KNOWLEDGE SPACE MODEL – HUMAN FACTORS AND OPERABILITY CONCEPTS IN THE SYSTEM OF AVIATION INDUSTRY

R. Morrison, P. Grommes, N. McDonald
School of Psychology, Trinity College Dublin
College Green, Dublin 2
Ireland

OVERVIEW

The Knowledge Space Model (KSM) is an innovative approach to Human Factors (HF) which is based on a model of operational reality and its dependencies as experienced by the human operator at different levels of the organisation.
In the KSM framework the knowledge of different maintenance stakeholders is translated into an operational system model. In TATEM, this enables driving the design and evaluation of how HM technologies transform the maintenance processes that deliver the A/C operability. A model of the real operational system including technical, social and information drivers of process activities is the prerequisite for

- supporting current activities
- vision of the future (e.g. technology benefits)
- driving implementation and evaluation of the envisaged changes

1. INTRODUCTION

The introduction of operability concepts reflects a shift in the business models in the aviation industry. It is now becoming more accepted that manufacturing does not just deliver technology for sale, but has to provide a system (or, more accurately, part of an operational system) and this has to deliver operability. Such a system has to work better, in all its functions, than the competitor's system.
Although operability is currently measured in terms of fairly high level indices of aircraft availability and reliability, it depends (amongst other things) on the effectiveness of the maintenance processes underlying the consistent delivery of airworthy aircraft to flight operations.
Maintenance is a 'people process' – it consistes of a discrete set of tasks done by people using tools and parts on aircraft systems. The co-ordination of different activties in the maintenance operation as well as the interfaces with other systems, such as flight operations, is done by people. Therefore managing human factors and social processes is fundamental to delivering operability.
New systems and new technologies do not just change the discrete jobs that people do – they can transform the whole process. Our argument in the TATEM project is that it is this process transformation which delivers/maximises the step change in operability. Therefore the manufacturer and technology provider have not only to engage with the Human-Machine-Interface, but also with how the technology fits into and facilitates the whole operational system. Today, information systems are already forcing this integration. Doing this in a way which pays attention to the human role in future systems must give competitive edge.
In order to facilitate this paradigm shift in industry business models, a radical shift in the discipline of Human Factors is required. It has to move from being concerned with cognitive models of the human operator to delivering models of the human roles and functions within a (socio-technical) system. We have been leading this shift in focus through our operational process modelling and 'Knowledge Space Model' evaluation framework.

2. CURRENT MAINTENANCE OPERATION

The maintenance operation of aircraft can be described as complex sets of co-ordinated tasks that are managed by people. Even though the technician is the person who executes the maintenance actions and manipulates the aircraft, the success of the process depends on many stakeholders' contributions. Research has shown that operational staff often is left to manage the resulting ambiguity and uncertainty designed into the operational system (e.g. AMPOS, ADAMS 1 & 2). In the increasingly competitive environment of today the main sources of instability are not located in the task but how the planning and support that lead into the tasks are managed and how their requirement for parallel activity is realized (see also table 1).

TAB 1. Sources of process strain (McDonald & Morrison, 2006):

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

Human factors are embedded in the system. While outcomes can be observed at the operational sharp end, the root sources can often be located in the upstream processes of the organisation. This relationship is not well managed in current processes, key reasons being (a) the dynamic of managing unscheduled tasks and (b) less than optimal utilisation of information available about the system. Solutions are sought locally in the organization without an integrated view of the system, something that the KSM approach aims to deliver.

A simplified summary of today's situation concludes that the main activities of planning and preparation for the check or transit are not well integrated with the local effort in managing the operational task. The local response to this situation is characterized by iterative interaction aiming to adapt. When the operational staff is executing a plan they are left to manage the residual ambiguity and changes that are introduced when confronted with changing requirements (e.g. new findings). This requires a local team effort that depends on good relationships and a shared understanding of what is an adequate response in the situations. As such the process is not sufficiently described by the technical activities outlined in manuals and procedures but it also manifests itself in the social processes which energise the formally described process activities. This can be summarized:

