Situation Awareness in railway traffic controllers

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1. Introduction

The Dutch railway system is a heavily utilised and complex network (Goverde, 2007; CBS, 2009, as in Meijer, 2012). What's more, it is one of the most utilised systems in Europe. One of the reasons for the heavy utilisation is due to the short stretch of rail per inhabitant (CBS, 2009). The planning efficiency is incredibly high, resulting in the second best punctuality in Europe (CBS, 2009). Improving the capacity is increasingly difficult, as the railway system is nearly maxed out. One of the problems that follows from a nearly maxed out system is the domino effect. If one train is delayed, it has consequences for a large part of the network. Despite this, the company that manages the Dutch railways (ProRail) has set the goal to increase the capacity by 50% till the year 2020. Growth is mostly sought in smarter management and traffic control processes. For this purpose, ProRail has contacted the Technical University of Delft (TU Delft) to do research in this field. The ProRail organization has taken up gaming simulation as a key method to improve the innovation process (Meijer, 2012). Gaming simulation is different from normal simulations. Where normal simulations try to have as much realism as possible, gaming simulation substitutes some parts of the simulation with something that only represents the information. For example, the information on a computer screen can be substituted with paper. In 2009, the research group on gaming of Delft University of Technology created three gaming simulation projects. Due to the success of the projects, ProRail and the TU Delft formulated a four-year research that would identify the most promising sections within ProRail for a large scale implementation of gaming simulation (Meijer, 2012). This research is now in progress.

Gaming simulation has many advantages. Meijer (2012) states that gaming simulations are highly detailed in both technical and process variables and the decision and communication function of real people in their real roles. This way, they can come really close to the reality of a situation. Gaming simulation at ProRail serves several purposes. It can be used for training, testing out new schedules and effects of delays, disasters and weather conditions on a schedule. However, gaming simulation is a relative new field of research. A part of gaming simulation for rail traffic controllers (TRDLs) is rooted in the Situation Awareness (SA). SA is also a relatively new field of research and brought forth many definitions, several approaches and just as many ways to test them. This article will describe a theoretical framework to compare the three theories. The individual SA view from Endsley (1995b), the Interactive Team Cognition (ITC) of Cooke (Cooke, Gorman, Myers, & Duran, 2013) and the Distributed Situation Awareness (DSA) of Hutchins (1995) will be compared with each other. This comparison will be used to find out which test best describes the SA of railway traffic controllers in ProRail.

2. Situation awareness

Some of the tests that can be utilised during a gaming simulation are SA tests. As stated before, SA is not well defined, although there is agreement that SA is an integration of several processes to gain an understanding of current events and to predict a future state of events (Endsley et al., 2003). For our research, the three main SA definitions come from the individual SA theory of Endsley, the DSA theory of Hutchins and the ITC theory of Cooke.

2.1 *Theory of Endsley*

The theory of Endsley and Jones (1997, as in Salmon, Stanton, Walker, Jenkins & Rafferty, 2010) is a very pervasive and popular definition. According to Endsley (1989, as in Salmon et al. 2010), team SA is "The degree to which every team member possesses the SA required for his or her responsibilities." This is "independent of any overlaps in SA requirements". Endsley's theory is mostly focused on the individual in a team and the individual is a stepping stone to the perspective on team SA. The individual SA is described at three levels. Figure 2.1.1 gives an overview of this process.

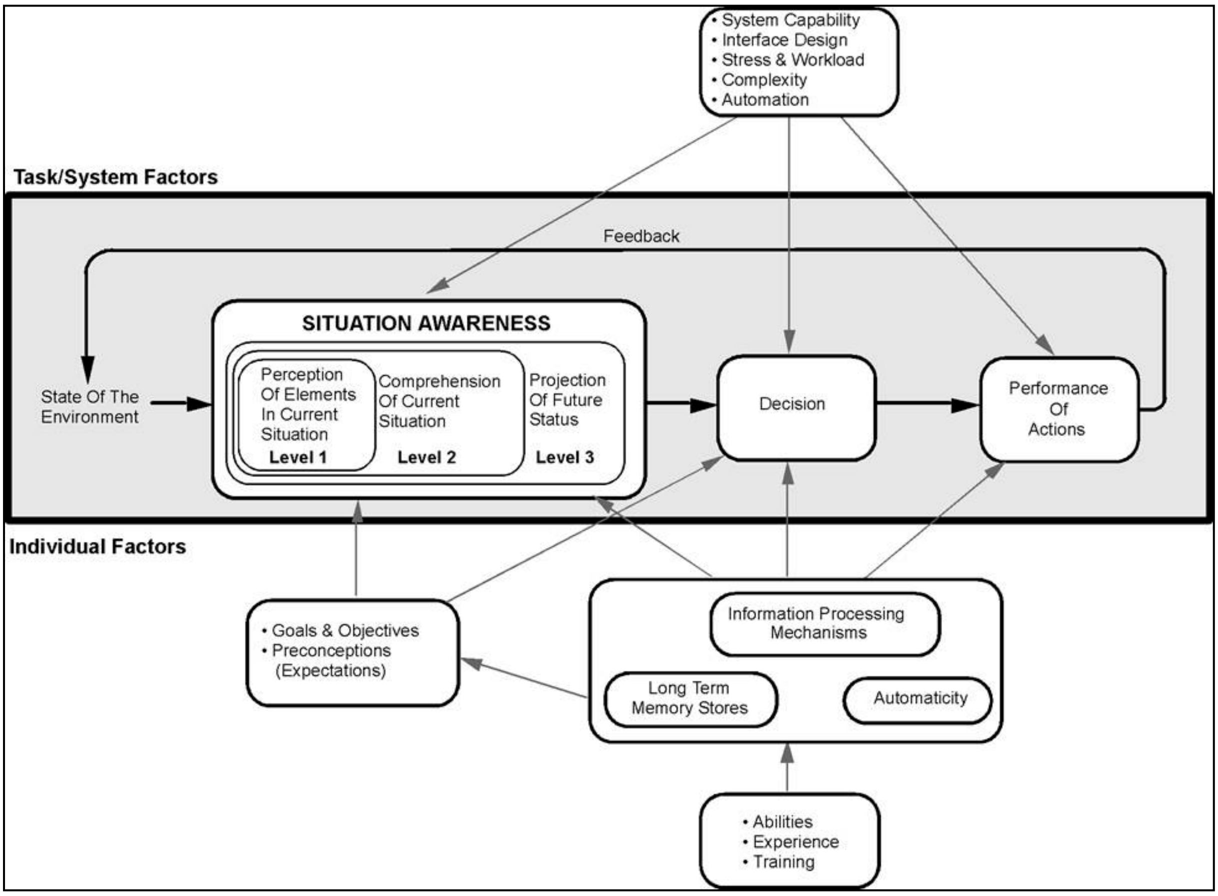

Figure 2.1.1: Endsley's theory of SA (Endsley ,1995)

The first level is the perception of the current situation. If there is no correct perception, all other levels will be flawed. Many factors can influence this perception. Experience and stress can modify perception, displays can represent extra information and goals induce a state of mind that prioritises some perceptual elements over others.

The second level is comprehension of the situation. After the correct perception of the situation, the actor needs to comprehend the perceived information. Endsley gives an example where a plane is shot down. An operator saw a plane in his airspace, which was a correct first level. His second level, the comprehension, went wrong. He saw a friendly aircraft as hostile. His further decision, shooting down the plane, was correct for his SA. This small difference took the innocent lives of many. The comprehension is, just like perception, modified by the person's abilities, the goals and the system that the individual interacts with.

The third level is the projection of the elements to the future. The projection can have several alternatives. Research from Klein (1989b, as in Endsley, 1995b) suggested that there are fewer alternatives if the individual is more certain of the situation. Again, this is modified by the person's abilities, the goals and the system that the individual interacts with.

In Endsley's theory, SA exists only in the mind of one person. External sources of information, whether real world or systems that portray information of the real world, only influence SA and are not part of SA.

According to Endsley, the step between individual SA and team SA is small. Endsley surmises that team SA is "the degree to which every team member possesses the SA required for his or her responsibilities. This is independent of any overlaps in SA requirements". See Figure 2.1.2. It is the same theory, with an added layer of team communication. This layer provides the individual with an extra source of information and does not differ from interacting with the environment.

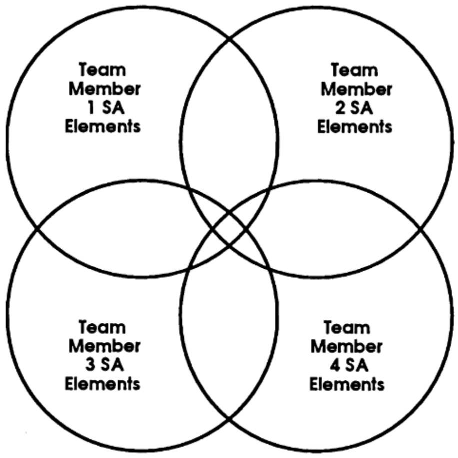

Figure 2.1.2: Team situation awareness in Endsley's theory (Endsley, 1995b)

Endsley's theory is simple, making it a popular theory. However, Salmon et al. (2010) argued that it is a fine theory for individual SA, but largely useless for team SA. This is because teamwork is a very complex phenomenon, which is hard to study (Salmon et al. 2010).

2.2 Distributed Situation awareness

Hollan et al. (2000) have a different approach to team SA; the Distributed Cognition (DC). As SA is a construct of cognition, the general theory of DC applies to DSA (Salmon et al., 2010). For the DSA, theories about cognition could be used to extract SA in the appropriate settings. Because of this, cognition will often be referred to as SA in this study. Hollan, Hutchins and Kirsh (2000) assume cognition can be measured in the functional relationships among the elements that participate in it. This means, in contrast to Endsley's theory, that SA is not limited to an individual. SA in the DSA can involve the coordination between internal and external environment. This is explained in the following DSA assumptions.

The first assumption is that cognitive processes like SA can be distributed across members of a social organisation. A consequence of accepting social organisation as a cognitive architecture, is that concepts, constructs and explanatory models of social groups can describe a cognitive ability. The DSA implies that the communication within the brain and communications between the brain and the outside world are perceived more or less alike. The second assumption is that cognition can be distributed over items in the environment. These two assumptions mean that cognition, and thus SA, is distributed in direct sources of the environment and in indirect sources, like notes, displays, members of the group or knowledge.

Figure 2.2.1: Speedometer with speed and Mach speed bugs

Cognition is distributed through time. The earlier events can transform the nature of later events. According to the DC theory you can rearrange the materials, changing the SA. An example of rearranging the materials can be found in plane speedometers. The arrows around the display can be adjusted to show which speeds are safe at certain flap positions, changing the interpretation and thus the internal and external processes (see Figure 2.2.1). A rearrangement of the arrows changes pilots SA in a very significant way, making sure they will not fly too fast or too slow.

2.3 Interactive Team Cognition

The third theory is the ITC as described by Cooke et al. (2013). Like in the DSA, SA in the ITC is not limited to the individual. Contrary to the DSA, the ITC states that SA only exists between people or the environment. This means that SA only exists the moment there is any form of communication. The differences are more apparent from the three premises of the ITC.

The first premise is that cognition is an activity. Similar to the DSA approach, it is not limited to the individual. It can be an emergent property of the communication between team members, the environment and items in the environment. The difference is that with the DSA cognition is within the team members, the environment and the items themselves. However, the ITC states that the cognition is in the *activities* between the team members, the environment and the items. Cooke et al. (2013) think that cognition only changes with activity. As an example, the nervous system gets information. Only then SA changes and works towards a new state. When the adjusted state is reached, the state does not change until other information is added.

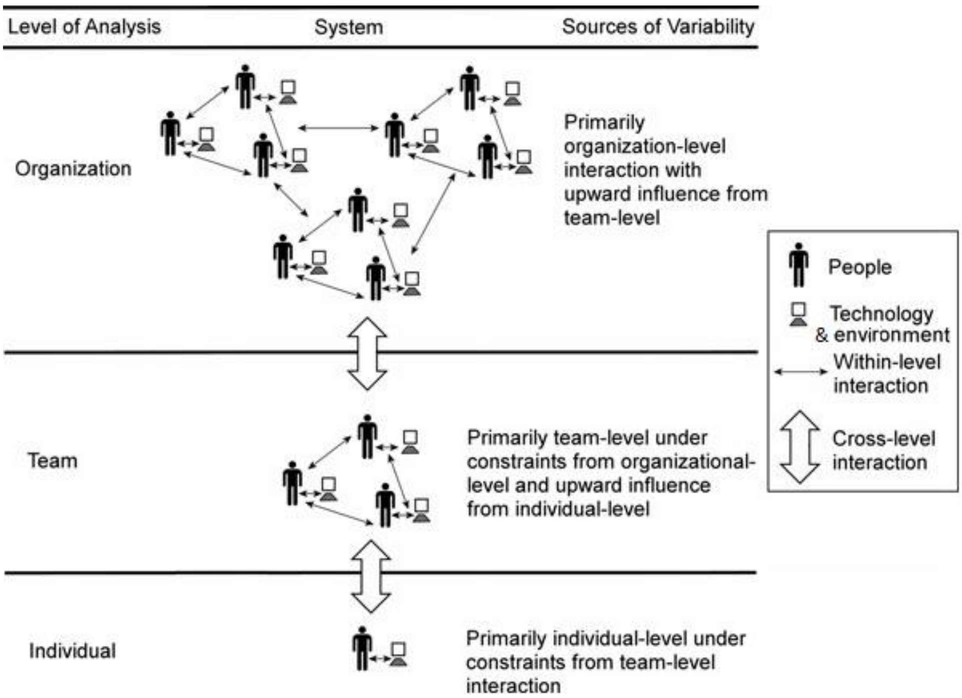

Figure 2.3.1: The difference between DSA and ITC is between the people, technology and environment, against the interaction respectively. Adapted from Cooke et al. (2013)

Figure 2.3.1 demonstrates the difference between de DSA and the ITC. The DSA theory states that the SA resides in the people, technology and environment. The ITC assumes SA is in the interaction arrows. The ITC can be applied to the individual and organisational levels as well. Another difference between the DSA and ITC is how the process of cognition is perceived. DSA has a focus on the process of cognition. There is input, it is processed and then there is output. Cooke et al. (2013) show that the ITC has a more dynamic process that drives cognition. As it is a dynamic activity, there is no clear input, process or output signal.

Premise two states that team cognition should be studied at the team level. The DSA has an identical premise, but as stated earlier, only the ITC measures the interaction between humans and their environment, instead of SA distributed over the environment. Cooke et al. (2013) argues that every analysis should be done on the correct level. When checking team cognition, there is no doubt you have to do analysis on the team level, as focusing on the subcomponents would lose information. The theory of ITC states that the components can be greater or less than the sum of its parts.

