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Integrated Strategic Performance Toolkit for Cooperative Scheme Comparisons in Inter-urban Intelligent Transport Services

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Abstract
A high level objective for many international governments and local operators is that highways should be managed in a way that is sustainable in terms of a Low Carbon Energy future. Recent initiatives such as the Strategic Transport Technology Plan and the policy and legal framework promoted by the European Commission's ITS Directive and ITS Action Plan may assist with this requirement. However, many levels of complexity are inherent within the Intelligent Transport System (ITS) schemes that are now part of highway management, due to the linkage of various technological components to complex systems and services. Maintaining efficient, sustainable co-operative performance is therefore a major task, with inconsistencies between product suppliers, network managers and operators. It is of great interest to road operators in particular that enhanced policy and technological alignment in the form of an inter-scheme comparison matrix should be created. This paper proposes an integrated strategic performance management framework (ITS-PMF) which can perform inter-technological comparisons of four key performance areas between ITS schemes in order to identify energy and emission hotspots. Appropriate action can then be taken to improve the energy and sustainable management of ICT and transport systems for the benefit of a smarter, sustainable and efficient future.

Keywords:
Low carbon energy futures, Impact assessment, Multi-Criteria Assessment, System Dynamics

1 Introduction

1.1 Problem Rationale

The environmental deficit has applied continuous pressure for increased sustainable technology development within the transport arena. Intelligent transport systems (ITS), based upon a synergy of embedded transport infrastructure and ICT are calibrated to support enhanced road network performance [1-2]. With ICT working as a natural enabler of systems, these technologies aim to offset, harmonise and adapt the performance of the road network in response to a more demanding low carbon future. According to [3] there has been a paucity of studies that actually focus on the embedded lifecycle emissions in the construction, operation and disposal of these ITS schemes. In addition, a gap identified within the ITS literature is a framework mechanism that attempts to assess the splicing of environmental performance measures with the integrated technical sustainability of ITS technology.

This process is coupled with the additional carbon offset that these technologies aim to deliver to the transport network. Internationally, road network operators require new performance indicators to be developed which need to differ from those aimed towards more conventional highways [4-5]. The National Cooperative Highway Research Program in America have recently published a report on the development of performance measures for sustainable transport [6] and also proposed how ITS can be implemented into the current transport planning process [7]. At the time of research, the ICT support infrastructure, physical transport infrastructure and the operational assessment of vehicle throughput have all been calculated in isolation. The lack of an established clear consensus on the overall emissions creates a confusing backdrop of black box 'cause and effect' chains, inconsistent emissions targets and hidden consequences. It can be argued that what is needed now is the introduction of performance indicators to not only monitor the potential carbon reduction using inter-urban ITS but also to assess its embedded emissions to ensure future technological harmonization and cooperation.

1.2 Defining a strategic performance management framework for ITS

This research proposes a strategic performance management framework for sectoral ITS scheme comparison. The toolkit is based upon a ‘bottom-up’ hierarchy of ITS technological performance management with three distinct layers – a strategic layer, tactical layer and operational layer as follows.

At its top level, an inter-scheme comparison matrix is currently being investigated by the authors of this paper. The tactical layer represents the various performance cornerstones necessary for managing ITS as defined by the overall scope of the research. The operational layer consists of the metrics, measures and environmental system analysis tools (ESAT) used to support the four KPI's.

The research presented here focuses upon the tactical and strategic layers of the toolkit. In the tactical layer, the proposed KPI's represent the general performance cornerstones across four main areas of managing intelligent transport systems within an inter-urban environment i.e. standardisation, data management, service resilience and EnvFUSION (a self-contained method aimed at assessing the sustainability of the physical road-side infrastructure and ICT data links), each comprising a technical performance index. The ITS performance management frameworks route to optimisation is expressed via the 'standards highway'. Three of the KPI's will be supported and represented via the appropriate standardisation KPI.

Finally, the strategic layer integrates all four performance areas and features a performance matrix designed to perform inter-scheme comparisons of ITS services within a national/sectoral region. Network operators will be able to develop their own criteria based upon their own requirements, vision and mission statement. Figure 1 illustrates the strategic performance management framework (ITS-PMF). As an example, the focus of the operational layer is tuned to the sustainability assessment – EnvFUSION and other elements within the tactical layer would have their own operational tools, metrics and measures.

