting traffic over other links); by repairing faulty components and restoring broken links.

Our objective in this article is to analyse the social dynamics of the interactions between operators who ensure the high degree of availability of the telecoms service. Our study does not cover the entire organization, but rather concentrates on the subset of workers who are responsible for handling perturbations. This subset comprises operators who work in local, regional and national supervision centres, as well as operators who are responsible for the maintenance of telecoms equipment in a given local area.

We are interested in identifying the organizational processes that allow a number of independent actors to cooperate in order to resolve a problem. We would like to identify and characterize the social mechanisms and organizational factors that contribute to the system's *robustness*; its ability to continue to function in the presence of perturbations without catastrophic effects on its environment. The perturbations considered include both technological failures (of network equipment or telecoms links) and social issues such as misunderstandings between operators, social conflicts, and tension or rivalry between different groups of supervision and maintenance operators.

A complex socio-technical system

A national telecoms system is organized as a hierarchical network. Individual subscribers are connected to a local exchange by a network of telephone lines. Local exchanges are connected to regional transit exchanges by a network of cables, and regional centres are interconnected by a national network. The network carries various types of traffic, from traditional circuit-switched telephone calls (more than 40 billion minutes of calls in 2004 for the studied system) to packet-switched data traffic.

The network is subjected to an endless stream of technical perturbations that can affect the reliability of the service provided to customers, such as hardware and software failures in telecoms switches, cable malfunctions, and traffic spikes. These disturbances are managed by two categories of operators, supervision and repair, who cooperate to ensure the dependability of the telecoms network. Supervision of the network involves the analysis of alarms generated by hardware elements, in order to detect anomalies. These alarms are classified according to their gravity, and are centralized by a management system and presented to supervision operators. Once the cause of an anomaly has been diagnosed, supervision operators decide on the most appropriate recovery action in order to mitigate the impact of the fault, such as rerouting traffic around the faulty equipment, and deciding on the most appropriate repair action. There are multiple levels of supervision: local, regional and national; these are handled by distinct groups of supervision operators. Maintenance and repair activities are carried out by a second category of operators, who intervene directly on the faulty equipment; these operators are organized at the local level.

Besides the technical threats to the availability of the telecoms service, there are social threats that result from the dependence on human operators. Key supervision operators can threaten strike action; social tension between different groups of operators (due to factors such as rivalry or jealousy) can impair productivity; individual operators can become upset and refuse to cooperate with certain colleagues. These “human factors” are more complex and difficult to analyze than technical threats, but their impact on the system’s robustness cannot be ignored. Our aim in this work is to characterize the relationships and social interactions between supervision and repair operators, in order to identify factors that contribute positively or negatively to the robustness of the overall socio-technical system.

METHODOLOGY

We have carried out an in-depth study of the social interactions between supervision and repair workers, over a period of three years, visiting 10 of the 20 sites in France involved in supervision and maintenance activities. Our work uses techniques developed in the field of organizational sociology. After an initial observation phase (more than 100 days in various supervision centres), data were collected through structured interviews with a subset of the personnel and with group leaders (over 250 people, who were chosen to be as representative as possible). The data collected during the interviews were analyzed to determine their each operator’s personal network, using an ego-centric approach. Operators were asked to identify the colleagues with whom they interacted and the nature of their interactions (both professional and personal interactions were considered; *c.f.* Figure 1). By extrapolating the results obtained on the subset of the population to the entire set of maintenance and supervision workers[1], we obtained a graph of the complete social network, shown in Figure 2. A social network (Lin 2001) is a graph where nodes represent actors and the links represent different types of relationships between actors; such graphs have been widely applied to model situations such as the spread of HIV in a population (Klovdahl et al, 1994), and co-authorship in academic publications (Newman 2004). Analysis of this network, which reifies the social structure of the organisation, allows us to extract sociological observations on the importance of various forms of interaction between operators, and their impact on the effectiveness of supervision and maintenance activities.

1. *Names* of the entities involved
2. *Type of situation* when the interaction arises : crisis situation or nominal activity
3. *Direction* of the interaction (from whom to whom?)
4. *Type of interaction*: information sharing, fault diagnosis, order, friendship … (what is the objective?)
5. *Mode of communication*: oral, written, or via the information system
6. *Competencies* of each entity used during the interaction
7. *Frequency* of the interaction
8. *Mean length* of each interaction
9. *Number of people* in each entity involved in the interaction
10. *Functional importance* of the interaction, from the interviewee’s viewpoint
11. *Quality* of the interaction (what works/doesn’t work) from the interviewee’s viewpoint

Figure 1: Characteristics of an interaction between two entities

[1] The extrapolation to obtain a complete social network from the subset of the operators who were interviewed takes into account the organizational structure of the operator network, and assumes that groups of operators who were not covered by the study have the same types of interactions with their alter groups as groups who were interviewed. We were able to assess the validity of this extrapolation by comparing the extrapolated social network with a graph of the operational interactions between supervision and maintenance operators (automated logs of telephone calls and information transfers); both methods produce very similar topologies.

