- developing mitigation measures and appraising them using the DfT's Strategic Appraisal Framework which is to be documented in the Phase 2 Final Report.

This report describes all but the final step listed above. This section goes on to describe the review of previous work, the information gathered from stakeholders within the Eastern Region and the preparation of the GIS database which would be used to display and appraise the information collected.

3.2 Literature Review

3.2.1 Previous Research

A seminal article on road vulnerability was published by Katja Berdica in 2002 in Transport Policy entitled "An introduction to road vulnerability: what has been done, is done and should be done"[1]. The paper sets down a number of definitions which are replicated in Table 3.1, below and supplemented by information from Husdal[2].

Table 3.1: Definitions

Item	Definition	Source
Serviceability	The **serviceability** of a link/route/road network describes the possibility of using that link/route/road network during a given time period.	Berdica, 2002
Incident	An **incident** is an event which directly, or indirectly, results in a considerable reduction or interruption in the serviceability of link/route/road network. An **incident** is, therefore, an event causing reduced capacity and/or increased demand.	Berdica, 2002
Risk	**Risk** is a composite of (1) the probability of an incident occurring and (2) the resulting consequences should the incident occur.	Berdica, 2002
Vulnerability	Vulnerability in the transport system is a susceptibility to incidents that can result in a considerable reduction in network serviceability.	Berdica, 2002
	A ***vulnerable*** network exhibits a low degree of operability as expressed by non-serviceability, non-accessibility, and variability under certain circumstances, due to the lack of redundancy, robustness, and resilience in the network.	Husdal, 2004
Reliability	**Reliability** is adequate serviceability under the operating conditions encountered during a given time period.	Berdica, 2002
	Reliability of connectivity (terminal reliability) = the probability of reaching a chosen destination.	Berdica, 2002
	Reliability of travel time = the probability of the reaching a chosen destination within a given time.	Berdica, 2002
	Reliability of capacity = the probability of the network being able to 'swallow' a certain amount of traffic.	Berdica, 2002

Item	Definition	Source
	A ***reliable*** network exhibits a high degree of operability as expressed by its serviceability, accessibility and non-variability under any circumstance, due to the presence of redundancy, robustness, and resilience in the network.	Husdal, 2004
Resilience	The capability of a system to 'return to normal' after having been disturbed. A question of stability: (1) maximum disturbance from which the system can recover and (2) speed of recovery.	Berdica, 2002

Berdica's work regards the road network as a whole and involved the identification of a range of incidents, collecting data on probabilities and consequences in order to estimate risk and analysing the data to try to set values for a desirable or acceptable level of performance (serviceability) as well as investigating the effects of mitigation and improvement strategies. Berdica states "road vulnerability analysis could thereby be regarded as a hub for the whole battery of transport studies needed to gain the insights necessary to describe how well our transport systems work in different respects, what steps to take and what policies to implement in order to reach desired goals".

Husdal[2] has raised questions as to why reliability, or conversely vulnerability, of the transport network is not a matter of evaluation in traditional cost-benefit analyses. For example, from a freight haulier's point of view, a vulnerable network, that is, one that is easily disrupted resulting in unpredictable delays is probably seen as a much bigger problem than a congested and slow-moving network that is relatively reliable and 'stable'. In the latter case, there is a greater guarantee that goods will arrive at their destination and, more importantly, that transport costs are calculable and lead times are predictable. In essence, vulnerability can be viewed as non-reliability.

Husdal noted that transport networks are subject to a wide range of vulnerabilities that can lead to operational problems. Husdal categorised the attributes and influences in terms of:

- Structure-related (the way the road is built and to attributes of the network itself, its physical characteristics such as geometry, width, curvature, gradient, weight restrictions, height restrictions, presence of bridges, tunnels)
- Nature-related (topography and the terrain the road traverses and natural incidents such as floods, snow, ice, fog, climate change and so on)
- Traffic-related (traffic flow and attributes causing change such as peak periods, special events, maintenance operations, accidents)

Typically, these vulnerabilities will manifest themselves collectively, although particular areas of the network may be susceptible to only one of these. Nonetheless, the whole network will be exposed to the full set of vulnerabilities, and all should be considered.

Godschalk[31] and Murray-Tuite[5] highlight the ten properties of a resilient transport system as follows:

- **Redundancy** – the transport system contains a number of functionally similar components which can serve the same purpose and hence the system does not fail when one component fails (for example, a number of similar routes are available with spare capacity).
- **Diversity** – the transport system contains a number of functionally different components in order to protect the system against various threats (for example, alternative modes of transport are available).

- **Environmental Efficiency** – a transport system which is environmentally efficient will be more sustainable, and capacity is less likely to be constrained due to environmental reasons.
- **Autonomy** – the components of the transport system are able to operate independently so that the failure of one component does not cause others to fail (for example, can the transport system operate safely in the event of a power cut?).
- **Strength** – the transport systems ability to withstand an incident (for example, how extreme a flood event can the system cope with?).
- **Adaptability** – or flexibility, can the transport system adapt to change and does it have the capacity to learn from experience (for example, an area-wide traffic management system can adapt to differing traffic conditions).
- **Collaboration** – information and resources are shared among components and/or stakeholders (for example, contingency plans in the event of an emergency and the ability to communicate with system users).
- **Mobility** – travellers are able to reach their chosen destinations at an acceptable level of service.
- **Safety** – the transport system does not harm its users or expose them, unduly, to hazards.
- **Recovery** – the transport system has the ability to recover quickly to an acceptable level of service with minimal outside assistance after an incident occurs.