The four KPI’s in the tactical layer represent not only the technical side of maintaining the performance via *continual service improvement* (ITS is built from an IT/technical infrastructure therefore scientific measures must be implemented objectively) but also to reinforce the governance of existing and future transport planning based upon governmental policy [8].

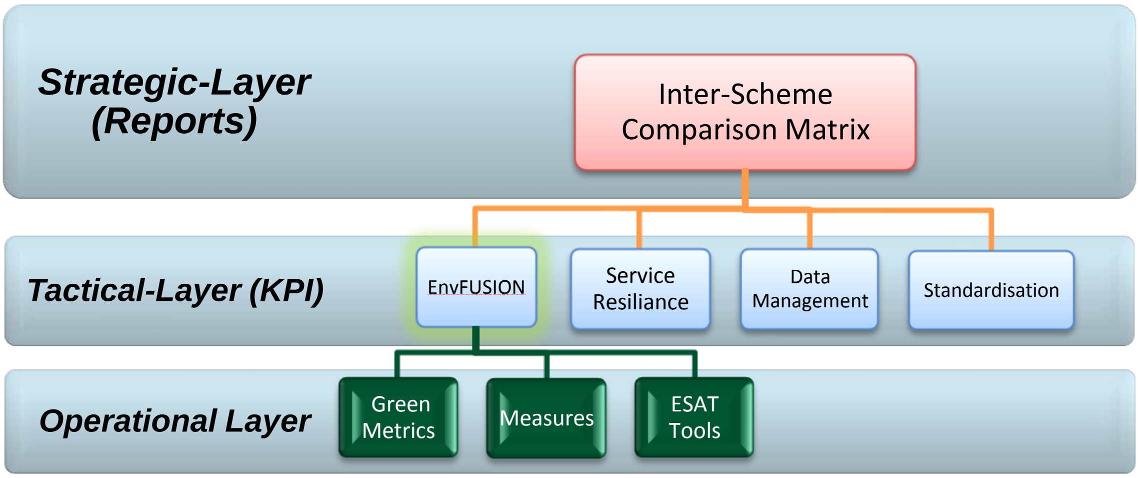

Figure 1 – ITS Strategic Performance Management Framework

2 Defining Performance Management for ITS

2.1 Overview

Performance and sustainability with regards to ITS can be defined within a multi-disciplinary approach to tackling a wider problem area. The ability of transport and IT services to blend seamlessly into a continuous and optimal state under a low-carbon mode requires analysis from different perspectives as well as varying levels of detail. The following factors may be taken into account that provide a holistic view on tackling ITS performance.

Some authors maintain that a future transport network [1, 9-10] will consist of a variety of integrated wireless communications delivering seamless real-time data to the transport network. Transmitting this data becomes complex due to a wide variety of data types and transmission sources [11-13]. In addition, these data sources need to be protected against malicious attacks (viruses, hackers etc) via maintaining its integrity [14].

Definitions of performance in ITS must take environmental issues into account in order to assist in the reduction of climate change. The 'low-carbon' infrastructure should be in place to negate the effects of carbon emissions and energy wastage from the road network [15-16]. In addition, the task is made fundamentally complex due to sectoral targets of not only reducing transport but also applying pressure on providing a 'green' ICT energy consumption [17-20]. Additional performance measures are needed to estimate the success of carbon and energy initiatives within ITS (Transport and ICT perspectives) in order to achieve the required goals for the future.

Performance for ITS also requires a certain level of resilience. For example, vehicular networks must be able to maintain a constant connection, defying environmental interference against natural landscapes (hills, mountains), weather systems, natural disasters and artificial data blockades such as tunnels [21]. In addition, a socio-technical perspective must indicate how future ubiquitous transparent (easily perceived) services will behave and perform in a way that allow users of the network reassurance of optimal safety, navigation and O-D (Origin-Destination) planning [22-23]. Indicators must be in place to define how transport services maintain user adoption.