Figure 2 is a representation of the extrapolated social network of supervision and maintenance operators. Each ego (either an individual person or a group of operators working in a given supervision or maintenance centre, or a subgroup of operators from a centre) is represented by an orange square. Other egos that were not studied (but were mentioned in interviews with members of a group that was included in our study) appear as red circles. The green diamond-shaped nodes in the graph represent local supervision centres, the oval yellow nodes represent regional supervision centres, and the square blue nodes in the middle of the figure represent the national supervision centre and the supervision centre for the Paris region (on the right). The size of each node in the figure is determined by the number of links it is involved in. The links between entities designate some form of relationship, such as information sharing, request for action, connivance, control and aid; the links are directed. Nodes in the graph are placed so as to minimize the length of links and the crossing of links; this leads to actors whose role is more “central” (who interact with the largest number of other actors) being placed in the middle of the graph. The graph layout is calculated by the *Réseau-Lu* program (Mogoutov 2004).

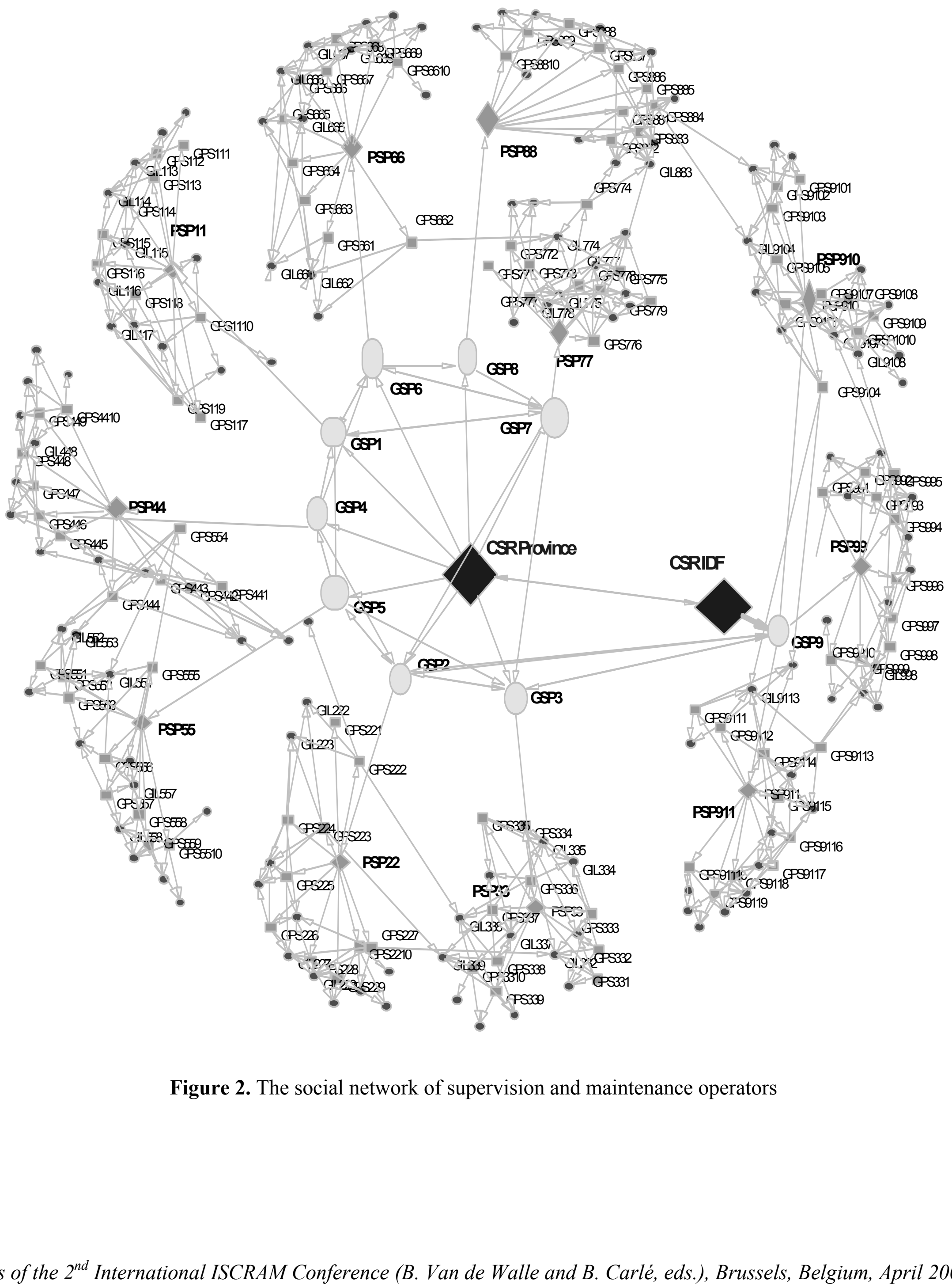

Figure 2. The social network of supervision and maintenance operators

ANALYSIS

Analysis of this social network, using techniques from organizational sociology, provides a number of insights into the social dynamics of the organization's management system, and the ways in which social interactions contribute to, or impair, the robustness of the socio-technical system. Our analysis is based on the structure shown in Figure 2, on other graphs that highlight factors such as the strength of links between egos or that analyze links depending on the type of interaction involved (not presented here for space reasons), on time-dependent information that is difficult to represent graphically, and on information obtained during interviews with the operators.

A strong collective response to technological risk

A first observation is that the social network is *dense*: on average, operators communicate with a large number of colleagues, and the frequency of the interactions is high. This indicates a strong collective action on the part of operators to manage the technological risk for which they are responsible. The level of density is higher than one would expect when considering the technical structure of the network and the formal structure of the organization, which is strongly hierarchical and centred around work groups. Indeed, the data collected show that hierarchical structure is largely ignored during everyday operational exchanges, in favour of horizontal cooperation between operators.

The density of the network implies a high level of *redundancy* in the interactions between operators. In the same way as redundancy between technical elements is often used to improve the overall reliability or availability of a system, the existence of multiple social paths between operators is a positive factor for robustness of the social network. For example a social link between operators *A* and *B* could be replaced by a link from *A-C-B* if the direct link between *A* and *B* were strained for social reasons, with *C* acting as an intermediary. The high degree of redundancy in the network means that each operator has easy access to the expertise of any member of the organisation, without social effects hindering the transfer of information.

