Modelling the human role in operational systems – theory and practice

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Abstract: The principles of relevance and leverage are proposed as criteria for assessing the adequacy of socio-technical models of operational systems. Relevance asks whether the model addresses the appropriate causal nexus and enables the drawing of valid conclusions. Leverage asks how the model identifies the requirement for change. An approach to modelling operational systems is outlined which has been developed in the context of aircraft maintenance. This is based on mapping a hierarchy of operational processes and modelling the dependencies and resources (human, information and material) that comprise the critical path through the process. Such a model could provide an independent criterion of system performance. The implementation of such a model to support the management and improvement of the system would provide the possibility of modelling the processes of adaptation and change.

1 THEORETICAL REQUIREMENTS FOR A SYSTEM MODEL

If an operational system is to exhibit qualities of resilience, then it has to maintain stability in the face of environmental turbulence. In order to evaluate the adequacy of such a system we need an independent criterion of system adequacy (e.g. when is it appropriate not to follow a standard operating procedure?). In order to understand how such a system needs to adapt itself to the turbulence in the environment we need good independent criteria to evaluate change and improvement.

Dominant models of humans in operational systems have fundamental problems in addressing these criteria. Models based on theories of cognition or social cognition have high validity in modelling the local relationships between people and technology, but support no independent criterion for action outside individual (or small group) intentionality and tend to be weak in gathering ecologically valid evidence. They tend to make an implicit appeal to unanalyzed external authority (e.g. in defining error or violation). Social constructivist theories are strong on representing reality as experienced, in a rich interpretation, but have no clear evaluation criteria and no way of exploring different patterns of causal influence.

Any useful model of the the human role in operational systems should ideally conform to two broad criteria – relevance and leverage. The criterion of relevance states that because it is never possible to have a complete and comprehensive description of any social process, it is necessary to focus the description on what is relevant to the enquiry. The principle of leverage directs attention towards those underlying mechanisms at each level of analysis where the relevant interdependencies are strongest, and where the possibilities of influence through system design are strongest.

Relevance helps us to answer two questions. First, where is the appropriate causal nexus we are trying to model and ultimately trying to influence? For example, different theories can focus on cognition, social cognition, social systems, socio-technical systems, etc. In relation to the problems to be solved, it should be clear (unfortunately, it not always is), why a particular theoretical focus is chosen. Second, does the model enable us to draw valid conclusions? Common problems that many theories run into which prevent the productive drawing of inferences include the following: reliance on post-hoc analysis of past events; indefinable theoretical constructs (e.g. safety margins); inability to resolve contradictory representations of similar action sequences (e.g. is intentionally not following a procedure an example of a violation or productive sense making, or both?); inconsistent definitions across the conceptual space (e.g. is error defined as intentional failure or system failure?); using basic theoretical terms which are not value neutral (e.g. error, violation).

The principle of leverage suggests the following questions: does the model address a causal nexus or does it simply offer an interpretation (e.g. modelling social reality vs. modelling culture)? Does the model address those issues that give the best possibility of change? Does it give an account of the change process (this often requires modelling influence at different system levels)? Does it give good criteria for evaluating change?

Models of ‘humans in the system’ can crudely be classified at different levels in terms of the extent to which they enable understanding and support intervention, as illustrated in Table 1, below.

Table 1. Models of humans in the system

Level of model	**Characteristics modeled**	**Operational functions enabled**	**Design functions enabled**
Descriptive classification of human factors	Factors which potentially affect performance	Taxonomies for incident analysis, performance reports	Checklist for design support
Analytic model of human operator(s)	How ‘human factors’ affect performance	Analyse & diagnose problems & events with respect to human operator	Evaluate HMI from user perspective
‘Leverage’ model of operational system	Functional relationships which support system outputs	Managing system & implementing change	Design and evaluate new system concepts

Many organisations manage Human Factors simply with a set of checklists, and this is often what design engineers say they want from human factors. However the level of inference that taxonomies support is very weak. Cognitive psychology has spawned many models of the human operator, either as an individual or in a small group, which can sometimes include tools as agents or actors. While such models can have great inferential power within their theoretical scope, they often do not address those factors that are critical to change if the operation is to be enabled to work better or designed to function more effectively in its environment. Therefore it is necessary to develop ‘leverage’ models, which seek to address precisely these issues.