Premise three states that team cognition is inextricably tied to context. Every person only needs the SA that is relevant for his or her job. This is the same for their history. Their history shaped them and created their current viewpoints within their job. Any SA that is 'shared', is looked upon from their own viewpoint. This makes the SA for each individual different.

3. Air traffic control and the railways

Theories about SA in aviation are used as a stepping stone towards a similar framework in railways. All SA theories have roots in the aviation, often focused on Air Traffic Controllers (ATCs). Air traffic control is a job that is in its basics very similar to the TRDLs. The guidance is done in part by people and in part by machines, the guidance is done in zones to prevent entanglement and the status of the schedules can be either normal or disrupted. Although the content of air traffic control might differ a lot from railway traffic control, using similarities should help creating further tests for the railways. When differences are found, the tests can be changed to accommodate for these differences.

3.1 Background comparison of Air Traffic Control and railway control, general setup

Both air traffic control and railway control are demanding jobs. Errors in judgement can claim lives and can have disastrous consequences for the environment. Gaining SA is difficult for both, but shows a large difference. Air traffic control needs to represent multiple objects at high speeds, all with different objectives and direction in a volume of space. The difficulty for the railway control stems from the rails the trains are bound to. There is a limited supply of tracks, creating flow problems (CBS, 2009, Goverde, 2007, Sulmann, 2000). These flow problems are often called the 'domino effect'. These are solved with blocking occupied tracks, limiting speeds and limiting manoeuvrability (Sulmann, 2000). Flow problems are not present with air traffic control, save major calamities, as planes can be 'parked' in the air at many speeds and different height and orientation with little consequence.

Soraji et al. (2012) described a typical air traffic control organisation. Air traffic is divided in many distinct and often independent sectors. Usually there are two controllers per sector, both having a distinct job. One is the radar controller, the other the coordination controller. Figure 3.1.1 and 3.1.2 give a typical ATC situation. Even though they have distinct jobs, they do cross over in roles sometimes. In effect, radar controllers coordinate all traffic in the sector and provide critical and non-critical information to the pilots. Coordination controllers communicate with the coordination controllers of other sectors and communicating this to the radar controller. Each sector is more or less independent. The flight plan is most often predetermined by other authorities and the planes have to stick to predetermined official airways as well. This setup does not have a central command hub, but needs coordination of sectors adjacent to each other. This is why the radar controllers together act as a sort of management layer for a larger view of the traffic.

Figure 3.1.1: A typical ATC situation. Foto from Soraji et al. (2012)

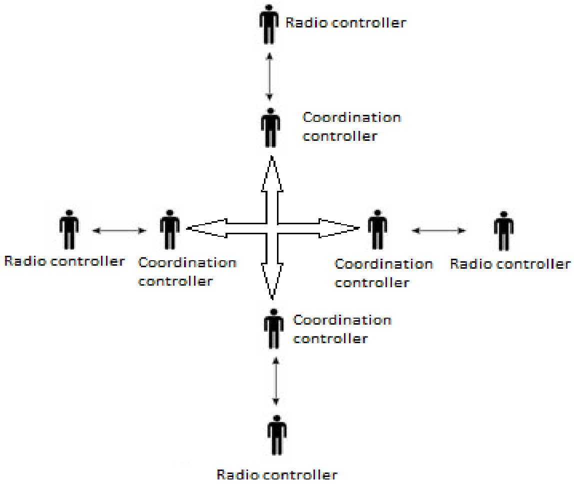

Figure 3.1.2: An example setup of 4 sectors that regularly communicate with each other. The setup can be modified at any moment, depending on the traffic.

Railway control is done much like the air traffic control, but has several key differences. Railway control has a tiered system to a national level. All TRDLs have each their own sector, and several TRDLs are led by two decentralized traffic controllers (DVLs). The decentralized traffic controller (DVL) surveys his sectors with a larger picture, making sure the details of the TRDLs do not come in conflict with more important flow of traffic. The DVLs are further in contact with DVLs that share a part of their corridor, creating fixed connections in communication that is not subject to change. All DVLs report to a national level. This national position is called the national traffic control (LVL). The national level is split in a north and a south part. They do the same as the DVLs, but only on a national scale. They supersede the DVLs to secure the national traffic flow. (ProRail Verkeersleiding, 2012b). This tiered system is much less flexible than the air traffic control system, but still has many of the same properties. TRDLs are like a radar controller. They focus on individual trains in the sector. They give this information to the DVL, who acts as a coordination controller. DVLs have a more global picture and communicate with other TRDLs to safeguard the flow of traffic. They in turn communicate with surrounding DVLs if necessary, log the progress for the LVL and will contact a LVL if there are situations that supersede their command. A LVL will guard the flow of traffic on a national level, making sure that the whole country operates with the highest efficiency. The whole tiered system is complemented by (regional) support teams who check the planning and give advice on available materials and personnel. See Table 3.1.1 for the tiered system and Table 3.1.2 for a quick overview of the differences between ATC and TRDL.

Table 3.1.1: Levels of control in Dutch Railways

Level	Name	Controller	Focus
3	National control	LVL	National and international corridors and connections
2	Network control	DVL	Corridor, connections, route setting on the corridor
1	Track control	TRDL	Track area, direct route setting at railway stations
0	Operations	Train operator	Train service
-	Support	Support teams	Advice in material and personnel availability, passenger flow and calamity assistance.

Table 3.1.1. is adapted from Meijer, van der Kracht, van Luipen & Schaafsma (2009) and expanded (ProRail 2012a, 2012b, Sulmann, 2000)

Table 3.1.2: Comparison between ATC and TRDL

	ATC	TRDL
Traffic	- Less traffic than TRDLs - Is “3D”, fixed trajectories that can be deviated from, do not have a domino effect. - Limited take-off and landing lanes, other planes can be ‘parked’ in the air with nearly no limitations	- More traffic than ATCs - Only “2D”, fixed trajectories, have domino effects to deal with - Limited manoeuvrability and space on the tracks. This counts for the stations as well as outside the stations.
Organisation	- Management done in sector, possibly in communications with relevant neighbouring sectors	- Management is done on national level, local level and per sector. LVL→DVL→TRDLs Also special calls for problems/extra material/etc. Sometimes extra communications to neighbouring colleagues of the same level.
Other	- SA can be high and low depending on the situation - Better instruments	- SA can be high and low depending on the situation - Smarter managing

3.2 Background Air Traffic Control, system setup

In the ATC there are three important systems that give information. The radar screen, the flight process strips and a microphone.

Radar screen. An ATC has only one screen to work from. It shows the current flight path and projected flight path of the plane, together with the plane’s ID and height, among other information, depending on the type of system. Zooming in on certain areas can be done depending on the controlled area and the type of system (Hauland, 2008, Civil Aviation Authority, 2013).

Flight process strips. Most stations use digital strips nowadays. The strip is simply a way to log the planes. The booth is divided in two parts; one approach and one departure. En-route ATC often have the strips mounted in order of height, but other subgroups can be made. The strips have different division according to their function and a matching colour for extra identification. The strips can even be moved left and right in their bay for further information. As this is a form of logging, it is used as reminders and for transferring information when changing shifts (Civil Aviation Authority, 2013).

Microphone. Although not specified in the manual, the microphone plays a central role in the communication. To communicate with pilots and other ATCs need a microphone.

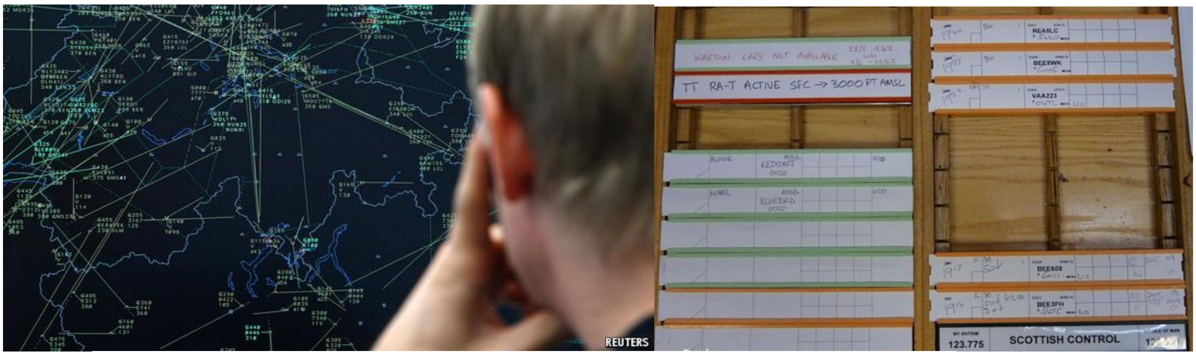

Figure 3.2.1 and 3.2.2. A Radar screen and a flight process strip bay

3.3 Background railways, system setup

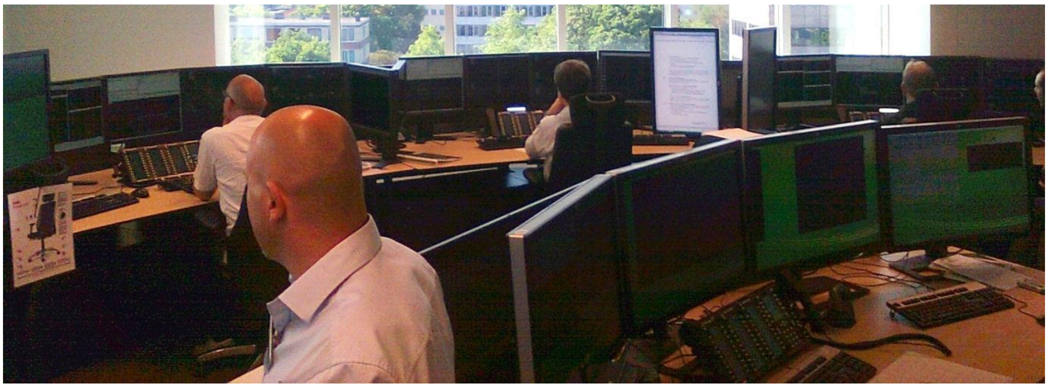

Figure 3.3.1: A four and six screen setup of a few TRDL

The system setup of the railways is much more complex in comparison with the air traffic control. Instead of a volume of air with several planes, all railways and trains need to represented. Sulmann (2000) described the setup of the TRDL. An overview follows with some backup of the ProRail Repository (2012). Like Sulmann (2000), the overview will only outline the most important functions.

The current system is mediated mostly by computers (Sulmann, 2000). A TRDL has between four and seven screens to work from, depending on his or her workstation. See Figure 3.3.1. The number of screens varies with the complexity of the controlled area. Simply put, sometimes more screens are needed to show all data. (Sulmann, 2000, ProRail Repository, 2012) The data are shown in several programs. Sulmann (2000) described the screens, which will be discussed in a short overview.

Figure 3.3.2: Planning screen

Planning screen. These screens show the current planning of the trains. This is a crucial part of the system, as the TRDL can directly change the planning to the circumstances.
If all is going according to the timetable, all text will be green. In this case, the automatic system (ARI) will coordinate everything automatically. The text will change to light green if the train cannot be implemented automatically. If ARI keeps failing to implement a train, the text will turn red. The TRDL can intervene with the process, changing the planning. The text will turn yellow, showing that the TRDL is busy changing the schedule.

The TRDL can also look through the history. These are either sea green or white of colour. Sea green shows that ARI handled the planning. White shows that ARI was off for that plan or if the train operator had to do the tracks on his vision alone.

The planning also has several other signals. Exclamation marks show the train is delayed, exclamation marks with ‘NB’ show that something unknown has stopped the train. If the train keeps standing still, it will get an ‘S’.

If a TRDL processes delays, the system will automatically send an update to relevant onlookers. These are the exploiters of the train, the neighbouring TRDL who are affected by the change, the DVL and by extension the LVL. TRDL can choose to postpone processing and make a receipt. This way he shows the onlookers that he has noted the delay, but decided to process it at a later time. Processing any planning can be done with one train, a whole track or a whole area.

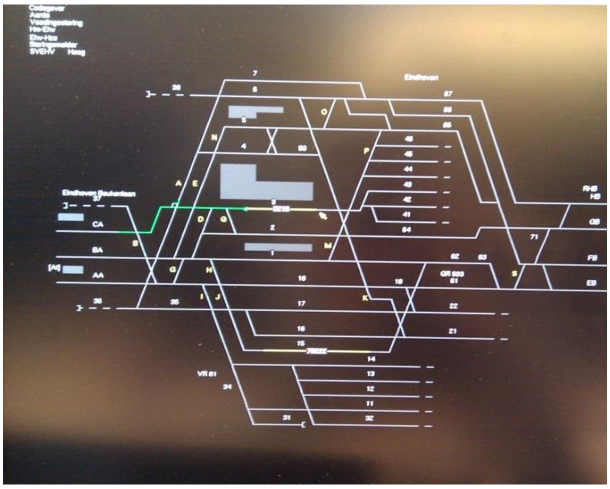

Figure 3.3.3: Overview screen

Overview screen. This screen gives a schematic view of the area where the TRDL is working. It is a direct translation of the planning screen into this schematic view. It shows the location of the trains and their status, as well as the status of the signals and the tracks. Important locations are also drawn into the screen, like the position of stations. Grey lines represent tracks without any events, showing that they can be used for planning. Blue lines represent tracks without power lines, making it unavailable for all electrical transport. The yellow lines represent a track part that is occupied by a train. If a line is interrupted, it shows that the track has no safeguard, making visual control of the train operator mandatory. The overview screen is purely a reference source, but parts can be selected to gain a control screen.

Control screen. When a part of the overview screen is selected, a control screen pops up. This screen has increased zoom, showing more detail than the overview screen. In addition, elements can be selected to show extra information. Besides more detailed information, the screen allows manual control of the selected network. Any changes to the planning in this screen is not automatically forwarded to onlookers, so this has to be done manually.

Other screens. The repository shows several other screens, all which are an extension of the available information. Often they give information of specific trains or routes through time. Figures 3.3.4, 3.3.5 and 3.3.6 give a few examples. 3.3.4 shows the past movement, current movement and projected movement of trains over a selected trajectory. 3.3.5 shows another way of tracking trains, and 3.3.6 shows a list of all processed operations.

