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# ANALYSIS OF COLLABORATION APPLIED TO TRAIN DRIVERS AND TRAIN TRAFFIC CONTROLLERS IN SWEDEN

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Earlier studies of human operators in complex and dynamic work situations have demonstrated the importance of understanding the operator's goal, mental model, observability, and controllability. Based on this model we have been able to analyse and design control systems and user interfaces supporting efficient control and high situation awareness. We now extended this model to include collaboration between different actors in complex control environments. This paper describes basic elements of the model, extension to collaboration, and its application to understand important problems and prerequisites for development of control systems in train traffic control in Sweden.

## **Introduction**

Control of a complex, dynamic system like train traffic involves many actors in different roles, often located at different places and part of different organisations. Each actor has specific ways to observe and influence the process. Efficiency in such contexts is highly dependent on the quality of collaboration. In reality, many factors hinder collaboration, e.g. lacking communication or limited knowledge about other roles. One consequence is occurrence of sub optimisation, where operators act optimal from their point of view, but suboptimal from a global perspective.

We have developed and applied a model (GMOC) supporting the analysis of human work in complex, dynamic systems. This model analyses the goals (G), mental models (M), observability (O), controllability (C), and their interplay, of actors in a process. Several studies (e.g. Andersson et al (1997), Kauppi et al (2006)) have been based on this model and proven its usefulness. These studies focused on one opera-

tor's or one role's work. Now we have extended our model to include collaboration. In this context, goals build a complex pattern including goals within the organisation. Mental models also cover behaviour of other operators. Observability and controllability gain from other operators' observations and controls. To test our model, we applied it in an analysis of collaboration between traffic controllers and train drivers in Sweden. We investigated their individual work context as well as the collaborative context. Even though the analysis was limited, our model gave us interesting insights about problems and missing links in today's systems and communication and possible improvements. This paper will present our model and results from our study of collaboration between train drivers and traffic controllers, as well as suggested solutions to detected problems.

### **A model for analysis of collaboration**

In control theory, the concept of goal, model, observability, and controllability has since long been known as necessary prerequisites for understanding and designing control systems. Kalman (1961) introduced the notions of controllability and observability, but the general ideas behind control theory can be traced back to Wiener (1948). Controllability and observability are main issues in analysis of a system, before deciding the best control strategy to be applied. Even though control theory is a branch of engineering, it has shown to be useful in related scientific contexts such as manual control (e.g. Powers (1973)). It has also been borrowed in social psychology (e.g., Carver and Scheier (1982)) and proposed as a framework in research for understanding human decision-making in control of complex systems (e.g. Brehmer (1992); Brehmer and Dörner (1993)). Our model, GMOC, is the result of continuation of this research. We have applied it in several studies, which helped to refine it. It proved to be useful during the whole development process of socio-technical systems for control of dynamic processes. The explicit inclusion of collaborative work environments such as polycentric control will be presented and applied in this paper. First, we will go more into detail about the main elements and their interplay.

#### *Description of work context in terms of GMOC*

**Goals** are the necessary description of what an operator must, want, or should achieve – they are the objectives of the control process. They are often seen as central, e.g. in Situation Awareness, goals are necessary for selection of mental models that direct the operators' attention (Endsley (2000)). Despite importance of goals and the complex structure they can develop, few literature discussing them exists. One exception is Dörner (1991), who deals with strategically thinking and problem solving in complex situations. His view on goals correlates very well with ours. In general, goals define states to be reached or to be avoided. They usually consist of many sub goals, e.g. in order to reach a destination, a driver needs to refuel. With a growing number of goals and sub goals, the number of correlations rises. Goal conflicts are common, e.g. if reaching a destination as fast as possible requires a higher speed, we might compromise in safety or fuel consumption. Goals can arise from process context or have a personal, social, or psychological motivation.

