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Coalition Command and Control in the Networked Era

The Use of Information Principles for Engineering NEC

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The Use of Information Principles for Engineering Network Enabled Capability (NEC)

Abstract

NEC as a concept will be realised by new and improved capabilities that support the achievement of decision superiority through improved design of information. A key element in the specification of decision superiority is effects management, which can be used to shape system behaviour. The mechanism is the design of information to produce the desired system-of-system behaviour.

The Integration Authority analysis team has considered an approach for a Design Framework for self-organising systems for desired behaviours. It became clear that, in order to achieve the requisite performance, the design of information has to support behaviour. We show how to design information using fundamental entities and information rules that exploit self-similar properties to generate patterns for behaviour.

An example is provided of the application of the Design Framework and how the derived information exchanges enable performance. A familiar problem is used in the example, to show how our approach employs transforms to the layers of our Design Framework to populate the Information layer and hence an integrated set of Information Exchange Requirements (IERs).

Introduction

Find, Fix, Strike is a useful summary of tactics that has served the West well in conventional warfare. This tactic is founded on the idea that it is possible to isolate a source of threat i.e. a target and respond before it can act. But, did it serve us in the case of 9/11? Government and the Intelligence establishment have been criticised for their failure to recognise what became evident in hindsight. Was this just a failure in system performance or evidence that we need a new way of working in the Network Enabled Capability (NEC) era? This paper proposes that there is a need to adopt new tactics and go beyond capability, to a higher level concept that is to manage effect at a fundamental level.

The idea is that the design of information is the foundation for future management of effect i.e. decision superiority in the NEC era and that recognition is the method to cluster real-world events that are causally unrelated. Recognition emerges in the systemic quality of information to represent meaning that is used as a formative influence to shape the decision process. Meaning is traced to the underlying patterns evident in information structures, and these are exploited to provide the basis for effects management. The basis of all the information structures is the ‘entity’ building block that contains all necessary elements and is described, along with examples of its use.

The need is to move beyond capability to a higher level managed effect, a step that requires us to move intelligent acquisition from requirements for capability to design guidance. Design guidance will then act as the basis of assured performance. A design framework is proposed that offers not only design guidance, but also a mechanism against which to evaluate NEC readiness of legacy and future systems.

The theme of the paper is that the use of information principles offers the governance at the heart of information design, more specifically the rules to use the ‘entity’, and thus is essential for engineering performance. The benefit of information enabled performance is that future commanders may avoid the critical judgement of hindsight, while benefiting from the wisdom of hindsight.

1 Framing the Problem

A critical problem faced by the MoD is that there is no common recognition system that is able to differentiate salient features. A potential solution to the problem is to develop a better version of the usual 'feed-forward-feed-back' command and control (C2) model that could support decision-making in the global environment. Better in this context would involve the ability to coherently develop emergent desired behaviour in all future operations.

The vision statement is an improved decision-making process that exploits information qualities. Desired behaviour is outlined (at a high Level), by the NEC themes and our proposition is that the design of information has to support the development of this desired behaviour.

1.1 A NEC Strategy Description

The 7 NEC Themes that define the essence of NEC provide a cross-Lines of Development framework against which emergent benefit can be described. As such they provide a high level description of areas for improvement. We have highlighted 3 particular themes below, representing a thread through the benefits chain focusing on the support to decision making as part of the command function.

NEC Theme	Objective
Agile Mission Grouping	Enabling the dynamic creation and configuration of task orientated mission groups that share understanding and that employ and co-ordinate available assets to deliver the desired effect.
Shared Understanding	Enabling each user to generate an understanding of the battlespace that is appropriate and adequate to their task and consistent with the understanding of other users.
Full Information Accessibility	Enabling users to search, manipulate and exchange relevant information of different classifications (respecting security constraints) captured by, or available in, sources internal and external to the battlespace.

Table 1 – Selected NEC Theme Objectives

In order to characterise the problem we need to make some assumptions and list the important constraints that affect our view of a NEC enabled future.