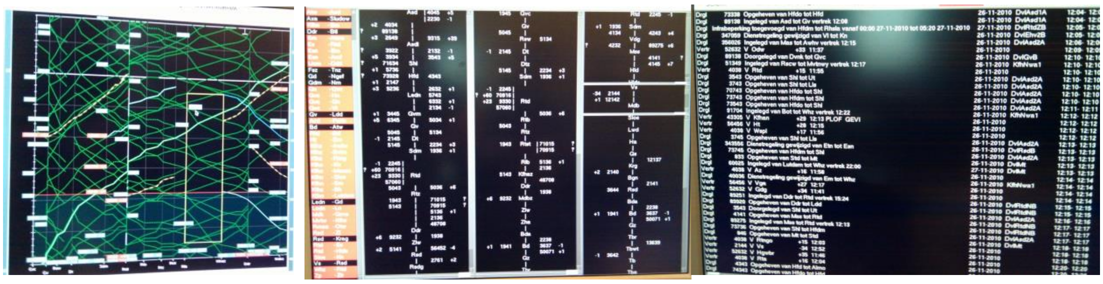

Figure 3.3.4 through 3.3.6: some examples of extra information screens.

Telephone. Although Sulmann (2000) does not mention this, the phone seems an important instrument for a TRDL. It is frequently mentioned in the documentation for TRDL, DVL and LVL (Prorail Verkeersleiding, 2012a, 2012b). The telephone connects the TRDL with train operators, other TRDL, DVL and LVL. This is vital for contact with the train operators and other people in the field, but can also provide a direct line of communication to other parties to clarify information.

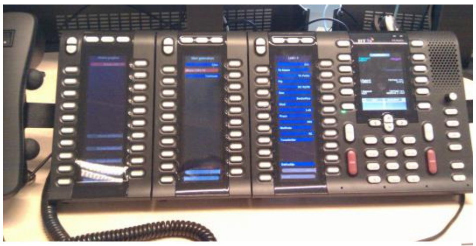

Figure 3.3.7: A phone in a control room

3.4 Differences between ATCs and the TRDLs

The first thing that has to be noted is the sheer amount of screens needed to monitor the situation. The ATC only has one screen and one log to monitor nearly all the data. The TRDL has many screens with many functions to monitor the whole or parts of the situation. The increase in screens seems justified by higher traffic and more micromanaging. A pilot steers for the ATC, while the ATC only has to monitor his height, planning and trajectory. A train operator only observes the situation and changes the speed for the TRDL, while TRDL has to oversee the lights, the switches, trajectory and planning.

4. Situation awareness in air traffic control and the railways

4.1 Situation awareness in air traffic control

Endsley's SA theory for Air Traffic Control

Endsley (1995b) distinguishes between three levels of SA in her theory. Endsley and Rodgers (1994) describe the ATC SA in detail. The first level is perception of the elements in the environment. For ATC it means that they need to perceive the status, attributes and dynamics of the aircraft, as well as any requests and communication of pilots and other ATC. This includes, but is not limited to, the ID, airspeed, position, route, direction of flight and altitude of the aircraft, as well as weather, pilot and controller requests and emergency information.

The second level of SA is the comprehension of the current situation. All elements are connected in the mind to understand significant elements in relation to his or her goals. This should give a complete and relevant picture for the controller. For example, from the data a controller receives, he or she can comprehend that a plane is going too fast, or is off course at that moment. As already described before, any problems with the first level of SA will almost definitely affect the second stage.

The final level is a projection of the future status. The full picture of the second level creates several possible status in the future, on which the controller will base a judgement for orders. For example, if an airplane is off course and going too fast, you can predict it can come too close to another aircraft. A possible judgement that follows is that the airplane can resume to its course without danger and orders the plane to redirect to its intended course and to reduce speed. This third level of SA is the hardest level to achieve, as a person needs to comprehend multiple possible situations, choose the most likely scenario while taking account for other possible scenarios. Within this realm of these possible scenarios they create an optimal plan to match the goals. It should also be noted that this is a continuous process and is build up over time.

Once the highest level is achieved, it changes with the situation. The ever changing situation shows that not all elements have equal importance at all times. Endsley and Rodgers (1994) give the example of weather. When the weather is clear, it is not a primary consideration. Then a depression with rain advances on the location, and the priorities shift as rain has a much larger influence on the flight schedule. Even while some information barely needs attention in some situations, it still adds to the SA of ATCs. Endsley and Rodgers (1994) also note that a lot of errors arise when secondary priorities are undervalued.

Endsley and Rodger (1994) describe several steps in their paper to gain a full picture of SA. The first step is a Goal Directed Task Analysis (GDTA). This analysis can be done with help of observation in real settings and simulation, field experts and looking into reports. The analysis should give a detailed picture of all tasks and goals, but in no particular order. As earlier stated, priorities shift per person and per situation, making a correct order difficult to achieve. Endsley and Rodgers (1994) started with a restructured CTA Job Task Taxonomy, looking into ATC documents and experiences of experts. These experts rated the SA needed for the goals. In the end they had a complete list with all the goals, sub goals and first, second and third level SA required.

For team SA, the next step is to determine the shared SA. This can be done with the method of analysing how much of the mental models are shared. According to Endsley (1995b), a high team effectiveness equals high ‘Shared Mental Models’ (SMMs). High SMMs equals high team SA.

SMMs are often used in a task analysis (Mathieu, Rapp, Maynard & Mangos, 2010). Mathieu et al. (2010) gathered the information for a task analysis nearly in the same way as Endsley and Rodger (1994) do for a GDTA. This means a GDTA can be used to create the mental models. After identifying the most critical elements to SMMs, the elements are customised to resemble the ATC environment for controlled simulation. This is then put into several simulations to be tested. Mathieu et al. (2010) analysed the data for consistency after the tests. Their conclusion was that the effectiveness of teams had a high positive correlation with the interaction of SMMs, confirming their hypothesis.

Distributed Situation Awareness in Air Traffic Control

The DC theory has several approaches to measure cognition (Soraji et al., 2012). The DC assumes observable interactions between people and artefacts and their resulting states (Rogers and Ellis, 1994, Fields et al., 1998, as in Walker, Stanton, Baber, Wells, Gibson, Salmon & Jenkins., 2010). DSA however needs more elaboration that is not included in the DC approach (Salmon et al., 2010). Such elaboration is provided by propositional networks (Salmon et al., 2008a,b, 2009, Stanton et al., 2009, as in Salmon et al., 2010).

The ATC task is described as a form of 'computation' to maintain separation between aircraft in a region of airspace' (Fields et al., 1998, as in Walker et al., 2010). As already described above in the concept of DSA, SA "does not reside solely in the heads of individual controllers, instead they are distributed across the entire air traffic control system, comprising numerous controllers, teams and technical artefacts" (Walker et al., 2010).

To analyse how the SA is distributed over these numerous controllers, teams and technical artefacts a propositional network is used. A propositional network is created by extracting keywords from relevant documents. The creation process takes several phases of a situation through time to capture the dynamic nature of SA (Salmon et al., 2010). As an example, Salmon et al. (2010) give a propositional network for a propositional DSA network in Figure 4.1.1.

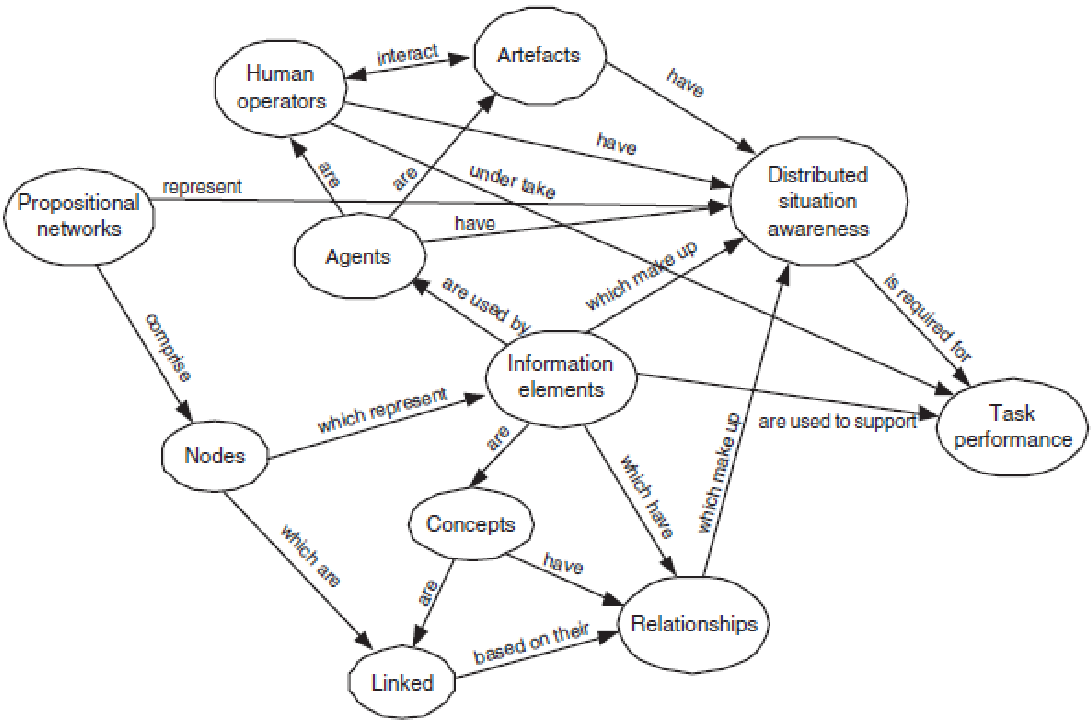

Figure 4.1.1: Propositional network diagram about propositional networks for the DSA (Salmon et al., 2010)

The propositional network shows the complete network. Teams and individuals will use different areas within the network. The circles in Figure 4.1.1 are the areas that can be used, or activated, within the propositional network. When the quality and overall activation of the network has been assessed, the SA can be determined from the resulting data. This can be assessed using mutual belief models.

Cognitive processes that contain team SA can be described well with mutual beliefs (Shu & Furuta, 2005, as in Soraji et al., 2012). Mutual beliefs encompass the intention of the controllers themselves, what they believe the other controller will do and the belief of what the other controller thinks they themselves will do. This leads to four beliefs and two intentions for two controllers. The intention comes forth from the cognition.

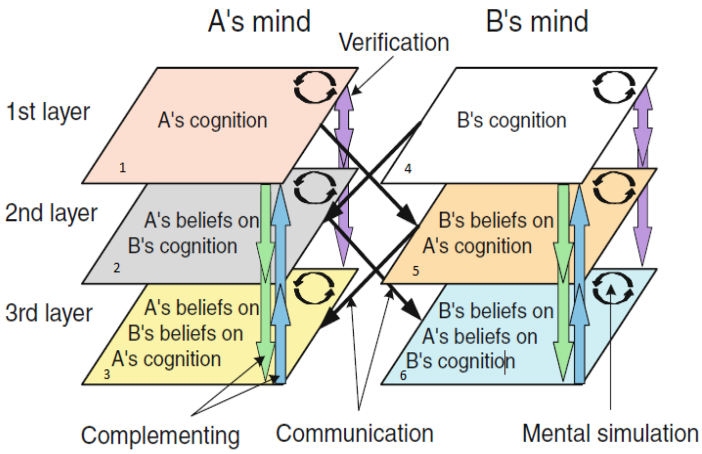

Figure 4.1.2: Mutual belief model representation (adapted from Soraji et al., 2012)

1. A's cognition to do A's own part of X. (intention)
2. A believes that B will do B's part of X. (belief)
3. A believes that B believes that A will do A's own part of X. (belief on belief)
4. B's cognition to do B's own part of X. (intention)
5. B believes that A will do A's part of X. (belief)
6. B believes that A believes that B will do B's own part of X. (belief on belief)

See Figure 4.1.2.

Of these six, 2, 3, 5 and 6 are the true mutual beliefs. The beliefs are created by mental simulation. A controller will make a mental simulation of the other controller his cognitive processes. If the simulation shows a doubt or misalignment with his or her own cognitions, the controller will communicate to realign the cognitive processes. This concept looks a lot like the two SMMs already discussed with Endsley's theory. They differ on a few key points, as the subjects can have their own SA and their own role perspective.

Interactive Team Cognition in Air Traffic Control

The ITC has not been tested like Endsley's theory and the DC. So far only an elaborate framework is described by Cooke et al. (2013), but they do not propose a method of research. However, team cognition has been researched before by Cooke, Gorman and Winner in 2007. The description, as well as the fact that two creators of the ITC wrote this, makes team cognition look like an earlier form of the ITC theory. In the absence of any research that stems from the ITC, team cognition will function as a basis for the research.

Team cognition starts like the DSA and Endsley's theory. The theory requires knowledge about the tasks and goals. Cooke, Gorman and Winner (2007) suggest a 'conceptual method'. In this method team members judge the domain-relevant concepts of each other. These are then submitted to several multivariate statistical routines (Cooke, 1999, Schvaneveldt, 1990, as in Cooke et al., 2007). Other methods creating groundwork use cognitive task analysis followed by analysis of the sequence of interaction between team members (Stout, Salas, & Carson, 1994, as in Cooke et al., 2007). These results can be used to create synthetic environments for testing and understanding team cognition (Cooke & Shope, 2002, 2004, as in Cooke et al., 2007).

The next step is the analysis. Cooke et al. (2007) suggest to let field experts check the tests created for synthetic environments. Furthermore, Cooke et al. (2007) suggest a holistic process that does not have breaks in the simulation or observation. Team SA is then measured by aggregating the overall accuracy scores of the team members (Cooke, DeJoode, Pedersen, Gorman, Connor, & Kiekel, 2004, As in Cooke et al., 2007). Another method is the Coordinated Awareness of Situation by Teams (CAST) (Cooke, Gorman & Winner, submitted, as in Cooke et al., 2007, Gorman et al., 2005). This assesses the coordinated perception and action that comes from team member interactions. This last method would be ideal to test the ITC.

Overview Situation Awareness in Air Traffic Control.

Air traffic control is a demanding job (Endsley, 1995b). To accommodate for more traffic per ATC, research is now mostly focused on support tools for SA (Soraji et al., 2012, Oprins, Zwaaf, Eriksson, Roe & van der Merwe., 2009, Oprins, Burggraaf & van Weerdenburg, 2006). Although Endsley's theory, DSA and ITC seem to have a similar way to assess the current situation to identify the SA elements, the methods to analyse the situation is radically different. This difference in perspective shows different ways to improve the support tools. As shown above, Endsley's theory focuses mostly on shared mental models of the individuals to gain team SA. DSA focuses on mutual beliefs of the involved parties and the role the technological systems play in connecting the people to the environment and to each other. The ITC assesses solely the interactions between the environment, team members and systems, believing that SA only exists when interaction exists. This interaction forms the basis for the SA in the railways for the ITC.