- TEAM: Local team depends on iterative co-ordination, based on mutual adjustment
- TRUST: Emphasis on personal relations locally (Trust) vs. segregation of support & operational departments globally
- COMPETENCE: Competence emphasis on (untrained) social skills, e.g. communication for flexible problem solving with adequacy of outcome negotiated per situation

Many of human factors issued in today's processes can be seen as consequences of how the system is designed and operated. In the current situation, the requirements for local adjustment forwards pressure and responsibilities onto the people working at the aircraft. With the system being under constant strain in the current situation, people are critical for the operation to perform well in these systemically adverse circumstances. The lack of serious incidents and accidents reflects that the active process management of the people involved maintains sufficient stability most of the times. The occasions on which the system strain is exceeds the available mitigation resources lead into so called 'human errors' which are rather instances of system failure.

3. FUTURE CHANGES

The philosophy of global health managed aircraft which is realised by TATEM technologies has the potential to change the maintenance processes. The following summarises some of the main axes of improvement that are introduced into the maintenance operation by advanced health management:

- Integration of information along and across processes (new and existing; onboard and off-board)
- Better quality of diagnoses and new prognostic capabilities (e.g. adequate confidence intervals; new sensors)
- Improved timeline, i.e. earlier availability of health status information and decision support in the maintenance operation

These improvements enable the process transformations. In the future there will be better control over the maintenance status and resulting requirements of the fleet. An improved evaluation of maintenance requirements facilitates better planning and resource allocation. Upstream processes are better linked with the operation, delivering seamlessly into more transparent operational requirements. The execution of maintenance will not only benefit from the better integration of support and operation, but the processes themselves are going to change. The most prominent examples include tasks becoming redundant (e.g.. health status information instead of inspection task) and additional maintenance tasks (e.g. for the new monitoring equipment such as sensors). Further changes to be considered are new system interfaces, changes in responsibilities, relationships between operator, manufacturer and maintainer as well as the impact on the human actors and their relationships. Some of the Human Factors issues can be summarised as follows:

- TEAM: Extended, more remote team with top down co-ordination, based on standardisation
- TRUST: Fewer personal relations in remote team but potential for genuine cross functional support.
- COMPETENCE: Clearer **c**ompetence definition for technical skills, e.g. new task features, & social skills, e.g. in defined management responsibilities.

The degree to which health management enables these changes depends on how far the technology can push towards an 'ideal world', i.e. improving the ratio of planned to unplanned tasks. The appropriate integration of onboard and off board data is critical to realise many of the potential benefits. The better management of the process as a whole (including planned and residual reactive management) requires an integrated maintenance information system (MIS) as developed in TATEM.
The transformation of the processes is what ultimately achieves the gains in operability. The success of implementing process transformations and maximising their benefits depends on having model that defines the critical dimensions of the system the change is aimed at. If managed from a socio-technical understanding of the system these transformations also reduce many of the sources of HF problems resulting in better working environment, less ambiguity, and improved safety.

4. KNOWLEDGE SPACE MODEL FRAMEWORK

The Knowledge Space Model (KSM) aims to provide a framework to manage current systems and designing new ones. The focus of the model is the operational system although this obviously exists in and is influenced by a wider systemic context, e.g. organisation or industry. Putting the spotlight on the point of production (the operation) requires an answer to the question: What is to be modelled to explain activity in the operational system? Operational activity broadly translates into people operating technology to achieve an operational goal. The actions of the human operator in the system are largely dictated by the technology operating in a particular environment and mediated by the way organisational support is designed and realised. Any model of an operational system has to facilitate an understanding of the causal dependencies in the real world and how their meaning is constructed in the social system operating on them.

