What You See Is What You Do: applying Ecological Interface Design to Visual Analytics

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ABSTRACT
In the SPEEDD project, we are developing approaches to the design and evaluation of Visual Analytics which are informed by Human Factors theories and methods. As part of this process, we are using the concept of Allocation of Function to inform the design of User Interfaces for Visual Analytics. The paper presents a case study of the development of a Road Traffic Management User Interface.

ACM Classification Keywords
H.1.2 User/machine systems; H.5.2 User interfaces

Keywords
Cognitive Work Analysis; Ecological Interface Design; Visual Analytics; Human Factors.

1. INTRODUCTION
Visual Analytics combines the power of data analytics with the insight and imagination of the human operator in response to the visualization of the output of these data analytics. In terms of output, visualization can be applied before the analysis on raw data (data visualization), or on output results (information visualization), or during the analysis phase (visual data mining), or on any combination of these [1]. This division of labor between an automated system, which mines massive data sets, and a human decision maker, who interprets the recommendations of the analytics, can be considered as Allocation of Function. One could allocate the analysis functions to the automation, leaving the human as the passive consumer of the system's outputs, and merely accepting the system's recommendations; anyone who has watched 'The Simpsons' will recall Homer pressing the 'any key' to confirm system status. Not only does the relegation of the human to an acceptor of system recommendations miss the point of the Visual Analytics concept, but it also removes the human operator from the analysis loop. A consequence of removing the person is that this can impair the person's ability to understand the meaning of the data, to interpret the system's recommendation or to intervene appropriately when required [2]. Furthermore, users tend to have more trust in their findings when involved in the discovery process than when the findings come from an automated system [1]. Thus, it would make sense to design the Allocation of Function between human and automation in such a way as to ensure both partners worked to their best potential. In general, the storage, transformation and processing of data is more suited to automatic systems, whereas hypotheses generation and interpretation of findings are considered more human led tasks [3].

2. ALLOCATION OF FUNCTION
Determining whether a particular function (in terms of system operation) should be performed by automation or human operator is known as Allocation of Function. While some functions (such as dealing with massive data sets) are clearly suite to automation and others (such as gaining insight from a collection of data) might be more suited to human operators, the challenge of Allocation of Function stems from the fact that some of the functions could be performed equally well by automation or human operator. Further, the way a function is performed is likely to change as a result of the task context. Thus, adaptive automation (in which Allocation of Function varies according to context) can improve operator ability in intervening in response to errors [4, 5, 6]. Moreover, by dynamically allocating tasks to either the user or the automated system user skills can be maintained [7.].

In this paper, we are interested in the question of whether it is possible to manage Allocation of Function through the visualization. In other words, the User Interface could indicate to the operator when and how they could intervene at particular stages in the process.

As the application of this work is linked to the traffic management use case, we start by presenting the requirements of the system as highlighted by traffic operators in our discussions with them. These requirements, in combination with the Cognitive Work Analysis (presented in the following section), informed the initial design of the User Interface (Figure 1). Following this, in order to appreciate how Allocation of Function might be applied to this use case, we turn our attention to the question of Situation Awareness and the design of Ecological Interfaces.

2.1 Requirements for Traffic Management Use Case

- Allow Operator to clarify and query notification
- Allow Operator to draw on experience of previous incidents
- Allow Operator to select Incident Type option
- Allow Operator to draw on several sources of information to confirm location
- Support Operator Situation Awareness
  - Of current incident
  - Of future conditions
- Allow Operator selection of response
- Allow Operator to challenge or negotiate response
- Support Operators in gaining Global and Local Situation Awareness of road user behaviour
- Supporting Operators in determining that the incident has no unexpected consequences.

Figure 1: SPEEDD Initial User Interface for Road Traffic Management Use Case v1.0

3. COGNITIVE WORK ANALYSIS OF ROAD TRAFFIC MANAGEMENT OPERATIONS

CWA, Cognitive Work Analysis [10, 11, 12], involves a number of phases, each of which contributes to an understanding of how stakeholders *could* work with a given system. In this way, the problem space represented by the system can be explored in order to determine ways of supporting activity in that space. Figure 2 shows the Abstraction Hierarchy from CWA of Road Traffic Management; we have used the phrase 'manage road network' as the Functional Purpose of the system.