4.2 Situation awareness in railway traffic control

Endsley's theory in railway setting

As in the air traffic control, Endsley's theory (Endsley & Rodgers, 1994) starts with distinguishing three levels. The first level will perceive the elements in the environment. For the TRDLs this means that they need to perceive the status, attributes and dynamics of the trains, as well as any requests and communication of train operators, neighbouring TRDLs, their DVL colleague and any requests from third parties (Sulmann, 2000, ProRail, 2012a, 2012b). This includes, but is not limited to, the ID, speed, position and route of trains, as well as weather conditions, schedule and emergency information.

The second level of SA is the comprehension of the current situation. All elements are connected in the mind to understand significant elements in relation to his or her goals. This should give a complete and relevant picture for the controller. For example, the data a TRDL receives can form the comprehension whether the train is on time, if the train can still make it in time and if any problems are occurring.

The third level is a projection of the future status. The full picture of the second level creates several likely situations on which you will base a judgement and orders. This is vitally important when predicting the flow of traffic in case of delays. All levels will then change dynamically during the progress of time.

Distributed situation awareness in railway setting

The DSA is distributed across the environment, systems and people (Rogers & Ellis, 1994, Fields et al., 1998, as in Walker et al., 2010, Walker et al., 2010, Soraji et al., 2012). With all the train IDs, schedules, locations and other information going directly to and through computers, most SA is stored in the computer systems (Sulmann, 2000). This information is available to TRDL, DVL and LVL alike, even if the information is presented in different forms suited for their function. Many forms of communication are also logged in the computers, available to correct parties when needed.

The cognition in ProRail is distributed mostly to the system, and a little to the actors and the environment. The system allows change quickly, transforming the nature of future events. This information can be distributed to the TRDLs, DVLs and LVL when needed, allowing them to process this SA and then act to it, changing SA again.

Interactive Team Cognition in railways

The last method comes from the ITC theory. As there is no research yet done in the ITC theory, this creates a problem. As said before, the team cognition seems like an early form of the ITC theory. These research methods will be used to test the ITC.

The ITC suggests that all interactions are cognition (Cooke et al., 2013). As SA is a construct of cognition, all interactions that are related to SA, can be treated like SA. The railways are perfect for ITC, as it fits all three premises described by Cooke et al. (2013). The first premise is that railways have activities that play a role in physical properties. As railways consists of high amounts of interaction between people and systems, this premise is valid. Also, ITC theory focuses on the process details instead of the input – process – output method. This fits the railways very well, as there is no definite outcome. The railway coordination continues all day, regardless of a positive or negative outcome. All outcomes can change continuously, becoming input themselves again. If ProRail fails to make a train go according to schedule, the process can still make the train drive on time at a later stage.

The second premise states that Team cognition should be studied at the team level. The railways consist not only of teams and can be studied as teams, but also “blurs the distinction between individual agency versus what emerges through interaction” (Cooke et al., 2013). The railways have clear behavioural constraints at the individual level, making team cognition inevitable. Without the team cognition, a lot of individual behaviours go unexplained.

The last premise states that team cognition is tied to context. This can be seen in many interactions of the TRDLs, DVLs and LVL. One example is that the TRDL will act on a delay of a train when it is sufficiently high. The requirements for action depend on the location on the route it is taking and the cargo it is transporting.

5. Method

A simulation will be used to determine which theory is best to analyse the SA of railway traffic controllers. Most air traffic control studies had a well-defined interaction that was analysed. In contrast, this study aims at clarifying which theory is best in many forms of interaction, focused on the TRDL, DVL and LVL. As such, a great many interactions will be rated for multiple goals, which will be set dynamically by the team, just like the real situation. Several steps are necessary to ensure the theories are comparable. The simulation will be continuous to facilitate immersion. The interactions are the only level that can all be analysed and quantified with a unified score: whether SA within an interaction can be analysed or not. The SA itself is not readily comparable between the theories, as SA in each theory is measured as either cognition, mutual beliefs or shared knowledge.

5.1 Method Endsley

Endsley's theory starts with a GDTA. With access to documents describing the process, field experts and footage of a few gaming simulations a GDTA can be constructed for the railways. The SA will be determined with SMMs. In Endsley's theory, a simulation is often paused to gain the SMMs from the participants. The other two theories rely on a continuous simulation, which will be used in this study. SMMs will be adapted for this change, so SMMs can be applied to transcripts after a continuous simulation. .

After we have determined the SA, we need to determine if the extracted SA was relevant to the goal. Endsley and Rodgers (1994) used the GDTA to examine one controlled interaction. The GDTA can also be used to check if the interaction served the goal correctly, which is useful to test the many dynamic goals in the simulation. This can be done by extracting the mental models from the GDTA, and see which are present at the interactions. If an interaction has wrong mental models, or is missing crucial mental models, the interaction does not serve the goal it should. If the goals are still reached, despite the incorrect interactions, it signals that the theory or the documents might be insufficient, or the GDTA itself is flawed. This gives doubt whether the interactions where really incorrect. Endsley's theory needs the whole interaction to be correct. If one side of the interaction is incorrect, it will automatically make the SMM between the people incorrect.

Determining the SA has several practical problems. For a high team SA, all parties need to have high SMMs, as described by Mathieu et al. (2010). In air traffic control there are at least two people on the same task, meaning they have high SMMs. However, the structure of the railway control system does not suggest high SMMs. Each control level has a different perspective on identical problems. This problem can even occur on the same level, as each controller has a perspective from his or her own control area. This suggests that SMMs will not be the same. This also suggests that mental models that are compared on the same operational level will be more shared than mental models between operational levels. Endsley's theory cannot explain why a team that has the same goals has so little SMMs. The same problem occurs when the LVL gains information from the DVL.

5.2 Method DSA

The first step described by Salmon et al. (2010), the propositional network, requires the same information as the GDTA. The DSA uses behavioural records to extract the most basic elements of the tasks. Afterwards the relations between elements are clarified and expert knowledge and judgement is identified. All this information is available within the GDTA requirements. After this, they analyse which elements are used by which role, according to the DSA theory.

The propositional network is also used to extract the SA. Each element in the propositional network shows part of the SA. The analysis shows whether the elements are present and how prominent they are in the interaction, resulting in a total SA. However, Stanton at al. (2006) and Salmon et al (2010) do not state a way to extract the elements from interactions. Salmon et al. (2010)

give a solution in a critique on the DC approach. They state that the DC is not suited for the DSA, as the DC typically uses observational study and interview data to develop basic textual descriptions of collaborative activity , which do not provide the necessary level of detail for the DSA. However, the method of extraction in this study focuses on observational study, breaking down the interactions to their basic cognition. This is done via the mutual belief model from Shu and Furuta (2005, as in Soraji et al., 2012). This method is rooted in the DC and meant to extract TSA. The cognition that is shown via the mutual belief model can also be used to identify which elements within the propositional network have been activated. Practically, the TRDLs, DVL and LVL will be observed for an extended period of time. A transcript will be created and every relevant interaction will be rated with the mutual belief model. This already shows a problem with the testing for the DSA. A mutual belief model cannot be imparted onto a computer system, even though a large part of the SA resides in this system. The mutual belief model needs a few adaptations to work for the DSA.

The mutual belief model has beliefs and cognition. The cognition in humans is the same as the cognition in the environment and the system, according to the DSA. This means that the mutual belief model does not need to be changed on this account. The problem resides in the belief. The environment cannot believe, nor can systems, meaning these cannot be analysed. To incorporate the environment and the systems, the mutual belief model can be tweaked for the system and environment cases. A system is built with certain assumptions, which are reflected in the system. If the system actively sends information, it is assumed the information will be received. Passively presenting information, like the timetables of the trains, is assumed to be used when needed. So even if the system cannot believe, the assumptions from the system builders are reflected in the actions. The build in assumptions can show the cognition within a system as well as a belief. When a system interacts with another information source, the assumptions change just like a belief in the mutual belief model. This is also correct for information on paper and many other man-made sources in the environment. This is not directly applicable to natural sources, as an assumption of use was not put in there by humans during their creation. However, the assumptions have been put there later by humans, as they assume the environment shows certain information. This way the environment reflects the assumptions of the humans when transferring this information. This means that the mutual belief model can be used normally, but when the environment or systems are used, the mutual belief model will use the assumptions instead of beliefs for the system or environment their side of the interaction. The assumptions will change depending on the status of the interacting party. This means that there can be a single sided interaction, which still change the assumptions of the system.

After we have determined the SA, we need to determine if the extracted SA was relevant to the goal. The propositional network as proposed by Salmon et al. (2008a,b, 2009 as in Salmon et al., 2010) and Stanton et al.(2009 as in Salmon et al., 2010) can be used to check if each interaction was correct. The propositional network will extract keywords from the relevant documents, and sorted per possible interaction. The keywords extracted from the interactions will then be compared to the keywords from the documents. This will tell us if the interaction was correct for the goal. If there are keywords present that do not belong there, or crucial keywords missing, then the interaction does not serve the right goal. If the goals are still reached, despite the incorrect interactions, it signals that the theory or the documents might be insufficient. This raises doubt about whether the interactions where really incorrect. This means that either the documents and persons from which the propositional network is extracted are delivered incomplete information, or that the propositional network itself is flawed. The propositional network views each side of the interaction individually, as the DSA assumes the SA resides in individual objects or organisms. The individual or object can impart his data correctly onto the other individual or object, regardless how well the other individual or object imparts his data.

The theory does show a problem when comparing air traffic control with the railways. The ATCs work in teams of two or more on the same area and have direct contact with each other, without a global control. They discuss and share the same information. The railways have a different setup. Every TRDL works alone and has only sporadic contact with his neighbours. He also reports his operations to a more global control, who can intervene if necessary. A TRDL can also gain SA from his screen and change the planning without consulting or sharing his SA. Without an extra controller to share this information directly, this information is obscured. This is a problem for the DSA, as they should test the system as well. The theory can still be tested despite these shortcomings, although not completely.

5.3 Method ITC

For research, Cooke and Shope (2002, 2004, as in Cooke et al., 2007) suggest a holistic approach that does not have any break in simulation or observation, similar to the DSA. The ITC method focuses on capturing emergent cognition. For team cognition, Cooke et al. (2007) specify this even more with the CAST method. This method focuses on the communication between people for each advancement of the process. It shows whether information was shared between persons and with the transcripts or observations the quality can be assessed. Because transcripts and observations can be used, the progress through time can be seen, showing the dynamic quality of team SA. For the process a real or synthetic environment is needed. For the real environment there is no need for a lot of preparation, but preparation is still prudent. This can be done with cognitive task analysis followed by analysis of the sequence of interaction between team members (Stout, Salas, & Carson, 1994, as in Cooke et al., 2007). These results can be used to create synthetic environments for testing and understanding team cognition (Cooke & Shope, 2002, 2004, as in Cooke et al., 2007), but can also be used as an information background for the real situation.

The propositional network looks applicable to the ITC, but differs on a few key operationalisations from the DSA. The propositional network proposed here focuses on the cognition transferred from one information source to another. This can be viewed from one side of the interaction. Even if the interaction goes wrong, the cognition transferred can be correct. The ITC on the other hand focuses on the interaction between two or more people. If one side of the interaction fails, both sides have an incorrect cognition. If the propositional network was applied with the ITC, it could result in false positives if the other side was not accounted for. The CAST method does not have this drawback.

After we have determined the SA, we need to determine if the extracted SA was relevant to the goal. Endsley and Rodgers (1994) used the GDTA to examine one controlled interaction. The GDTA can also be used to check if the interaction served the goal correctly. This can be done by extracting the mental models from the GDTA. Afterwards the expected mental models for such an interaction are compared to the actual mental models of an interaction If an interaction has wrong mental models, or is missing crucial mental models, the interaction does not serve the goal it should. If the goals are still reached, despite the incorrect interactions, it signals that the theory or the documents might have insufficient information, or the GDTA itself is flawed. This gives doubt whether the interactions were really incorrect. The ITC assumes the cognition from an interaction is SA, so if one side of the interaction is flawed, the whole SA is flawed.

A great amount of the interaction goes via computers (Sulmann, 2000). This can create a problem, as it is not always clear which interactions are happening. These interactions can only partly be deducted by watching further interactions. This, coupled with the more individual nature of a TRDL, will cloud some of the information. Otherwise, there seem to be few problems with the ITC approach for this research.

5.4 Method shared by all theories

After determining whether the extracted SA was relevant to the goal, it is prudent to check if the SA was consistent with the expectation of the theories. According to the theories, high SA would result in more solved goals, while low SA would result in more unsolved goals. If the SA is consistent with the theories, it would support their outcome. If the SA is inconsistent with the theory, then it raises doubt on the outcome of the SA of the theory, making the result unreliable. This information is gained by comparing the differences in the amount of SA for each goal. These differences are then compared to what is expected from the theories.

6. Experimental setup

The experiment is set up in several phases. The first step is a simulation of a possible problem on the tracks. Afterwards a transcript will be created of all interactions of the railway traffic controllers, of which each interaction relevant to the simulation will be selected. . Next, each interaction will be checked via each theory for the ability to extract SA and the ability to check if the interaction was correct. A statistical analysis will then show if a theory is superior to analyse SA in the railways.

The simulation will test a traffic intensive area around Amsterdam. It will start with a normal situation on the tracks, and after a few minutes it will introduce a calamity in the form of a train on fire at the Uitgeest station. The railway traffic controllers will then try to minimise or solve the disruption. There will be ten persons in the simulation and several people assisting the simulation. There is one game leader to ensure everything is going correctly. The roles within the simulation consist of a DVL of Amsterdam, the southern LVL, the backoffice, LBC, RBC and RBC monitor of the Amsterdam area, and 4 TRDLs that control the areas around Amsterdam. Every role in the simulation is filled with a person that occupies an identical role in his daily life. The environment is simulated by normal telephones to call each other and a limited version of their logging screen. The overview screen is simulated on paper where the schematic situation has been drawn from reality. The trains are represented by sponges with the train numbers written on them. Instead of digital protocols and manuals, there will be access to paper versions for the teams. The simulations is continuous, to ensure immersion and will be taped to review later.

As stated before, a transcript will be created of all interactions of the railway traffic controllers after the simulation . The relevant interactions for trains and stations will be extracted and sorted. The interactions are broken up so that they will only analyse the interaction of two people. This way all interactions can be viewed and analysed in full. The theories will then be used to analyse the interactions with the described methods. The resulting data will then be consolidated to show two sets of binary data. The first is whether a theory could gain SA from the interaction, the other whether the interaction was correct according to the data extracted via each theory from the documents.

Endsley's theory will identify SA via mental models. The mental models will be extracted from the GDTA, which in turn is extracted from the documents of the railway traffic controllers. The mental models of both parties of the interaction should be identical for a correct SA. Identical SA will result in a positive score. If both parties have mental models but they are not identical, it will tell that no or only some SA was shared, thus telling something of SA, also resulting in a positive score. If there is no mental model available, they cannot extract any SA, resulting in a negative score.