For a deeper discussion of **mental models** we refer to Payne (2003) and Gentner and Stevens (1983). Here we only shortly describe their purpose in our model. Goals define *what* to achieve, while mental models reflect all the operators' knowledge and experience telling them *how* to achieve a goal. Mental models can be developed by learning and training or by experience. We can consciously decide how to operate clutch and gearshift or we can have automated their handling. Mental models are our understanding of technical systems, surrounding, physical laws, behaviour, etc. They can have very different degrees of complexity and accuracy, ranging from complete blueprints of a system to a "black box" with some expected correlation between in- and output. Even if mental models are incomplete or erroneous, they usually fit the purpose. Analysing them can be difficult when dealing with experienced operators. If actions have become automated it is difficult to explain what decisions were based on or even to describe which decisions have been made. Mental models also compensate for a system's lack in observability and controllability.

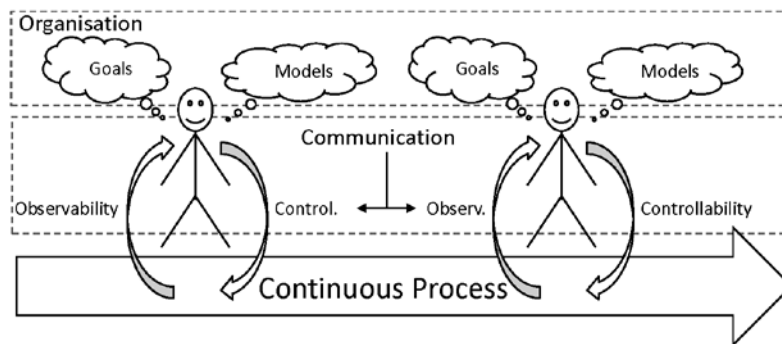
**Observability** and **controllability** are the means a system offers to observe and control a process. All perceivable information from environment, instruments, and indicators of a system, including feedback such as vibrations or noise, add to observability. This information will be used to understand the current situation. Fed to mental models, it will result into desired actions. These have to be related to the controls available to (i.e. known, reachable, and understood by) the operators.

The elements influence each other in many ways. Operators use mental models that allow them to reach their goals with the available controls. Changes in controllability might lead to adaption of goals. Goals influence observability by directing attention, while observation of certain situations requires a reorganisation of goals. Mental models generate actions. They can also lead attention if certain behaviour is expected. If goals, observability, or controllability do not match the operators' mental models, they have to be adapted or newly developed.

#### *Extension to collaborative scenarios*

In practice, usually several operators or actors work together in the same process. This section will discuss extended use of our model to interpret such collaborative scenarios. Characteristic is that different actors partially have their individual (e.g. personal) as well as shared goals. They have their own, individual mental models, which need to be compatible among each other. Additional to those of the process, mental models of other actors exist. The outcome of one operator's work is effecting and observable by others. These actors in turn might be needed in order to carry out certain kind of control. Collaboration typically takes place in some kind of organisational environment. This does not necessarily have to be exact the kind dealt with in organisational psychology (see e.g. Agyris and Schön (1996)). Organisation of collaboration develops its own dynamics, own types of learning, and defines formal and informal strategies and goals. This can have a huge impact on the development and deployment of new systems, which always requires the organisation to adapt.

Our model for collaboration is illustrated in Figure 1. The operators' goals and models are influenced by the organisation, while the process is influenced by several actors, which implies different requirements on and possibilities for observability and control. Important goals have to be shared among different stakeholders, in order to efficiently cooperate. Shared goals with a colleague will improve the possibility to find a consensus on the right thing to do – working on different goals will increase the likelihood of conflicts and suboptimal solutions. The same is true if actions to reach goals are contradicting. This could be caused simply by contradicting sub goals or, even when goals are shared, by different mental models. Co-workers also influence the operators' goals, e.g. when it is possible to direct the process towards a trend that is positive for colleagues.