A final note on performance definition is the ability to standardise and allow true network compatibility across the varying technologies both now and in the future. Network standards should be developed which are universally compatible with infrastructure, data types and transmissions [11, 24-25].

Figure 2 gives a schematic representation formulated to structure the expected issues each KPI will attempt to tackle. For the purpose of this paper, only the EnvFUSION sustainability assessment is in focus.

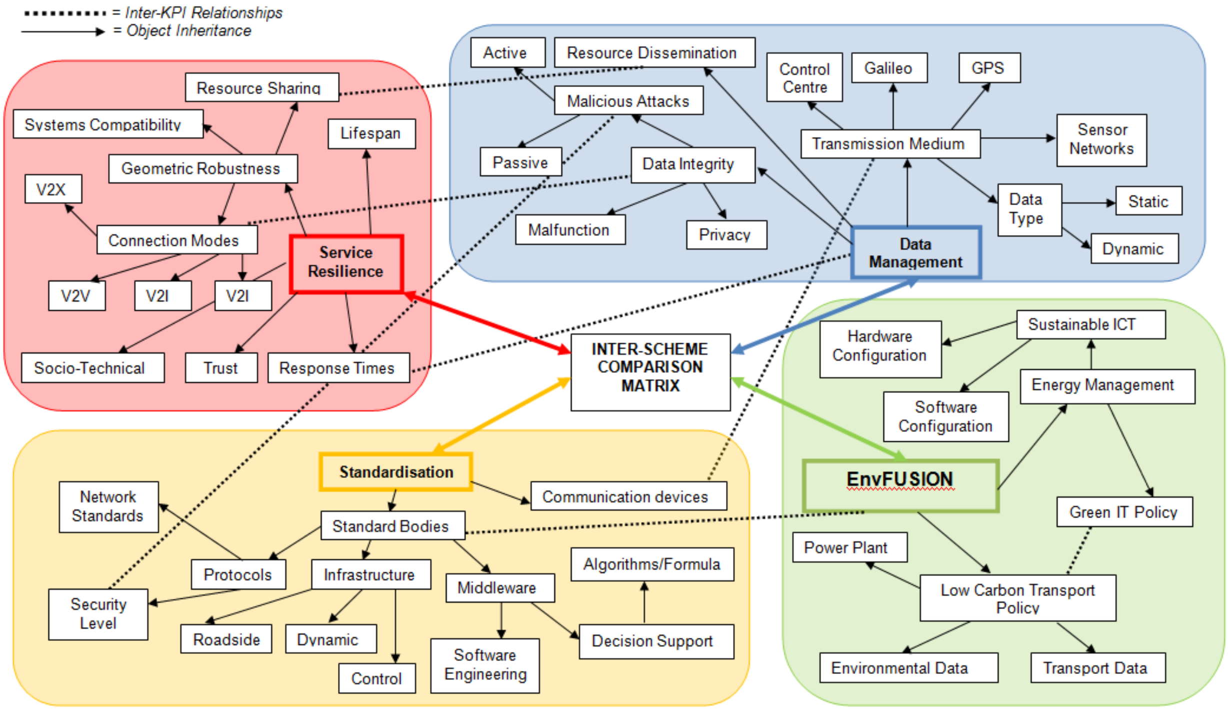

Figure 2 - ITS Performance Mind map

2.2 EnvFUSION - Integrated Sustainability Assessment

In order to ensure ITS achieves true sustainability, performance must be measured from a variety of different perspectives. While it is important for the transport system (including road-side infrastructure and eventually vehicles) to be enhanced using a low-carbon vision, it is also necessary to maintain a carbon neutral data management system [18, 26-28]. According to [29] Forrester research has estimated that the future market for green IT services will reach around 3 billion pounds by 2013. The use of ICT within intelligent transport provides an integral platform to implement and maintain advanced traffic services, therefore any ICT infrastructure that is directly involved in maintaining transport services must also be environmentally balanced [30].