Having defined a Functional Purpose, the next step is to define the Value and Priority Measures of the system (the second row of Figure 2). These represent those aspects of performance that the system could use to indicate how well it is performing. Through observation and interviews, we defined the following aspects:

- To ensure minimal congestion in the road network
- To ensure minimal risk to road users
- To enable minimal journey times for road users
- To ensure informed road users
- To support maintained infrastructure
- To encourage compliant road users
- To support immediate response to incidents
- To produce an auditable record of activity

These aspects map on to the generally accepted set of objectives for traffic management [13.]:

- Maximize the available capacity of the roadway system
- Minimize the impact of incidents
- Contribute to demand regulation
- Assist in the provision of emergency services
- Maintain public confidence in operations and information provision

The main difference between the two sets concerns the issues of providing support to the emergency services (although we have 'immediate response to incident' which we suggest would include this), and maintaining public confidence in control center provision (which we do not include but which could relate to the priority for ensuring 'compliant road use').

In the control room environment (in the scope of the SPEEDD project), because of the introduction of the automated system, the goals (derived from CWA) are shared between the two entities – the operator and the automation. Each entity contributes to achieving the system goals through different means (see Figure 3). Besides the operators' role to deal with uncertainty and spot errors in the data and analysis outputs, the system should allow them to inform (train) automation. The latter can be achieved through the action of overriding the automation outputs.