**Figure 1: GMOC in collaborative scenarios**

Mental models in collaborative contexts contain an understanding of roles, including responsibilities and obligations, but also personality such as being conservative or willing to take risks, mental models, and goals of their co-workers. Operators with a better picture of each other's tasks and different ways to approach them will be able to anticipate actions by others and to cooperate more efficiently. Similar to mental models about a process or a system, mental models about other actors can be constructed via observation. The possibility for construction of mental models is limited, if actors in a process cannot communicate. Goals and mental model can be influenced by the strategy of an organisation. An organisation that wants to implement the strategy of energy saving might have special training for energy efficient control of a process – a way of influencing the construction of operators' mental models. Additional feedback, e.g. in form of statistics and rewards, will support establishment of energy saving as a goal.

Lack of control over the whole process is a main constraint in scenarios with multiple operators. Observation and anticipation will help to arrange one's own work with influences from colleagues and avoid sub-optimisation. Furthermore, other operators have additional means to observe and control a process, which become available through collaboration. Two operators in different roles can have more problems in collaboration than operators in the same role. They might have gone through different trainings and developed different goals and mental models. Thus it can be harder

to understand work of a person in a different role. Especially if there exists a distance in hierarchy or location, it makes communication difficult – better support for collaboration, e.g. via observability and controllability, is even more important.

### **Application to train traffic in Sweden**

Train traffic serves as a very good example to test our model. Train drivers and traffic controllers have different roles and even belong to different organisations. Despite limited possibilities for communication, their tasks have huge effects on each other. Since organisation of operational traffic control is very different in each country, it is important to be aware of the quite unique situation in Sweden. Here the roles of traffic planning and train dispatching/signalling are integrated in one single role: the train traffic controller. Sweden has eight centralised traffic control centres spread over the country. In each control centre, at least one head controller organises collaboration of traffic controllers inside one and in dialogue with the other centres.

#### *Work context of train drivers and traffic controllers*

In the following, we describe the roles of traffic controller and train driver in terms of our model. We will ignore collaboration for now, as it is part of the next section. Our analysis is based on experience gathered during many projects, interviews, observations, and collaboration with traffic controllers, train drivers, railway undertakers, and authorities. Note that this data was not gathered following certain patterns and its presentation does not focus on completeness. Especially factors describing complexity, e.g. sub-goals, are reduced. Here we aim on exemplification of our model, but already note interesting results, which we summarise later in this paper.

Table 1 illustrates some important GMOC aspects of train drivers and traffic controllers. The first column lists the context of train drivers. Main goals are maintenance of safety and punctuality. With growing experience, train drivers are usually able to perform smoother rides, resulting passenger comfort and less wearing on material. They are able to save energy and to avoid incidents, e.g. failure of infrastructure caused by too rough driving or a stop at a place where it might be time consuming or even impossible to get the train going again. One goal often mentioned by train drivers is delivery of good information to passengers.

Mental models of train drivers usually cover technology, e.g. behaviour of different types of trains and safety systems. These models are created during initial training and further developed, internalised, or even unlearned (if a certain type of train has not been used in a while) during practice. Train drivers who regularly serve the same route, develop route knowledge, a special type of mental model containing information specific to a route, such as slopes, speed limits, distances, landmarks, common infrastructure problems etc. Train drivers repeatedly mentioned the importance of development of route knowledge and a sense for the train, e.g. slipping or skipping. Other specific mental models are knowledge of routines (e.g. handling of signal errors) or behaviour of passengers at platforms.

**Table 1: GMOC in train traffic (omitting collaborative factors)**

Element	Train drivers	Traffic controllers
Goals	Maintain safety; Punctuality; Smooth ride/comfort; Provide good information to passengers; Energy saving; Minimise Wearing; Control workload	Maintain safety; Maintain smooth traffic; Minimise delays; Efficient execution of train routes; Optimising the traffic plan and track usage; High capacity utilization
Mental models	Train behaviour (retardation, acceleration); External influences (weather); Timetable; Route knowledge (landmarks, track layout); Safety systems and technical barriers (signal boxes, train protection); Minimize wearing (points, overhead contacts); General traffic procedures and rules	Traffic process (anticipate train movement, different types of traffic); Infrastructure (track layout, environment, signal boxes, points, traffic control system, automatic functions); Timetable (possible routes, track usage)
Observability	Instruments (speed, engine status) ; Train protection system; Signals and signs; Tracks and environment (position, slope, curves, weather); People at platforms; Vibrations and noise	Infrastructure layout (signals and points, position and state); Signal safety system, signal boxes, train control system (type, state, alarms); Automatic functions (on/off); Protected train routes; Train position per track section; Timetable (delays, maintenance)
Controllability	Train speed and position (acceleration, retardation); Energy retrieval; Door opening; Passenger information	(plan and execute) Settings of signals, switches, train routes, and automatic systems

