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Achieving Optimal Human Performance and Safety using Applied CWA Methodology

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Introduction

With the growing complexity of our facilities and about 90% of industrial accidents traceable to human errors, integrating human factors into facilities design and construction has become imperative. Although, human errors are not the root cause of these accidents, a deficient system made the human error possible leading to disasters. In today's design world, human factors integration into design is all about designing the facilities to make human error almost impossible (i.e. make it difficult for operators to make mistake that will lead to a disaster by using human-oriented displays/controls, interlock systems etc.). Before these human-oriented elements are designed, human factors analyses need to be done to determine possible error scenarios and error resilience of the systems. The results of these analyses are then integrated into the design of the facilities to enhance safety and human performance. This is why human factors analysis has now become an important part of safety and risk management. In spite of this new focus on human factors integration, there is still a lot of confusion and misunderstanding universally on how this can be adopted by companies using a generic framework for consistent application. This is as a result of absence of common approach from industries. To analyze complex novel or existing socio-technical systems, human factors experts tends to apply set(s) of methodologies that will give sufficient human factors information for safer systems design.

This paper presents how optimal human performance and safety can be achieved by incorporating Applied Cognitive Work Analysis (ACWA) methodology as a design and analysis tool within the human factors integration efforts during design/analysis of complex novel or existing socio-technical systems. An exploratory analysis of road system using Applied Cognitive Work Analysis (ACWA) with a view to identifying the constraints faced by road users in interacting with the road systems shows how roadway elements can best be designed to support road users in improving performance and enhancing safety.

Human Performance within Complex Socio-technical Systems

Socio-technical systems are based on a theory founded on two main principles. The first principle being that social (human) and technical factors create the conditions for overall systemperformance with linear interactions that are often predicted and designed, and non-linear interactions that are often unpredicted/unexpected.[1] The non-linear interactions are difficult to deal with which makes the system more complex and these interactions has been the focus of human-system analysis efforts. These non-linear interactions are mainly attributable to the social (human) factors while the technical system often behave in a linear and predictable manner, but some advanced technical systems can have a non-linear behaviour.[1]

The second is the principle of joint optimization which means that both social (human) and technical factors have to be considered when optimizing system performance.[1]Optimizing just one of these two factors at a time increases the unpredictable non-linear interactions and relationships that actually decrease system performance. A change in the system – either a new technical component or new procedure can affect the user interaction with the system technique which in turn affect system performance in unexpected ways. The effects will be mainly on the social factors (human performance).

Given these principles, achieving optimal human performance and overall system performance would mean using pragmatic methodologiesin analyzing the human-system interactions to capture possible non-linear relationships and incorporate them into the system design and development. The Applied Cognitive Work Analysis (ACWA) methodology can be handy here to model human–system interactions to explore the constraints and demands that result in non-linear behaviours within a complex socio-technical environment. Also, when considering changes in a complex socio-technical system, effects of the changes on the human-system interactions (social and technical factors) can be analyzed to inform how joint human-system optimization can be achieved so as not to increase the unpredictable/unexpected non-linear relationships.

Usually, the linear interactions can be identified by applying normative approaches while ACWA approach is equipped to reveal non-linear interactions in systems that support emergent behaviour.This type of analysis is said to be 'formative' instead of 'normative' and focused not on the objects within a particular situation, but on the 'constraints' that exist and the behaviours they may afford.[2]Improving human performance within a complex socio-technical system involves creating affordances that allow users to work at a formative level. Users should not always follow the detailed prescriptions of normative task approaches, the performance of tasks should be focused on the purpose and constraints of the domain.[2]– which the design artefacts of ACWA methodology presents.

Walker, G., Jenkin, D., Stanton, N., Salmon, P. 2009. *Cognitive Work Analysis: Coping with Complexity*. Farnham, UK: Ashgate Publishing Company

[2]Walker, G. 2011. *Human Factors Methods – Course Material.* Edinburgh: Heriot-Watt University

Modelling Road Transport System using Applied Cognitive Work Analysis (ACWA)

The road transportation system is a typical socio-technical system in which human interacts with roadway elements and facilities to successfully accomplish the driving or other road usage tasks. In the design, representation and evaluation of complex, socio-technical systems and their components technologies, cognitive work analysis (CWA) offers a comprehensive methodical framework to achieve this.[1]As driving and other road user-roadway interactions are cognitive tasks, a careful analysis of these tasks using the cognitive work analysis framework will reveal the decision requirements and psychological processes used by road users in accomplishing results. It is based on these that elements of roadways are designed to best support road users in navigating the roadway safely. There is a great potential for applying methods within the CWA framework in the design of road transport system, particularly in the design, development and evaluation of driver training programmes and the design and development of road transport technologies, vehicle cockpits and roadway elements/artefacts.[1]

The CWA framework informs the Ecological Interface Design (EID) concepts to be used in the design of interfaces, systems and procedures. Ecological Interface Design allows users to take effective action with the interface and understand how those actions will move them towards the achievement of their goals.[2]CWA is currently receiving increased attention from system designers and engineers owing to its strength in formative modeling of human-system interaction. The focus of CWA is on the properties of the work domain, tasks, artifacts and agents that constrain activity within a particular system.[1] A literature review of the application of CWA indicate that the framework has been used in several domains including aviation, nuclear power, military, air traffic control, road transport etc.