1.2 Assumptions about a NEC Enabled Future

The environment of the problem imposes certain system-wide constraints. Therefore, it is helpful to characterise the nature of the problem domain and expose some of the issues that will shape the design approach.

Nature of the Threat. There is a growing realisation that homeland defence involving operations in an urban environment against a non-conventional threat represents a substantially different problem to that faced in similar environments on deployments to Afghanistan or Iraq. The nature of new and widely differentiated threats requires us to be able to respond more dynamically to changes in the environment.

Enduring Characteristics - Roles. From a command and control perspective we have assumed that there are a core set of enduring roles, essentially those of Commander, Controller, Operator and Identification Authority (IA). The Identification Authority has particular importance and relevance for the information domain. These roles underpin the approach to designing for information.

1.3 NEC Implementation – Constraints

We must also acknowledge the existence of real-world constraints as we design for the transition to NEC:

- **Command and Control**. There is a commitment to 'tried and trusted' procedures which have been developed and refined over generations. The transition to new ways of working must be evolutionary, exploiting the best of the present together with demonstrations of benefits of adopting the new.
- **Security**. Constraints associated with information security, not all of which can be defined objectively or with enduring relevance, will affect information accessibility, particularly within multinational environments.
- **Technology and Standards**. The rates at which technology and standards mature (and change) is likely to place constraints on future capability.
- **Legacy Capability**. We have a set of fielded equipments, doctrine and human resources which have developed as a collection used to support all problem areas.

2 NEC Analysis

We briefly examine each of the three NEC themes in turn to identify how well current systems and approaches are working and highlight critical gaps in performance and areas requiring attention.

2.1 Agile Mission Grouping

The commander needs assured agility in order to create and configure task orientated mission groups able to respond to novel situations on a global basis. Whilst we have the knowledge to manage and design large complex equipment platforms, we do not yet have sufficiently robust design guidance to support the development of information-centric behaviour that can be dynamically reconfigured and recompiled as operational circumstances dictate. Instead we are constrained to the assembly, commissioning and testing of information as a precursor to employment. An alternative, more desirable approach would be to design information as part of a coherent and dynamic process so that pre-integrated and tested information 'lego-bricks' can be used and re-used to compile capabilities that are optimally tailored to complex tasks.

2.2 Shared Understanding

The Information Age commander will need sufficient relevant information to understand, decide, influence and monitor effect. There is recurrent evidence from post incident enquiries that failures in shared understanding are an important contributory factor to disastrous outcomes. The development of shared understanding requires some degree of shared context which is necessary feature for the achievement of synchronised effect. Our model for the development of shared understanding should have features that enable characterisation and optimisation of what it is necessary to know in order to complete a complex task successfully. Our proposition is that the provision of a form of schema[1] (that can be used to construct a temporal and spatial context for relevant information) would enable the provision of appropriate information to all entities within a System of Interest.

2.3 Full Information Accessibility

The key to accessibility lies in the qualities of information; the occurrence of relevant information must be the trigger for updates so that a system of interest always has access to the latest relevant information.

To be effective within a dynamic, shared System of Interest (SOI), the enterprise must generate understanding and maintain coherence. The key for a knowledge-centric enterprise is a NEC 'lingua franca' to construct a context for relevant information, which can be applied within a System of Interest (SOI).

[1] Representation of temporal context and sequential structure Grafman (1989) Plans, actions & mental sets.

