2017

H-Workload Models and Applications: the First International Symposium on Human Mental Workload: Models and Applications

2017

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Recommended Citation
Evans, J. (2017). A systems approach to predicting and measuring workload in rail traffic management systems. *H-Workload 2017: The first international symposium on human mental workload*, Dublin Institute of Technology, Dublin, Ireland, June 28-30. doi:10.21427/D79S5T

A Systems Approach to Predicting and Measuring Workload in Rail Traffic Management Systems

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Abstract. The introduction of systems such as Traffic Management (TM) will result in a number of changes in how the railway is managed for operations and maintenance staff such as, an increase in collaborative working styles and shared responsibilities. In order to react to these changing operational demands and user needs, TM workstation designs need to have greater flexibility and be configurable to support the information requirements for each specific role as well as support each role during different scenarios. Although this flexibility in system design has the potential to enhance performance, it increases the complexity of measuring operator workload. The In2Rail project explored these issues and this paper summarises the outputs; key future workload principles to consider, a proposed toolset to forecast workload and modifications to existing measurement techniques.

Keywords: Workload, Traffic Management Systems, Rail.

1 Background to In2Rail Project

The In2rail project [1] aims to address the growing demand for growth in the transport industry and is split into three technical sub-projects; Smart Infrastructure, Intelligent Mobility Management (I2M) and Power Supply and Energy Management Systems. As part of the I2M sub-project a report was written to determine the key considerations for future workstation design in the context of Traffic Management (TM) Systems; *'D7.3 Specifications of the Standard Operator Workstation',* co-authored by Thales and contributed by Network Rail, Siemens Aktieengesellschaft, Indra Sistemas S.A, Ansaldo STS and Rete Ferroviaria Italiana. The report captured not only best practice in workstation design but also security management systems and operator workload as they are seen as closely related in the context of TM Systems. This paper discusses the key findings, with respect to workload, from the In2rail D7.3 Specifications of the Standard Operator Workstation.

2 Workload in the Context of the Rail Industry

Cognitive workload in rail signalling is a multi-dimensional concept and it is made up of a number of factors such as the number and complexity of tasks over a period of time and the load perceived by an individual over a period of time [2]. The factors that can affect workload in operational centres today are generally well established and understood. For example, a greater complexity of infrastructure, an increased number of assets in an area and an increased amount of traffic in an area of control are all likely to increase an operator's experience of workload. The boundaries of each area of control are fixed and well defined in terms of workload variables and so an operator's normal level of workload can be assessed to a high degree of confidence using specific workload toolsets developed for the rail industry. As well as measuring the objective and subjective levels of workload experienced in a particular Rail Operating Centre, due to the amount of workload data collected from rail specific toolsets and current deployments, it is also possible to predict the level of workload experienced should a change to an operating system occur, or if a new operating centre is being deployed. Examples of workload methods used today are; Network Rail Activity Analysis Workload Profiling, Integrated Workload Score (IWS), Operational Demand Evaluation Checklist (ODEC) and Predictor of Signaller Time Occupancy (PRESTO) [3].

2.1 Effects of Future TM Systems on Workload

Over the coming years there are expected to be a number of developments in the technologies available for use within the operator's workstation design. The changes in technologies will have an effect on people, (the users), and the processes that support the users in utilising the technology available.

Due to the expected changes in types of tasks required by operators, an increase in collaborative working styles and shared responsibilities, future TM workstation and HMI designs need to have greater flexibility in order to react to changing operational demands and user needs. TM Workstations and HMI displays therefore need to be configurable to support the information requirements for each specific role as well as support each role during different scenarios.

As stated in section 2, there is a large amount of supporting literature regarding workload measurement techniques for the signaller role using conventional rail systems. However, as a result of the development of TM systems there will be a number of changes from conventional rail signalling systems that affect workload, these changes include:

- Flexible Areas of Control,
- Increase in automation;
- System design;
- Roles and processes;
- The type and quantity of tasks that the operator is required to perform;
- The characteristics of the operators (including training and experience);
- The complexity of the task(s) that the operator has to perform;
- Timetable (traffic type and density);
- Network (track features and signalling technologies) etc.

All of the above changing factors will have different effects on workload, for example;

- Some elements of workload will be reduced or eliminated;
- Some elements of workload will be changed without an overall impact;
- Some elements of workload will be exaggerated, and
- Some new elements or sources of workload will be introduced.