Due to the broad scope of the CWA, the issue of repeatability of analysis results, and the usability of analysis results in the design of scalable decision support systems, Applied Cognitive Work Analysis (ACWA) was developed to satisfy the critical challenges to making Cognitive Task Design part of the mainstream systems engineering efforts.[3] The ACWA approach is a structured, principled methodology to systematically transform the problem from an analysis of the demands of a domain to identifying visualizations and decision-aiding concepts that will provide effective support.[3]

In this exploratory analysis, the road system was considered as a work environment and a functional abstraction modeling identified the constraints and demands that are faced by road users within the road transport system.From the functional abstraction model, cognitive work requirements, information/perceptual requirements and a ‘model of support’ for safe road usage were developed.

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[1]Salmon, P., Stephen, K., Lenne, M. and Regan, M. 2005. *Cognitive Work Analysis and Road Safety: Potential Applications in Road Transport*, Proceedings of Australasian Road Safety Research Policing Education Conference, Victoria: Australasian Road Safety Research Policing Education Conference, 2005.
[2]Burns, C. B., & Hajdukiewicz, J. R. 2004. *Ecological interface design.* Boca Raton, USA: CRC Press
[3]Elm, W.C., Potter, S.S., Gualtieri, J.W., Roth, E.M., and Easter, J.R. 2003. *Applied cognitive work analysis: A pragmatic methodology for designing revolutionary cognitive affordances*. In Hollnagel, E. (Ed) Handbook for Cognitive Task Design. London: Lawrence Erlbaum Associates. pp. 357–382

Methodology

The data used for this exploratory analysis were gathered through observational studies of selected road usage scenarios and interviews of road users. During the observational studies and interviews, a template of the standard task analysis table common in the road transport domain was used to acquire data from the field. After selecting driving/road usage scenarios to be analyzed, a simple task analysis table was developed for each scenario and the driving tasks and sub-tasks were populated by direct observation of a driver/road user in each scenario. Three pilot runs and five actual field trips were organised with different competent drivers in areas they were not too familiar with, so navigating the roadways were mainly on perceptual cues from the road environment. For each driving task, I recorded the observed roadway features/elements and physical activities of the driver in response to the roadway elements. Same technique was used to observe cyclists and pedestrians. In addition to the observations, a questionnaire which was part of the task analysis table was used to collect information on perceptual cues they retrieved from the road environment and how they interpreted them in taking appropriate actions.

In addition to the data gathered during the field trips, drivers, cyclist and pedestrians were interviewed to capture the essential concepts of the road transport domain, knowledge and strategies used by road users to cope with tasks demands within the roadway system. The observation part is to analyse how tasks are actually being performed by road users. The knowledge elicitation from the domain practitioners (road users) was used to construct the functional abstraction network (FAN) of the human-roadway system interaction.

The exploratory analysis of road user – road system interaction using the Applied Cognitive Work Analysis (ACWA) framework comprised of:

1. Modeling the Work Domain using Functional Abstraction Network (FAN)
2. Modeling Cognitive Demands – deriving Cognitive Work Requirements (CWR)
3. Capturing the support Needs – identifying Information/Relationship Requirements (IRR)
4. Developing a ‘model of support’ using Representation Design Requirements (RDR)

Modeling the Work Domain using Functional Abstraction Network (FAN)