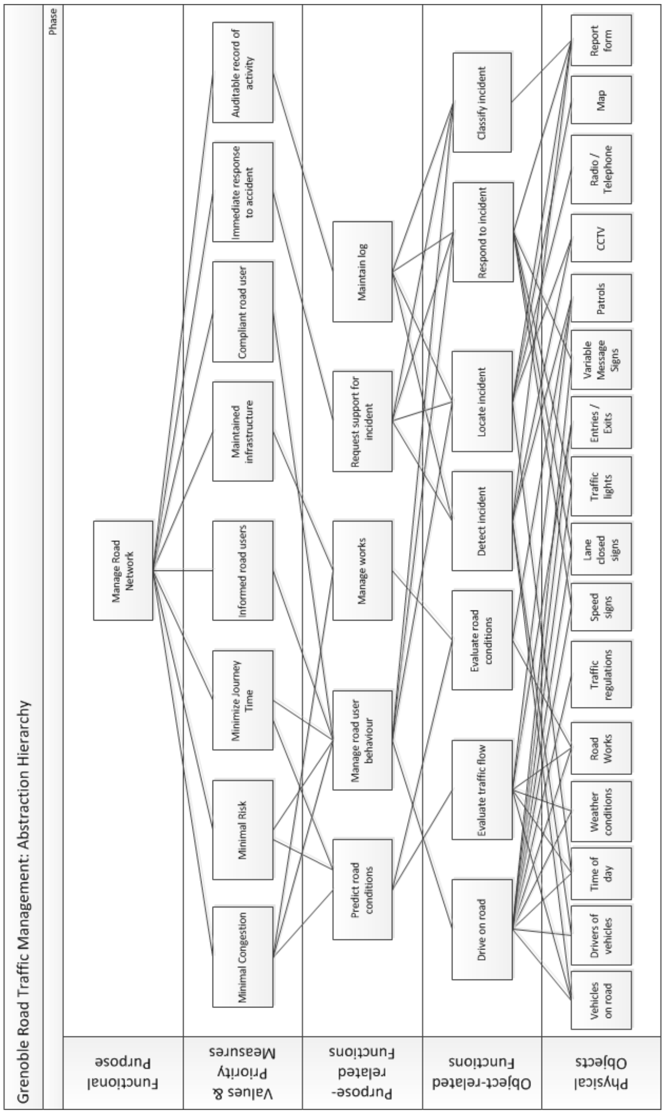

Figure 2: CWA Abstraction Hierarchy

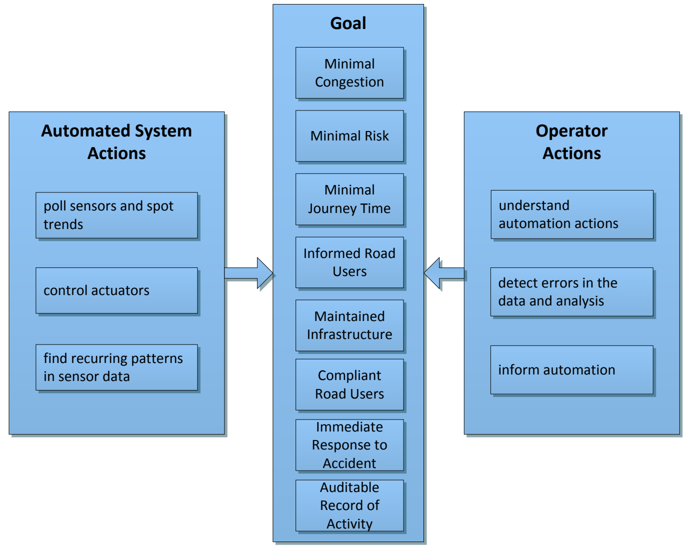

Figure 3: Contribution of System Components to System Goals

As in any Socio-Technical System, there will be a range of actors who will perform functions in order for the system to achieve its Functional Purpose. For instance, apart from automation and operators, there will be the individual road users who are driving vehicles through the road network and whose behavior the operators in a control room are seeking to influence. In addition, there might be specialized roles, dedicated to maintaining the infrastructure of the road network or to dealing with accidents and incidents, which are called upon at specific times. Figure 4 takes the Object-related Functions (from Figure 2) and shows how these can be performed by different actors (shown by color coding) and in different circumstances. In this Figure, the circumstances are presented as examples of different 'modes' in which the system could be assumed to operate, i.e., normal conditions (managed roads), disrupted conditions (response to incidents), or scheduled disruptions (planned works). Figure 4 shows how the different circumstances can lead to different distribution of these object-related functions across the range of actors.

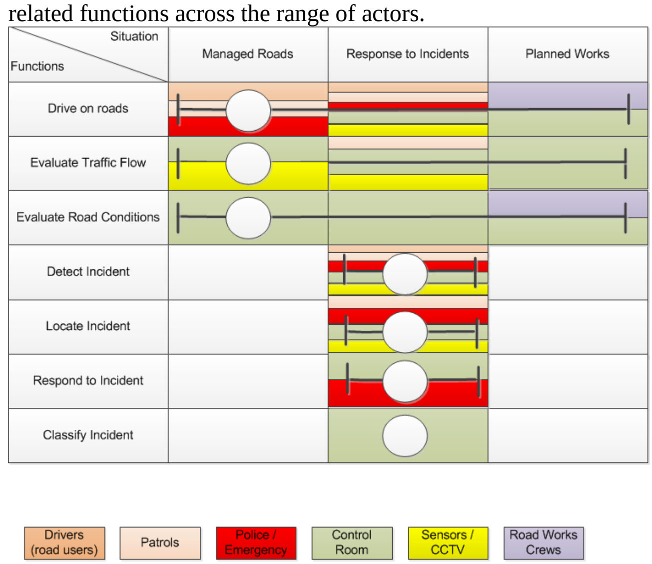

Figure 4: CWA SOCA

The Object-Related Functions in Figure 2 represent a form of task analysis. The 'decision ladder' in Figure 5 should be read from the bottom left (beginning with an input to the operator) up to the top (Functional Purpose, or overall goal of the operator / system). From the Functional Purpose, the right-hand leg of the ladder descends to the action that the operator will make. There are various 'short-cuts' that the experienced operator might apply (indicated by dotted lines), perhaps in light of particular patterns of data or reports from previous responses.