It is important to clearly identify the above factors and how they might change as a result of TM in order to influence system design, task design and process design, See section 3.1.3.

2.2 Aim of Designing for Optimum Workload

The aim of designing for an optimum workload in TM systems is unchanged from conventional systems; however the capabilities in achieving these goals have the potential to be enhanced. The aim of designing for an optimum workload is to:

- ensure the human is supported by the system such that the performance of the user is optimised;
- ensure the number of errors are reduced that could lead to safety related incidents;
- ensure optimum capacity of the running of the railway but have sufficient spare capacity and flexibility to manage an incident if it occurs;
- provide a balance between operational cost and safety, performance or reputational risk.

3 Systems Approach to Workload

As a result of the changing work practices of the railway changing from silo working, where individual signallers have the responsibility of controlling a defined area of the railway, to a more collaborative team working approach, workload needs to considered more holistically. Therefore it is no longer enough to measure the workload experienced by each individual separately, but there is a need to consider the effects of workload experienced by the team and the entire system. The following should be taken into account when evaluating workload holistically:

- The environment consists of objective workload demands related to traffic, infrastructure and operations. For example, the amount of traffic and the complexity of infrastructure in an area of control impacts on demand;
- The capability of the system is made up of people, process and technology;
- The system can experience different levels of workload depending on the objective demands from the environment;

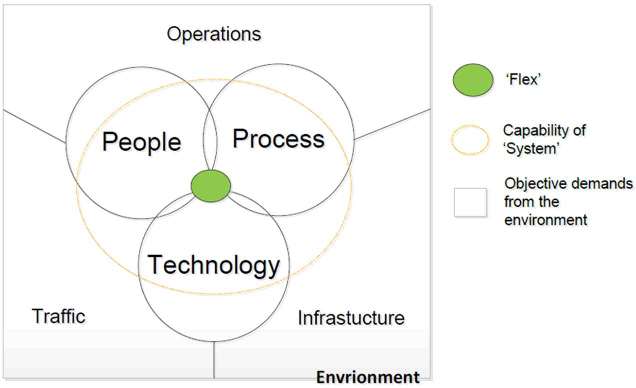


Fig. 1. Systems Approach to Workload *(model developed during In2Rail D7.3)*

- When the capabilities of the system cannot cope with the objective demands, this is when higher workload is experienced by the system;
- The system must be designed so that an optimum level of workload is achieved and there is a suitable level of resilience to cope with the changing objective demands;
- The 'Flex' of the system is the ability to flex people, process or technology to meet the objective demands of the system. For example, a flexible area of control enables workload to be distributed across the system depending on each sub-systems current experience of workload.

It should be noted that the overall goal of the system is still to reduce delays and maximise safety, however, people, processes and technology will need to adapt in order to meet this goal.

3.1 Predicting Future Workload for TM Systems

As the introduction of fully integrated[1]TM systems in the UK is still in the early stages there is a lack of data to baseline the effect that TM systems have on the experience of workload. It is also difficult to predict the effect that TM systems will have on workload. This is due to the fact that there are a number of variables with a level of uncertainty related to expected sources of future workload which have not yet been assessed in practice. In order to reach a stage where we are able to make workload predictions for future TM systems with a higher level of confidence, the following activities must occur:

[1] Fully Integrated TM systems are where planning tools are integrated with the signalling layer to enable planning decisions to directly link to signalling commands.

1. Identify variables we believe, based on current understanding, will affect workload in the future due to TM,
2. For each project or deployment of TM, develop a forecast of expected workload to be experienced by the system,
3. Use this forecast to make assumptions about the number of roles required, to influence system design and develop processes,
4. Develop the TM system and measure the level of workload experienced by the system to ensure it is suitable to commission the system,
5. Continuously measure the experience of workload and use data to feed into subsequent TM deployments, process improvements and system design.

The TM future Workload toolset as developed during the In2Rail project begins to describe in more detail how the above steps should be followed.

3.1.1 In2Rail Workload Toolset

This section describes the suggested tool set to be followed to forecast and measure workload in future TM Systems. The toolset is an initial framework developed as part of the In2Rail project and has been developed using the TM 1st Deployment project in the UK as a use case. However, the toolset should continue to be developed overtime through subsequent TM deployments. Table 1 provides an overview of the In2Rail toolset.