Whilst a further strand to the research (currently a work in progress) concerns the development of a sustainability index to assess the performance of a scheme in isolation, the focus of this paper is at the strategic level of the EnvFUSION key performance indicator which is considered as an enabler of inter-scheme comparison from a sustainable perspective. Given current economic pressures alongside the political imperative to achieve national and international targets relating to energy and the environment, the ability to compare performance across alternative schemes will have considerable impact within the ITS stakeholder community of operators, suppliers, policy makers and funders. The flexibility to incorporate bespoke detail within the ITS-PMF means that the framework as a whole is both adaptable and transferable across regions and countries.

3 Management and Assessment of Sustainable Performance Relationships

3.1 System Dynamics Problem Rationale

In order to determine how performance relationships are formed it is necessary to discuss the system dynamics problem rationale. The reason for using a System Dynamics method within performance management is two-fold. From an external perspective, the idea of maintaining performance of ITS without historical data is an understood technicality. Researchers therefore attempt to develop evaluation frameworks which do not depend on past data by incorporating the ITS process into existing methods [31-33]. Sterman (2000) argues that the system dynamics methods' primary use is to assess the long-term effects of a complex and dynamic system, and due to the various unpredictability in setbacks and concerns that the ITS evaluation frameworks will encounter in the future, it is clearly apparent that the use of a model could aid in the development of a sound performance methodology. For EnvFUSION, Figure 3 illustrates the cause and effect relationships affecting the transition of the road network to a low carbon future from the perspective of a road network operator.

3.2 Relationship Definition, Data Elements and Internal Relationships

With reference to figure 3 the low carbon transition features multiple elements of uncertainty which the feedback loop attempts to resolve.

The diagram starts with two exogenous (external input) elements - the *Supply Chain Sustainability Level* and *Component Energy Rating* which affect the level of energy that is consumed within the infrastructure. The *Energy Usage for Infrastructure* element relates to the current levels of energy that are used to maintain power within the various components. *Energy Overhead* is the overall level of potential waste energy that exists within the network. Some power that is drawn from roadside components may be due to inefficiency and will have a direct impact on enforcing sectoral environmental targets. *Procurement Optimisation* is based upon an external assessment of the network providers upstream supply chain (a focus for EnvFUSION).