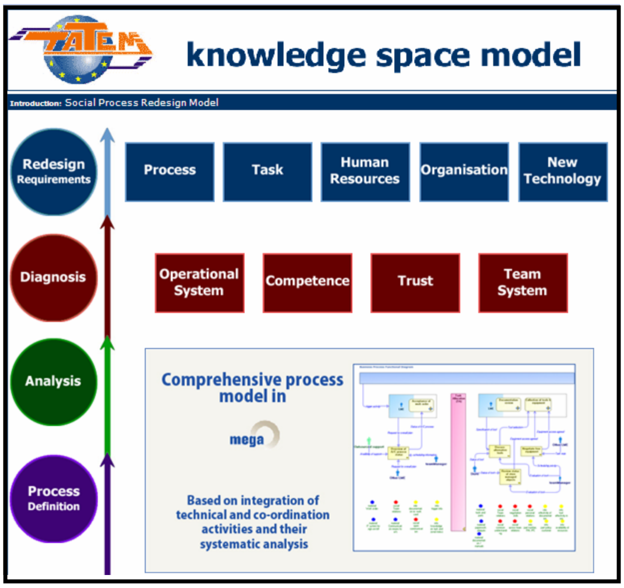

FIG 1. Knowledge Space Model framework (TATEM D6102, Morrison et al 2006)

The overall Knowledge Space Model framework consists of an integrated set of sub modules:

- Operational process model (OPM)

A core component is a comprehensive operational process model which (in a generic way) describes process activity and models its underlying causal logic. The process model provides the platform for more complex evaluation to be conducted, e.g. social process evaluation (including team, trust and competence) that requires HF expertise.

- HF evaluation modules (SPM)

The evaluation of the operational system serves two purposes: (a) feeding back into the process model, e.g. for comprehensively identifying required resources such as common understanding in a team situation, and (b) driving requirements and recommendations e.g. for technology system implementations. Compared to the current mostly ad hoc HF approaches and initiatives (see McDonald, 2007) the assessment in the KSM benefits from the model providing systematic support for a HF evaluation that is integrated in the operational process reality.

- Requirements derivation process

Modelling the causal patterns in activity and the evaluation of their origins in socio-technical dimensions enables the systematic derivation of requirements for change. These are implemented in the process model, and their success verified in an iteration of the KSM approach.
Categories include operations (process and task), new technology, Human Resources, organisational system.

4.1. Operational process model (OPM)

The operation of an organisation can be described as a socio-technical system, i.e. people manipulating technology. Thus, any attempt to model activity in such a system should include considerations about the roles of technology and people as well as the information exchanged between them.

TCD's operational modelling differs from standard process modelling in (a) the scope of what is considered as critical elements and (b) consequently modelling the relations between these elements and their underlying mechanisms.

The key parameters are organised in 4 diagrams which are discussed in the following section..

4.1.1. System levels

Any system can be described in terms of its subsystems. Thus, its processes can be structured accordingly, i.e. operational activities can be analysed at different levels. Processes are organised hierarchically which results in a description of activities at different levels of granularity (moving the analysis from a micro to a macro level). At each level the constraints are set by the next higher level. For the maintenance operation the following organising principles are suggested:

- Maintenance operation (fleet level)
- Work pack (aircraft level/fleet level)
- Unit of tasks (aircraft level)
- Maintenance tasks (aircraft level)

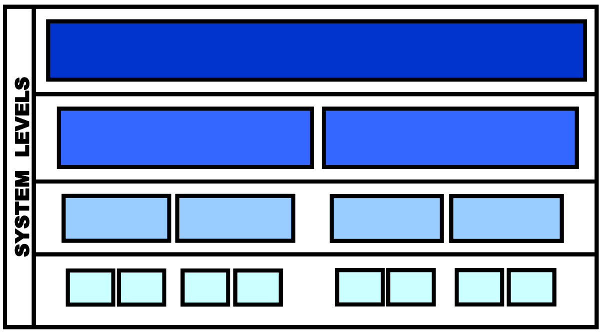

FIG 2. System levels illustration

4.1.2. Operational activities

At each level the process activity two sets of activity are modelled: technical activity and coordination activity

Technical activity is required to manipulate the technology object and thus is technically defined by the object operated on. While to a large extent, it is described in manuals, procedures or formal processes, some variability is left for modifications to occur, e.g. customised tools, or additional steps..

Co-ordination activity is only partly accounted for in manuals and procedures, but most of it occurs in the process ('systematically ad hoc') as a means to enable the progression from one process state to the next. Co-ordination is defined as managing interdependencies between activities and is a key nexus that links information, social and material resources as inputs into the functional logic of the process.