Phase 1 has been split into three main stages:

1. Pre design Stage:
   - Evaluate Existing Systems: Evaluate existing systems to baseline current workload experienced and use the results to identify areas of overload or under load the future system can support, or mitigate the effects of;
   - Forecasting: Forecast future levels of workload, based on assumptions of known changes related to equipment or technology changes, role and task changes. See section 6 for details of forecasting;
   - Iterations: Use the output from the forecasting to influence the number of roles required, the areas of control required, the design of the system itself and training required.
2. Design Phase Stage:
   - Develop System: TM system development, made up of people, process and technology.
   - Prior to conducting workload assessments, it's necessary to train participants in new functionality or changes in system design as unfamiliarity can have an impact on usability and workload.
   - Prototype Workload Evaluation: Using either prototype systems or low fidelity systems, initial workload assessments should be conducted to identify early areas of under load or overload. Results from these assessments can then be used to influence the TM system design further, (including people, process and the technology). In this phase a number of iterations are likely to take place as the system design develops and the users understanding of how the system will be used increases. It should be noted that if a simulator is not available at this

stage then forecasting may be required to be completed again using more mature information regarding people, process and technology.

3. Design Review and Evaluation Stage:
   - Similarly to the design phase, prior to conducting workload assessments, it's necessary to train participants in new functionality or changes in system design as unfamiliarity can have an impact on usability and workload.
   - Final System Workload Evaluation: Measure the workload of the system, (people, process and technology); to ensure final design has appropriate levels of workload in order to commission the system.

Table 1. Descriptive Overview of In2Rail Toolset Phases

Phase of TM	Description of In2Rail Workload Phase
A first deployment of TM	**Phase 1: Forecasting** Phase 1 has the following characteristics: • There is high uncertainty and a lack of previous TM workload measures[2] to baseline and inform decisions such as determining type and number of roles required, suitable size of areas of control and changes to concept of operations required. • Predictive methods to determine the above are nearly impossible due to the number of uncertainties, number of changing variables and lack of TM workload baseline. Therefore a 'forecasting method' has been developed to help inform initial first deployments people, process and technology decisions.
Live system of first TM deployment is available	**Phase 2: Measure** • Once the first deployment of TM has been implemented and commissioned onto the live railway, workload should be continuously reviewed by both the supplier and the operating company. Data collected from this continuous review cycle will be used to develop the forecasting model so that it is more mature to be used in subsequent TM deployments as well as influence people, process and technology enhancements for TM.
Subsequent TM deployments	**Phase 3: Predict** • Once a suitable number of TM deployments have occurred and the workload experienced by the system has been evaluated, the forecasting method will become more mature and reach a state where the forecasting tool output matches the measured workload of the final system. Once the forecasting method has reached this 'steady state' it can now be used as a predictive model with higher level of confidence for subsequent deployments.

