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Golightly, David and Dadashi, Nastaran (2016) How do principles for human-centred automation apply to Disruption Management Decision Support? In: 2016 IEEE International Conference on Intelligent Rail Transportation, 23-25 Aug 2016, Birmingham, UK. (In Press)

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How do principles for human-centred automation apply to Disruption Management Decision Support?

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Abstract— **While automation of signal and route setting is routine, the use of automation or decision support in disruption management processes is far less common. Such support offers significant advantages in optimising re-planning of both timetable and resources (crew and rolling stock), and has value in offering a 'shared view' of re-planning across the many actors manage disruption. If this vision is to be realised, however, disruption management decision support and automation must adhere to proven principles for effective human-agent cooperation. This paper synthesises data from a programme of work to understand user requirements for automated disruption support tools. It then compares these outputs with two frameworks for human-centred automation - one general (Klein et al's [2004] ten challenges for automation) and one transport specific (Balfe et al's [2012] principles for transport automation). Emergent design requirements include the need for iterative modification of rescheduling parameters throughout a disruption, visibility of the reasoning behind options, accountability remaining in the hands of disruption controllers, and the need for the automated disruption support tools to take a multi-dimensional view of disruption that varies depending on the event encountered. The paper reflects on the practical utility of high-level design principles for automated disruption support tools.**

Keywords—Disruption, automation, traffic management, human factors.

I. INTRODUCTION

Delay and disruption on the railways has a financial cost in terms of lost patronage and delay attribution penalties [1]. The high priority placed by travellers on reliability [2] means delay both undermines existing passenger confidence and inhibits potential mode shift from the car to the train. Tackling disruption is therefore a critical challenge if the railways are to offer a viable, sustainable travel option [3]. New solutions to minimise disruption could restrict the temporal impact of delay (how long the disruption persists) and the geographical spread of delay (how widespread are the delays). This would have significant benefits for improving capacity. There are a number of technical solutions that might be useful for those with control or replanning roles (as opposed to, say, drivers) within

rail disruption – these include specific tools for (e.g. tools for shared views of disruption management plans) or tools that support traffic management more generally but maintain their robustness in a disruption situation.

Proposed solutions include traffic re-planning and operational decision-making tools [4, 5] complemented by support tools for short-term crew and rolling stock re-planning. Re-planning tools such as predictive, interactive train graphs [6], could not only help individual decision makers to plan alternatives, but can act as a visual, shared representation so that a number of relevant stakeholders can see the proposed plan (also see [7]). Technology also applies to passengers and the need to provide accurate information on the duration of delays and potential alternatives. This kind of information is transmitted through traditional means such as station staff, but also through more recent forms of technology such as mobile travel applications [8] and social media [9, 10]. Social media also offers the opportunity of crowdsourcing information regarding either the causal event itself, or sentiment of passengers during the disruption [11] highlighting needs for intervention.

Automation plays a key role in many of these disruption management solutions. This may be in the form of full automation, such as automated route setting being able to seamlessly adapt to replanning on the part of signallers / dispatchers or partial automation and decision-support, for example by proposing crew and rolling stock schedules to enable alternative schedules.

The implementation of automation within train traffic management has however not been without problems. Lessons learned from the implementation of automatic route setting is that signallers / dispatchers must have a clear understanding of the proposed actions and rationale of the automation that allows them to interpret intended actions. Decisions made by the automation must be effective, with sufficient time for the signaller / dispatcher to intervene should the proposed action be sub-optimal. Where this has not been achieved, there is a reluctance of signaller / dispatchers to engage with the automation, even leading to turning the automation off altogether [12]. This can have a profound impact on the feasibility of operations in situations where workstation design

and / or the timetable are predicated on the anticipated efficiencies afforded by functioning automation.