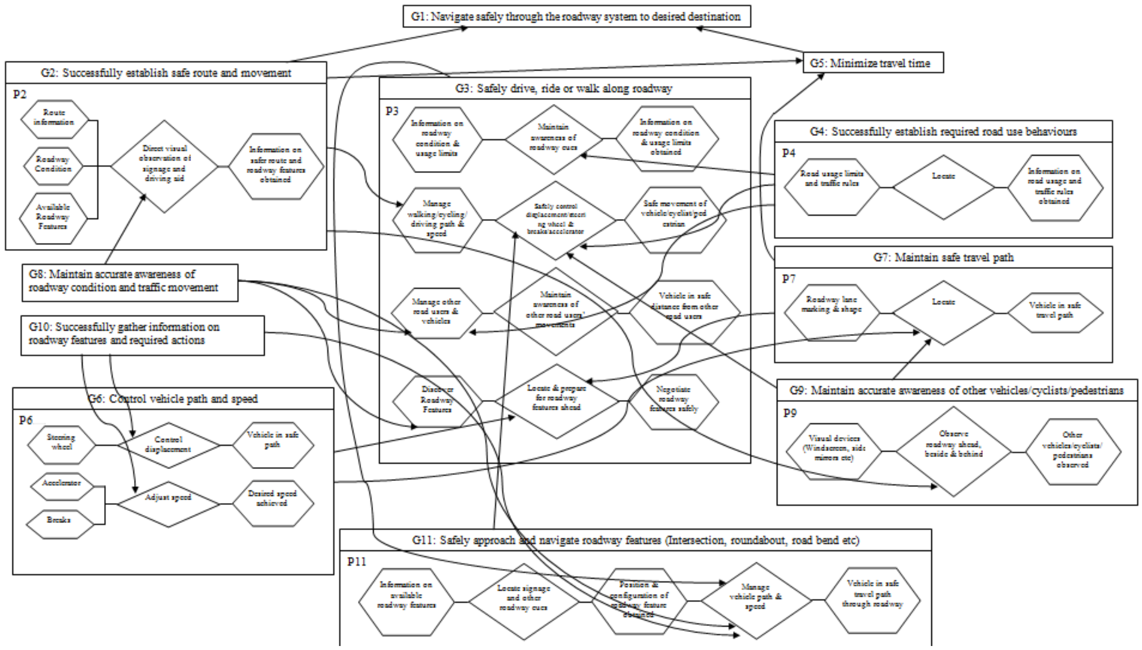

Figure 1. Functional Abstraction Network (FAN) of Human-Road System Interaction

Modeling Cognitive Demands – deriving Cognitive Work Requirements (CWR)

Cognitive Work Requirements (CWR)
CWR G1-1 – “Monitor success of navigating through roadway”
CWR G2-1 – “Monitor success of establishing safe route and movement”
CWR G2-2 – “Choose safer route”
CWR P2-1 – “Monitor roadway conditions, signage and driving aids”
CWR P2-2 – “Monitor success of roadway condition/route information obtained”
CWR P2-3 – “Determine the safety impact of roadway conditions”
CWR G3-1 – “Monitor success of driving/cycling/walking through roadway”
CWR P3-1 – “Monitor roadway cues”
CWR P3-2 – “Monitor success of driving within usage limits and road conditions”
CWR P3-3 – “Adjust driving/cycling/walking path and speed”
CWR P3-4 – “Monitor success of path and speed control”
CWR P3-5 – “Monitor the movement of other road users”
CWR P3-6 – “ Monitor success of keeping safe distance from other road users”

CWR P3-7 – “Determine the right road intersection or roundabout to turn”
CWR P3-8 – “Determine configuration of road intersection , roundabout etc”
CWR P3-9 – “Determine the amount of steering displacement and speed required to negotiate road intersection , roundabout etc”
CWR G4-1 – “Monitor success of establishing traffic rules and road usage limits”
CWR P4-1 – “Determine if road usage is in accordance with required usage limits and traffic rules”
CWR G5-1 – “Monitor travel time”
CWR G6-1 – “Monitor the success of path and speed control”
CWR P6-1 – “Determine when speed and path adjustment is required”
CWR P6-2 – “Choose safe driving/cycling/walking path”
CWR P6-3 – “Monitor driving/cycling/walking path and speed”
CWR G7-1 –“Monitor success of keeping vehicle in safe travel path”
CWR P7-1 – “Monitor roadway perspective and markings”
CWR P7-2 – “Determine if vehicle is in safe/required travel path”
CWR G8-1 – “Monitor the success of maintaining accurate awareness of roadway condition and traffic movement”
CWR G9-1 – “Monitor the success of maintaining accurate awareness of other vehicles/cyclists/pedestrians”
CWR P9-1 – “Monitor roadway ahead, beside and behind”
CWR G10-1 – “Monitor the success of gathering information on roadway features and required actions”
CWR G11-1 – “Monitor the success of approaching and negotiating roadway features (intersection, roundabout, road bend etc)
CWR P11-1 – “Monitor signage and roadway cues”
CWR P11-2 – “Determine configuration of roadway features (intersection, roundabout, road bend etc)”
CWR P11-3 – “Determine the amount of steering displacement and speed required to negotiate roadway features (intersection, roundabout, road bend etc)”
CWR P11-4 – “Monitor success of keeping vehicle in safe travel path through roadway feature (intersection, roundabout, road bend etc)”
CWR P11-5 – “Monitor traffic movements at road feature”
CWR P11-6 – “Estimate the potential of hazards on roadway feature”

Table 1. Cognitive Work Requirements associated with safe navigation along a roadway

Capturing the Support Needs – identifying Information/Relationship Requirements (IRR)

Information Relationship Requirements (IRR)
CWR G1-1 – “Monitor success of navigating through roadway”
IRR G1-1.1 – “Indication of conformance with or deviations from safe road use practices over time”
CWR G2-1 – “Monitor success of establishing safe route and movement”
IRR G2-1.1 – “Indication of safe route and current route”
IRR G2-1.2 – “Present deviations from target/safe route over time”
CWR G2-2 – “Choose safer route”
IRR G2-2.1 – “Indication of route alternatives”
IRR G2-2.2 – “States of route alternatives”
IRR G2-2.3 – “Location and distance of route alternatives to desired destination”
CWR P2-1 – “Monitor roadway conditions, signage and driving aids”
IRR P2-1.1 – “Indication of roadway conditions”
IRR P2-1.2 – “Indication and location of road signage”
IRR P2-1.3 – “Indication and measures of vehicle control parameters (speed, heading, acceleration etc.) and route plan on the driving aids
CWR P2-2 – “Monitor success of roadway condition/route information obtained”
IRR P2-2.1 – “States of roadway and route guidance received over time”
CWR P2-3 – “Determine the safety impact of roadway conditions”
IRR P2-3.1 – “Indication of roadway condition and physical hazards present”
IRR P2-3.2 – “Estimated contribution and severity of the roadway condition and physical hazards present”
CWR G3-1 – “Monitor success of driving/cycling/walking through roadway”
IRR G3-1.1 – “Present deviation from target driving/cycling/walking behaviours over time”
IRR G3-1.2 – “Measure of satisfaction which the road user derived from the directional/guidance and safety elements of the roadway”
CWR P3-1 – “Monitor roadway cues”
IRR P3-1.1 – “Indication of roadway design elements and required actions”
IRR P3-1.2 – “Estimated intent of particular roadway design and elements”
CWR P3-2 – “Monitor success of driving within usage limits and road conditions”