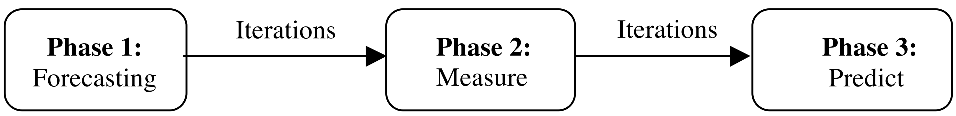


Fig. 2. Overview of In2rail Toolset Phases

[2] Relevant to that location, type or scale of deployment

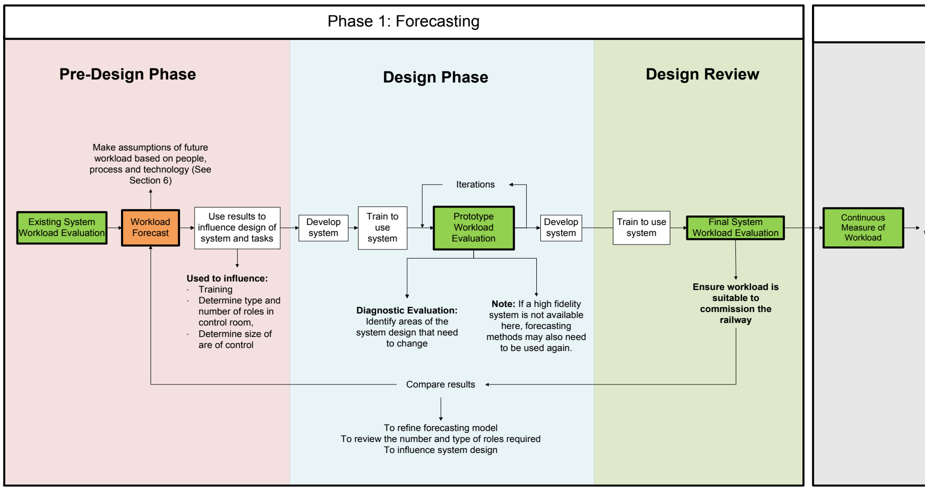


Fig. 3. Overview of In2rail Toolset Phase 1

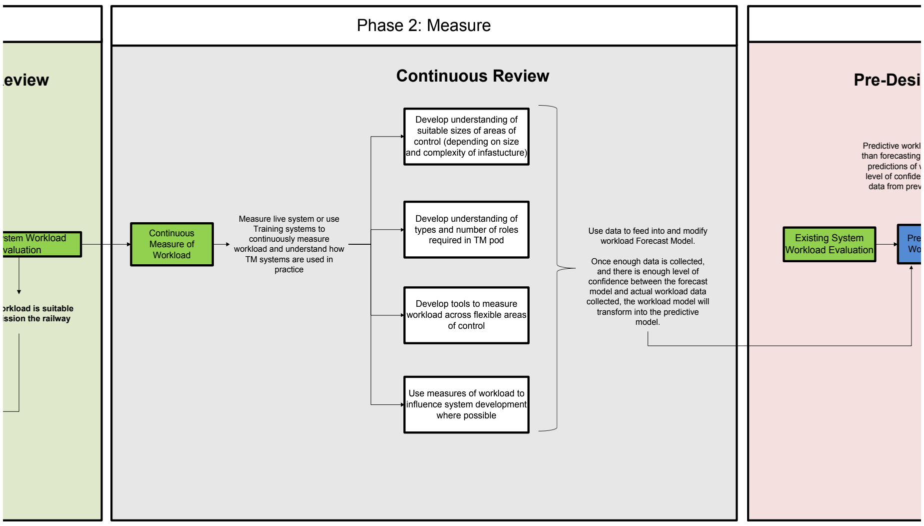


Fig. 4. Overview of In2rail Toolset Phase 2

Phase 2: Measure (Live System of TM First Deployment Available)

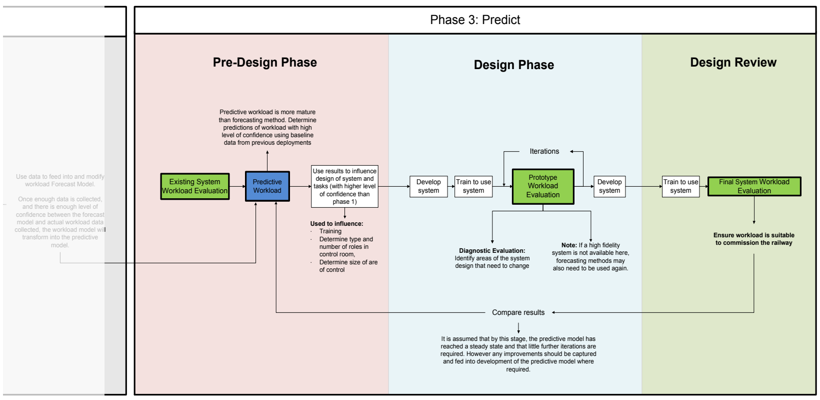
During Phase 2, the forecasting method in Phase 1 will inform the predictive model in phase 3. Once the first deployment of TM has been implemented and commissioned onto the live railway, workload should be continuously reviewed by both the supplier and the operating company. Note that data could also be collected from any training simulators that were developed during the project if rail operating centres chose to continue to use these systems for further training or process enhancements. Data collected from this continuous review cycle should be used to develop the forecasting model so that it is more mature to be used in subsequent TM deployments as well as influence people, process and technology enhancements for TM. The main areas that should be considered in continuous review are:

- Develop a better understanding of suitable sizes of areas of control (depending on size and complexity of infrastructure) - determine if there is more or less workload than expected and if areas of control can be increased in size;
- Develop a better understanding of types and number of roles required in the TM pod, and ensure processes are adapted to support new ways of working;
- Develop the tools to measure workload across flexible areas of control, and collaborative TM pods;
- Use measures of workload to influence system development.