The experience of automated route setting is not atypical. The introduction of automation in other transport settings, manufacturing, process control, healthcare and beyond is littered with similar experiences. Historically, attempts to integrate automation in many domains have taken a functional allocation approach [13]. One or more functional aspects of a process are identified as amenable to automation, and this aspect of the process is taken out of the control of the human and placed in the hands of some automated system. While this approach appears pragmatic, it can have significant negative repercussions for other tasks that remain within the remit of the human operator, for the maintenance of human skill, knowledge and motivation, and for the ability of humans to re-establish effective control if the automation fails [14, 15].

These negative effects are felt most acutely when the automation is taking over a cognitive aspect of control, such as decision-making or planning. These effects include both

1) decreased situation awareness for the operator who, without active involvement in the process, feels 'out of the loop' in both the status of the process, and the actions of the automation

2) the automation only considering a subset of the tacit and contextual cues, or secondary planning considerations, that a human operator brings to the problem. As a result, the functionally limited scope of the automation leads to suboptimal solutions that a human operator must repair. The operator may be forced to turn off the automation altogether or, in the most extreme cases, may not realise that the automation is in a completely unanticipated state, with potentially fatal consequences.

As we now turn the power of automation and intelligence to support those roles involved during disruption it is critical to ensure that new technologies are designed and embedded to avoid these problems. However, help is at hand in the form of human- and systems-centred principles for automation. Based on the experiences with signalling automation, Balfe et al [12] propose principles for the successful deployment of automation. While these principles are derived from signalling they are proposed as a general set of principles that can be used within transport automation. Additionally, Klein et al [16] identify 10 challenges for making automation a "team player". These challenges can be reformulated as principles applied to the design of automated systems [17].

Therefore we have two potential sets of principles – one specific to transport, one generic, that can be used to inform the design of automated disruption management systems. The rest of this paper will review these principles in order to assess their relevance to disruption management tools. Section 2 presents further details on the two sets of principles. Section 3 presents more detailed background on the complexity of disruption management. Section 4 elaborates on the sets of the principles to meet the needs of disruption management. Section 5 presents future directions.

In order to set the scope of the rest of the paper, the focus is not only signaller / dispatchers but also those involved in higher-level re-planning functions. We follow the convention from Farrington-Darby et al [18] and GB rail operations by calling these more strategic disruption management roles 'controllers', though we note that with the advent of sophisticated traffic management solutions, many signallers / dispatchers will start to take on at least some aspects of the controller function.

II. GUIDELINES FOR AUTOMATION DEPLOYMENT

It is a considerable challenge to develop and deploy automation support that can avoid general problems of human-automation cooperation outlined in the introduction. However, there are frameworks and principles for the effective design of technology.

The first of these is from Balfe et al [12]. Based on substantial observational and experimental work in the use of automated route setting (ARS), including analysis of both motivations for acceptance and rejection of automation by signaler / dispatchers, Balfe et al propose principles for the design of transport automation systems. The principles have emerged from consideration of

- Signalers general opinions and attitudes toward ARS, their desire or reluctance to work with automation, and how they view it in terms of their role

- System performance issues with the ARS – how effective is the ARS is being able to run the timetable as required; how is this impeded by, for example, having an accurate and feasible model of the timetable

- Knowledge of ARS and expectations of behavior – signalers understanding of what ARS is doing and how it is arriving at the decisions it makes

- Interaction with ARS, the need to intervene with the ARS, confidence in ARS and the responsibility of the ARS and signaler to regulate the trains.

From these four general considerations, ten specific principles for the design of automation are proposed, presented in Table 1.

While these principles are specific to transport, the longstanding issues with successful deployment of automation have led to more general approaches and principles. Emerging from cognitive systems engineering, Klein et al. [6] argue that collaboration between human actors and agents should be based around more fundamental principles of collaboration. These requirements are

1. The basic compact – This is the agreement, often tacit, between parties to work towards a common goal. This agreement also entails the understanding that this is a process that needs investment and ongoing maintenance to ensure that goals remain current, mutual and shared. Critically, parties may need to explicitly indicate when they are temporarily or permanently suspending their involvement in the compact.