Both sets of activities are dependent on inputs and produce outputs through which they are linked within and across processes. Although the coordination activity only occurs because the technical task exist and is worked on, in turn its technical realisation would not be possible without the social interaction that facilitates it.

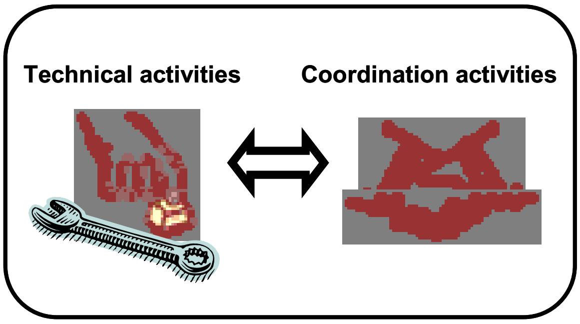

FIG 3. Activity diagram illustration

4.1.3. Overview of stakeholders

At each level the key stakeholders who have a contribution into the processes at this level are identified and their main relationships mapped. It summarises the social system whose actors have an influence on the progress and outcome of the process at this level. These are the actors whose activities are modelled in the different process maps.

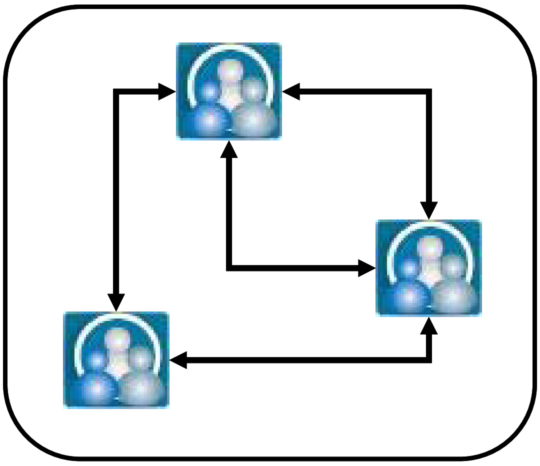

FIG 4. Stakeholder relations illustration

4.1.4. Critical path

Standard process mapping is concerned with the flow of activities of different roles along a timeline. In the KSM modelling framework this sequence of activities is an entry point into a more comprehensive process model that identifies the functional structure that sustains the process outputs. The critical path links process states within and across processes (along their respective timelines) and models their mutual dependencies which define the demands that have to be met by resources to achieve a particular process state.

The critical path reflects the logic of the technical and coordination activity that enables progression along the process. It follows the sequence of states that need to be achieved to deliver the operational outcome. Dependencies inform the links between not only states within the same level of analysis but also other levels and pre-requisites.

Each state is dependent on a set of other states in the critical path. Their achievement (all or in part) is an input to satisfy its demands (which set prerequisites for process activity).

The series of states contributing to the achievement of one particular process defines a critical path. It is a derivation of the logic of the process activities described, analysed and evaluated in the KSM process modelling and is its key organising principle.

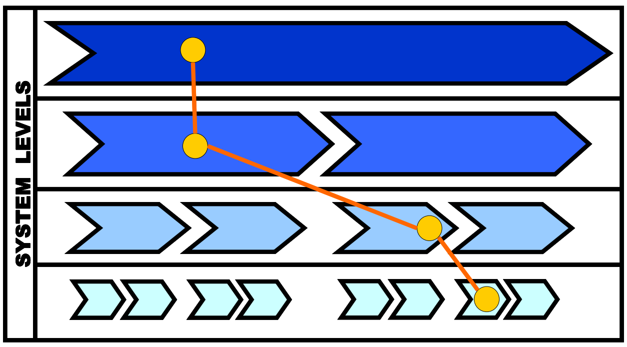

FIG 5. Critical path illustration

4.2. Human Factors evaluation

Reviewing the technical and coordination requirements for achieving critical process states, the relevance of social dimensions becomes apparent. Requirements for a team and its competence are not only defined by the technical activities (e.g. qualifications), but also by the co-ordination activities that manage the dependencies posed by those.