IRR P3-2.1 – "Indication of road usage limits and state of roadway"
IRR P3-2.2 – "Indication of deviations from /conformance with target road usage limits over time"
CWR P3-3 – "Adjust driving/cycling/walking path and speed"
IRR P3-3.1 – "Estimated measure of current path and location"
IRR P3-3.2 – "Measure of current speed in relation to other road users"
IRR P3-3.3 – "Estimated time available to adjust path and speed"
CWR P3-4 – "Monitor success of path and speed control"
IRR P3-4.1 – "Indication of required road path and speed limit"
IRR P3-4.2 – "Current deviation from target road path and required speed"
CWR P3-5 – "Monitor the movement of other road users"
IRR P3-5.1 – "Relative positions and appreciation of the movement of other road users"
CWR P3-6 – "Monitor success of keeping safe distance from other road users"
IRR P3-6.1 – "Present distance from other road users"
IRR P3-6.2 – "Deviations from the target safe distance over time"
CWR P3-7 – "Determine the right road intersection or roundabout to turn"
IRR P3-7.1 – "Indication of the road intersection or roundabout configuration"
IRR P3-7.2 – "Roadway signage/directional signs in relation to desired destination at road intersection or roundabout"
CWR P3-8 – "Determine configuration of road intersection, roundabout etc"
IRR P3-8.1 – "Indication of roadway configuration on signage"
CWR P3-9 – "Determine the amount of steering displacement and speed required to negotiate road intersection, roundabout etc."
IRR P3-9.1 – "Estimated roadway configuration from the immediate forward view"
IRR P3-9.2 – "Indication of current speed and heading in relation to roadway configuration"
IRR P3-9.3 – "Current deviations from required speed and path adjustment"
CWR G4-1 – "Monitor success of establishing traffic rules and road usage limits"
IRR G4-1.1 – "Indication of traffic rules and road usage limits"
IRR G4-1.2 – "Deviations from the target behaviour and road usage limits over time"
CWR P4-1 – "Determine if road usage is in accordance with required usage limits and traffic rules"
IRR P4-1.1 – "Deviations from the target behaviour and road usage limits over time"

CWR G5-1 – “Monitor travel time”
IRR G5-1.1 – “Indication of current time”
IRR G5-1.2 – “Indication of expected time of arrival at destination”
IRR G5-1.2 – “The time required to navigate through roadway to destination”
CWR G6-1 – “Monitor the success of path and speed control”
IRR G6-1.1 – “Indication of required road path and speed limit”
IRR G6-1.2 – “Current deviation from target road path and required speed”
CWR P6-1 – “Determine when speed and path adjustment is required”
IRR P6-1.1 – “Current path in relation to roadway lane marking”
IRR P6-1.2 – “Measure of current speed in relation to speed limit and other road users”
CWR P6-2 – “Choose safe driving/cycling/walking path”
IRR P6-2.1 – “Indication of available paths/routes”
IRR P6-2.2 – “Condition of road paths/routes and indication of hazards present”
IRR P6-2.3 – “Location and distance of road path to desired destination”
CWR P6-3 – “Monitor driving/cycling/walking path and speed”
IRR P6-3.1 – “Indication of current driving/cycling/walking path and speed”
IRR P6-3.2 – “Present deviation from target driving/cycling/walking path and speed over time”
CWR G7-1 –“Monitor success of keeping vehicle in safe travel path”
IRR G7-1.1 – “Indication of current travel path”
IRR G7-1.2 – “Deviations from target travel path over time”
CWR P7-1 – “Monitor roadway perspective and markings”
IRR P7-1.1 – “Indication of roadway design, lane markings and required actions”
IRR P7-1.2 – “Estimated intent of roadway design and elements”
CWR P7-2 – “Determine if vehicle is in safe/required travel path”
IRR P7-2.1 – “Indication of current travel path”
IRR P7-2.2 – “Current deviation from target travel path”
CWR G8-1 – “Monitor the success of maintaining accurate awareness of roadway condition and traffic movement”
IRR G8-1.1 – “Indication of roadway condition and traffic movements”
IRR G8-1.2 – “Indication of road usage actions in accordance with roadway conditions and traffic movement over time”
CWR G9-1 – “Monitor the success of maintaining accurate awareness of other