TABLE 1 – PRINCIPLES OF TRANSPORT AUTOMATION

Principles of automation
Reliable – Automation should function consistently
Competent – Automation should perform correctly given the information that is input
Visible – All decision-relevant information should be available
Observable – Effective feedback to allow awareness of system state
Understandable – The state of the automation and the world should be understandable given the current state of the environment
Directable – It should be possible to direct the automation easily and efficiently
Robust – The automation should perform effectively under a variety of conditions
Accountable – The operator should be responsible for overall performance
Proactive control – The automation should support the operator in predicting ahead
Skill degradation – The automation should incorporate a method to protect against skill degradation

2. Mutual predictability – Any party involved in a collaborative activity must be able to predict and influence the actions of others in the compact.

3. Directability – A party must also be able to shape another party's activity and requires the other party's adequate responsiveness.

4. Common ground – Common ground is shared beliefs, knowledge and awareness requisite to complete a task. As important as the common ground itself is the need for all parties to work to maintain that common ground by sharing information about overall task status, and their own status, or by acknowledging when a party's knowledge may be incomplete.

From these four principles for collaboration, Klein et al. argue that there are ten challenges to address when one or more of the team players in a collaborative control setting is an automated agent. These challenges are particularly acute when intelligence (i.e. decision making) might be distributed between human and non-human actors. The ten challenges are presented in Table 2. These challenges can serve as design principles that can inform human-automation deployment configurations, and have been used to specify requirements for agent design, HMI, context sensitive and competency in automated assembly [17].

TABLE 2 – CHALLENGES FOR MAKING AUTOMATION A TEAM PLAYER

Challenge 1: To be a team player, the agent must take part in the basic compact Automation must be able to say when it is able to engage in mutual activity. The human operator must be aware of when automation is no longer available to support goals.
Challenge 2: Agents must model other actors' intentions In the counterpart to Challenge 1, agents must also be able to understand the availability and intentions of other actors within the system.
Challenge 3: Humans and agents must be mutually predictable The actions of agents must be predictable to human operators. This is a challenge when decision-making or action is emergent from a number of other processes or when algorithms are opaque to humans.
Challenge 4: Directability Agents must be governed or directed in some manner, and having the means to do so effectively is critical to the success of human-automation collaboration.
Challenge 5: Making status and intentions obvious One of the key difficulties typically encountered with automation is that the operator does not have an understanding of the plans or actions of the automation. Therefore, agents must make their intentions clear in a manner that matches the control responsibilities of the operator.
Challenge 6: Agents must be able to observe and interpret other actors' intentions Agents must be able to infer from signals the implications of other actors' actions for overall collaborative control. In this sense, the agent has to, to a degree, model other actors.
Challenge 7: Agents must engage in goal negotiation In order to maintain the compact, agents must communicate their goals and leave them amenable to adaptation by human users. Likewise they must be able to express their goals and communicate their priority should the human actor need to adapt their own goals in response.
Challenge 8: Technologies for planning and autonomy must take a collaborative approach Plans are typically iterative and subject to change. Agents developing and executing plans must be open to renegotiation of resources in response to changing conditions.
Challenge 9: Agents must participate in managing attention Automated agents should not just highlight when they are at the edge of performance, but also indicate when performance barriers are being reached or when system changes are about to take place.
Challenge 10: All team members must help control the cost of collaborative activity Coordination has a cost, and agents should have a model of workload in order to anticipate and manage demands placed on the operator. Likewise, the human operator should have a model of the capabilities and limits of the automation.

III. CHARACTERISTICS OF DISRUPTION MANAGEMENT

Disruption management is linked to signaling / dispatching but also involves other functions and roles. To that end, the following section outlines the major characteristics of disruption management. These factors have been derived from literature, and specific investigations involving disruption analyses [19] and expert knowledge elicitation [20] conducted as part of the On-time EU FP7 project to improve capacity.