In Endsley's theory an interaction can be reviewed by checking if mental models are present that are expected in such interaction. Mental models change per kind of interaction. If the mental models are correct for both sides of the interaction, the SA gained from the interaction is correct. This will gain a positive score. If any incorrect mental model for that interaction is present, or all are missing from one or more sides, it will gain a negative score. Incorrect interactions can show SA, but will not serve the task at hand. Attachment A shows the mental models per interaction, as well as an example how an interaction is analysed.

The DSA uses the adapted mutual belief model to identify the activation of the propositional network, which in turn shows the SA. The mutual belief model can analyse an interaction directly, showing whether SA was exchanged. This will result in a positive score unless the responses of one side are missing. Attachment B shows an example of the mutual belief model.

The DSA checks an interaction with the propositional network. The network consists of keywords that are extracted from the document. The keywords are first sorted per role and then per interaction (See Attachment C and D). If the keywords from the interaction matched those that where extracted from the documents, it is regarded as correct. If keywords from different interactions appear or there are important keywords missing, then the interaction is seen as incorrect.

The ITC uses the CAST method to extract SA. Each interaction will be judged on the cognition that is exchanged. If cognition can be extracted from the interaction, SA can be extracted, resulting in a positive score. If no cognition can be extracted, it results in a negative score. For an example, see Attachment E.

The ITC uses the same method as Endsley's theory to check the interactions.

The binary statistics will allow the chi-square for testing. Each theory will be paired, resulting in a total of six tests. The first three tests will compare the theories their ability to extract SA. Table 6.1 shows the setup. If there is a significant difference, the theory with the highest count in the "able" category will be the better theory.

Table 6.1: Example chi-square test.

			Extracting SA		
			Able	Not Able	Total
Theory	Theory 1	Count	X	X	X
		Expected Count	X	X	X
	Theory 2	Count	X	X	X
		Expected Count	X	X	X

The other three tests will compare the amount of interactions that are correct for each theory. This is an important step, as it will show how much of the extracted SA is actually relevant to the goal. Table 6.2 shows the setup.

Table 6.2: Example chi-square test.

			Check of interaction		
			Able	Not Able	Total
Theory	Theory 1	Count	X	X	X
		Expected Count	X	X	X
	Theory 2	Count	X	X	X
		Expected Count	X	X	X

All tests will be checked by the Pearson Chi-Square, unless not all assumptions have been met. If the assumption of all expected counts of the cells are above 5 is not met, Fisher's exact test will replace the Pearson Chi-Square to safeguard validity.

To test whether the solved and unsolved goals are explained per theory, the solved and unsolved goals will be compared within each theory. The amount of correct, incorrect and unknown SA on an interaction will be compared to the solved and unsolved goals via a chi-square test. The SA will already have been rated for each theory to determine if an interaction yields SA. An example can be seen in Table 6.3.

Table 6.3: Example goal * SA Crosstabulation theory X

			correctness			
			correct	incorrect	unknown	Total
solved	solved	Count	X	X	X	X
		Expected Count	X	X	X	X
	unsolved	Count	X	X	X	X
		Expected Count	X	X	X	X

7. Results

The simulation has been conducted in advance of this study. Transcripts where created in this study from the resulting video material of all parties involved. Afterwards the methods of each theory have been applied to gain clear data. The data has been consolidated until there were two variables left. The first are interactions that a theory can analyse SA from. The second are interactions that a theory could not analyse SA from. To analyse three theories with each two categorical variables, the study required a chi-square test, as recommended by Field (2009). A significant difference will show that the theories differ. If there is a significant difference, the theory with the highest frequency in “able to analyse SA” will be the best theory to analyse SA. All tests have an N of 344, consisting of 172 for each theory.

First the DSA was compared to the ITC. The amount of SA that each theory could analyse did not differ significantly for the DSA and the ITC, $\chi^2(1, N=344)=.627$, $p=.428$. As the expected counts are all above 5, the prerequisites for the chi-square have been met. See Tables 7.1 and 7.2.

Table 7.1 DSA *ITC Crosstabulation.

			Extracting SA		
			Able	Not Able	Total
Theory	DSA	Count	163.0	9.0	172.0
		Expected Count	164.5	7.5	172.0
	ITC	Count	166.0	6.0	172.0
		Expected Count	164.5	7.5	172.0

Table 7.2 Chi-Square Tests DSA * ITC

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.627[a]	1	.428
N of Valid Cases	344		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 7.50.

S

econdly the DSA was compared to Endsley’s theory. The amount of SA that each theory could analyse did differ significantly for the DSA and Endsley’s theory, $\chi^2(1, N=344)=101.932$, $p<.001$. The DSA was significantly more able (163) than Endsley’s theory (77) to analyse SA. As the expected counts are above 5, the prerequisites for the chi-square have been met. See Tables 7.3 and 7.4.

Table 7.3 DSA *End Crosstabulation.

			Extracting SA		
			Able	Not Able	Total
Theory	DSA	Count	163.0	9.0	172.0
		Expected Count	120.0	52.0	172.0
	End	Count	77.0	95.0	172.0
		Expected Count	120.0	52.0	172.0

Table 7.4 Chi-Square Tests DSA*End

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	101.932[a]	1	.000
N of Valid Cases	344		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 52.00.

Lastly Endsley's theory was compared to the ITC. The amount of SA that each theory could analyse did differ significantly for the Endsley's theory and the ITC, $\chi^2(1, N=344)=111.022$, $p<.001$. The ITC was significantly more able (166) than Endsley's theory (77) to analyse SA. As the expected counts are above 5, the prerequisites for the chi-square have been met. See Tables 7.5 and 7.6.

Table 7.5 End*ITC Crosstabulation

			Extracting SA		
			Able	Not Able	Total
Theory	End	Count	77.0	95.0	172.0
		Expected Count	121.5	50.5	172.0
	ITC	Count	166.0	6.0	172.0
		Expected Count	121.5	50.5	172.0

Table 7.6 Chi-Square Tests End*ITC

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	111.022[a]	1	.000
N of Valid Cases	344		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 50.50.

The next series of tests were to check if the interactions themselves where relevant to the goal. Without this check all SA they find might not serve the goal they intended. The N is 344. 172 for each theory.

First the DSA was compared to the ITC. The amount of interactions that each theory could check did differ significantly for the DSA and the ITC, χ^2 (1, N=344)=106.728, p=.000. The DSA was more able (164) than the ITC (76) to check if the interactions are correct. As the expected counts are above 5, the prerequisites for the chi-square have been met. See Tables 7.7 and 7.8.

7.7 DSA_C*ITC_C Crosstabulation

			Check of interaction		
			Able	Not Able	Total
Theory	DSA_C	Count	164.0	8.0	172.0
		Expected Count	120.0	52.0	172.0
	ITC_C	Count	76.0	96.0	172.0
		Expected Count	120.0	52.0	172.0

7.8 Chi-Square Tests DSA_C*ITC_C

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	106.728[a]	1	.000
N of Valid Cases	344		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 52.00.

Secondly the DSA was compared to Endsley's theory. The amount of interactions that each theory could check did differ significantly for the DSA and Endsley's theory, χ^2 (1, N=344)=104.829, *p*=.000. The DSA was more able (164) to check the interactions than Endsley's theory (77) As the expected counts are above 5, the prerequisites for the chi-square have been met. See Tables 7.9 and 7.10.

7.9 DSA_C*End_C Crosstabulation

			Check of interaction		
			Able	Not Able	Total
Theory	DSA_C	Count	164.0	8.0	172.0
		Expected Count	120.5	51.5	172.0
	End_C	Count	77.0	95.0	172.0
		Expected Count	120.5	51.5	172.0

7.10 DSA_C*End_C Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	104.892[a]	1	.000
N of Valid Cases	344		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 51.50.

Lastly Endsley's theory was compared to the ITC. The amount of interactions that each theory could check did not differ significantly for Endsley's theory and the ITC, χ^2(1, N=344)=0.012, *p*=.914. As the expected counts are above 5, the prerequisites for the chi-square have been met. See Tables 7.11 and 7.12.

7.11 End_C*ITC_C Crosstabulation

			Check of interaction		
			Able	Not Able	Total
Theory	End_C	Count	77.0	95.0	172.0
		Expected Count	76.5	95.5	172.0
	ITC_C	Count	76.0	96.0	172.0
		Expected Count	76.5	95.5	172.0

7.12 End_C*ITC_C Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.012[a]	1	.914
N of Valid Cases	344		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 76.50.

Goals solved vs unsolved

Each theory has also been tested to see whether the solved and unsolved goals are explained per theory. First the amount of correct, incorrect and unknown SA are compared to the amount of solved and unsolved goals. Afterwards the interactions that served the goal where tested. All are tested per theory. All tests have an N of 163.

For the ITC, the Chi-square did not make all requirements as two cells had an expected count lower than 5. A Fisher's exact test was used to solve this problem. The ITC shows no significant difference between the solved and unsolved conditions, Fisher's exact test(N=163)=.697, *p*=.747. For both the solved and unsolved goals, the largest category was 'correct'. See Tables 7.13 and 7.14.

Table 7.13 goal * SA Crosstabulation ITC

			correctness			
			correct	incorrect	unknown	Total
Goals	solved	Count	99.0	22.0	4.0	125.0
		Expected Count	98.2	22.2	4.6	125.0
	unsolved	Count	29.0	7.0	2.0	38.0
		Expected Count	29.8	6.8	1.4	38.0
Total		Count	128.0	29.0	6.0	163.0
		Expected Count	128.0	29.0	6.0	163.0

Table 7.14 Chi-Square Tests

		Monte Carlo Sig. (2-sided)		
			95% Confidence Interval	
	Value	Sig.	Lower Bound	Upper Bound
Fisher's Exact Test	.697	.747[b]	.738	.755
N of Valid Cases	163			

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is 1.40.

b. Based on 10000 sampled tables with starting seed 1993510611.

For the ITC interactions, the Chi-square did not make all requirements as two cells had an expected count lower than 5. Fisher's exact test showed there was no difference for the ITC between the correct, incorrect and unknown interactions, Fisher's exact test(N=163)=.354, *p*=.911. For both the solved and unsolved goals, the largest category was 'correct'. See Tables 7.15 and 7.16.

Table 7.15 goal * interaction Crosstabulation ITC

			correctness			
			correct	incorrect	unknown	Total
Goals	solved	Count	109.0	11.0	5.0	125.0
		Expected Count	108.9	10.7	5.4	125.0
	unsolved	Count	33.0	3.0	2.0	38.0
		Expected Count	33.1	3.3	1.6	38.0
Total		Count	142.0	14.0	7.0	163.0
		Expected Count	142.0	14.0	7.0	163.0

Table 7.16Chi-Square Tests

		Monte Carlo Sig. (2-sided)		
			95% Confidence Interval	
	Value	Sig.	Lower Bound	Upper Bound
Fisher's Exact Test	.354	.911[b]	.906	.917
N of Valid Cases	163			

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is 1.63.

b. Based on 10000 sampled tables with starting seed 475497203.

For the DSA, the Chi-square did not make all requirements as three cells had an expected count lower than 5. Fisher's exact test showed the DSA had no significant difference between the solved and unsolved conditions, Fisher's exact test(N=163)=2.075, *p*=.366. For both the solved and unsolved goals, the largest category was 'correct'. See Tables 7.17 and 7.18.

Table 7.17 goal * SA Crosstabulation DSA

			correctness			
			correct	incorrect	unknown	Total
Goals	solved	Count	114.0	6.0	5.0	125.0
		Expected Count	114.3	4.6	6.1	125.0
	unsolved	Count	35.0	0.0	3.0	38.0
		Expected Count	34.7	1.4	1.9	38.0
Total		Count	149.0	6.0	8.0	163.0
		Expected Count	149.0	6.0	8.0	163.0

Table 7.18 Chi-Square Tests

	Value	Monte Carlo Sig. (2-sided)		
		Sig.	95% Confidence Interval	
			Lower Bound	Upper Bound
Fisher's Exact Test	2.075	.366[b]	.354	.379
N of Valid Cases	163			

a. 3 cells (50.0%) have expected count less than 5. The minimum expected count is 1.40.

b. Based on 10000 sampled tables with starting seed 126474071.

For the DSA interactions, the Chi-square did not make all requirements as one cell had an expected count lower than 5. Fisher's exact test showed the DSA interactions had no significant difference between the solved and unsolved conditions, Fisher's exact test(N=163)=.413, *p*=.839. For both the solved and unsolved goals, the largest category was 'correct'. See Tables 7.19 and 7.20.

Table 7.19 goal * interacion Crosstabulation DSA

			correctness			
			correct	incorrect	unknown	Total
Goals	solved	Count	90.0	30.0	5.0	125.0
		Expected Count	90.5	29.1	5.4	125.0
	unsolved	Count	28.0	8.0	2.0	38.0
		Expected Count	27.5	8.9	1.6	38.0
Total		Count	118.0	38.0	7.0	163.0
		Expected Count	118.0	38.0	7.0	163.0

Table 7.20 Chi-Square Tests

	Value	Monte Carlo Sig. (2-sided)		
		Sig.	95% Confidence Interval	
			Lower Bound	Upper Bound
Fisher's Exact Test	.413	.839[b]	.832	.846
N of Valid Cases	163			

a. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 1.63.

b. Based on 10000 sampled tables with starting seed 1507486128.

For Endsley's theory, the Chi-square did not make all requirements as two cells had an expected count lower than 5. Fisher's exact test showed Endsley's theory had no significant difference between the solved and unsolved conditions, Fisher's exact test(N=163)=.644, *p*=.794. For both the solved and unsolved goals, the largest category was 'incorrect'. See Tables 7.21 and 7.22.

Table 7.21 goal * SA Crosstabulation Endsley's theory

			correctness			
			correct	incorrect	unknown	Total
Goals	solved	Count	4.0	52.0	69.0	125.0
		Expected Count	4.6	51.4	69.0	125.0
	unsolved	Count	2.0	15.0	21.0	38.0
		Expected Count	1.4	15.6	21.0	38.0
Total		Count	6.0	67.0	90.0	163.0
		Expected Count	6.0	67.0	90.0	163.0

Table 7.22 Chi-Square Tests

		Monte Carlo Sig. (2-sided)		
			95% Confidence Interval	
	Value	Sig.	Lower Bound	Upper Bound
Fisher's Exact Test	.644	.794[b]	.786	.802
N of Valid Cases	163			

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is 1.40.

b. Based on 10000 sampled tables with starting seed 1122541128.