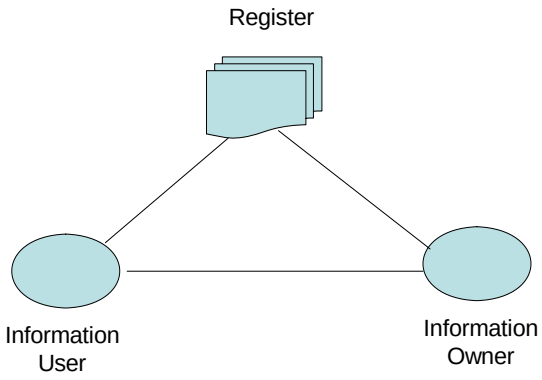


Figure 1 – Information Accessibility

The information ownership model featured in figure 1 can lead to important information being lost or not recognised as relevant to a situation in the time available for even low tempo operations. It fails to meet Information Accessibility objectives in terms of the capability to search, manipulate and exchange relevant information. An alternative would be to replace this 'ownership' based model with one that directly exploits information to act as the trigger for information accessibility.

3 *Designing for Desired NEC Behaviour*

Our proposition is that we need to be able to provide design guidance for desired behaviour (which is a high level emergent property of a system-of-systems) via a Design Framework.

3.1 Design Framework

The organisation and structure of a simple, but sufficient, Design Framework that captures necessary design constraints is presented in Figure 2. Its structure allows profiles through the stack to be selected to develop and evolve desirable NEC behaviour.

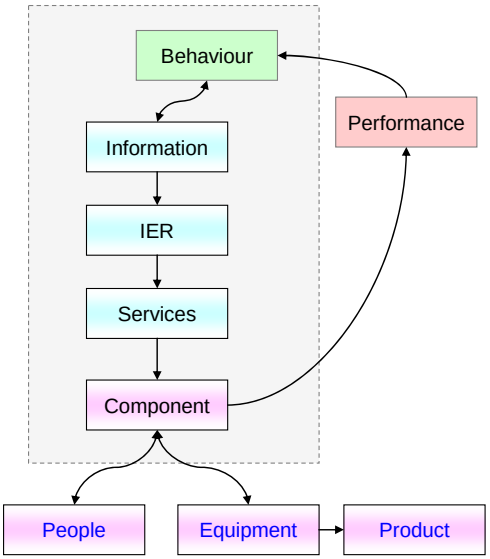


Figure 2 – Design Framework

The Design framework identifies an explicit hierarchy, driven top-down by required system behaviour that emerges from the nature of a task to be performed. The choice of action, in a given situation, is guided by information that plays an active role in shaping the nature of responsive behaviour. The key benefit is that we can develop and execute a plan that is not only predictive, but also has a greater probability of success in the real world.

Features of the Design framework are:

- The structure is hierarchical, with beneficial behaviour driving design
- The order of layers is set, enforcing critical dependencies. Layer interaction is constrained to nearest neighbour. Interaction is via defined access interfaces
- Stable layer definitions assure clarity associated with demands on the next level down

4 Use of the Design Framework

The use of this design framework is illustrated using a non-defence example, chosen because of its familiarity.

Example – Route Planning Using a Traffic Management System. The example is based on a familiar problem area - traffic management. Traffic Message Channel (TMC) technology is a technology for delivering traffic and travel information to drivers. It is typically digitally coded and broadcast to deliver accurate, timely and relevant information, in the language chosen by the user. When data is integrated directly into a navigation system, it may give the driver the option of taking alternate routes to avoid traffic incidents (desired behaviour).

Data related to traffic flows, incidents, weather etc. are gathered from traffic monitoring systems, emergency services, motorists' calls etc., and are collated at a central traffic information centre. They are then passed to the traffic information service provider, who generates event messages. Each traffic incident is sent as a TMC message consisting of an event code, location code and time details. The message is encoded according to a standard, which contains a list of events which can be translated by a TMC receiver into the language of the user. The standard method of encoding ensures that an Alert both triggers the correct part of the TMC location topology, and successfully integrates the event information.

The scenario adopted in the example is that of a taxi driver taking a fare to his destination. There are several options for routes but there is unusual congestion indicating some traffic problem. The driver decides to use the taxi traffic management terminal to help decide on a route.