vehicles/cyclists/pedestrians”
IRR G9-1.1 – “Present indications of other road users”
IRR G9-1.2 – “Deviations from the required safe behaviour in relation to other road users over time”
CWR P9-1 – “Monitor roadway ahead, beside and behind”
IRR P9-1.1 – “Indication of roadway complete view on visual devices”
IRR P9-1.2 – “States of roadway as viewed on visual devices over time”
CWR G10-1 – “Monitor the success of gathering information on roadway features and required actions”
IRR G10-1.1 – “Indication of roadway features and required actions”
IRR G10-1.2 – “Indication of road usage actions in accordance with roadway features over time”
CWR G11-1 – “Monitor the success of approaching and negotiating roadway features (intersection, roundabout, road bend etc)
IRR G11-1.1 – “Indication of current maneuver through roadway feature”
IRR G11-1.2 – “Deviations from required travel path through roadway feature”
CWR P11-1 – “Monitor signage and roadway cues”
IRR P11-1.1 – “Indication of roadway design elements and signage”
IRR P11-1.2 – “Estimated intent of signage and particular roadway design”
CWR P11-2 – “Determine configuration of roadway features (intersection, roundabout, road bend etc)”
IRR P11-2.1 – “Indication of roadway configuration on signage”
CWR P11-3 – “Determine the amount of steering displacement and speed required to negotiate roadway features (intersection, roundabout, road bend etc)”
IRR P11-3.1 – “Estimated roadway configuration from the immediate forward view”
IRR P11-3.2 – “Indication of current speed and heading in relation to roadway configuration”
IRR P11-3.3 – “Current deviations from required speed and path adjustment”
CWR P11-4 – “Monitor success of keeping vehicle in safe travel path through roadway feature (intersection, roundabout, road bend etc)”
IRR P11-4.1 – “Indication of required travel path through roadway feature”
IRR P11-4.2 – “Current deviation from target travel path”
CWR P11-5 – “Monitor traffic movements at road feature”
IRR P11-5.1 – “Positions of other vehicles in relation to roadway feature”

IRR P11-5.2 – “Indication of traffic control device at roadway feature”
CWR P11-6 – “Estimate the potential of hazards on roadway feature”
IRR P11-6.1 – “Positions of other road users in relation to roadway feature”
IRR P11-6.2 – “Indication of pedestrian devices at roadway feature”

Table 2. Information/Relationship Requirements associated with safe navigation along a roadway

<u>Developing a ‘model of support’ using Representation Design Requirements (RDR)</u>

From the decisions (CWR) and supporting information requirements (IRR) derived from the FAN, a Representation Design Requirements (RDR) was produced which informs the design of intelligent transport systems, roadway signage, vehicle cockpits, roadway layout and other roadway elements to effectively support road users in decision-making performance.

<table>
<tr><th colspan="2">Representation Design Requirements (RDR)</th></tr>
<tr><th colspan="2">Goal Context</th></tr>
<tr><td colspan="2">Improve cognitive affordance of roadway design/elements and assist the road users in decision-making to safely navigate the roadway.</td></tr>
<tr><th>Decision and Information Requirements</th><th>Visualization Requirements</th></tr>
<tr><td>CWR G1-1 – “Monitor success of navigating through roadway”</td><td rowspan="10">1. Provide a depiction of navigation progress in terms of time, position and speed
2. Depict an indication of deviations/conformance with traffic rules
3. Visualize changes in route and roadway conditions
4. Visualize required and actual speed and path/heading
5. Visualize roadway features and physical hazards ahead
6. Visualize current position and distance of route alternatives to desired destination
7. Visualize required action from roadway design and elements
8. Visualize relative positions</td></tr>
<tr><td>IRR G1-1.1 – “Indication of conformance with or deviations from safe road use practices over time</td></tr>
<tr><td>CWR G2-1 – “Monitor success of establishing safe route and movement”</td></tr>
<tr><td>IRR G2-1.1 – “Indication of safe route and current route”</td></tr>
<tr><td>IRR G2-1.2 – “Present deviations from target/safe route over time”</td></tr>
<tr><td>CWR G2-2 – “Choose safer route”</td></tr>
<tr><td>IRR G2-2.1 – “Indication of route alternatives”</td></tr>
<tr><td>IRR G2-2.2 – “States of route alternatives”</td></tr>
<tr><td>IRR G2-2.3 – “Location and distance of route alternatives to desired destination”</td></tr>
<tr><td>CWR P2-1 – “Monitor roadway conditions, signage and driving aids”</td></tr>
</table>