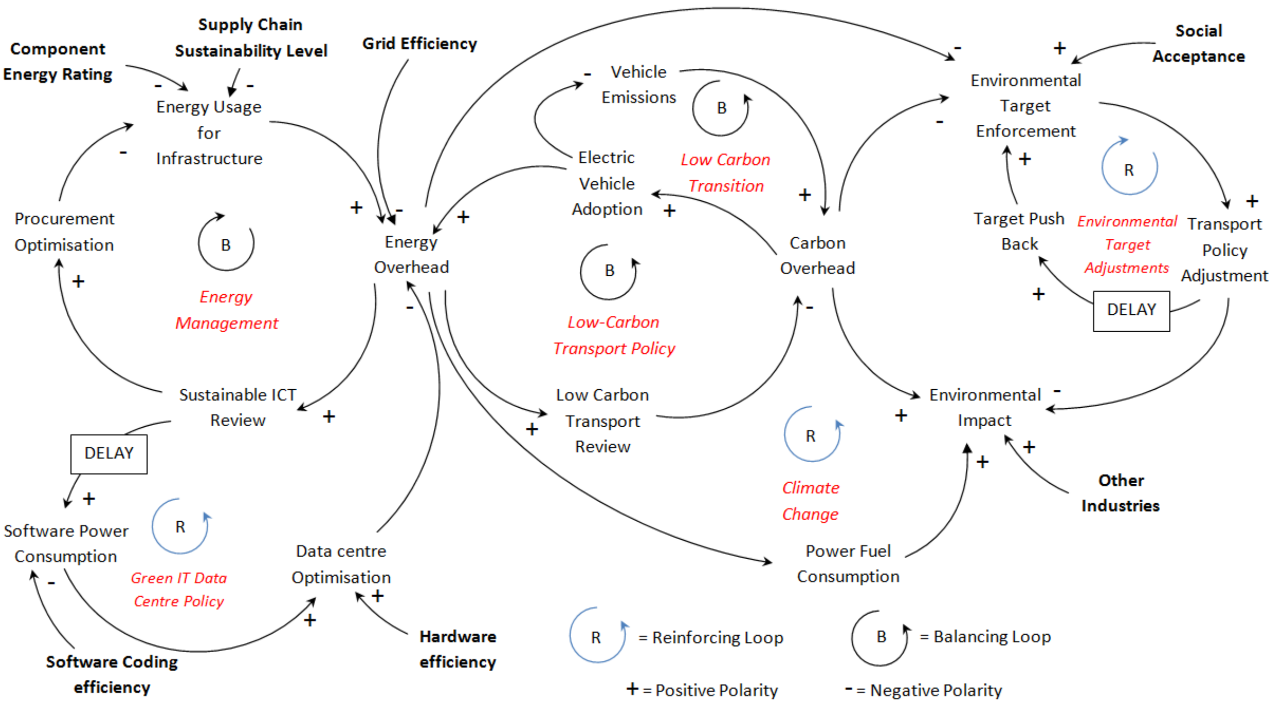

Figure 3 - Feedback loop diagram (Perspective of Strategic Road Network Operator)

A lifecycle assessment of the supply chains emissions may enable the network provider to optimise procurement, thereby reducing the embedded emissions of the ITS infrastructure. Within the ICT data centre policy loop, a *sustainable ICT review* is given which is implemented to increase energy efficiency [34]. The review attempts to increase energy efficiency of both *software energy consumption* (based upon *software coding efficiency*) and *hardware* (facilities and support equipment) efficiency via selecting service providers that meet the required energy efficiency targets of the network provider. Enhancing *data centre optimisation* of ICT Service providers influences energy efficiency through the provision of efficient hardware and software equipment that is procured through their own supply chain, however this particular area is not included within the scope of the framework.

In addition to the ICT Review, increasing energy and emissions overheads result in *a low carbon review* which aims to reduce vehicle emissions. This places pressure on manufacturers to produce more energy efficient vehicles which in turn will reduce the carbon output through the introduction of hybrid engines. The *vehicle emissions* element is based upon the number of vehicles taking to the UK roads as well as the effectiveness of the vehicle to reduce its own emissions. Some manufacturers will attempt to introduce fully electric vehicles which will cause a percentage of vehicle owners to push towards *electric vehicle adoption*, however, electric vehicles will require charging from the grid. This draws more energy directly from the national supply further increasing the energy overhead. Grid efficiency determines the sustainable effectiveness of power production within a sectoral area. As the energy supply to the network increases, the *energy overhead* rises. The *carbon overhead* is the current level of emissions that exist within a region. An increase in carbon overhead underlines the need for a *low-carbon transport review*. The *environmental impact* is based upon all hazardous emissions from the road transport sector and *other industries* that are affecting the state of the ecosystem that are external to the focus of the SD model.

The refining of *transport policy adjustment* is based upon historical data and the need to reduce emissions which is key to meeting the targets of the government and EU (Kyoto Protocol etc). *Target push-back* is the reconfiguration of the low-carbon policy to achieve the targets at a different date or to sell excess carbon units via emissions trading (one of the tools of the Kyoto protocol)[35-37]. The adoption of these targets via *Environmental target enforcement* depends on social acceptance and can be defined as the ability of stakeholders to support and enforce emissions reductions.

Table 1 describes the positive/Reinforced loops.

Positive/Reinforced Loop	**Description**
Green IT Data Centre Policy	This loop deals with the impact of the network providers data centre policy and includes the iterations of data centre optimisation. It aims to reduce the energy in IT hardware via removing the bloat in software code. This makes the software easier to compile and manage therefore requires less processing time from the hardware. Within ITS services the impact of ICT is linked with the energy and emissions output of the road-side infrastructure.
Climate Change	This is a simple loop where the planets eco-system cannot handle excess emissions therefore the carbon overheads increase which causes the temperature to rise.
Environmental Target Adjustments	This loop is based upon the UK governments plan to meet baseline carbon reduction targets that were agreed under the Kyoto protocol. However, if the level of carbon is increasing these targets must be pushed back.

Table 1 - EnvFUSION Positive/Reinforced Loop Description (Source: Author)

Table 2 below describes the negative/balancing loops.