The density of the network also leads to low mean *distances* between operators, where the distance is the number of intermediaries involved in an interaction between two nodes (if *A* tells *B*, and *B* tells *C*, and *A* does not interact directly with *C*, then actors *A* and *C* are at a distance of two). The mean distance is an important macro-characteristic of the social network, since it affects the rate at which information flows through the organization, and affects the degree of efficiency of interactions between operators.

Elasticity: variable-sized groups respond to perturbations

A second important observation is that the social network is *elastic*, and adapts to respond to severe incidents. While most common incidents can be resolved by interactions between a limited number of operators (or groups of operators), certain severe incidents require input from a large number of actors. The elastic nature of the social network is not immediately apparent from Figure 2, which includes *all* interactions between operators and thus represents the maximal size of the network, without representing evolution over time. By associating interactions with a corresponding *action* (a coordinated response of several operators to a perturbation), we can measure the mean number of operators involved in an action; elasticity is measured by the standard deviation of this measure. Elasticity is important for effective handling of crisis situations, without introducing excessive overheads during nominal activity. Our study shows that supervision and repair activities are based on the creation of *temporary collective groups* of variable sizes that adapt to the changing requirements of the problem at hand.

A decentralized operational structure

The social network is *decentralized*, and is not directly aligned with the officially sanctioned structure of the organization. Operational repair activities are mostly transversal between technicians, and often do not involve interactions with the hierarchy. This supra-hierarchy effect is apparent from the heterogeneity of the leaf nodes in the graph: in certain cases they are subgroups of the same organizational entity, in other cases a node is a group, and in some cases an individual operator. This fragmentation of the hierarchical structure blurs the official frontiers between workgroups, and demonstrates that the structure of the social network is very different from the official structure of the organization. Indeed, agents higher in the organizational scale are often at the margins of the social network, indicating that their role in operational activities is marginal. Group leaders interact primarily with operators from the group they command, and mostly in an administrative or management role. The operational handling of the supervision and maintenance process is mostly transversal, and follows functional structure rather than hierarchy; upper management only intervenes in rare circumstances such as global crises, which leaves a large degree of freedom to the supervision and maintenance operators in the everyday handling of technical perturbations.

Organizational factors that contribute to cooperation

During interviews, operators were asked to identify factors that they saw as encouraging collaboration with colleagues (thus improving the robustness of the socio-technical system), and other factors that discouraged sharing and increased the level of social conflict between individuals and between different groups of operators. The result of these interviews is synthesized in Figure 3.