Several instruments in the drivers' cabin show state of the train. Tactile or aural feedback gives information about effects on material, weight of load, influence of weather conditions on tracks etc. Monitoring of environment, signs, and signals besides the track are also part of train drivers' observability, but they usually lack updated knowledge of the current traffic plan. The only information they have are train protection systems (ATP), a paper list including timetable and deviations known prior to the ride. Their controls are mostly limited to the controls offered by the train (electrical brakes can be used to retrieve energy, acceleration has to be adjusted to a level that minimizes wearing on the train).

The last column of Table 1 shows the GMOC elements for traffic controllers. Their goals are maintenance of safety and smooth traffic, in order to minimize delays and avoid rushes, which might overstrain their cognitive capabilities. In order to reach these goals, traffic controllers need to have knowledge of track layout and behaviour of the control system, especially different automation systems. They also need mental models of the train traffic process itself and have an advantage if they have certain knowledge of local conditions at the infrastructure; otherwise it might happen that a train will be stopped by a signal at a point where it really should not have to, e.g. before a considerable ascending slope.

Traffic controllers can access many systems providing e.g. scheduled timetables, infrastructure maintenance plans, delays, and train details as type, weight, length, speed limit etc. Still, track displays, showing train positions and progression, are their most important source of observability. However, they just indicate blocked track segments, which means that the train can be anywhere on a segment, sometimes with the length of tens of kilometres. Only when a train moves from one segment to another, the exact position is obvious; the rest of the time, traffic controllers have to derive these dynamic parameters by mental models and their memory of the latest segment passing. Traffic can only be controlled at few locations, via setting of points, signals, train paths etc. Even this controllability is further reduced by different automated switch boxes, which might set signals autonomously.

### *Collaborative work context*

The overview just given does not at all represent full complexity, but it already reveals significant differences between the two work contexts. A matching of both roles GMOC analyses could give a first indication for problems and possibilities in collaboration. Figure 2 shows the collaborative work context of multiple train drivers and train traffic controllers. Our model helps us to identify additional conditions, requirements, and possibilities that arise with collaboration. Several of these possibilities are not effectively used today; we will discuss some of them.

Goals and mental models are related to the wish to gain from collaboration. Mental models are created following the performance of other actors in order to anticipate their behaviour. This anticipation in turn will allow planning one's own actions in a way beneficial for the whole process. However, the benefit is limited to precision of the anticipation. Today's systems provide almost no observability on the other actors' actions. Thus according mental models cannot be accurate. This leads to formation of prejudices, often shared by colleagues in the same role. Traffic controllers e.g. commonly have the preconception that train drivers mainly care about their own train: *"They just hit the gas until they reach a stop signal, and then they complain"*. An interesting point considering eco-driving is the fact, that train drivers indirectly control other trains. If a train lies ahead of schedule, a driver might slow down in order to save energy. This would delay clearance of the track segment, which might result in a stop signal for a following train. Collaboration between traffic controllers on the other side is especially needed to exchange information about trains passing between each other's control areas. If this exchange is not properly done, train drivers notice a gap between two different control areas.

Table 1 shows that traffic controllers do not really have many possibilities to control trains other than to define their routes and stops. However, basic prerequisites for better controllability exist. With presentation of the current plan, train drivers would be able to see exactly what is desired from them. This would make the traffic situation much more controllable. Train drivers in turn can indicate if a plan can be fulfilled. They could also inform the traffic control about factors that might improve planning or safety, e.g. specific weather conditions or technical defects on infrastructure and vehicles. As one traffic controller said: *"They are our only eyes on the*



tracks.” Furthermore a shared plan could facilitate collaboration between traffic controllers, e.g. by holding back trains from entering a control area, where a colleague is confronted with a complicate situation.