4.1 Population of the Behaviour Layer

The purpose of the behaviour layer is to develop and evolve an action plan that will be successful given the taxi driver scenario. This is rather more difficult than it may seem from a simple organisation and structure[2] description of the task:

Task: Route Planning,

- Sub-tasks include;
    - Log on with a service provider
    - Set destination and route constraints (for route design)
    - Establish System of Interest
    - Route Planning
- Background:
    - Inputs - from environment e.g. event messages about traffic problems
    - Outputs - all physically completed actions e.g. log onto system

Good performance requires that the behaviour layer provides solutions to system issues, such as those in the route-planning example:

- The example involves a taxi driver who is the decision maker. He may be reluctant to use the technology due to previous experience of the system not exhibiting traits that align with his intent.

[2] Elman (1990). Finding Structure in Time an approach based on a recurrent network model.

- In the real world the driver will get distracted or just forget to carry out some step in a setting up procedure. The technology will have equivalent errors, so the system must be able to recognise the nature of errors in behaviour and evaluate how they will affect the operation of the task. The system must then alert the decision maker about the error and prompt a response.

Assuming the task steps are completed then the system will represent a route plan e.g.

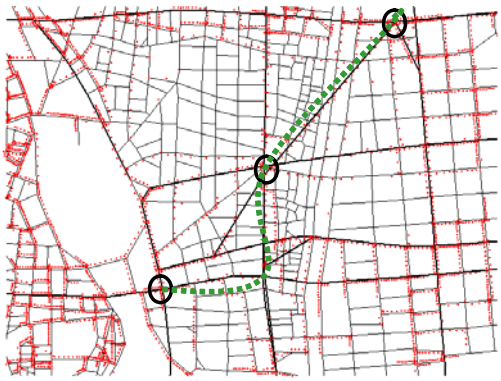


Figure 3 - Traffic Congestion & Route Planning Information

Figure 3 can be thought of as an operational overlay to a city topology that outlines the course of action (i.e. system state). Once on route, system cues (based on observed behaviour e.g. traffic problems), must support the realisation of the decision maker's intent.

The operational overlay represents a possible solution to the decision problem; the solution is represented in Figure 3 as the dashed green line, and the journey is divided up into staged sub-tasks with decision points 'the circles'. The planning process behaviour demands traffic and travel information that is accurate, timely and relevant and in the language chosen by the user. This active information guides the organisation and structure of the decision matrix, and thus how the decision process unfolds.

4.2 Population of the Information Layer

The information layer must provide information in an appropriate form to match behaviour e.g. if the language chosen by the user is English then the form provided is English. The information layer provides the global big picture essential for the decision matrix, but also ensures that structural representations are available to enable subtle differences to be detected for individual decision points. The demands of the decision matrix for stimulus traces, i.e. cues, must be encoded correctly such that recognition is effectively supported at various levels of complexity.

In the route planning using TMC example, standard user messages provide basic items of broadcast information:

- Event description, traffic problem
- Location, the area, highway segment or point location affected
- Diversion advice, whether or not drivers are advised to find an alternative route.

Essential to population of the information layer are:

4.2.1 Entity - the entity provides the 'gene pool' for all constructs within the information layer. Constructs range from representing real world things (people, cars, mountains etc) and things about things (concepts). An entity also provides the building blocks for

complex information layer constructs, i.e. schema, context and alarm. The entity is shown in its schema role in Figure 4. The governance of these constructs is set in information principles.

	Entity Elements	Entity Schema
1	Goal Received	Passenger request
2	Context Supplied	TMC London City Topology
3	Goal Transmitted	Destination Paddington Station
4	Local Context	System of Interest (SOI), guidance for decision matrix
5	Name	Taxi Identity
6	Certificate	Recognition mechanism
7	Intent	Dynamic update for decision points; see standard user message

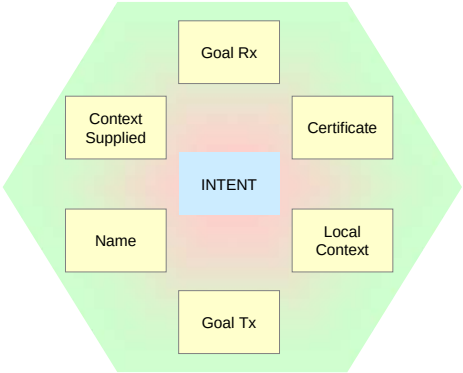


Figure 4 – Information Layer Population for Taxi Driver Schema.