Negative/Balancing Loop	Description
Low-Carbon Transport Policy	This loop deals with the low-carbon transport policy. It is a culmination of energy and carbon overheads which deal with the solution to adopt electric vehicles. However, this adoption would lead to an even greater demand on the power grid because of the vehicles requiring a charging platform.
Energy Management	This loop concerns itself with the reduction of energy demand via introducing a sustainable ICT review which in turn will lead to reduced energy consumption.
Low carbon Transition	Low carbon transition tracks the gradual decline in road emissions via the introduction of less carbon intensive vehicles.

Table 2 - EnvFUSION Negative/Balanced Loop Description (Source: Author)

4 Inter-Scheme Comparison Matrix

4.1 Overview

An inter-scheme comparison matrix will be created in order to correlate the data between the four KPI's. It will also include targets set by the government (baselines) and relationships between the four areas for performance analysis. An evaluation of the four KPI's via the data produced within the matrix will then be conducted to determine if the analysis has met its objectives. One of the main benefits of the matrix is the ability to compare between various schemes in a cost effective manner via utilizing a range of strategic criteria using existing data. Strategic road network operators may request from their upstream suppliers data regarding the performance of the road-side equipment for example, although an agreement will need to be made between the two entities as to the integrity and validity of the data to be extracted.

The inter-scheme comparison matrix attempts to exhibit a granularity that allows geographical identification of poorly performing sectors. For example, a particular junction or link within a network can be scrutinized. The three layered framework, supported by the EnvFUSION performance sustainability assessment allows stakeholders to drill down to understand the root cause of a poorly performing sector and allow comparison between similar links or junctions. The direct benefits of this approach is that network operators may rank and identify elements of sustained optimal performance which can be immediately applied to poorly performing ITS schemes at the microscopic (road-side infrastructure instance such as a single gantry) or the macroscopic level i.e. the UK's managed motorway ITS scheme.

4.2 Matrix Characteristics

The scheme comparison matrix aims to follow the general characteristics of a multi-criteria performance matrix with some methodological development represented via the three performance layers. According to [38] a Multi Criteria Analysis (MCA) features a traditional performance matrix which possesses the following attributes. Each row may describe one of the individual ITS schemes that are being considered. Each column corresponds to a criterion, or performance dimension which is considered important to the comparison of different schemes. Various criteria are developed which are decided by the road network operator depending upon their level of focus. For example, from a sustainable perspective, the power consumption of lighting within the scheme as well as the power utility rating which connects the grid to the infrastructure may fit into this category. Finally, the entries in the body of the matrix assess how well each option performs with respect to each of the criteria. In the case of multiple evaluators various letter codes are given to differentiate the stakeholders of the scheme.

The individual measurements are often numerical but can materialise in color coded or bullet-point style indicators. The weights will feature a range of 0 to 100 with the least being 0. The weights are then assigned in order to provide 'scope' and relevance to the numerical figures.

The matrix for the KPI performance measures will be developed using the methodological approach for the creation of an inter-scheme matrix as detailed in the traditional MCA literature. While traditional matrices have a flat based structure, the development of the inter-scheme comparison matrix will be significantly more detailed, therefore it may be desirable to develop the KPI suite in a literal three-dimensional format. Because the KPI's are generic and cater for a wide variety of ITS technologies, the tool will have a superior advantage over current transport planning and ITS component/Infrastructure selection. The advantage of using such a format is three-fold. Firstly it allows for a greater sense of depth in measuring performance which will aid better decision making. Secondly, because of its multi-dimensional properties, the inter-scheme comparison matrix will be able to cater for a wider group of bodies that are linked to ITS performance management. For example, the strategic layer gives an overview of current trends in comparing the performance of certain ITS technologies such as Galileo etc. The tactical layer will be able to move into greater depth within a KPI and can focus on more specific issues such as understanding response times in a specific environment. Finally, the operational layer would allow a user to customise the KPI using metrics, environmental assessment tools and measures.