A model that provides leverage over the design and management of socio-technical systems has to be able to represent those factors that potentially causally influence the system’s functioning. Some of these requirements for a model are represented in figure 1 below.

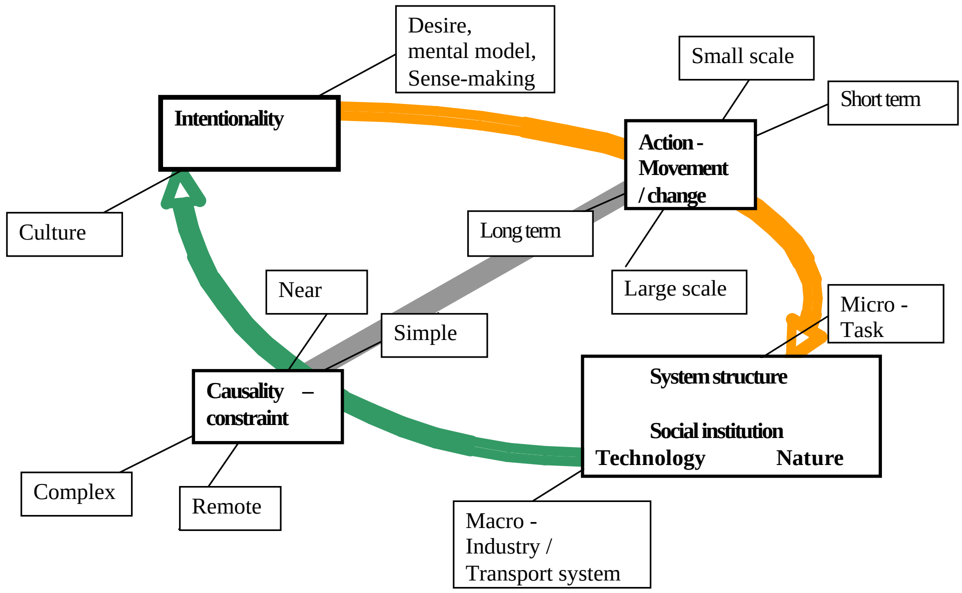

Figure 1. Dimensions of a possible socio-technical model

Most especially it should seek to model those factors that are amenable to modification, change or re-design in such a way as to transform the pattern of causal relationships that influences the required output of the system. Such factors include the intentional origins of human action through which the social structures of operations are activated. But human action in social systems forms only part of the causal systems of technologies operating in their natural environment (for example aircraft flying through the air). A socio-technical model should provide a seamless integration of human action and material causality (the actions of technology in the environment). The way in which the operator understands this whole causal structure conditions and constrains his or her intentional action. These actions in turn activate the technologies and reproduce the social systems that govern the operation. Accounts of these relationships should encompass different levels of explanation – individual and collective, short and long term, small and large scale, etc. Is it possible to model such complexity? Possibly, but only by focusing on those aspects that (1) are directly relevant to the models' purposes and (2) give most leverage over the main causal influences.

MODELLING OPERATIONAL SYSTEMS

Our initial attempts to model operational systems in aviation have focused on operational processes as the core functional structure of the activity. Operational processes represent the way in which an input is transformed by various sequential task activities into the required output. Our work in aircraft maintenance has provided ample evidence that factors outside the immediate performance of the maintenance task were rather more important than internal task dynamics in influencing the outcome. Initial comparisons between heavy (base) maintenance, line maintenance and dispatch, and the approach and landing phase of flight suggest a crude comparison of dominant causal influences on each type of process, in order of strength of influence (see table 2). This indicates that it is important to map all the influences within a set of processes that impinge upon task performance and hence influence the task outcome. The framework for developing this model is known as the Knowledge Space Model (KSM) and it has been developed under the TATEM project[1].