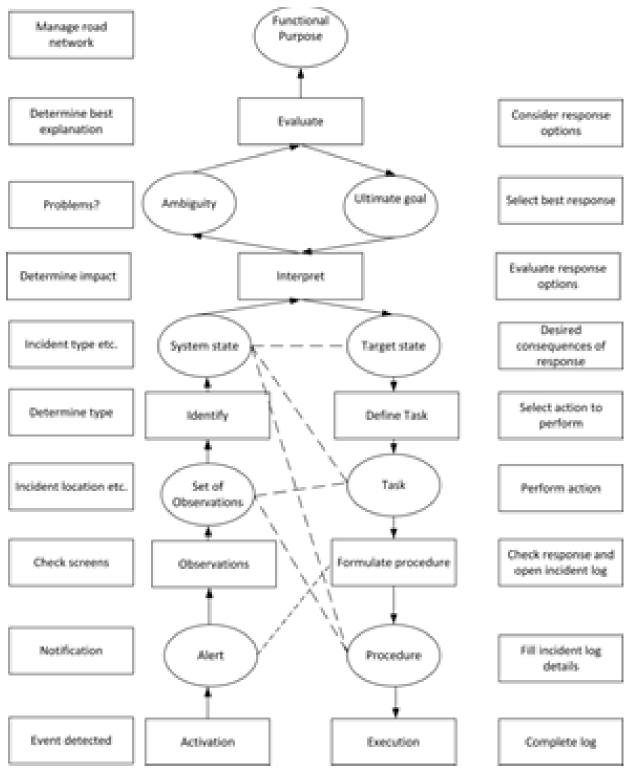

Figure 5: CWA 'Decision ladder'

4. DESIGN CONCEPTS AND IMPLEMENTATION

At the top level, the Abstraction Hierarchy (Figure 2) presents the Functional Purpose of the system. For example, if the system is intended to respond to incidents quickly, then this display could show the time spent responding to incidents, perhaps against targets or against historical data. The usefulness of such a display would depend on the nature of the work.

At the next level of the Abstraction Hierarchy, the Abstract Function (values and priorities) would be reflected by the parameters that the 'system' is seeking to balance. It can also be beneficial to present subgoals (Purpose-related functions), tasks (Object-related functions) or information sources (Physical objects). These can either provide cues for the operators to interact with the system at a lower level or can provide alternative means of alerting operators to change in system state. Thus, for example, the output of a CCTV (Physical Object) could be manipulated by the operator (Object-related function) in order to determine the location of an incident (Purpose-related function). In this situation, it might be useful for the operator to directly mark and record this information, say by marking this frame (and its associated metadata defining location, direction of view, time etc.) and capturing this directly into the report.

Table 1: Relating Information Requirements for different Stakeholders to the levels of Abstraction Hierarchy

	Control Room Operators	**Road Works Crews**	**Drivers (Road users)**
Domain purpose			
Values Priorities	Congestion Incident Record activity	Congestion Infrastructure	Congestion Risk Journey time Information
Knowledge semantics insight	Support to response Update log	Conditions {repair / works, weather, traffic flow / density, environmental}	Driver behaviour Compliance
Facts ideas opinions	Availability {signage, CCTV}	Availability {lane, road, exit / entry}	Movement Accident
Source objects	Location {signage, CCTV} Content {signage, CCTV}	Map	Vehicles Motion Compliance

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In Table 1, relations are mapped and examples of the type of information which might be used in the system to support these relations are indicated. This provides a simple means of eliciting the information which *might* be useful for this system. Finally, taking the relationships defined in Table 1, we sketch the concept layout (Figure 6) for the User Interface.

4.1 Graphic Options

Figure 6 contains 8 regions. The following list outlines some of the options that are being considered in the design. Items in the list marked * correspond to existing information displays in the control room.

1. Road status (traffic conditions), e.g., displayed as a fundamental diagram. This could also compare current traffic conditions with the same time last week, or predicted traffic conditions and likely trends;
2. Values / trends / forecasts: this display could provide operators with views of the predicted traffic, or driver behavior, to allow comparison between alternative courses of action;
3. Road user goals: this display could indicate information which might be relevant to road user activity, for instance, alternative routes which drivers might take if there is congestion;

4. Driver behavior and compliance: this display could indicate how road users are behaving. This could include average speed in each lane or average distance between vehicles;
5. CCTV content / control*: this display would present the images from the selected CCTV camera to the operator, and allow the CCTV camera to be controlled;
6. Control activity, signage content*: this would show the actions that the operator is able to perform and the content which could be presented on variable message signs;
7. Log, open tasks, scheduled events*: this would show the log of the current incident that the operator is working on, together with open tasks or any scheduled events that need to be dealt with;
8. Map of road network*: displayed as a map of the ring road (either a schematic as in the current design or a more detailed map of Grenoble and the road network), with key Objects indicated, e.g., CCTV and sign locations, junction (ramps) etc. This could also be used to display the location of incidents, such as congestion.