The above data, and any additional data or findings collected from assessing the impact of TM in practice should be fed into the workload Forecast Model for further development. Once enough data is collected, and there is enough level of confidence between the forecast model and actual workload data collected, the workload model will form into the predictive model in phase 3.

Phase: Predict (Subsequent TM Deployments)

Phase 3 is similar to Phase 1 in that it is also split into three main stages, however the key difference is that the forecasting method from phase 1 is assumed to of now formed a predictive model based on a number of iterations and data from previous TM deployments.



Pre

Figure 5: Overview of In2rail Toolset Phase 3

design Stage:

- Evaluate Existing Systems: Evaluate existing systems to baseline current workload experienced and use the results to identify areas of overload or under load the future system can support, or mitigate the effects of;
- Predicting Model: Once a suitable number of TM deployments have occurred and the workload experienced by the system has been evaluated, the forecasting method will become more mature and reach a state where the forecasting tool output matches the measured workload of the final system. Once the forecasting method has reached this 'steady state' it can now be used as a predictive model with higher level of confidence. Using the predictive model, you will be able to predict future levels of workload, based on workload data captured in Phase 2 as well as known changes related to equipment or technology changes, role and task changes based on Phase 2;
- The output from the prediction model can then be used to influence the number of roles required, the size of the areas of control required etc. with a higher level of confidence than in Phase 1 to more accurately influence design.

Design Phase Stage:

- Develop System: TM system development; made up of people, process and technology;
- Prior to conducting workload assessments, it's necessary to train participants in new functionality or changes in system design as unfamiliarity can have an impact on usability and workload;
- Prototype Workload Evaluation: Using either prototype systems or low fidelity systems, initial workload assessments should be conducted to identify early areas of under load or overload. Results from these assessments can then be used to influence the TM system design further, (including people, process and the technology). A number of iterations are likely to take place as the technical system design develops and as it becomes more understood how the system will be used in practice. However less iteration is likely to take place than in Phase 1 due to previous evaluations of TM in practice;
- It should be noted that if a simulator is not available at this stage then prediction may be required to be completed again using more mature information regarding people, process and technology.

Design Review and Evaluation Stage:

- Similar to in the design phase, prior to conducting workload assessments, it's necessary to train participants in new functionality or changes in system design as unfamiliarity can have an impact on usability and workload;
- Final Workload Evaluation: Measure the workload of the system, (people, process and technology); to ensure final design has appropriate levels of workload in order to commission the system;
- Compare Results: It is assumed that by this stage, the predictive model has reached a steady state and that little further iterations are required when comparing the final workload output with the predictive model. However any improvements should be captured and fed into development of the predictive model where required.

3.1.2 TM Deployment Additional Use Case

This section describes an additional use case that could be considered and describes how the In2rail toolset supports it; change to existing TM Deployment area Use Case.

There a number of changes that an operating company may need to implement post commissioning of TM such as:

- Add a certain amount of geography into an existing Rail Operating Centre and TMS System;
- Modify the size of the areas of control to determine its impact on workload;
- Modify the number and type of roles in the TM pod and determine its impact on workload.

Phase 3 of the In2rail toolset supports this process of further TM software drops into existing deployments. By this phase, the predictive methods are expected to have an even greater level of confidence due to the ability to baseline against the current workload experienced for that TM deployment. The changes in variables can be inputted into the predictive model to determine whether the workload of the system will be higher, lower, or unchanged due to the changes required. Therefore the need for extensive simulation and prototype reviews may not be required. However, if a training system is still available from development stage, the updated software could be added to the existing training system to simulate how tasks or processes may be required to change as a result of the system update.

3.1.3 Workload Measurement Techniques for Traffic Management

During each of the In2Rail Toolset Phases 1, 2 and 3, there are a number of different times when workload measurement assessments were required. Although the existing workload measurements methods as stated in Section 2 are not expected to need to be modified too much in order to be suitable for the measurement of workload for TM systems, there are some elements to consider.

The most common workload measurement techniques where there is the most supporting evidence in rail are subjective tools, activity analysis tools, performance measures and general observations. However, there is less supporting literature for physiological workload methods within the rail industry. This may be because these methods can often be more intrusive. As a result, physiological measures may need to be adapted to enable them to be used on an operational railway in order to be a technique that could be used to continuously monitor a user's workload during operation.