The social process modules of the overall model are a structured inquiry that draws information from the rich operational process models. The modules are based on the on research in various projects[1]. The social process analysis requires HF expertise and is performed offline. The output of the analysis is the consolidation of the inquiry into key dimensions that relate to the requirements defined by the critical path. Thus it defines the social resources required by the comprehensively resourced operational process model to meet the demands of the process logic and its related co-ordination, and thereby to ensure the safe and efficient realisation of the operational goal.

Key dimensions identified in maintenance research are

- Team system – design and support
- Competence
- Quality of relations, e.g. Trust

These are evaluated in relation to the operational process model defined above. Their realisation and support needs to adequate to the requirements of the process, expressed in the critical path.

This diagnosis details how changes potentially affect the socio-technical system and leads to the recommendations.

4.3. Requirements derivation

Deriving requirements for change initiatives whether technology design or implementation of HR strategies depends on a profound understanding of the system and the integration of the perspectives of both the people involved in changing the system and those being affected by it. The KSM provide a systematic evaluation of the socio-technical system which is the input into a process of knowledge transformation.

5. KNOWLEDGE TRANSFORMATION

The knowledge transformation process takes the information structured in the KSM framework and uses it in a social activity of deriving requirements for design and improvement.

The knowledge about how a system or process sometimes malfunctions does not necessarily give the right insight as to how to transform the process to eliminate the source of the problem. It is necessary to transform knowledge so that it can be effectively used in a different context from where the knowledge originated. The KSM is designed to support this transformation of knowledge about how the operation normally goes into what requirements are necessary to make it function better. However, this is not an automatic process and it involves the use of a variety of expertise to interpret that knowledge in terms of the fundamental process dynamics and to work out how to apply that knowledge in coming to an effective solution.

The model for understanding this knowledge transformation process which has influenced the KSM is derived from the work of Nonaka (2002) on new product development. This is one of the few models which directly studies the innovation process of using operational and technical experience as a source of new product ideas. Tacit knowledge has a very important role in this process. Tacit knowledge is acquired through direct ‘hands-on’ experience. In this model the organisational process for sharing tacit knowledge is through self-organising teams which are cross-functional, spanning organisational boundaries, in which leading members will have had multiple job functions, and which may include people from outside the organisation. Thus such teams have the “requisite variety” to synthesise different experiences in the knowledge conversion process of ‘externalisation’ – transforming a tacit understanding of how the operation works into explicit knowledge that can drive change initiatives.

In TATEM the integration and evaluation tasks are using aspects of this knowledge transformation process in a series of workshops to

- define the validity of future maintenance scenarios and the technologies that realise them
- Evaluate their operational benefits
- Manage concerns regarding their implementation

For future maintenance concepts to bring competitive advantage they need to integrate activities across the lifecycle, from design through operation to disposal. Their success depends on process integration, not just within an organisation but across the aviation industry, the ‘system of systems’. Sustaining any viable concept into the future requires all stakeholder in the aviation system (operator, integrator, OEM, maintainer) to develop a shared understanding of how their respective interdependent processes are affected. This is the key objective of the workshops undertaken in TATEM, bringing together the relevant roles in the technology providers and end user organisations.

The TATEM architecture is based on the Open systems architecture condition based maintenance (OSA CBM) standard (MIMOSA, 1998-2207). Figure 6 identifies the key stakeholders at each layer, from data acquisition to information presentation. The KSM approach to operational system modeling opens up the possibility of defining a further layer, al layer of maintenance action (as discussed in TATEM). Figure 6 demonstrated how the TATEM technologies development is mapped on the OSA CBM architecture. The third column in the figure indicates key stakeholders at each layer of data acquisition and management.

[1] Previous projects (AMPOS, ADAMS 1&2); Ward (2005), Liston (2005), Baranzini (2007)

Examining the range of stakeholders in the TATEM technology system demonstrates the significant task of sustaining a shared understanding of how the technology impacts their respective interdependent processes.
The role of the KSM framework is to facilitate both horizontal and vertical integration in a common process model. Enabling this requires a transformation of the initially separate understanding of each stakeholder into an integrated vision of the potential impact of the new technology.