Transport disruption can be defined as an event that leads to significant re-planning of a transport service. Specifically, for this paper, the focus is on unplanned disruption, as opposed to planned engineering. Unexpected events such as train failures or overhead line dewirements, or widespread restrictions due to high-winds or flooding, are a daily occurrence on the railways. Events such as these may take hours to resolve, and cause significant delay and frustration to passengers and freight customers. While this paper focusses on the experience of the railways of Great Britain, such disruption is common to all forms of heavy and light railway, globally.

Various approaches are proposed to support the management of incidents and disruption on the railways. One is to prevent disruptions, but it is not feasible, however, to anticipate all forms of potential failures or incidents. An alternative approach is therefore to manage and mitigate disruption more effectively as it occurs. Stages of the disruption include the notification and initial containment of an event, then coordinating and mobilising any trackside response such as maintenance staff or emergency services, re-planning the service to maintain continuity during the event including informing passengers, restoration of infrastructure to service and, finally, return to normal [19]. All of this is conducted within the key performance criteria of safety, punctuality and cost effectiveness.

Critically this process crosses functional and geographical boundaries, as the disruption will often involve the support of train or track maintenance or repair, signaling and dispatching, route replanning, and roles to coordinate information internally and to passengers. In Great Britain, this process is led by incident controllers who have central responsibility for coordinating response. These responsibilities include making operational decisions to manage the rectification of disruption and to organise and disseminate alternative service arrangements (further detail on the orchestration of incident control is presented in [18]). These decisions are acted upon, and informed by, signallers, train crew, station staff, maintenance staff and sometimes external parties such as the emergency services. Naturally, a major set of stakeholders in the disruption are the passengers themselves, delayed in trains or stations.

Disruption is not, however, a unitary phenomenon. First, events such as infrastructure failure do not always lead to disruption and this can be down to the way the incident is managed, minimising or avoiding altogether any impact on timetabled services. Disruptions are dynamic, with different stages requiring different types of information and coordination amongst various stakeholders. For rail disruption, the opening stages, where the event is first noticed and immediate containment action is applied, may be brief (in the order of a few minutes) but critical if the situation is not to escalate [21]. However, tools such as crew and rolling stock rescheduling may only be relevant to a later phase of re-planning to put alternative service plans in place. Also, railway disruptions do not always follow a single, linear process. Major incidents such as a break in the overhead electrification may take many hours to resolve. During the course of such incidents there may be many cycles of investigation, rectification and adaption of plans before normal service is restored [19]. Another consideration is that incidents vary – their causes, timing and location can all influence the choice of effective strategy [20]. For example, at the busiest times on the busiest parts of the network the most adaptive course of action may be to apply temporary (though safe) repairs to keep a partial service running, and complete the fix overnight when there are fewer train services.

The handling of incidents involving the railways requires close coordination between many parties across different organisations, such as different train operating companies, some of whom have conflicting priorities [22]. For the most severe incidents and emergencies, these groups are rapidly configured between parties who do not regularly cooperate, such as the emergency service or air ambulance and may often be physically distributed, communicating primarily through telephones. These types of incidents may draw on different skills and competence compared to 'routine' disruption. For example, even highly experienced control staff feel least confident when dealing with third party emergency services during incidents [23].

In many settings the coordination of these plans is a manual activity through the telephone or face to face conversation. This means that a single, agreed plan is rarely communicated and understood by all parties. Instead, partial plans are communicated. This is exacerbated by few, if any, predictive tools, meaning that individuals extrapolate plans in to the future based on experience. A lack of a single picture of disruption is common [4].

One major drawback for potential disruption management tools is that each event is so specific and so linked to the particulars of the disruption event that is difficult to define generic solutions or algorithms [24]. Furthermore, there is a question of whether tools should be specific to disruption or of more general utility. One principle from the world of emergency response information systems is that technologies that are specific to emergencies, and are therefore unused the rest of the time, are unfamiliar and unused in the actual emergency [25] and there is some anecdotal evidence from rail to support this.