IRR P2-1.1 – “Indication of roadway conditions”	and appreciation of the movement of other road users 9. Visualize roadway ahead, beside and behind 10. Visualize and appreciate roadway layout and limits
IRR P2-1.2 – “Indication and location of road signage”	
IRR P2-1.3 – “Indication and measures of vehicle control parameters (speed, heading, acceleration etc.) and route plan on the driving aids	
CWR P2-2 – “Monitor success of roadway condition/route information obtained”	
IRR P2-2.1 – “States of roadway and route guidance received over time”	
CWR P2-3 – “Determine the safety impact of roadway conditions”	
IRR P2-3.1 – “Indication of roadway condition and physical hazards present”	
IRR P2-3.2 – “Estimated contribution and severity of the roadway condition and physical hazards present”	
CWR G3-1 – “Monitor success of driving/cycling/walking through roadway”	
IRR G3-1.1 – “Present deviation from target driving/cycling/walking behaviours over time”	
IRR G3-1.2 – “Measure of satisfaction which the road user derived from the directional/guidance and safety elements of the roadway”	
CWR P3-1 – “Monitor roadway cues”	
IRR P3-1.1 – “Indication of roadway design elements and required actions”	
IRR P3-1.2 – “Estimated intent of particular roadway design and elements”	
CWR P3-2 – “Monitor success of driving within usage limits and road conditions”	
IRR P3-2.1 – “Indication of road usage limits and state of roadway”	
IRR P3-2.2 – “Indication of deviations from /conformance with target road usage limits over time”	
CWR P3-3 – “Adjust driving/cycling/walking path and speed”	
IRR P3-3.1 – “Estimated measure of current path	

and location”	
IRR P3-3.2 – “Measure of current speed in relation to other road users”	
IRR P3-3.3 – “Estimated time available to adjust path and speed”	
CWR P3-4 – “Monitor success of path and speed control”	
IRR P3-4.1 – “Indication of required road path and speed limit”	
IRR P3-4.2 – “Current deviation from target road path and required speed”	
CWR P3-5 – “Monitor the movement of other road users”	
IRR P3-5.1 – “Relative positions and appreciation of the movement of other road users”	
CWR P3-6 – “Monitor success of keeping safe distance from other road users”	
IRR P3-6.1 – “Present distance from other road users”	
IRR P3-6.2 – “Deviations from the target safe distance over time”	
CWR P3-7 – “Determine the right road intersection or roundabout to turn”	
IRR P3-7.1 – “Indication of the road intersection or roundabout configuration”	
IRR P3-7.2 – “Roadway signage/directional signs in relation to desired destination at road intersection or roundabout”	
CWR P3-8 – “Determine configuration of road intersection, roundabout etc.”	
IRR P3-8.1 – “Indication of roadway configuration on signage”	
CWR P3-9 – “Determine the amount of steering displacement and speed required to negotiate road intersection, roundabout etc.”	
IRR P3-9.1 – “Estimated roadway configuration from the immediate forward view”	
IRR P3-9.2 – “Indication of current speed and	

heading in relation to roadway configuration"	
IRR P3-9.3 – "Current deviations from required speed and path adjustment"	
CWR G4-1 – "Monitor success of establishing traffic rules and road usage limits"	
IRR G4-1.1 – "Indication of traffic rules and road usage limits"	
IRR G4-1.2 – "Deviations from the target behaviour and road usage limits over time"	
CWR P4-1 – "Determine if road usage is in accordance with required usage limits and traffic rules"	
IRR P4-1.1 – "Deviations from the target behaviour and road usage limits over time"	
CWR G5-1 – "Monitor travel time"	
IRR G5-1.1 – "Indication of current time"	
IRR G5-1.2 – "Indication of expected time of arrival at destination"	
IRR G5-1.2 – "The time required to navigate through roadway to destination"	
CWR G6-1 – "Monitor the success of path and speed control"	
IRR G6-1.1 – "Indication of required road path and speed limit"	
IRR G6-1.2 – "Current deviation from target road path and required speed"	
CWR P6-1 – "Determine when speed and path adjustment is required"	
IRR P6-1.1 – "Current path in relation to roadway lane marking"	
IRR P6-1.2 – "Measure of current speed in relation to speed limit and other road users"	
CWR P6-2 – "Choose safe driving/cycling/walking path"	
IRR P6-2.1 – "Indication of available paths/routes"	
IRR P6-2.2 – "Condition of road paths/routes and indication of hazards present"	
IRR P6-2.3 – "Location and distance of road path to	

desired destination”	
CWR P6-3 – “Monitor driving/cycling/walking path and speed”	
IRR P6-3.1 – “Indication of current driving/cycling/walking path and speed”	
IRR P6-3.2 – “Present deviation from target driving/cycling/walking path and speed over time”	
CWR G7-1 –“Monitor success of keeping vehicle in safe travel path”	
IRR G7-1.1 – “Indication of current travel path”	
IRR G7-1.2 – “Deviations from target travel path over time”	
CWR P7-1 – “Monitor roadway perspective and markings”	
IRR P7-1.1 – “Indication of roadway design, lane markings and required actions”	
IRR P7-1.2 – “Estimated intent of roadway design and elements”	
CWR P7-2 – “Determine if vehicle is in safe/required travel path”	
IRR P7-2.1 – “Indication of current travel path”	
IRR P7-2.2 – “Current deviation from target travel path”	
CWR G8-1 – “Monitor the success of maintaining accurate awareness of roadway condition and traffic movement”	
IRR G8-1.1 – “Indication of roadway condition and traffic movements”	
IRR G8-1.2 – “Indication of road usage actions in accordance with roadway conditions and traffic movement over time”	
CWR G9-1 – “Monitor the success of maintaining accurate awareness of other vehicles/cyclists/pedestrians”	
IRR G9-1.1 – “Present indications of other road users”	
IRR G9-1.2 – “Deviations from the required safe behaviour in relation to other road users over time”	