The idea of a schema is also represented in Figure 4 and is key to how the information layer can support the behaviour layer task. The schema is an emergent system property, i.e. it is the explicate form rather than an explicit representation of the task.

4.2.2 Schema - A schema represents an enduring transform between the information space and physical space and will be populated (in part at least) from the physical space. A populated information schema acts as a formative pattern that has an active role in shaping system behaviour (so that event information has a formative effect on the behaviour). It will ensure that the development and evolution of the action plan is driven not only by local conditions, but also global awareness of the whole SOI environment. The schema ensures that the unfolding of the global picture accurately represents the real world i.e. of solid bodies in unambiguous locations in space and sequential time. It is core to building this explicate form[3] from the fragments of information provided by individual parts of the system e.g. monitor systems.

4.2.3 Context - Context encapsulates what the enterprise knows about a situation. Context largely becomes the semantic/static model that gives an initial topography for the planning process. In the example a London TMC location map would be provided as the basis for the taxi route planner function.

4.2.4 Information Principles - The operation within the Information layer is guided by Information Principles that tell us something about governance of entities and the information constructs i.e. Context, Schema and Alarms. We have derived a concise set of well integrated principles, two examples of which are shown at Table 2. As discussed previously, Context ID Authority is particularly important in the information layer – only an ID Authority can generate a 'local' Context. The selected principles clearly illustrate the importance of such enduring roles in the design of information.

	Information Principles
1.	- A local CONTEXT can be generated by an entity. - Only an entity able to act as a CONTEXT ID Auth can generate a 'local' CONTEXT - The extent of the local context is defined by the entities identified
2.	- Trust must be verified and GOAL must be validated at the global level - Establishment of trust at the local level, verification at the global level - ID auth must have mechanism for authentication before trust can be established

Table 2 – Information Principles

[3] Bohn & Peat 'Science, Order & Creativity' (87)

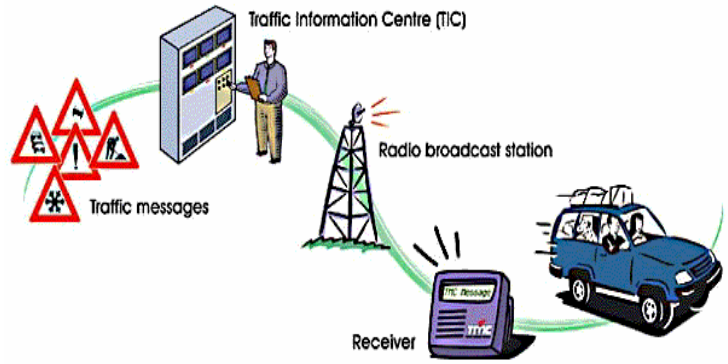
4.3 Population of the Information Exchange Requirements (IER) Layer

The purpose of the IER layer is to coordinate the exchange of information between discrete parts of the system. Its role is to ensure that the appropriate system functions are identified and triggered to provide the right sequence of actions to support the information layer.

IERs	Category
Received	Authentication
	Received Goal
	Context (SOI & Doctrine)
	SOI definiton
Distributed	Transmitted Goal
	SOI Information distributed
	Authentication

Table 3 – Categories of IERs

A broad categorisation for IERs is given in Table 3. A function of the IER layer is to represent a distribution network that will couple discrete parts of the system. This coupling occurs between identified system components if some condition set by one discrete part is satisfied by messages generated by the action of another part of the system. A distribution network for the example is illustrated below.