	Category	Meaning
Factors seen as promoting cooperation	*Mutual acquaintance*	The fact that people know each other "personally"
	Recognition	Recognition that a colleague's work is useful/legitimate
	Solidarity	The sense of belonging to the same collective group
	Learning	The possibility of improving one's skills and competence set
Factors seen as favorizing conflict	*Tension*	Rivalry between groups of operators (due to competition)
	Organizational change	Restructuring of the official hierarchy/organization
	Institutional communication	Top-down information accompanying an organizational change
	Competence	Level of competence required (of oneself, and of others)

Figure 3. Organizational factors that influence cooperation

The *mutual acquaintanceship* factor measures the impact of informal friendship relationships (or *comradeship* rather than friendship, since the people involved may never have met face to face if they work in different geographic zones). This factor is particularly significant in crisis situations. Operators instinctively prefer to call upon a comrade to help them resolve a difficult or urgent problem, because they feel that a friend will make a greater effort to assist them in a timely manner; we call these "strong links" between operators. The fact that the colleagues have already worked together in the past, and established mutual understanding and professional recognition of each other's competence, improves the efficiency of their interactions when responding to an unexpected event. This factor is particularly important in a large organization where groups of operators are spread out over a wide area, and have often never met face to face.

This "organizational intelligence" displayed by operators, who use the relationships they have built up in their social network to ensure the robustness of the socio-technical system, is difficult to characterize and quantify; it is not a part of the official handbooks that describe (and prescribe) supervision and maintenance activities. Its importance is generally underestimated by the operators' managers, who tend to feel that "we don't pay them to chat". This underestimation of an important factor in the system's robustness is a potential source of vulnerability for the system.

Continuum between nominal and crisis situations

Detailed analysis of the supervision and maintenance activities shows that successful handling of crisis situations results from preparation during routine activities, before crises arise. Operators are able to react effectively to contain the effect of a major perturbation because during non-crisis periods they have developed social relationships that include confidence and even friendship. This observation contrasts with the prevailing wisdom in crisis management research, which makes a clear distinction between nominal activities and crisis situations (for example see Gilbert 2002). Sociologists often assume that during nominal activity, work and its organization depend on informal "rule-breaking" arrangements. In contrast, it is generally assumed that the negotiations and adaptations which result in differences between prescribed and real activity disappear when dealing with risk prevention and reaction to a potential danger, leading to an almost miraculous conformance to regulations (Saglio 2001).

This clear separation between crisis and nominal situations does not appear in our study. The social network we have identified contains both professional and personal interactions and relationships, and thus represents both informal and formal aspects of the organizational structure. In the system we have studied, nominal and crisis situations can be seen as opposite extremes on a continuum of supervision and repair activity. During certain periods the technical system operates with little need for human intervention, whereas in other circumstances the level of perturbation is high, and requires multiple coordinated activities to avoid failure. In these circumstances (which clearly are not representative of all crisis management activities), it is interesting to study the manner in which the social interactions that arise during crisis situations are influenced by nominal activity. They do not appear spontaneously, but result from the everyday interactions which we have modelled via the construction of the social network.

CONCLUSION

The robustness of the organisation we have studied, which we characterize as its ability to provide telecoms service to its clients despite the failure of hardware elements and despite social tension between operators, arises from the elasticity of the ever-changing relations of cooperation between supervision and maintenance workers. Robustness results neither from some unattainable ideal of a system built from perfectly reliable technical elements, nor from a rigid hierarchical organization of operators who apply predefined operational procedures. The ability of the system to tolerate faults is assured by the flexibility of the social network formed by the operators, which "bends but does not break", absorbing the impact of inevitable surprises.

We have identified characteristics of the social network that influence the efficiency of the activities that are "carried" by social interactions: these include density, elasticity, and the presence of strong links. Our study suggests that in most large socio-technical systems, where social interaction is necessary to the continued provision of the service provided to users, social network theory is an important instrument to assess the organization's vulnerability to crisis situations.

REFERENCES

1. Lin, N. (2001) Social capital: a theory of social structure and action. Cambridge University Press.
2. Klovdahl, A., Potterat, J., Woodhouse, D., Muth, J., Muth, S., and Darrow, W (1994) Social networks and infectious disease: the Colorado Springs Study, Soc Sci Med. 1994 Jan; 38(1):79-88.
3. Mogoutov, A. RéseauLu software package, available from aguidel.com.
4. Newman, M. E. J. (2004) Coauthorship networks and patterns of scientific collaboration, Proc. Natl. Acad. Sci. USA 101, 5200-5205.
5. Gilbert, C. (2002) From One Crisis to the Other: The Shift of Research Interests in France, Journal of Contingencies and Crisis Management, vol.10, number 4, p.157-158.
6. Saglio, J. (2001) Souplesse du quotidien et raideur dans la crise: l'organisation du travail sur un bateau de guerre, in Organiser la fiabilité (ed. M. Bourrier), L'Harmattan, p. 161-182.