5. SITUATION AWARENESS AND ECOLOGICAL INTERFACE DESIGN

For the operator, Situation Awareness involves selecting the most appropriate information source (or combination of sources) and then analyzing the information in order to make sense of the system being controlled. This raises questions such as what is the 'system' that is being worked with, and what constraints might affect interaction with this system. In other words, the focus of operator activity can be described in terms of the problem space in which humans make decisions, the sort of tasks and decisions that humans make, and the constraints which affect performance of these activities. Ecological Interface Design addresses these concerns [8.].

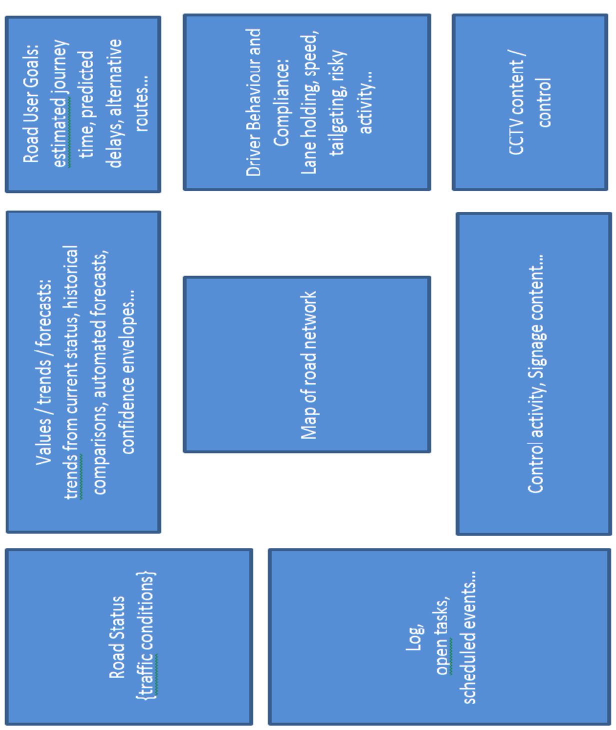

Figure 6: Schematic User Interface for Road Traffic Case

The concept of Ecological Interface Design (EID), developed from Cognitive Work Analysis (see next section), draws on Gibson's [9.] concept of direct perception (later encompassed by the 'ecological psychology' movement). For User Interface design, this leads to the assumption that people are able to perceive meaning of objects *directly* (i.e., with no need for cognitive intervention) when the situation in which they encounter those objects provide a suitable context for interpretation. A further assumption of EID is that the task constrains the ways in which information is interpreted and defined to be salient or meaningful. Within this 'task ecology', it is plausible to assume that different people will interpret the information in different ways (according to their current tasks, goals, experience and training). Thus, the 'task ecology' of a system is defined by the range of states in which it can develop and the constraints that these states place on people interacting with the system.

Relating Situation Awareness to EID, we might expect operators to be able to spot patterns in the data and then respond to these by selecting a course action. It is interesting to contrast guidance for the design of User Interfaces from the perspective of Situation Awareness with that presented for EID. As Table 2 shows, there are strong similarities between the approaches (even if the underlying theory and the terminology used differ). Both emphasize the benefit of 'direct' display of information and both imply the need to represent the system in terms of user goals and in terms of different levels of system operation and performance.