As an example of a particular instance of an IER; a monitor system camera covering a road junction detects an event and categorises it as road accident, see Figure 5.

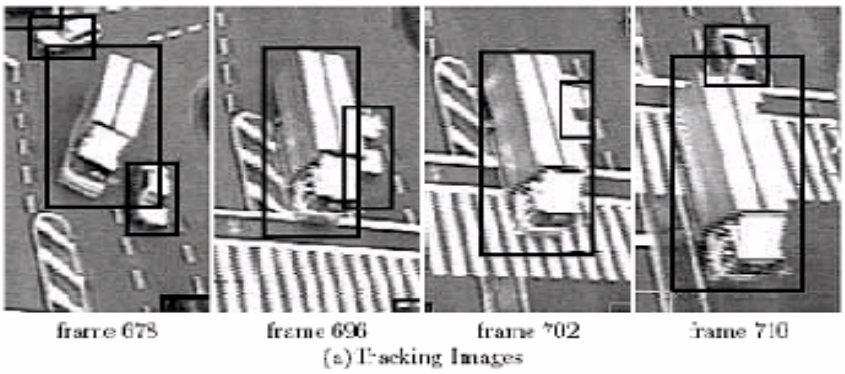


Figure 5 – Monitor System Event

Categorisation of the event (which is part of the SOI definition, see Table 3), not only sets internal conditions for the monitor e.g. camera instructions, alert settings for prioritisation, but also triggers an outgoing message that is added to the monitor system output message queue. The message conditions will be interpreted by the IER output interface and tagged for distribution.

In the case of our example the event message would be coupled to the Traffic Information Centre (TIC). When the taxi ID registers with the TIC, the resulting IER exchange is shown in Figure 6 IERs – Route Planning Registration. The taxi component will be tested for conditions for dissemination, added to the IER distribution network and coupled to the Traffic Information Centre; i.e. the IER layer will not build the coupling between the taxi entity and the service provider entity unless its conditions are met.

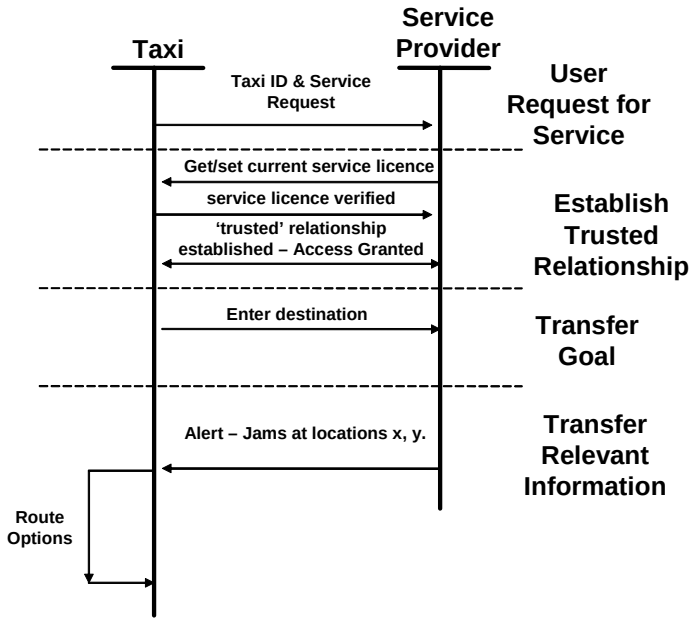


Figure 6 IERs – Route Planning Registration

The prioritised message will be delivered to the information layer interface for further processing, which may result in the generation of an information layer alarm. This IER example introduces the alarm and affords the opportunity to trace the alert in its journey up the layers and return for onward information exchange. A general definition of an alarm is as follows:

> **Alarm**. Alarms are the mechanism for initiation of changes in attention within or between entities and will usually be the precursor to the initiation of action. They arise as one of the outputs of the entity planning process; this consumes entity or relationship changes within local context and is triggered by physical space (taking into account received (global) context and goals), to generate intent, transmitted goals and alarms. The alarm represents an emergent transform of local context, expressed as a discrete and uniquely identifiable entity within information space. For the alarm to be able to generate effect it must then be transformed into physical space and routed to a command entity.