Table 2: Critical Sources of Process Strain

	Base maintenance	**Line maintenance & dispatch**	**Approach and landing**
Preconditions for initiating process	**1**	**2**	**3**
Parallel dependencies between tasks	**2**	**1**	**2**
Internal task dynamics	**3**	**3**	**1**

2 PROCESS MODEL

The process models provide the platform for the KSM. Their functional logic is core to defining the demands for delivering the system's outcomes (safety and efficiency); not only in terms of material inputs but also adequate social and information resources. Every process model is informed by a set of analytic modules modelling the different resources demands. This enables the evaluation of process realisation in terms of risk (relative match of demand/resources and its potential consequences) as well as the derivation of requirements for improvement.

[1] The TATEM project (www.tatemproject.com) is supported by the 6th European Research Framework Programme.

The assumption is that processes delivering an operational goal follow a generic functional sequence. The actualisation may vary across companies, e.g. the sequence of substeps or the support of function by technology, but overall the same logic applies to equivalent processes. In general, the technology defines the fundamental logic of the operation, which is reflected in the functional order of tasks as well as in internal task dynamics

The process models in the KSM framework have the following characteristics.

2.1 Hierarchical logic of process modelling

Processes are modeled at different levels of analysis, always in a generic way. The organisation of operational activities into these levels and their respective internal logic are defined by the technology operated in a certain environment. This provides the key features that define the critical path within a process. The operators' management of the given technology constraints then mediates how the critical path is achieved in practice.

Depending on the question of interest, any one level can be of predominant interest. Task support tools may focus on the detail of the task process modelling while taking into account information from other levels as it applies. Strategic management interests may be concerned with a consolidated picture at a higher level, only reviewing conclusions from more detailed/lower levels of analysis. The proposed levels establish a hierarchy in which the analysis of each also informs the adjacent levels. For example, while there is a particular logic to the sequence of states between tasks (e.g. from inspection of a component to its repair), this logic only makes sense in terms of the achievement of the states within each of these tasks (see table 3).

Table 3: Levels of analysis

Aircraft Maintenance (hangar or line)
Maintenance operation (all A/C)
Check/ work pack level (one A/C)
Functional sets of tasks
Maintenance task

2.2 Co-ordination activities

Co-ordination is defined as managing interdependencies between activities that are defined by the process logic. In the case of the functional task taxonomy the relationships between the categories of tasks define the points of co-ordination, e.g. the inspection identifies the problem while the repair rectifies it. In this example, between inspection and repair co-ordination ensures that the results of inspection lead to setting up the repair task. Co-ordination can be identified as a key activity in the critical path of the process and accordingly should be modeled explicitly.

The extent to which co-ordination activity is (implicitly) referred to in technical manuals does not reflect the contribution it has in realising the process and achieving operational goals. Co-ordination is a key nexus that links information, social and material resources as inputs into the functional logic of the process. Through this, prerequisites become relevant as the process progresses and co-ordination plays a role in achieving and consolidating states at each level of analysis. Co-ordination is critical in governing the sequence of activities in the process, and thus delivering its operability.

Recurring co-ordination activities in processes have particular generic functions, examples being: identify requirements/demands; activate/introduce inputs; reduce ambiguity; resolve conflicts; etc. The aspiration is to model those as part of the process models which requires a generic taxonomy of activities and their functions.

2.3 Critical path

Process mapping is generally concerned with the flow of activities of different roles along a timeline. In the KSM framework this sequence of activities is only the entry point into a more abstract process model that identifies the causal structure that sustains the process outputs.

Each process is described in terms of its critical path, identifying key states that need to be achieved for the process to progress and modelling their dependencies with previous, parallel or future states (within or outside the selected process). Each process can be modeled as a sequence of transformations from one state into the next. The success of each transformation depends on the adequate resources (namely social, material and information) delivered into the process. As such the set of dependencies that a state comes with can be described by the social, information or technical mechanism that underlies or delivers it.

Defining the sequence of states and their causal logic is facilitated by the logic of the process levels, especially the functional task taxonomy that defines the key units of operational activities, but also needs to be validated empirically. Modelling the resources is facilitated by dedicated modules, which address social processes, information and technology.

2.4 Social processes

The social resources required by the process are an aggregation across the social requirements defined at each dependency in the process. The social process analysis feeds into the default narrative at each point in the critical path, which is then consolidated into the overall social requirements for the comprehensively resourced process model; e.g. a generic removal/installation process.