Table 2: Comparing EID and SA

Design for Situation Awareness	Ecological Interface Design
Relate to operator's major goals	Represent function and meaning in the task ecology
Present information directly	Design to support direct perception of visual information
Assist system projection	
Display global status	Reveal underlying system process and constraints
Support global-local trade-offs	
Support perception-action schemata	
Take advantage of human parallel processing capability	Integrated capabilities permit more work with less cognitive effort
Filter information judiciously	

5.1 User Interface for First Prototype Trials

While Figure 1 presents the User Interface derived from our analysis of operator activity and information requirements, the first prototype for the SPEEDD demonstration focuses on a specific subset of this use case. In the demonstration, the operator needs to monitor ramp metering and to accept (or challenge) the automated systems control of ramps around the city. The User Interface for this task is presented in Figure 7. In addition to the User Interface supporting the demonstrator task, it also provides an opportunity for controlled experiments which will allow testing of the decision models and the eye-tracking metrics. For these experiments, participants will be presented with a series of ramp metering scenarios and will need to respond as quickly as possible to the automated system's recommendations. Using reaction time, it is possible to distinguish between different levels of performance, e.g., when all windows in the display contain corresponding information versus situations when information in one window conflicts with the others. In addition to reaction time, the experiments will also employ eye-tracking to ascertain which information sources participants tend to focus on under the different conditions.

Figure 7: User Interface for first SPEEDD demonstration

6. DISCUSSION

Key to the development of Visual Analytics is an appreciation of how Visual Analytics operates in a working environment in which other actors will share information with each other, or will interact with systems outside the core Visual Analytics system. This means that it important to appreciate the Socio-Technical Infrastructure in which the technology will be used (Figure 8). Consequently, the challenges this paper aims at addressing are the relating to information need, rather the information visualization. The latter is concerned by *how* the available information is presented, whereas the former shows *what* information shall be presented.

In this paper we demonstrate the application of Cognitive Work Analysis to the derivation of an Ecological Interface Design of the User Interface for the SPEEDD project's Road Traffic Management Use Case. Understanding operator tasks and information requirements (in terms of a Socio-Technical Systems) allows us to develop concepts for User Interface designs which reflect the job of the operator. This helps define the 'task ecology' in which operators perform their work, and helps define one aspect of the 'ecological' interface. The User Interface also reflects a desire to present information in formats which operators can spot patterns, trends and combinations of data using a form of 'direct perception'. The intention is to develop such designs so that operators can monitor system status by glancing at the displays during normal operations, rather than needing to engage in lengthy search and retrieval processes to discover information. The benefit of providing intuitive system overview is that it support operator Situation Awareness of steady-state, normal operations.

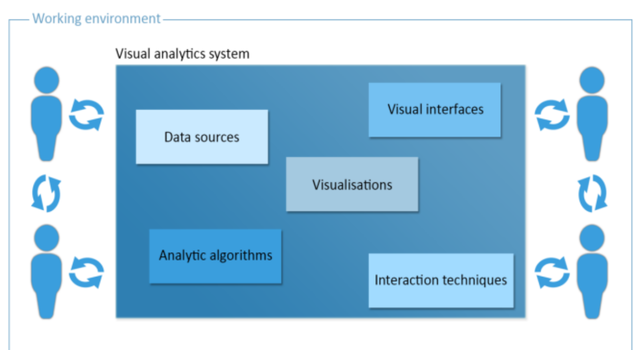

Figure 8: Visual Analytics in a Socio-Technical System

When operations deviate from normal, e.g., due to an actual or predicted incident, then the role of the operator changes from system monitor seeking to maintain Situation Awareness, to active responder seeking to ensure that system status returns to normal as quickly and efficiently as possible. In the SPEEDD project, this role is also performed by automated systems which detect system activity and perform responses to the activity. This means 'control' is now allocated between operator and automated system. We are developing the User Interface to not only inform the operator of system status, and automated system behavior but also to cue operators as to when (and how) they might need to intervene.

The User Interface shown in Figure 7, for instance, allows the operator to request that the system <explain> current settings and decisions, at any time during the operation. However, if the operator feels that a setting or decision is not appropriate or correct, then the ramp being controlled can be selected and the decision can be queried, using the <challenge> button. This then allows the operator to either reset parameters or engage in some other form of intervention. While this is a simple example, it highlights how User Interface can be used to indicate the constraints under which the operator can act (where 'constraint' is seen as a positive means of shaping operator activity and indicating which function the operator is expected to perform).

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