For Endsley's theory interactions, the Chi-square did not make all requirements as one cell had an expected count lower than 5. Fisher's exact test showed the Endsley's theory had no significant difference between the solved and unsolved conditions, Fisher's exact test(N=163)=.062, p=1.000. For both the solved and unsolved goals, the largest category was 'correct'. Tables 7.23 and 7.24.

Table 7.23 goal * interaction Crosstabulation Endsley's theory

			correctness			
			correct	incorrect	unknown	Total
Goals	solved	Count	45.0	11.0	69.0	125.0
		Expected Count	45.2	10.7	69.0	125.0
	unsolved	Count	14.0	3.0	21.0	38.0
		Expected Count	13.8	3.3	21.0	38.0
Total		Count	59.0	14.0	90.0	163.0
		Expected Count	59.0	14.0	90.0	163.0

Table 7.24 Chi-Square Tests

	Value	Monte Carlo Sig. (2-sided)		
			95% Confidence Interval	
		Sig.	Lower Bound	Upper Bound
Fisher's Exact Test	.062	1.000[b]	1.000	1.000
N of Valid Cases	163			

a. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 3.26.

b. Based on 10000 sampled tables with starting seed 605580418.

8. Discussion

Theory

To test which theory was best for analysing the SA in the railways, 172 interactions have been rated. This data has then been consolidated to check if the method of each theory could extract SA from the interactions. The results show that the DSA and ITC can gain SA in a statistically equal number of interactions. This statistic gives no exclusion of a theory. The DSA compared to Endsley's theory shows a significant difference. The DSA can analyse more interactions (163) than Endsley's theory (77), showing that the DSA is better to analyse SA. The ITC compared to Endsley's theory shows another significant difference. The ITC can analyse more interactions (166) than Endsley's theory (77), showing that the ITC is better to analyse SA. This set of data shows that the DSA and ITC are better than Endsley's theory to analyse SA, but do not differ statistically from each other.

The ITC and DSA both score statistically the same. The extra measure that shows whether the interaction is correct will complete the analysis and give a definite answer. The DSA compared to the ITC shows a significant difference. The DSA can check more interactions (164) than the ITC (76), making it the better theory. The DSA compared to Endsley's theory shows a significant difference. The DSA can check more interactions (164) than Endsley's theory (77), making it the better theory. Endsley's theory compared to the ITC does not show a significant difference, ITC. To conclude, DSA is the best theory to check the interactions.

The DSA is the best theory to check the SA in railway traffic controllers. This can easily be explained by the resilience of the theories. The ITC and DSA could both analyse an interaction where people other than railway traffic controllers were present. These theories could rate the interaction itself without any prior knowledge of background information of the participating roles. In contrast, Endsley's theory needed the background information of all roles involved. As the focus of the experiment were the railway traffic controllers , no documents where procured to create GDTAs for people outside these roles. Endsley's theory might prove well or even best when all possible roles are documented in a new experiment. Still, its lack of resilience when extra roles are added can be detrimental for analysing SA. The ITC and DSA can just focus on several people you need to know the SA of. This decreases the time for analysis and increases utility. With the next analysis, the control of the interactions, the ITC loses its resilience. The ITC and Endsley's theory both gain the interaction check from the GDTA. The GDTA suffers from the same weakness as with the analysis of the SA, meaning that all roles without background information cannot be analysed. The DSA however can still analyse one side of the interaction, regardless of missing background information on the other side of the interaction. This makes the DSA the most versatile in many situations where not all information is available. In addition, the DSA also allows to select the source that you want to know the SA from. While these are significant conclusions, it is important to know which theory is best when all information is available. New research should give an answer to the question which theory is best when as many parameters as possible are known. There is only one argument against the DSA. Theoretically, the DSA should only be applied to the team level. The focus of this study has been on several individuals within the team, which loses information according to the DSA. Despite this argument the DSA worked best of all three theories.

During the analysis one thing became very clear. The computer systems were left out in the transcripts, only showing itself in a few direct interactions with a TRDL. The interactions with the system are important, as it acts autonomously at most times and also assists in nearly every decision involving the tracks. This is in contrast with the air traffic control, where in the end nearly every action is controlled directly by a human. The system in railway control can be regarded as an entity like a human, as it is directly responsible for the actions, following a set of rules. It might not be part of Endsley's theory, but could still be implemented that way if the system is regarded as a fully capable actor, sharing SA with other actors. The GDTA that the ITC and Endsley's theory both use will also accept the system if enough documents are available. Although the term mental models might not be appropriate, the system can still work towards a goal via its system models. Regarding the system as a fully capable actor is not part of the CAST method. Gorman et al. (2005) and Cooke et al. (2007) only talk about the CAST in relation to the interactions of team members. However, the ITC does assume the computer system is capable of interactions that are similar to interactions between the team members. The change for the CAST method would not be severe, as it would only add another interaction box for the systems. This way the ITC and Endsley's theory can both implement the system into their measures, giving a complete picture of the SA. The DSA has implemented this in an adapted mutual belief model, making the assumptions reflected in a system a substitute for belief. Without this change, the mutual belief model would show no SA every time the environment or a system is used.

Something else that should be noted is that the goals in railway traffic control are set much more dynamically than in air traffic control. This dynamic setting fits the ITC theory better. The DSA focuses more on an input-process-output method. While the DSA is fine if applied to the goals, its input-process-output analysis is troublesome for the individual interactions. The DSA assumes that all information of earlier interactions is used again. This isn't clear in the individual interactions, losing or obscuring information important for the DSA. Endsley's theory also has an input-process-output method, but doesn't have the problems of the DSA. Endsley's theory is focused on the individual and only needs to gain the shared information. This means for Endsley's theory, that a setting can be dynamic on levels higher than the individual with little consequence. However, all theories in this study had problems with the dynamic nature of railway traffic control on the higher levels. The best course of action is determined by judging several scripts that can be applied, of which multiple can have a desired outcome. This means that the goals set during a simulation can differ even if the situation is the same. At the same time, many scripts are not solutions to the problem, but will just reduce the problems on the tracks. As the scripts were not discussed at length during the simulation, it was hard to determine if an interaction was truly wrong or right, possibly obscuring data for all theories.

The theories expect that high SA results in more solved goals, while low SA would result in more unsolved goals. The data does not support this. For each theory, the solved and unsolved conditions have statistically the same amount of correct and incorrect interactions. This questions the result of the study, as no theory can explain why a goal was achieved or not achieved. A closer look reveals that for the DSA and the ITC all tests had more correct cases in both the solved and unsolved conditions. For Endsley's theory, only the interaction test had more correct cases in both the solved and unsolved conditions. The hypothesis that the solved goals would have more correct cases due to higher SA is supported. The hypothesis that the unsolved goals would have more incorrect cases is not supported. The cause of this might be that the simulation was to time constraint, stopping many goals before completion. The more correct cases trend would be visible before a goal reaches completion, skewing the current data. A new study should be done to find whether the theories can explain the unsolved situation well in a more controlled condition. In contrast, Endsley's SA test for the solved and unsolved goals showed the opposite. Both solved and unsolved goals had a higher number of incorrect cases, reversing the hypotheses. The hypothesis that the solved goals would have more correct cases due to higher SA is not supported. The hypothesis that the unsolved goals would have more incorrect cases is supported. There are no obvious mitigating circumstances, meaning Endsley's theory could not explain the SA for the goals correctly. This is another reason Endsley's theory is not the best theory to explain the SA of rail traffic controllers.

With railway traffic control studies it should be taken into account that the train traffic is a continuous process. The communication for a train might go wrong, but this could be corrected later one way or another. The initial failed goal will be corrected. As this information of an initial failure is hard to gain from the transcripts, many failures might have gone by unnoticed. Another problem is that exact SA measures are missing. Although the exact SA cannot be compared between the theories, within the theories they are valid.

Simulation

The simulation can be improved too. Several information sources were missing for all of the theories. All data of the computers, such as the orders to the trains and all logs, should have been available for analysis. The communication of the TRDL to the trains via the system has been much greater than via telephone. The transcripts often did not show any communication to the machinists, but many actions where mentioned as finished in later conversations. The environment information is also in the core concepts of the ITC and DSA. Missing this information is missing SA for these theories, making the study incomplete.

New studies and suggestions

The railway traffic control system is controlled for a larger part by the system than by air traffic control. It communicates the routes, sets the switches and signs and does most of these actions without any human intervention. Air traffic control needs much more direct human control in comparison. The system in railway traffic control is an actor in both the physical and the digital world and without this system nearly all actions of railway traffic controllers seem incomplete and insufficient. All theories should accommodate the system, or not be used at all in the railways.

This study should be done anew. In the new study, the true SA can be measured. Although SA cannot be compared between the theories, the true SA might show why some cases are solved and others are not. The theories should also try to gain as much information as possible to create the GDTA for all people involved, so the ITC and Endsley's theory can be applied to all human interactions.

For the ITC it is actually advised to replace the GDTA and find something that can accommodate also inanimate sources. In addition, the CAST method seems to become too big to gain any useful information, unless broken down into small pieces. With three people it is instantly clear how the communication flows, but with many people on the same goal and sometimes taking long times to communicate, the CAST method will sooner obscure the data.

9. Conclusion

This study showed that the DSA is the best theory to analyse SA in the railways. The DSA is tied best to analyse SA and best to check the interactions, making it the most versatile in its ability to analyse SA of railway traffic controllers. This suggests that the SA can be extracted easiest from railway traffic controllers, other team members and their environment with the DSA. This also suggests that the interactions, from which the ITC gains SA, or the overlap of knowledge between people, from which Endsley's theory gains SA, where more difficult to extract SA from.

The solved and unsolved goals showed that Endsley's theory was flawed in execution. The solved and unsolved goals showed that the ITC and DSA where impossible to explain without deeper analysis of the SA. The lack of explanation does question the outcomes of this study. In addition, several information sources where missing for a complete analysis, like system communication and the background information for all roles. It is very well possible that the lack of this information, as well as the dynamic nature of the railway traffic control, has skewed the data in favour for the DSA. Regardless, the DSA seems the best theory in the railways when limited information is available.

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11. Appendix

Attachment A: *Mental models per interaction*

TRDL safety communication with backoffice

TRDL mental models:

1.1 global perspective of the situation on the tracks
    1.1.3 to keep a correct understanding of the situation on the tracks
1.2 predictions for possible deviations from the allocation plan
1.3 keep contact and up to date with important contacts
    1.3.1 Keep contact via telephone
        1.3.1.4 Keep contact and up to date with backoffice/KnoCo
    1.3.2 keep contact via logs
        1.3.2.3 keep contact and up to date with backoffice/KnoCo
2.2 Timely and safe handling with small corrections
    2.2.1 guarantee safety in several operation conditions

TRDL communication with machinist

TRDL mental models:

1.1 global perspective of the situation on the tracks
    1.1.3 to keep a correct understanding of the situation on the tracks
1.2 predictions for possible deviations from the allocation plan
1.3 keep contact and up to date with important contacts
    1.3.1 Keep contact via telephone
        1.3.1.5 Keep contact and up to date with machinist
2.2 Timely and safe handling with small corrections
    2.2.1 guarantee safety in several operation conditions

TRDL communication with DVL

TRDL mental models:

1.1 global perspective of the situation on the tracks
    1.1.3 to keep a correct understanding of the situation on the tracks
1.2 predictions for possible deviations from the allocation plan
1.3 keep contact and up to date with important contacts
    1.3.1 Keep contact via telephone
        1.3.1.2 Keep contact and up to date with DVL
    1.3.2 keep contact via logs
        1.3.2.2 keep contact and up to date with DVL
2.3 Efficient and safe handling with light or heavy calamities

2.3.1 discusses with DVL for optimal plan

DVL mental models:

1.1 Global perspective on the allocation plan of the region or area
    1.1.1 determine punctuality on regional level
    1.1.2 determine disruptions, emergencies and calamities on regional level
2.4 monitors TRDL
    2.4.1 checks logs or contact via telephone

DVL communication with LVL

DVL mental models:

1.3 Coordinates with LVL for optimal plan
    1.3.1 Passing down the chosen strategies
        1.3.2 Avioding of conflicts, change strategy if LVL thinks the corridor flow is in danger
2.3 Keeps contact with LVL
    2.3.1 keeps contact with LVL for accountability on logs and strategies

LVL mental models:

1.1 global perspective on the national situation of the tracks
    1.1.1 determine punctuality of the trains on corridor level
        1.1.1.1 determine size and cause of delays
        1.1.1.2 avoid clogging of the corridors
1.1.2 determine disruptions, barricades and calamities on corridor level
    1.1.2.1 determine disruptions
    1.1.2.2 determine local disruptions
    1.1.2.3 determine prognosis disruptions
    1.1.2.4 determine possibilities to restore or reduce the calamities
2.3 coordination between DVLs
    2.3.1 finding of a balance between possibilities and restrictions of posts
        2.3.1.1 evaluate capacity of posts
        2.3.1.2 determine amount of disruptions and calamities in a DVL region
        2.3.1.3 expectation of spread of the calamity to other posts
    2.3.2 Keep common understanding with DVL
        2.3.2.1 keep a good collaboration between LVL and DVL
        2.3.2.2 exchange information with DVL

LVL communication with LBC

LVL mental models:

2.2 coordination between transport companies and the traffic control

    2.2.1 finding of a balance between wishes of transport companies and possibilities of posts

    2.2.2 keep a common understanding with contacts and other parties

DVL communication with TRDL

DVL mental models:

1.1 Global perspective on the allocation plan of the region or area

    1.1.1 determine punctuality on regional level

    1.1.2 determine disruptions, emergencies and calamities on regional level

1.2 Collaborates with TRDL for optimal plan

    1.2.1 avoid conflicts for train flow

1.4 Gives frameworks and strategies to guide train flow (To reduce or eliminate ripple effects)

    1.4.2 determine disruptions and calamities on a regional level

1.5 correctly processing of order in local area

    1.5.1 set priorities and process them in order

2.4 monitors TRDL

    2.4.1 checks logs or contact via telephone

TRDL mental models:

1.1 global perspective of the situation on the tracks

    1.1.3 to keep a correct understanding of the situation on the tracks

1.3 keep contact and up to date with important contacts

    1.3.1 Keep contact via telephone

        1.3.1.2 Keep contact and up to date with DVL

    1.3.2 keep contact via logs

        1.3.2.2 keep contact and up to date with DVL

2.3 Efficient and safe handling with light or heavy calamities

    2.3.1 discusses with DVL for optimal plan

TRDL communication with system (ARI)

TRDL mental models:

1.1 global perspective of the situation on the tracks

    1.1.3 to keep a correct understanding of the situation on the tracks

2.1 Process minimal corrections for train flow

    2.1.1 find a balance between options of new orders and available capacity

    2.1.2 minimal but important corrections for ARI

2.2 Timely and safe handling with small corrections

    2.2.1 guarantee safety in several operation conditions

        2.2.1.1 correct and accurate applying of safety activities (VKAs)