Subjective rating scales such as instantaneous subjective measures could also be developed to be built into the system itself so that the user can input their experienced level of workload electronically whenever the system requests it. This would support facilitators during the evaluation phase as it reduces the demand on the facilitators in terms of data collection. Digitalising IWS type tools would also support continuous improvements as it would enable workload scores to be continually collected and evaluated during operation to improve processes to reduce the number of high workload experiences.

There is also a need to consider the change from fixed areas of control to flexible areas of control and the increase in collaborative pod working. This will add to the complexity of measuring workload and therefore existing workload measurement techniques will need to be adapted to effectively measure these changes.

3.1.4 Initial Application of In2Rail Toolset

This section describes how the toolset was validated using the TM 1st Deployment project in the UK as a use case. For the initial deployment(s) of TM forecasting will be required to take place or determine future levels of workload based on assumptions of known changes related to equipment or technology changes, role and task changes.

These forecasts will then be used to influence the number of roles required, the design of the system itself and training required.

So in order to forecast the future level of workload, the variables that we expect to effect workload in the future need to be defined. In order to ensure the forecast of the expected workload is accurate; the variables should be defined based on the entire system as defined in Figure 1.

Variables that affect the system's ability to cope with the objective demands of environment are: People, Process and Technology. The variables that affect the objective demands of environment are: Operational Environment and Control Room Environment.

People

- **Experience:** What experiences do they have in TM systems? What experiences do they have in using predictive systems?
- **Training:** What level of training is required for individuals to be able to use TM effectively? Is there a generational gap with regards to ease of learning new technologies? What novel methods or tools for training are available to utilise? Can the training needs' be reduced through simple, user friendly, easy to use HMI's that draw upon gaming or consumer design principles?
- **Competence:** How competent are individuals in using traffic management systems? How competent are individuals at working as part of a team? What are their non-technical skills? Is someone a novice or an expert? How mature is their local knowledge, system knowledge and rules knowledge?
- **Fatigue:** Are the patterns of shift work designed to reduce fatigue? Do the normal operations of the role generate high levels of physical or cognitive strain that could result in fatigue? Are there wider factors such as commuting time or pressures outside of work which could affect their experiences of workload?
- **Culture:** Are individuals supported if they are over or under loaded? How do individuals get support if they are overloaded?
- **Roles:** Are there a sufficient number of roles? What should the type of roles be?
- **Shift Patterns**: How long has a user been working for? Has a sufficient hand over occurred?

Process

- **Communication:** What are the changes in communication required to support team working?
- **Team working:** how is team working managed? Does team working to problem solve reduce workload in some circumstances, but increase it in others? Does shared responsibility spread the effect of workload?
- **Process and Procedures:** Are processes well defined to reduce miscommunication, duplication of effort or complacency? Are the allocations of functions efficient?

Technology

- **Automation:** What is the effect of new technologies level of automation on workload? Does automation reduce some experiences of workload but increase other areas? Does automation lead to complacency and errors? Do the tools support conflict detection? What is the complexity and frequency of conflict detections?
- **Usable Interface:** Does the HMI support the user in their decision making process? Does the HMI present the right users, with the right information at the right time? Is the HMI easy to use?
- **Equipment Layout:** Is equipment in an accessible location? Is equipment arranged to match the limitations of the user?

Operations:

- **Areas of Control (AoC):** How does the change from fixed to flexible areas of control effect workload? How do you define what is a suitable workload for each workstation when each area of control may have a different level of associated workload?
- **Tasks:** Have the number of tasks, the types of tasks e.g. complexity and the frequency of tasks changed? How does the change from reactive to proactive tasks effect workload?
- **Degraded Modes:** Are the effects of degraded modes supported by TM?

Infrastructure:

- **Track:** Is the complexity of infrastructure staying the same? How can you compare workload across each location or deployment of TM if the size of the geographical area or complexity of infrastructure changes?
- **Assets:** How many points, LX Controls, signals, interlocking's and stations should be in an AoC? Are these assets changing as a result of TM? Does TM help monitor these assets?

Traffic

- **Traffic:** Has the type and frequency of traffic changed due to TM?
- **Timetable:** Is the timetable conflict free and high in quality?

Control Room Environment

- **Lighting:** Can the lighting be adjusted to meet users individual or task needs? Is there glare?
- **Temperature:** Are they comfortable?
- **Noise levels:** Are noise levels increased due to increased communication?