CWR P9-1 – "Monitor roadway ahead, beside and behind"	
IRR P9-1.1 – "Indication of roadway complete view on visual devices"	
IRR P9-1.2 – "States of roadway as viewed on visual devices over time"	
CWR G10-1 – "Monitor the success of gathering information on roadway features and required actions"	
IRR G10-1.1 – "Indication of roadway features and required actions"	
IRR G10-1.2 – "Indication of road usage actions in accordance with roadway features over time"	
CWR G11-1 – "Monitor the success of approaching and negotiating roadway features (intersection, roundabout, road bend etc.)	
IRR G11-1.1 – "Indication of current maneuver through roadway feature"	
IRR G11-1.2 – "Deviations from required travel path through roadway feature"	
CWR P11-1 – "Monitor signage and roadway cues"	
IRR P11-1.1 – "Indication of roadway design elements and signage"	
IRR P11-1.2 – "Estimated intent of signage and particular roadway design"	
CWR P11-2 – "Determine configuration of roadway features (intersection, roundabout, road bend etc.)"	
IRR P11-2.1 – "Indication of roadway configuration on signage"	
CWR P11-3 – "Determine the amount of steering displacement and speed required to negotiate roadway features (intersection, roundabout, road bend etc.)"	
IRR P11-3.1 – "Estimated roadway configuration from the immediate forward view"	
IRR P11-3.2 – "Indication of current speed and heading in relation to roadway configuration"	
IRR P11-3.3 – "Current deviations from required speed and path adjustment"	
CWR P11-4 – "Monitor success of keeping vehicle in safe travel path through roadway feature (intersection,	

roundabout, road bend etc.)"	
IRR P11-4.1 – "Indication of required travel path through roadway feature"	
IRR P11-4.2 – "Current deviation from target travel path"	
CWR P11-5 – "Monitor traffic movements at road feature"	
IRR P11-5.1 – "Positions of other vehicles in relation to roadway feature"	
IRR P11-5.2 – "Indication of traffic control device at roadway feature"	
CWR P11-6 – "Estimate the potential of hazards on roadway feature"	
IRR P11-6.1 – "Positions of other road users in relation to roadway feature"	
IRR P11-6.2 – "Indication of pedestrian devices at roadway feature"	

Table 3. Representation Design Requirements for intelligent transport systems, roadway signage, vehicle cockpits, roadway layout and other roadway elements

The last phase of the ACWA – Presentation Design Concepts (PDC) was not done in this exploratory analysis/study. The PDC explores design options available to implement the representation requirements produced by the RDR which is beyond the scope of this work. This analysis effort is an attempt to establish 'safe road system design' requirements which will provide human factors and cognitive design information that can be used in designing roadway elements to improve cognitive affordances and supporting the goals of road users.

Conclusion

These results (CWR, IRR & RDR), which can be used as design artefacts, show that ACWA is a reliable design/analysis methodology for improved road user performance within the road transport system. This exploratory ACWA analysis revealed that ACWA/CWA can be a useful design and analysis tool as one of the methods within the human factors integration efforts in road system development. Even though design of elements within the road transport system domain and task demands looks obvious and simple, the ACWA methodology presents a conceptual structure of abstract and tangible interactions between the road user and the roadway system upon which an effective model of road transport technologies, vehicle cockpits and roadway elements/artefacts can be designed.

Using Applied Cognitive Work Analysis(ACWA) Methodology in Analyzing Complex Novel and Existing Socio-technical Systems

Everysystem designer aims to communicate the intents and functionalities of all system elements to users according to their expectations, and in turn system users areexpected to comprehend what the system designer expects them to do with minimal cognitive processing. This would minimize the probability of human errors and thus help prevent undesirable consequences. Achieving this requires optimal integration of the system environment, equipment and the system user.

This study has shown that the Applied Cognitive Work Analysis (ACWA) framework can be used to modelhuman–system interactionsto explore the constraints and demands that shape domain users behaviours within a complex socio-technical environment. The result of this modelling will inform the design of domain elements*(interfaces, systems and procedures)* so as to assure optimal performance of tasks leaving negligible margin for human error (minimizing the probability of human errors) which often lead tooperational and safety issues.