Murray-Tuite[5] concedes that each of these dimensions and their interactions are complex which makes the derivation of a comprehensive measure of resilience difficult and her research focuses on measuring resilience with respect to adaptability, safety, mobility and recovery using simulation. The Murray-Tuite[5] paper concentrates on quantifying the differences in the resilience measures obtained using two assignment modelling techniques, the performance of both are very similar (in measuring adaptability, safety, mobility and recovery). Interestingly, the paper does conclude that the other dimensions (redundancy, diversity, efficiency, strength and collaboration) will play a large role in determining the resilience of a transport system.

It is clear from the references accumulated during the literature review that no-one has attempted to develop a comprehensive measure of resilience using the ten properties highlighted above. Di Gangi and Luongo[4] used a modelling technique which centred on the the estimation of the number of alternative paths chosen (in the model) between each origin and destination and estimating indices to measure 'resilience' based on the number of paths chosen, and the level of demand. Baughan, Constantinou and Stepanenko[3] also used modelling techniques which were first developed from research funded by the US Air Force Research Laboratories to look at the resiliency of data communication networks. Their approach was focussed on measuring and displaying the fragmentation resulting from the loss or degradation in performance of a number of key links in a transport network (based on the Netherlands). The approach is only applicable to networks consisting of bi-directional links and whilst it was applied to a multi-modal network and could be used to determine those links with the biggest impact, the overall measure of resilience used is a very narrow one.

Whilst certain aspects may appear to lend themselves to computer modelling (such as mobility, safety, recovery) although we maintain that common transport modelling tools are often based on equilibrium assumptions at a macroscopic level. These assumptions do not lend themselves to looking at the behaviour of a transport system under extra-ordinary conditions. In any event, data on actual re-distribution of traffic during extra-ordinary conditions would be needed in order to calibrate and validate models and, clearly, this information is very rarely, if ever, collected due to the nature of the events that we would wish to analyse.

The timescale for the conclusion of Phase 1 of this study would not have allowed for the use of third-party models to develop resilience measures and given the foregoing, our approach would need to be more pragmatic. However, this would enable us to take into account all the resilience properties mentioned previously, rather than a sub-set.

3.2.2 Study Area Challenges

Demography

The East of England is the second largest English Region and covers 15% of the total area of England. It contains the counties of Bedfordshire, Cambridgeshire, Essex, Hertfordshire, Norfolk and Suffolk and the unitary authorities of Central Bedfordshire, Bedford Borough, Luton, Peterborough, Southend-on-Sea and Thurrock.

The major cities and towns in the region include Norwich, Cambridge, Peterborough, Stevenage, Ipswich, Colchester, Southend-on-Sea and Luton and two of the five international 'London' airports are in the region (Luton and Stansted). The major sea ports of Felixstowe and Harwich are located on the east coast.

Currently 16% of the population in the region are aged 65 or over whilst 2% are aged 85 or over; this is in line with the average for the UK. The region is projected to have a higher population growth than most other regions over the next twenty years with a particularly large increase in the older age group. There has been an increase of 24% in the number of people aged 85 and over in the region between 1990 and 2008 and the trend is set to continue. Half of the population is expected to be over 50 by 2020.

In terms of households, there were an estimated 2.37 million households in the region in 2006. This is projected to be around 3.06 million by 2026; in increase of 29% which is above the national average of 24%. The projected increase in households is higher than that predicted for population reflecting an increasing trend single person households. The increase in the proportion of elderly people in the region could also contribute to the increase in the number of people living on their own. As a result, access to transport and accessibility to public services is and is likely to become more intense over time. Maintaining a transport network that can cope with these demands will be a challenge and ensuring and improving the resilience of the transport networks should be seen as a key goal.

Economy

In terms of the labour market, the East of England has maintained above average rates of employment compared with the rest of the UK. Unemployment rates have also remained consistently below the UK average. However, in some areas in the region, around the region's northern and eastern periphery, the unemployment rate is significantly higher than the regional average. Norfolk, King's Lynn, Thetford and Great Yarmouth all have substantial concentrations of urban deprivation and there are significant pockets of deprivation in rural Norfolk. Economic activity rates, expressed in terms of gross value added (GVA) per head, indicate that the areas of Hertfordshire, Peterborough, Cambridgeshire and Luton significantly outperform the other areas in the region.

London has an influence on the Eastern Region being most intense within an arc from Watford and Hemel Hempstead in the West to Chelmsford in the East. This region has the highest average earnings in the region due to it containing the strongest skills base and, no doubt, due to the proximity of London. Clearly improving transport infrastructure/network resilience should bring economic benefits but there is the possibility of leakage of economic activity out of the region.