Key social dimensions identified and elaborated are

- Co-ordination mechanisms, e.g. mutual adjustment. This elaborates on the basic co-ordination mechanisms within the critical path.
- Task structure. This builds on the generic task taxonomy, which defines the core functional relationships in the critical path.
- Team definition within and across org units. Team characteristics are compared to the functional requirements of the task and co-ordination mechanisms.

- Competence requirements are expressed in terms of common understanding, knowledge, skills and key behaviours, which are derived from the earlier modules.
- The quality of relationships (e.g. trust) is derived from an analysis of specific contradictions or incompatibilities in the earlier modules.

The ultimate outcome for the social resource evaluation should be based on an index evaluating the relative match of each social dimension with the requirements of the process (either aggregated across the social processes (e.g., team, competence, trust) or kept independent to be aggregated in the risk evaluation). An example is in figure 1.

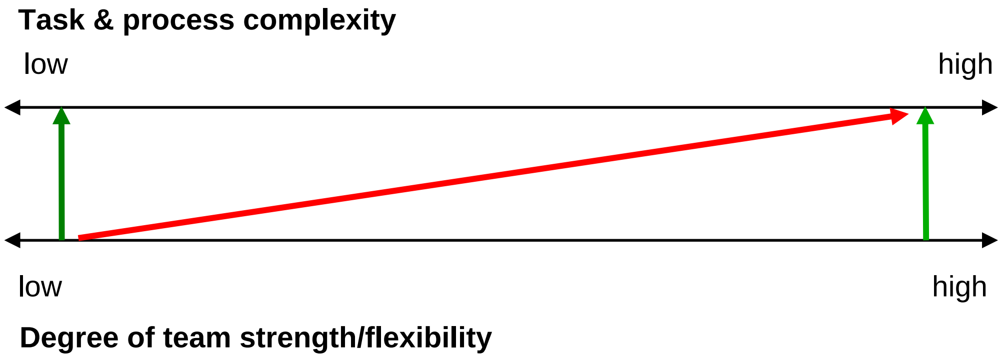

Figure 2: Task and team compatibility

Any discrepancy (e.g. low team strength, high task complexity) elicits the in-depth social process analysis the results of which guide improvement recommendations (for example, team composition) to meet the process requirements.

2.5 Information model

Information has been captured in the original process map for each step. This concept has been advanced and is to be developed into an information model that links social requirements to the technical process logic.

Key features are the information content, its source, its format, the producer and user of the information, the medium of transmission etc. This includes information that is in the current system (formal and explicit) as well as operational knowledge that is less formal but seems to follow established patterns nonetheless. The latter is closely linked to the co-ordination activities in which a lot of informal or less explicit information is exchanged. It is not just what is already in the systems but also shared knowledge that is repeatedly applied across specific processes.

2.6 Consolidation of the model

An operational system model is being developed which consolidates the above characteristics. This model is currently populated by the qualitative results of extensive research into the aircraft maintenance industry. An immediate goal for the model is to evaluate the implications for operational systems of the introduction of new technologies. A further goal is to incorporate the model in a management tool, which would routinely populate the model with operational data. This would enable both an empirical test of the causal structure of the model and the continued derivation of requirements for system change.

3 CONCLUSION

The argument is that modelling relevant dimensions of social reality is a necessary precursor to developing a fully socio-technical model of an operational system. The aspiration of such a model is to fulfill the criteria of relevance and leverage outlined above. Such a model gives the possibility of an independent criterion of system adequacy, which is essential, both to assessing a system in a stable mode as well as the requirements for change. Dimensions of such a 'realist' model have been outlined. These address the causal structure of operational processes that enables the assessment of risk and evaluation of performance. Addressing change, on the other hand, involves the capacity to extrapolate from present contingencies to future possibilities. Cultural constraints on understanding and sense making (at all levels of the system) then become central to understanding the mechanisms of change (as well as the maintenance of organizational stability). Thus social realist models are appropriately complemented by critical accounts of the role of culture in the reproduction and transformation of that reality. If the first stage of a strategy for research and development in relation to organizational resilience is the development of a system model, then the second stage is to implement and evaluate this model as part of a methodology for managing and improving the system. That second stage will allow us to explore and model the dimensions of adaptation and change, which are essential to organizational resilience in a dynamic environment.