In summary, there are some key challenges with meeting the needs of disruption support :-

1. There is a fundamental need to minimize the impact of disruption both in geographical scope, and by limiting the time the disruption persists.

2. There may be many different functions involved across different organisations with different views and priorities.

3. There are challenges with giving all functions in the disruption management process a shared view of events – currently, much of this is conducted over the phone, and people develop their own plans.

4. Each disruption event is different – different location, timing, causes and impact – and employing generic or flexibly re-usable solutions is difficult.

5. Projection and prediction of the impact of an event is based on expertise and experience, and people have different levels of competence depending on the type of disruption.

6. The event changes – new information comes to light, new priorities emerge and this means plans may have to change during the course of a disruption event.

7. Technologies that are only used during disruption, or are only applicable to specific types of disruption run the risk of being disregarded.

IV. APPLYING PRINCIPLES TO DISRUPTION MANAGEMENT

It is possible to interpret the principles of Balfe et al and Klein within the requirements of rail disruption management tools. To that end, Table 3 takes the requirements and identifies specific principles that apply to each need.

There are common themes across the table, and these highlight some factors for design and deployment that go beyond the basic effectiveness of the algorithms built for the purposes of the automation.

Performance – Being able to define competent automation that meets the needs of the basic compact requires a clear understanding of the whole system performance targets. We would venture that an approach informed by cybernetics / Cognitive Systems Engineering [15] can be powerful in clarifying the true purpose and parameters of the joint cognitive system that is disruption management plus automation.

Processes – A key requirement from the principles is the need for automation to be adaptable / for goals to be negotiable depending on the changing information during the process of disruption. An adequate model of the disruption process can give a clearer picture of what information is involved and when, depending on the type of disruption (see [20]). This is coupled with…

Role mapping – The need to understand the types of users, their competencies and their functions, is critical to understanding roles and information needs. Moreover, the ideal automation will have some form of model, at least of the key roles, of its users. This can be achieved through effective mapping of roles, functions and their decisions. These functions, and their constraints, come in and out of play as the disruption proceeds, and therefore role modelling is allied with process modelling.

Human-Machine Interface – All too often, HMI is simply treated as the question of how to present information. While this is critical, and should be sensitive to factors such as role, these principles also highlight the need to develop an effective interaction model. That is, what are the points of contact between the automation and the user that allow user inputs to be considered in the solution, not just once, but as the solution is evolving and adapting over the course of the disruption. It is only through the interaction model that qualities such as the ability to support goal negotiation (Klien et al's challenges 7 and 8) can be achieved.

Human Competency – While the emphasis of this paper has been on needs to design technology to bring it closer in line with the needs of users, the approach of Klien et al in particular highlights this is still a cooperative relationship. To that end, there are points at which developing operator competence will have benefits. This includes an understanding on the part of operators to know the feasible limits of, and expectations upon, the automation, and to find a deployment strategy whereby the automation is viewed as a team player with a specific function or functions within the overall system of disruption management, rather than a pure replacement for existing skills and knowledge within a disruption management team.

V. CONCLUSIONS AND FUTURE DIRECTIONS

Infrastructure managers and the supply chain are turning to automation and decision-support as tools to help them manage disruption. Importantly, and encouragingly, the introduction of automation naturally affords two major benefits to the disruption management process rather in addition to using sophisticated algorithms to optimize performance. These are the ability to have a standardized prediction and, almost as an useful by product, the ability to communicate or share that predicted plan rapidly (via screens, rather than the phone) with relevant parties in the disruption process. However, design and introduction is not a trivial task. The challenges faced are to some extent similar to those faced in the deployment of automated route setting and dispatch automation, but are compounded by the very diverse nature of different disruptions [19, 20], the lack of shared predictive views [4] and the complexity of communications [18].