2.3 Efficient and safe handling with light or heavy calamities

DVL communication with RBC

DVL mental models:

2.5 informs railway companies
    2.5.1 relay information by logging and telephone

LVL communication with DVL

LVL mental models:

1.1 global perspective on the national situation of the tracks
    1.1.1 determine punctuality of the trains on corridor level
        1.1.1.1 determine size and cause of delays
        1.1.1.2 avoid clogging of the corridors
    1.1.2 determine disruptions, barricades and calamities on corridor level
    1.1.2.1 determine disruptions
    1.1.2.2 determine local disruptions
    1.1.2.3 determine prognosis disruptions
    1.1.2.4 determine possibilities to restore or reduce the calamities
2.1 optimal correction of the frameworks on corridor level
    2.1.1 avoiding of conflicts (for corridor flow)
2.3 coordination between DVLs
    2.3.1 finding of a balance between possibilities and restrictions of posts
        2.3.1.1 evaluate capacity of posts
        2.3.1.2 determine amount of disruptions and calamities in a DVL region
        2.3.1.3 expectation of spread of the calamity to other posts
    2.3.2 Keep common understanding with DVL
        2.3.2.1 keep a good collaboration between LVL and DVL
        2.3.2.2 exchange information with DVL

DVL mental models:

1.3 Coordinates with LVL for optimal plan
    1.3.1 Passing down the chosen strategies
        1.3.2 Avioding of conflicts, change strategy if LVL thinks the corridor flow is in danger
2.3 Keeps contact with LVL
    2.3.1 keeps contact with LVL for accountability on logs and strategies

TRDL communication with TRDL

TRDL X mental models:

1.1 global perspective of the situation on the tracks
    1.1.1 complete of the situation of the tracks when changing shifts
    1.1.2 correct evaluation of the status of the allocation plan
    1.1.3 to keep a correct understanding of the situation on the tracks
1.2 predictions for possible deviations from the allocation plan
1.3 keep contact and up to date with important contacts
    1.3.1 common understanding via telephone
        1.3.1.1Keep contact and up to date with neighbouring TRDL
    1.3.2 common understanding via logs
        1.3.2.1 Keep contact and up to date with neighbouring TRDL

TRDL X mental models:

1.1 global perspective of the situation on the tracks
    1.1.1 complete of the situation of the tracks when changing shifts
    1.1.2 correct evaluation of the status of the allocation plan
    1.1.3 to keep a correct understanding of the situation on the tracks
1.2 predictions for possible deviations from the allocation plan
1.3 keep contact and up to date with important contacts
    1.3.1 common understanding via telephone
        1.3.1.1Keep contact and up to date with neighbouring TRDL
    1.3.2 common understanding via logs
        1.3.2.1 Keep contact and up to date with neighbouring TRDL

TRDL communication with KnoCo

TRDL mental models:

1.1 global perspective of the situation on the tracks
    1.1.1 complete of the situation of the tracks when changing shifts
    1.1.2 correct evaluation of the status of the allocation plan
    1.1.3 to keep a correct understanding of the situation on the tracks
1.3 keep contact and up to date with important contacts
    1.3.1 common understanding via telephone
        1.3.1.4 Keep contact and up to date with backoffice and KnoCo
    1.3.2 common understanding via logs
        1.3.2.3 Keep contact and up to date with neighbouring backoffice and KnoCo

TRDL communication with calamity officer: correct

TRDL mental models:

1.1 global perspective of the situation on the tracks
    1.1.3 to keep a correct understanding of the situation on the tracks
1.2 predictions for possible deviations from the allocation plan
1.3 keep contact and up to date with important contacts

1.3.1 Keep contact via telephone

1.3.1.3 Keep contact and up to date with ‘Algemeen Leider’ (Calamity officer)

Example:

16:54

(DVL)	(LVL)	Hey <LVL>, hier de DVL van Amsterdam, <DVL>. Want ik kreeg de melding van de TRDL Uitgeest dat de trein 61262 daar waren wat problemen met de loc, wat rookontwikkeling en de treindienstleider die zou even laten kijken. Nu hoor ik het zo meteen nog. <stilte> Ja, Uitgeest. Hij wil de loc omrijden, maar er waren die problemen met die loc. <stilte> Eh ja ik heb nog niet gehoord dat de trein het verkeer gestaakt heeft. <stilte> ja ok goed zo <LVL>. Uit.
(LVL)	(DVL)	<onverstaanbaar>. Hij staat op Uitgeest zelf? <stil> Ok. <stil> Je blijft dus wel rijden daar. <stil> Prima, ik hoor zo van jou. Ja dank je.

Shared Mental Models	DVL	LVL	Consistency
Model:	2.3.1 keeps contact with LVL for accountability on logs and strategies	1.1.1.1 determine size and cause of delays	No
		1.1.2.1 determine disruptions	No
		1.1.2.3 determine prognosis disruptions	No

Endsley: **Incorrect**

Endsley docs: correct

DVL GDTA in documents:

1.3 Coordinates with LVL for optimal plan

1.3.1 Passing down the chosen strategies

1.3.2 Avioding of conflicts, change strategy if LVL thinks the corridor flow is in danger

2.3 Keeps contact with LVL

2.3.1 keeps contact with LVL for accountability on logs and strategies

DVL GDTA: correct

LVL GDTA in documents:

1.1 global perspective on the national situation of the tracks

1.1.1 determine punctuality of the trains on corridor level

1.1.1.1 determine size and cause of delays

1.1.1.2 avoid clogging of the corridors

1.1.2 determine disruptions, barricades and calamities on corridor level

1.1.2.1 determine disruptions

1.1.2.2 determine local disruptions

1.1.2.3 determine prognosis disruptions

1.1.2.4 determine possibilities to restore or reduce the calamities

2.3 coordination between DVLs

- 2.3.1 finding of a balance between possibilities and restrictions of posts
  - 2.3.1.1 evaluate capacity of posts
  - 2.3.1.2 determine amount of disruptions and calamities in a DVL region
  - 2.3.1.3 expectation of spread of the calamity to other posts
- 2.3.2 Keep common understanding with DVL
  - 2.3.2.1 keep a good collaboration between LVL and DVL
  - 2.3.2.2 exchange information with DVL

LVL GDTA: correct

Attachment B: *Mutual belief model*

Example

(DVL)	(LVL)	Hey <LVL>, hier de DVL van Amsterdam, <DVL>. Want ik kreeg de melding van de TRDL Uitgeest dat de trein 61262 daar waren wat problemen met de loc, wat rookontwikkeling en de treindienstleider die zou even laten kijken. Nu hoor ik het zo meteen nog. <stilte> Ja, Uitgeest. Hij wil de loc omrijden, maar er waren die problemen met die loc. <stilte> Eh ja ik heb nog niet gehoord dat de trein het verkeer gestaakt heeft. <stilte> ja ok goed zo <LVL>. Uit.
(LVL)	(DVL)	<onverstaanbaar>. Hij staat op Uitgeest zelf? <stil> Ok. <stil> Je blijft dus wel rijden daar. <stil> Prima, ik hoor zo van jou. Ja dank je.

DVL 61262 (broken, spread SA) → LVL 

Mutual belief model: before	DVL	LVL
Cognition person	61262 broken, possibly unable to move	61262 on schedule
Beliefs on others cognition	61262 on schedule	61262 on schedule
Beliefs on others cognition of self	61262 on schedule	61262 on schedule

Mutual belief model: after	DVL	LVL
Cognition person	61262 broken, possibly unable to move	61262 broken, possibly unable to move
Beliefs on others cognition	61262 broken, possibly unable to move	61262 broken, possibly unable to move
Beliefs on others cognition of self	61262 broken, possibly unable to move	61262 broken, possibly unable to move

Before: Unequal belief

After: Equal belief

Propositional network DVL**: Emergencies, LVL, classify, report, planning (Allocation plan), ProRail employees, oral communication, regional**

Propositional network LVL: **Emergencies, DVL, monitoring, planning (allocation plan), ProRail employees, oral communication**

Propositional network DVL documents: Report, LVL, ProRail employees, (deviations/interference/emergencies), (limit), (strategies), (planning (allocation plan)), (advice), (infrastructure), (correct availability), (oral communication/system communication), (regional)

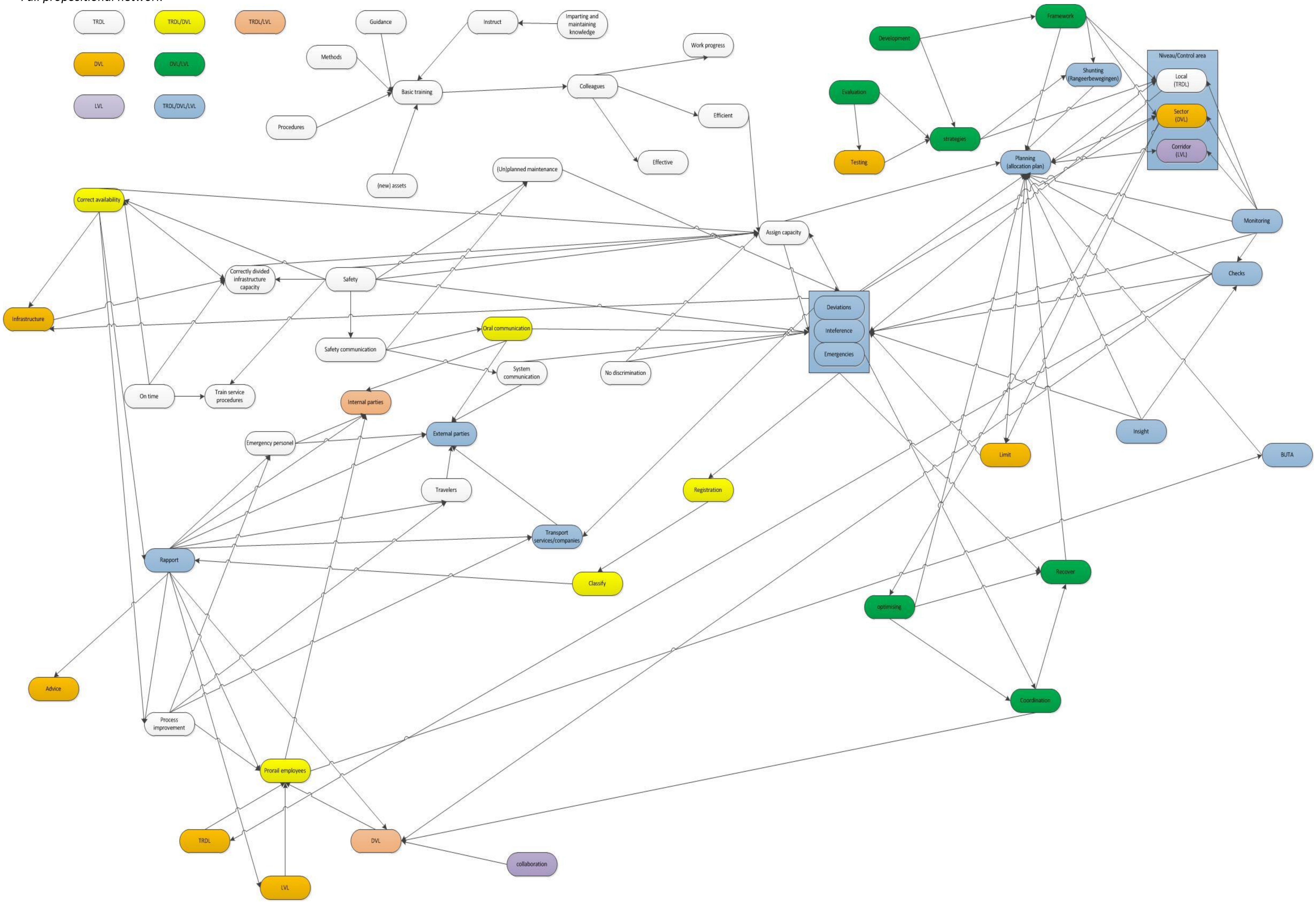
Propositional network DVL: correct

Propositional network LVL documents: monitoring, (checks), (planning (allocation plan)), (strategies), (oral communication/system communication)
Propositional network LVL: correct