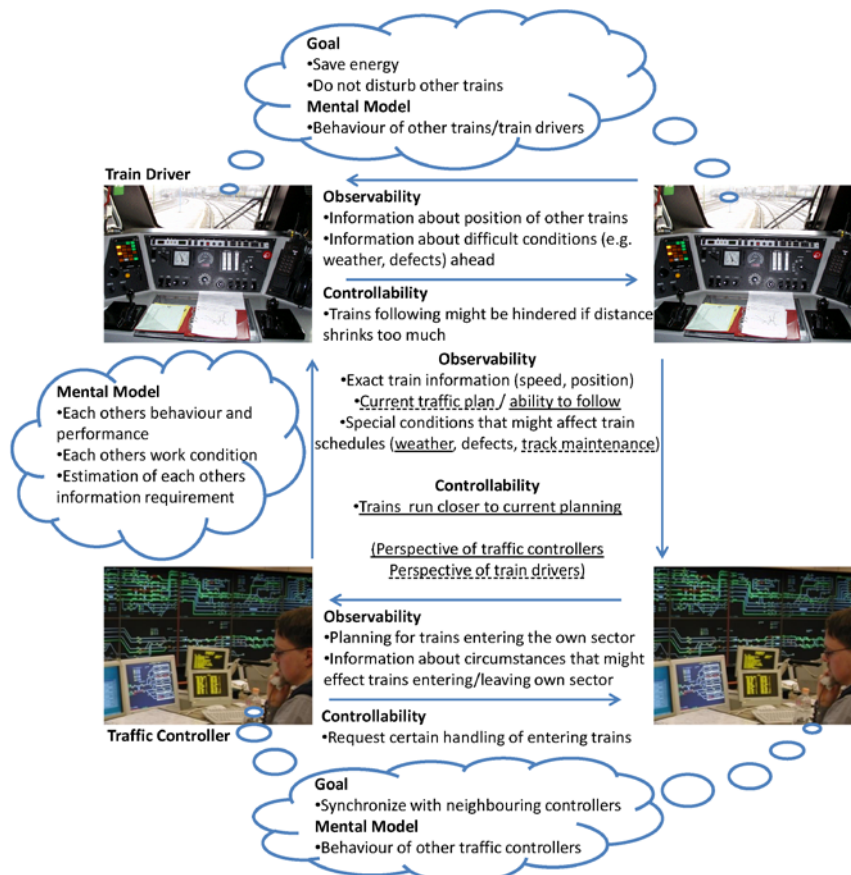


Figure 2: Collaborative aspects in train traffic

## Results obtained from our analysis

Table 2 gives an overview of our main findings. We list problems, related GMOC elements, and impact on collaboration. Our main conclusion from this is the need for improved, accurate information and a shared, continuously updated traffic plan. We believe that these two improvements will radically improve collaboration and thus the overall situation in train traffic. Additionally we need to introduce further channels and even automatic systems for communication, which give train drivers possibilities to easily report problems and comment on planning. This would improve and reduce the need for cumbersome communication by phone.

**Table 2: Results from our analysis of collaboration**

Problem today	GMOC element	Impact on collaboration
Low accuracy of information or missing information about state of process and other actors' actions	Observability	It is hard to develop accurate mental models of each other, this leads to bad premises for planning and development of (negative) prejudices
	Mental Model	
Traffic controllers have almost no possibility to influence train drivers' actions in detail	Controllability	Train drivers and traffic controllers follow conflicting (sub) goals, when drivers are not aware of changed plans
	Goal	
Limited possibilities for traffic controllers to inform about changed planning	Controllability	Suboptimal planning, less possibilities for support in complicated traffic situations
	Observability	
Limited possibilities for train drivers to get knowledge of traffic situations and plans	Observability	Train drivers cannot improve planning with their knowledge about trains and infrastructure
	Controllability	