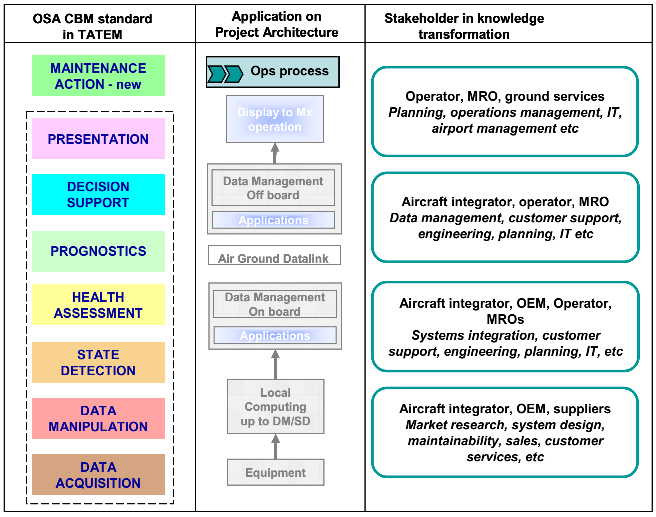

FIG 6. Knowledge transformation requirements based on TATEM project architecture

6. CONCLUSIONS

Operability is a key driver in the TATEM project. Operability is realised in maintenance through processes which are formally defined by the technology but put in practice by people. This makes an understanding of the role of humans in operational systems central to designing technologies to meet system goals.
thus, the current shift in industry business models is an opportunity to integrate HF as a discipline that can contribute in understanding how future concepts are realised in a socio-technical system such as the aviation industry.
The presented approach is part of a strategic shift in thinking which says that in the next generation of systems, managing the human component will be central. Consider the following points:

- A human social activity is what enables processes to function.
- Humans manage the interface between subsystems in aviation – redesign and integration of system functions through new technologies (such as TATEM is developing) has to be built on an understanding of that role, if that role is to be transformed successfully
- Operators (airlines, maintenance organisations) compete largely on the basis of their management of their human resource – this is most obvious in the low cost revolution which is driving system utilisation closer to the boundaries of human capacity.
- The application of new health management technologies as in TATEM makes possible the development of new service concepts to deliver operability from the manufacturer to the airline. These new business models require profound understanding of how to deploy people across teh system to maximise value in service delivery.

Therefore innovation for next generation systems should draw heavily on valid ways of understanding current operational reality (what really happens rather than what should happen), and transforming that understanding into requirements for new systems.

References

[1] ADAMS 2 Project 2001-2004. Project No. GRD-2000-25751. Funded under EU 5th Framework
[2] AMPOS (1999 - 2002) Aircraft maintenance procedure optimizing system. Esprit project: 29053.
[3] Baranzini, D (2007) In Preparation Doctoral Thesis, The University Dublin, Trinity College.
[4] Liston, P (2005) Doctoral Thesis, The University Dublin, Trinity College.
[5] McDonald, N. (2007) Human Integration in the lifecycle of aviation systems. HCI International Conference, Beijing, China.
[6] McDonald, N. & Morrison, R. (2006): Modelling the human role in operational systems – theory and practice. 2nd International Symposium on Resilience Engineering, November 9-10 2006, Juan-le-Pins/Cannes, France
[7] MIMOSA. OSA CBM standard. www.mimosa.org
[8] Morrison R., McDonald N., Grommes P., Baranzini D., Liston P., Ward M. (2006): Specification of the Knowledge Space Model, TATEM Deliverable 6102, Report to the European Commission, February 2006
[9] Nonaka I, Toyoma R and Konno N (2002) The SECI, Ba and leadership: a unified model of dynamic knowledge creation. In Little S, Quintas, P and Ray T (Eds) Managing knowledge: an essential reader. London: Sage.
[10] Ward, M (2005) Contributions to Human Factors from three case studies in aircraft maintenance, Doctoral Thesis, The University Dublin, Trinity College.

Acknowledgements:

This work was funded by the 6th framework EU project TATEM and supported by our industrial partners that enabled the required field work. An educational version of the MEGA process modelling tool by MEGA International is used in the project.