Analyses of these problems against principles for automation – both transport specific [12] and general [16] have highlighted the need to go beyond pure algorithm design to consider performance, roles and processes, HMI including interaction models, and competency as part of deployment strategy. Future work will involve drilling down into greater detail on these points to determine design and deployment strategy. To this end, current work is looking at more nuanced models of disruption events, elaborating in the work in [19] and [20], to understand the performance requirements of different disruptions, the communication flows involved (including to the passenger), and the timings associated with events such as full line blockages to develop a clearer teamworking model and 'DNA' for different types of disruption.

TABLE 3 – MAPPING OF DISRUPTION MANAGEMENT AUTOMATION NEEDS TO PRINCIPLES FOR AUTOMATION DESIGN

Requirement	Transport automation principles	Automation as a team player
1. There is a fundamental need to minimize the impact of disruption both in geographical scope, and by limiting the time the disruption persists.	Competency – technology needs to be able to support core tasks of disruption management Accountable – key roles are ultimately responsible for safety and performance during disruption. These roles should be the principle points of contact with the automation	Challenge 1 – Automation must be available and appropriate to take part in the fundamental processes of disruption management. The limits of the scope of a technology must be clear and understood by all.
2. There may be many different functions involved across different organisations with different views and priorities	Visible- information needs to be presented according to decisions (identified in Golightly and Dadashi [20]) and tailored to roles	Challenge 2 – Automation should have a model of the different functional roles that it is likely to work with, as this may affect the type of decisions needed and HMI. Challenge 3 The automation itself must be designed and deployed as a team player, with goals, responsibilities and boundaries understood by all.
3. There are challenges with giving all functions in the disruption management process a shared view of events – currently, much of this is conducted over the phone, and people develop their own plans	Observable – automation and associated HMI offers new opportunities for sharing information across the disruption management process. This should not only include the status of the automation but of the whole disruption state, including predictions.	Challenge 5 – The outputs of automation can be (and should be) shared to all functions within the disruption management process. Challenge 10 Disruption management comes with other workload. The design of the automation must be sensitive to the costs of this work and the availability of roles for coordination.
4. Each disruption event is different – different location, timing, causes and impact – and having generic or flexible re-usable solutions is difficult,	Robust – automation must be designed to reflect the variety of situations where disruption occurs, and variety of constraints Reliable – the automation should perform to a similar degree, and in a similar manner, across disruption settings	Challenge 7 – Automation and actors must be able to clearly specify goals and parameters to match the specific nature of any given disruption. Challenge 1 – The automation should be able to indicate when it is not appropriate to the disruption scenario it is being faced with.
5. Projection and prediction of the impact of an event is based on expertise and experience, and people have different levels of competence depending on the type of disruption,	Proactive control – Automation should be predictive, providing views of not just current plans but future impact of plans. These plans may be contextualized for different roles (route control, rolling stock control, information control). Understandable – Different levels of competency are also likely to be reflected in different levels of knowledge in using the automation.	Challenge 3 – Humans operators may need, to a degree, to upskill to match the competency required from the automation. Challenge 6 – Automation should have a model of functions and competence of other actors.
6. The event changes – new information comes to light, new priorities emerge and this means plans may have to change during the course of a disruption event,	Directable The automation (and produced plans) must be amenable to change and adaptation during the course of a disruption as new information and priorities emerge	Challenge 8 – Automation must be amenable to a change in plans and renegotiation of goals as the event progresses Challenge 9 – As targets change, automation and users together should be aware of when they are reaching the limits of performance.
7. Technologies that are only used during disruption, or are only applicable to specific types of disruption run the risk of being disregarded.	Skill degradation – Technologies that are amenable to a wide range of disruption or, indeed, have value in non-disruption situations, are more likely to be understood and used than ones relevant to specific situations.	Challenge 8 – The ideal automation is embedded and flexible to all operations, not just disruption.

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