To ensure that the considerations and variables as stated above were complete and useful to forecast the effects of TM, they were reviewed by Thales and Network Rail against the TMS 1st deployment project in the UK and Table 2 was fully populated and captured as an output to the In2Rail Project.

A summary of the findings from the evaluation can be seen below:

- The evaluation of the forecasting model showed there are a number of areas of workload that may be higher at the start when TM is first commissioned due to lack of experience, such as system knowledge. However over time the effect of this should be reduced and performance should be enhanced;
- In general the experience of workload is predicted to be lower due to increased collaborative problem solving and functions such as flexible areas of control;
- There are a number of areas of high uncertainty that need to be evaluated further once a training or live system is available for testing such as the effects of automation and areas of control.

4 Next Steps

The next steps to develop the workload toolset as described in this paper are:

- When a training system is available and or live system, the workload of the system should be measured. The workload assessment should include all elements in the In2rail forecasting model;
- The data captured from the workload assessment should be compared against the forecasting model to clarify assumptions, modify assumptions where required and add additional relevant variables or considerations where required;
- The forecasting model should be continuously reviewed against actual workload data collected until the forecast matches the actual workload measured from the system;
- Once the forecast model has reached a steady state it will form the predictive model that will be used to influence future TM deployments with a higher level of confidence.

The outputs from the In2Raill work packages will form the basis for the next phase of the European Commission initiative Shift2Rail [4] which aims to seek *'focused research and innovation (R&I) and market-driven solutions by accelerating the integration of new and advanced technologies into innovative rail product solutions'*. During Shift2Rail, Thales aim to take forward the workload principles explored in this paper and continue to develop the maturity of the workload forecasting toolset.

Table 2. In2Rail Workload Variables Table

System Approach to Workload	Workload High Level Variable	Detailed Workload variable	Description of effect on Workload	Summary of Workload Change (+1, -1, 0)	Description of effect on Safety or Performance	Legacy systsmes to Use	Recommendations for Project
Variables that affect the system's ability to cope with the objective demands of environment	People	Experience					
		Training					
		Competence					
		Fatigue					
		Culture					
		Roles					
		Shift Patterns					
		Job Design					
	Process	Communication					
		Team Working					
		Process and Procedures					
		Rules and Standards					
	Technology	Automation					
		Usable Interface					
		Equipment Layout					
		ARAMIS Task List					
Variables that affect the objective demands of environment:	Operations	Areas of Control (AoC)					
		Tasks					
		Degraded Modes					
	Infrastructure	Track					
		Assets					
	Traffic	Traffic volume					
		Timetable					
	Control Room Environment	Lighting					
		Temperature					
		Noise					

5 Conclusions

There is a large amount of supporting literature regarding workload measurement techniques for the signalling role using conventional rail systems. However, as a result of the development of TM systems there will be a number of factors of workload that change from conventional rail signalling systems. The introduction of TM systems will result in a number of changes in how the railway is managed for operations and maintenance staff due to greater flexibility in information systems, an increase in collaborative working styles and shared responsibilities. Although this flexibility in system design has the potential to enhance performance, it increases the complexity of measuring operator workload. Therefore, it is important to clearly identify the workload variables and how they might change as a result of TM in order to influence system design, task design and process design.

Being able to accurately measure and predict operational workload means that control centres of the future can be appropriately sized and manned. The findings from the In2Rail workload toolset proposes a comprehensive set of techniques that can be used to measure workload. It then shows how these measurements can be used to predict the impact on staff or future systems so that changes can be proposed, evaluated and decided upon in a controlled manner.

The In2Rail Tool set was developed in order to reach a stage where we are able to make predictions of workload for future TM systems with a higher level of confidence. The toolset also highlights where existing rail workload measurement techniques need to be adapted in order to support continuous development of people, process and technology. It should be noted that during this phase of In2rail, it is difficult to define a detailed workload toolset as there are still a number of unknown variables in future technology used and role changes required. Nevertheless, it is useful to develop a generic tool set which draws upon established workload principles from supporting literature as well us current TM projects. This is to ensure that the system and workstation design meets the operational future needs of control rooms, taking into account workload principles and Human Factors best practice.

Following this paper and phase of In2rail, Thales aim to continue to develop the workload toolset further and adapt the model as part of the Shift2Rail initiative as people, technology and process continue to change as a result of systems such as TM.

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