### *Improved accuracy*

Interestingly, traffic controllers consider having exact knowledge of a train's position. This is simply not true. In fact, they have developed very advanced mental models allowing them to extrapolate the positions of trains. These models demand a high cognitive capacity and lead to wrong expectations, when a train driver does or cannot behave as anticipated. A track diagram could be complemented with GPS data, indicating where on a track segment and at what speed a train is located. More accurate display of train speed and position will also help the traffic controllers to develop more accurate models of the train drivers' behaviour. They will be able to see e.g. if a driver "is eco-driving" or if a train has reduced acceleration.

### *Shared, continuously updated traffic plan*

A shared traffic plan will allow traffic controllers to react earlier to changes in neighbouring control areas. This will lead to earlier awareness of deviations and to a planning that can improve a colleague's work. Train drivers will have much better possibilities to follow the current planning and thus to behave optimal in a global perspective. They are also able to give more useful feedback to the traffic controller and their passengers. The traffic controllers in turn will realise that train drivers are able to follow their planning very exact, which in conclusion will allow and encourage much more optimisation and trust in the train drivers' abilities.

## **Conclusions**

We presented a model that can be used to describe complex work contexts and its extension to collaborative scenarios. This paper described exemplary application of our model to collaboration between train drivers and traffic controllers in Sweden.

The case study showed an interesting picture of their work contexts and allowed us to draw several conclusions about their current work situation and possibilities to improve collaboration. Our listing of the four elements in each work context made clear, that with today's systems and without intensive communication, a train driver can only have a quite egocentric view and thus not much chance to contribute to a globally optimal traffic flow, while traffic controllers were very limited in observability and control. Our model helped especially to identify indirect correlations, e.g. a shared real-time traffic plan would allow train drivers to improve eco-driving, but the traffic controllers would need a more precise presentation of the drivers' behaviour to be fully aware of their changed behaviour, so that in turn the plan could be even more exact.

## References

- Kalman, R.E. 1961, *On the general theory of control systems*, In: Proc. 1st IFAC, vol. 1, (Butterworth, London), 481—492
- Wiener, N. 1948, *Cybernetics: Control and communication in the animal and the machine*, (MIT Press)
- Powers, W.T. (1973). *Behavior: The control of perception*, (Aldine, Oxford)
- Andersson, A.W., Frej, I., Gideon, A., Hellström, P. and Sandblad, B. 1997, *A systems analysis approach to modelling train traffic control*, Proceedings of WCCR '97
- Kauppi, A., Wikström, J., Sandblad, B. and Andersson, A.W. 2006, *Future train traffic control: control by re-planning*, Cogn. Technol. Work, 8(1), 50–56
- Brehmer, B.. 1992, *Dynamic decision making: Human control of complex systems*, Acta Psychologica, 81, 211 – 241
- Brehmer, B. and Dörner, D. 1993, *Experiments with computer-simulated microworlds: Escaping both the narrow straits of the laboratory and the deep blue sea of the field study*, Computers in Human Behavior, 9(2-3), 171–184
- Carver, C.S. and Scheier, M.F. 1982 *Control theory: A useful conceptual framework for personality–social, clinical, and health psychology*, Psychological Bulletin, 92(1), 111–135
- Dörner, D. 1991, *Die Logik des Misslingens (in German)*, (Rowohlt, Hamburg)
- Endsley, M.R. and Garland, D.J. editors. 2000, *Situation awareness: analysis and measurement*, (Lawrence Erlbaum Associates)
- Payne, S.J. 2003, User's mental models: The very ideas. In J.M. Carroll, (ed.) *HCI Models, Theories, and Frameworks 2003*, (Morgan Kaufmann, San Francisco), 135–156
- Gentner, D. and Stevens, A.L. editors. 1983 *Mental models*, (Lawrence Erlbaum Associates, Hillsdale, N.J.)
- Argyris, C. and Schön, D.A. 1996 *Organizational learning II: Theory, method and practice*, (Wesley)