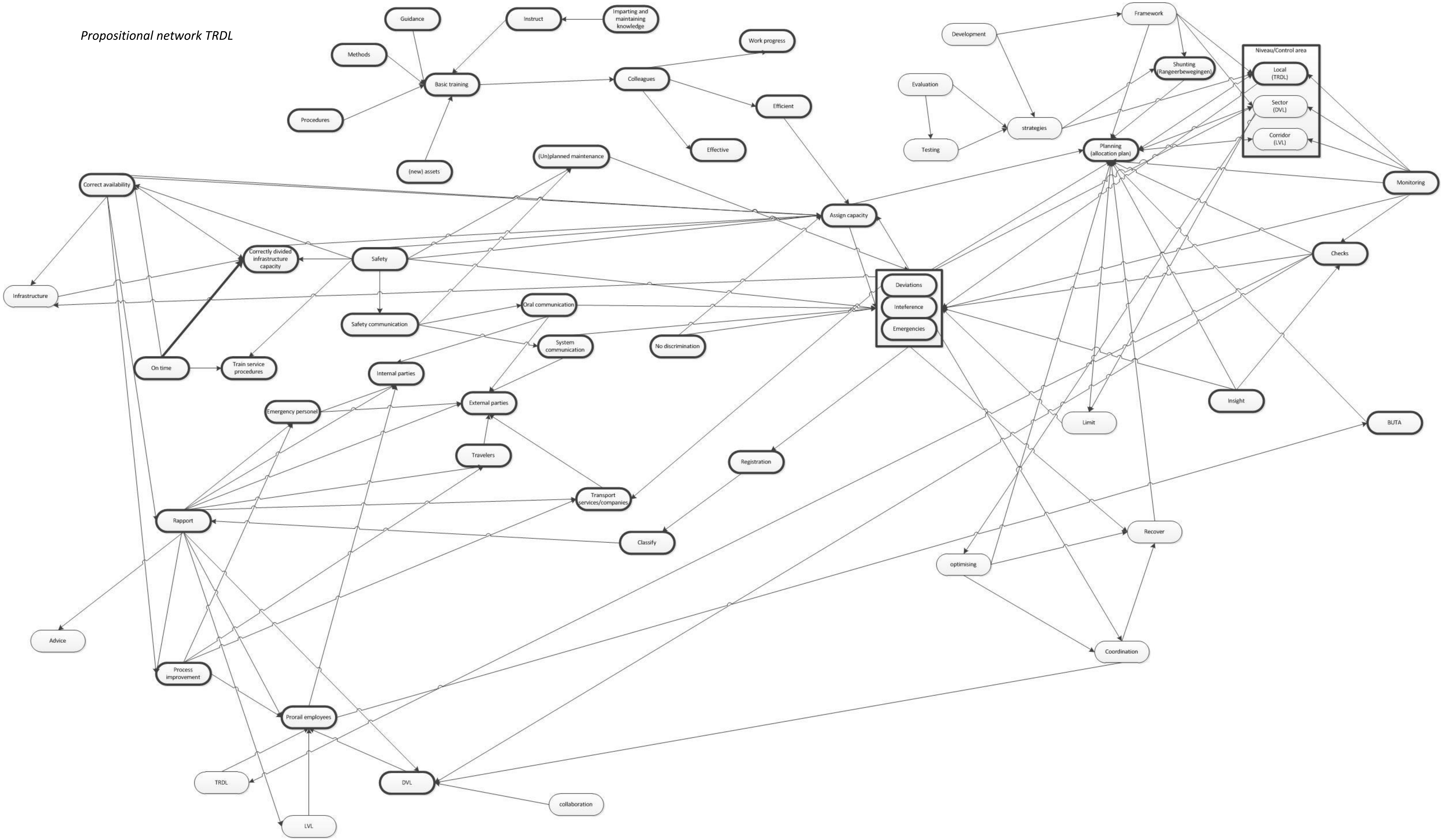
DSA: correct
DSA docs: correct

Attachment C: *DSA Propositional networks*

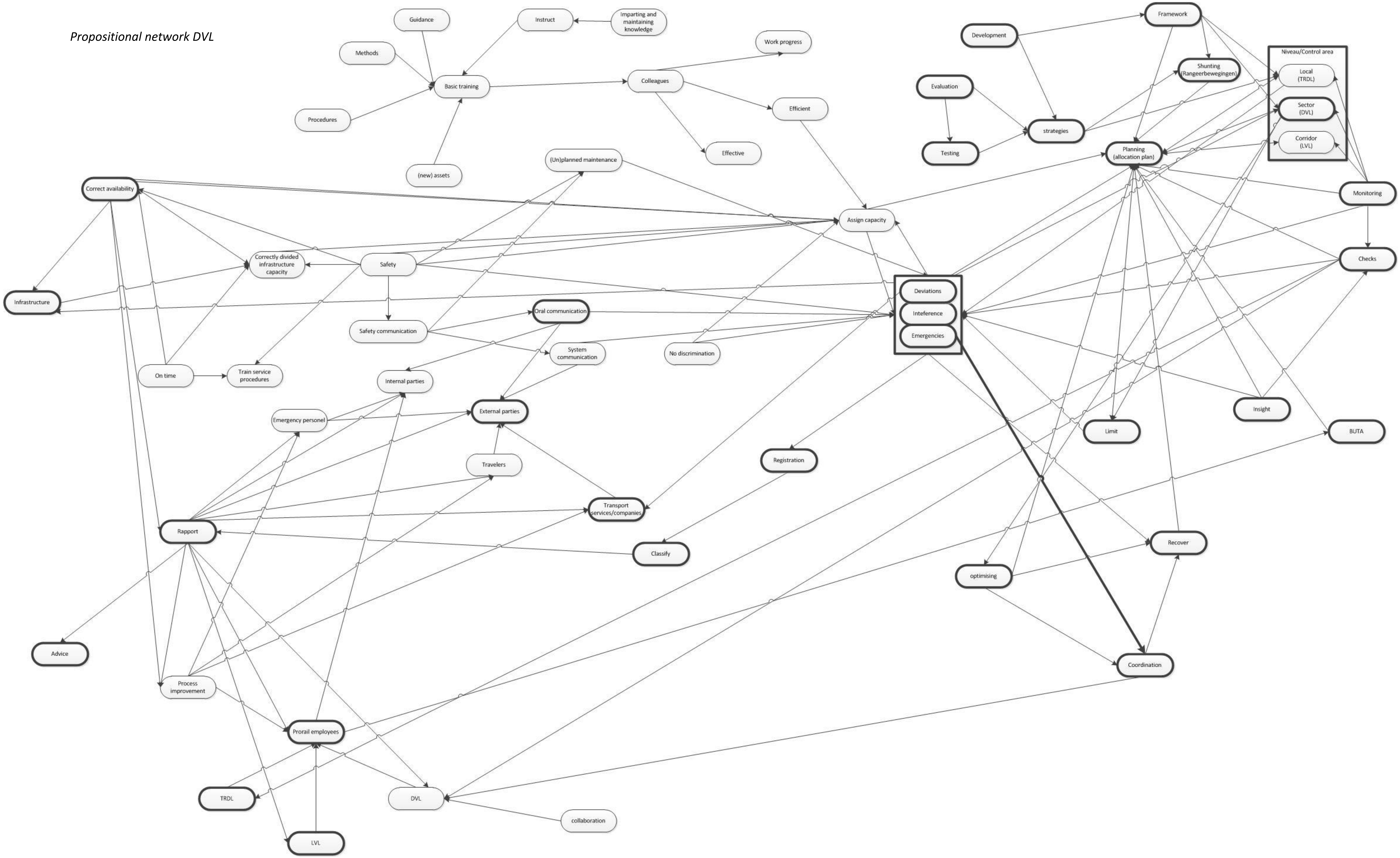
Full propositional network



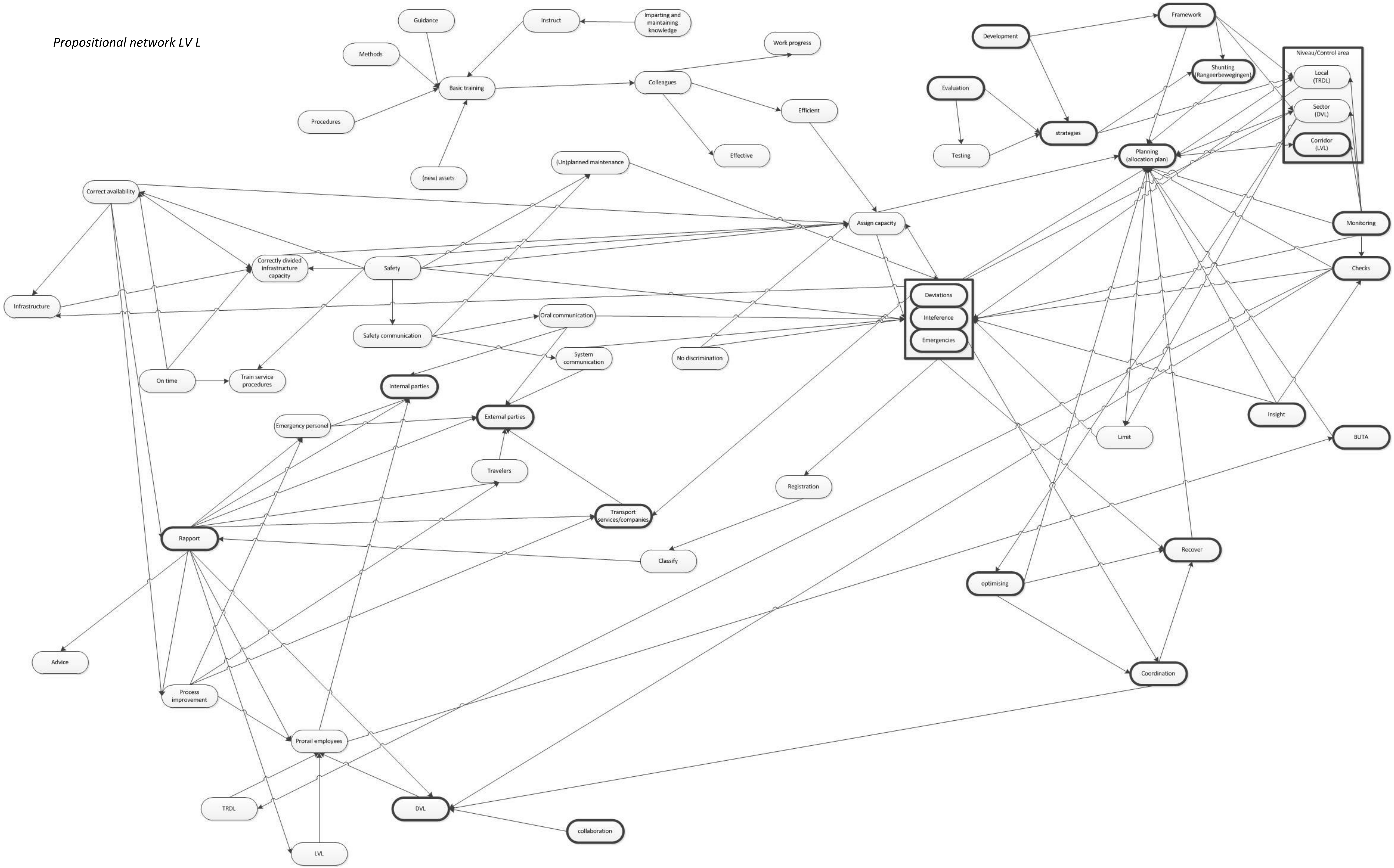
Propositional network TRDL



Propositional network DVL



Propositional network LV L



Attachment D: *DSA propositional network keywords per interaction*

TRDL safety communication with backoffice: correct

Propositional network TRDL documents: safety/safety communication, oral communication, ProRail employees, (Emergencies/Deviations/interference), (correctly divided infrastructure capacity), (infrastructure), (planning (allocation plan))

TRDL deviation or problem prevention communication with machinist: correct

Propositional network TRDL documents: Planning (allocation plan), Oral communication, external partners (correctly divided infrastructure capacity)*, (*correct availability), (Safety), (on time), (train service procedures), (deviations/interference/emergencies), (monitoring), (checks), (assign capacity), (registration)

TRDL communication with DVL: correct

Propositional network TRDL documents: Report, Deviation/interference/emergencies and/or planning (allocation plan) and correctly divided infrastructure capacity/correct availability, ProRail employees, DVL (on time), (safety), (safety communication), (shunting), (oral communication), (system communication), (local)

Propositional network DVL documents: Monitoring, planning (allocation plan), TRDL, ProRail employees, (checks), (correct availability), (infrastructure), (oral communication), (registration), (classify), (system communication), (emergencies/deviations/interference)

DVL communication with LVL: correct

Propositional network DVL documents: Report, LVL, ProRail employees, (deviations/interference/emergencies), (limit), (strategies), (planning (allocation plan)), (advice), (infrastructure), (correct availability), (oral communication/system communication)

Propositional network LVL documents: monitoring, (checks), (planning (allocation plan)), (strategies), (oral communication/system communication)

LVL communication with LBC: correct

Propositional network LVL documents: deviations/interference/emergencies/report/planning(allocation plan), internal partners, national, ProRail employees, (monitoring1), (checks1), (insight), (strategies), (coordination), (optimising), (recover)

DVL communication with TRDL: correct

Propositional network DVL documents: Strategies/planning (allocation plan)/deviations/interference/emergencies, oral communication/system communication, TRDL, ProRail employees, (correct availability), (report), (advice), (regional), (planning (allocation plan)), (optimising), (coordination), (recover), (limit), (insight), (monitoring), (checks), (infrastructure), (shunting), (local)

Propositional network TRDL documents: Report/planning (allocation plan)/deviations/interference/emergencies, oral communication/system communication, DVL, ProRail employees, (safety communication), (safety), (correct availability), (infrastructure), (on time), train service procedures), (shunting)

TRDL communication with system (ARI): correct

Propositional network TRDL documents: Assign capacity/system communication/correct availability/on time/planning (allocation plan)/shunting, (monitoring), (checks), (insight), (deviations/interference/emergencies)

DVL communication with RBC: correct

Propositional network DVL documents: Planning (allocation plan)/strategies/emergencies/interference/deviations, report, internal partners, ProRail employees, oral communication/system communication, (infrastructure), (correct availability), (monitoring), (checks), (insight), (collaboration), (limit), (regional), (local)

LVL communication with DVL: correct

Propositional network LVL documents: planning (allocation plan)-monitoring/deviations/interference/emergencies/strategies, oral communication/system communication, ProRail employees, DVL, (checks), (insight), (recover), (optimisinig), (coordination), (registration), (classify), (national)

Propositional network DVL documents: emergencies/interference/deviations/planning (allocation plan), oral communication/system communication, LVL, (limit), (correct availability), (infrastructure), (regional), (national), (report)

TRDL communication with TRDL: correct

Propositional network TRDL X: Planning (allocation plan)/shunting/infrastructure/safety communication/emergencies/deviations/interference, local, oral communication/system communication, ProRail employees, TRDL, (assign capacity), (correctly divided infrastructure), (strategies), (on time), (train service procedures), (report)

Propositional network TRDL X: Planning (allocation plan)/shunting/infrastructure/safety communication/emergencies/deviations/interference, local, oral communication/system communication, ProRail employees, TRDL, (monitoring), (checks), (correctly divided infrastructure), (strategies), (on time)

TRDL communication with KnoCo: correct

Propositional network TRDL: Local, planning (allocation plan)/shunting/correctly divided infrastructure capacity, oral/system communication, ProRail employees, (train service procedures), (on time), (report), (monitoring), (checks)

Attachment E: *ITC CAST method*

16:54

(DVL)	(LVL)	Hey <LVL>, hier de DVL van Amsterdam, <DVL>. Want ik kreeg de melding van de TRDL Uitgeest dat de trein 61262 daar waren wat problemen met de loc, wat rookontwikkeling en de treindienstleider die zou even laten kijken. Nu hoor ik het zo meteen nog. <stilte> Ja, Uitgeest. Hij wil de loc omrijden, maar er waren die problemen met die loc. <stilte> Eh ja ik heb nog niet gehoord dat de trein het verkeer gestaakt heeft. <stilte> ja ok goed zo <LVL>. Uit.
(LVL)	(DVL)	<onverstaanbaar>. Hij staat op Uitgeest zelf? <stil> Ok. <stil> Je blijft dus wel rijden daar. <stil> Prima, ik hoor zo van jou. Ja dank je.

DVL communication with LVL: correct

DVL 61262 (broken, spread SA) → LVL 

ITC: correct

Attachment H: *abbreviations*

ARI – Automatic train management system (Automatische Rij Instelling)

ATC – Air Traffic Controller

DC – Distributed Cognition

DSA – Distributed Situation Awareness

DVL – Decentral traffic control (Decentrale VerkeersLeider)

GDTA – Goal Directed Task Analysis

ITC – Interactive Team Cognition

LVL – National traffic control (Landelijke VerkeersLeider)

SA – Situation Awareness

TRDL – Railway traffic control (TreinDienstLeider)