In this particular case the effect on the driver's route will be evaluated by the planning process (the behaviour layer) and changes of circumstances result in the initiation of alarms (by the information layer) are routed to the driver (command entity/decision maker).

4.4 Population of the Services Layer

The purpose of the Services Layer is to maintain system-wide properties, i.e. systemic qualities, by instituting some form of control over the formerly autonomous parts of the system or system-of-systems. The design of the services architecture is organised into areas that support increasingly sophisticated control mechanisms which orchestrate the operation order of the services. A graphic illustration of a service layer topology is

given in Figure 7 - Service Layer Patterns. (An analogy for this type of representation would be the patterns seen in brain scans). The service layer pattern must include a 'categorisation' service which must meet the condition set by the IER. In summary, tasks are allocated to services, services allot components.

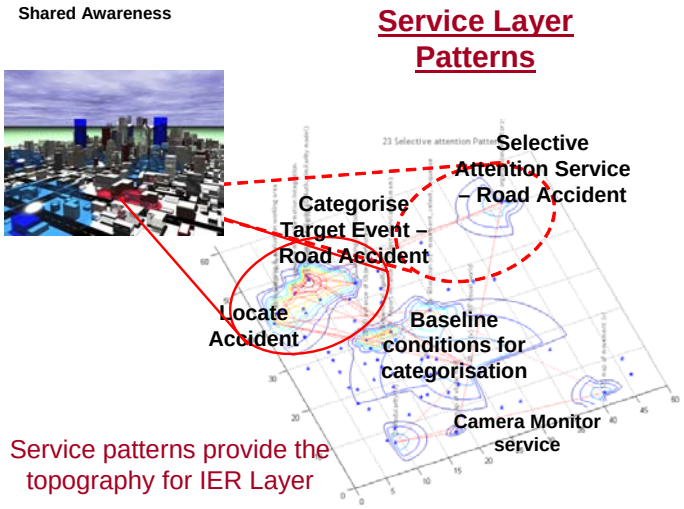


Figure 7 - Service Layer Patterns

The parts of the system activated (like the parts of a brain), are associated with a task but only interact to solve a particular problem. In this case the activated areas associated with the monitor camera and the TMC receiver interact to collect information about a particular situation e.g. Road Accident at Location X. The camera might equally well be feeding other emergency service customers simultaneously.

The environment for this problem imposes some external constraints on these interacting parts which are characterised as system-wide constraints. For example many cameras may be unsighted and not meet the IER conditions. However, assuming that external (system wide) constraints are met, the imaging system technology can be matched to services to provide useful systemic qualities. For example common services might include 'event monitoring' and 'name service'[4], which together with higher-level systemic features (time-constraints and evolve-ability) can be configured via the service layer to provide useful systemic qualities, (such as computability[5], advanced error recovery and adaptability). This aggregation of service interaction might be thought of as the first representation of task capability.

4.8 Population of the Component Layer

The purpose of the component layer is to provide the functional and structural framework for a componentised system. It is the encapsulation of design best-practice i.e. modular systems. The component layer allots physical components (in a Command and Control model, a Command component allots 'troops to task' that are equipped with appropriate information systems) Note that compilation and initialisation of high-level conceptual components provides the baseline for the service layer patterns.

There are a number of ways of interpreting the definition of what components are, however, it is useful to think of components as design patterns that can be used to support global design decisions. For example in the case of the monitor camera whose

[4] The concept of a naming service is central to the distributed computing environment.

[5] The concept of computability will support ideas of composability.

image information will act as a ‘cue’ for global system behaviour, its system configuration must include a common ‘Recognition Component’, including an ‘Encode Image’ sub-component (figure 8). This approach lends itself to the development of an initial high level conceptual view/configuration for the system as the basis for subsequent design.