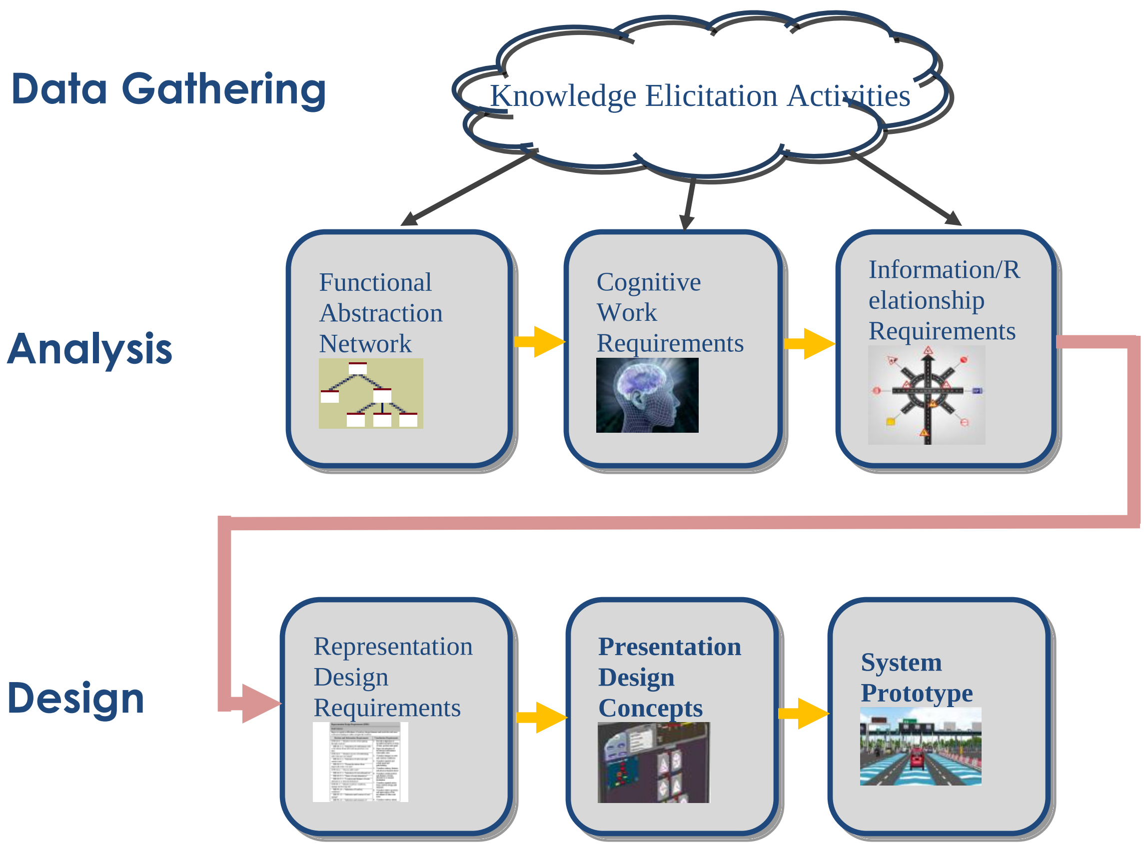

Figure 2. ACWA methodology as an integrated System Analysis and Design Approach

<u>Analyzing Complex Novel Socio-technical Systems using ACWA</u>

The difference between modelling a novel and existing socio-technical systems is in the first stage of the design/analysis effort which is data gathering methodology. As novel systems are non-existent yet, accurate representation of the human-system interactions is usually a challenge. The best option here is to combine available conceptual design information with data from domain practitioners in similar domains. In addition to data that would be gathered through other design documentations, these domain practitioners would be interviewed to capture the closest essential concepts of the novel domain, knowledge and strategies that would be used by them to cope with tasks demands within the domain. Data can also be gathered through observations in simulated exercises with scenarios crafted to address specific aspects of the domain. Data from these knowledge elicitation activities would then be used to construct a functional abstraction network (FAN) of the human-system interaction. The functional abstraction modelling will identify the constraints and demands that would be faced by domain practitioners within the novel socio-technical system. From the functional abstraction model/network, cognitive work requirements, information/perceptual requirements, a 'model of support' for optimum performance/safety, and presentation design concepts would be developed. Model of support (RDR) will generally specify ways to improve domain practitioners' performance *(form part of training requirements, procedure development requirement, design requirements for user interfaces, design requirements for decision aids etc.)*. While the PDC explores design options available to implement the representation requirements produced by the model of support (RDR).

<u>Analyzing Complex Existing Socio-technical Systems using ACWA</u>

Human factors efforts on exiting socio-technical systems are geared towards analyzing the systems to identify improvement opportunities in terms of human performance. Unlike the complex novel systems, gathering data for the analysis of existing socio-technical systems is usually through observational studies of the operational system/domain and well-structured interviews of domain practitioners. The observation part is to analyse how tasks are actually being performed by domain practitioners while the interviews would reveal essential concepts of domain, knowledge and strategies used by domain practitioners to cope with tasks demands within the socio-technical environment. The knowledge elicitation from the domain practitioners is used to construct the functional abstraction network (FAN) of the human-system interaction. From the functional abstraction model/network, cognitive work requirements, information/perceptual requirements, a 'model of support' for optimum performance/safety, and presentation design concepts would be developed. Model of support (RDR) will generally specify ways to improve domain practitioners' performance *(new training requirements,procedure improvement/update, new design requirements for user interfaces, new design requirements for decision aids etc.)*. While the PDC explores design options available to implement the representation requirements produced by the model of support (RDR).

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