The final benefit would be the ability to measure performance under a low-carbon future, thus any technology that is developed would be given a rating to reflect the predicted impact the technology would have upon the environment. More specifically, the level of carbon that currently exists in the region or zone could be measured. The development of an inter-scheme comparison matrix could play a pivotal role in the future pathways for many governments internationally with a desire to attain a low-carbon future.

4.3 Overview of Matrix Data Flow

As ITS projects are based largely on decoupled IT virtual services, the data between ITS attributes and actors is likely to vary as time passes.

Figure 4 illustrates the general data flow of the KPI' when connected to the matrix. The perspective is perceived from viewing the ITS-PMF ‘top down’, with the four key performance cornerstones visible.

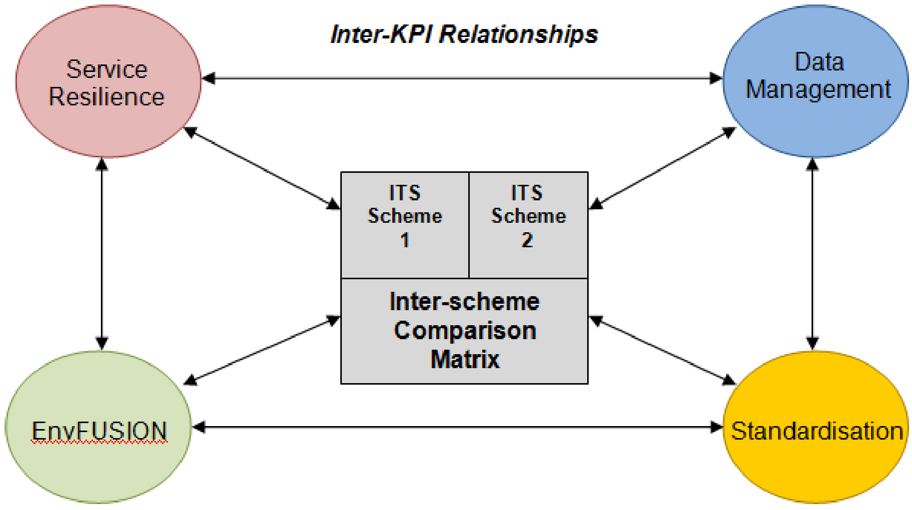

Figure 4 - Inter-Scheme Comparison Matrix and KPI Data Flow (Top-down view)

Data that is fed into the performance management framework will first be designated to a KPI based upon the type of attribute the data belongs to. Attributes will share common relationships with other attributes in different KPIs. As discussed earlier, it is important to note that the relationships between KPI's must be mapped in order to determine the cause and effect relationships from indirect and direct scenarios such as those shown in figure 2. For example, some attributes such as the security level within the network will directly affect the integrity of data, therefore performance levels may fluctuate depending upon the relationships between the KPI's.

The advantages of this approach are that it tries to remove aspects of policy resistance that arise from underdeveloped or hidden reactions to data elements which is one of the key goals of the SD methodology.

5 Conclusions

This paper has introduced an integrated strategic performance toolkit known as ITS-PMF. An overview of the strategic performance management framework has been given indicating EnvFUSION as one of four cornerstones for managing intelligent transport technologies. Identifying the cause and effect relationships of the low carbon transition provides a rare glimpse of transparency to stakeholders involved in managing the road network which can assist in developing criteria for a robust ITS scheme comparison. By comparing ITS schemes, crucial benefits are realised such as the triangulation of energy and emission hotspots, data can be quickly generated and procured at a low cost and the use of a three-dimensional performance assessment allows the framework to adapt to the needs of all stakeholders involved within ITS performance evaluation. Finally, the comparison matrix also exhibits a granularity that allows geographical identification of poorly performing sectors at the microscopic and macroscopic level.

To date, there is still no real commercially viable alternative for assessing the embedded and consumed emissions of physical transport infrastructure and their ICT datalinks. The proposed strategic toolkit aims to provide the methodological foundations in order to improve this paucity of integrated and cooperative inter-scheme assessment tools. It is important to note that without the contribution of such tools as ITS-PMF and its KPI method - EnvFUSION, technological and cooperative improvement of the transport network may be overshadowed by the environmental deficit, currently shaping our future life.

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