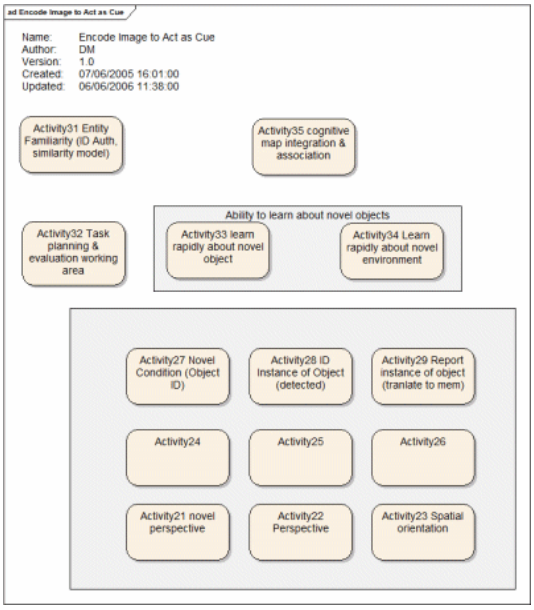


Figure 8 – Encode Image Sub-Component

Best design practice may be to start with the conceptual architecture view that can be systematically taken forward as a module architecture and subsequently as execution architecture. This approach would give important traceability and accountability and allows us to deal with legacy components and structures. In this case, TMC technology and Camera Imaging are already fielded products (see Figure 2) with explicit executable architectures developed as part of the component layer.

Requisite performance might be described in terms of a satisfactory outcome: in the example the taxi driver successfully delivers his passenger after selecting a route option.

Conclusions

Coalition command and control in the networked era looks forward to a decision making process that will benefit from improvements in the areas of agility, shared understanding and information accessibility. It has been shown that there are gaps in the current strategy which may preclude the achievement of the desired benefit.

Alternate strategies for achieving predicted benefit for each of three NEC areas are identified. For Agile Mission Groups the direction is to design information as part of a coherent and dynamic process so that pre-integrated and tested information 'lego-bricks' can be used and re-used to compile capabilities that are optimally tailored to complex tasks. For Shared Understanding the direction is to exploit a form of schema[6] that can be used to construct a temporal and spatial context for relevant information to enable the provision of appropriate information to all entities within a System of Interest. Finally, for Information Accessibility, to replace the current 'ownership' based model with one that directly exploits information qualities to act as the trigger for information accessibility. The idea of design for emergent desired behaviour sits at the heart these alternate strategies.

The Design Framework provides structured design guidance that is simple enough to understand, but sufficiently robust to be scalable and adaptable to user needs. It has the potential to provide the assurance mechanism to track behaviour, capability and equipment programmes for legacy, future legacy and future systems. The idea of active information is critical to the operation of the framework.

The idea of 'active' information is that it will guide and shape the desired emergent behaviour, and thus fundamentally influence the decision making process. Active information is represented in three information constructs, namely Schema, Context and Alarm, and which act together to organise the operation of the Information Layer. The Schema represents the physical world; events are integrated to provide the latest information. Context encapsulates what is known about a situation and will usually provide the initial population of a schema. Alarms are the trigger mechanism for changes in attention within or between entities and will usually be the precursor to the initiation of action. The 'gene' pool for these constructs is the entity which can be formed to represent real world things (people, cars, mountains etc) and things about things (concepts). Governance of these constructs must be set within information principles.

Information principles are high level instructions that help us to understand how to use information constructs and entities. A generic set of principles has been developed and successfully tested against various system problems. It is believed that they are coherent and sufficient to support the provision of initial design guidance. Thus it is concluded that the use of these information principles sits at the heart of effective design for required performance and behaviour and therefore the engineering of NEC.

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[6] Representation of temporal context and sequential structure Grafman (1989) Plans, actions & mental sets.