Cross sector resilience decisions using AI and CARVER methodologies

This article will set up a few fundamentals on BIM and the step into Digital Twins and National Digital Twins and demonstrate some of the methods used to ensure we have resilient infrastructure to support our societies. Including how to map the various infrastructure networks and create a cross sector analysis so that the reader can work out what is Critical and Vulnerable in their networks for national strategy writing and post crisis management.

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Resilient cross sector asset management decisions through BIM and a national digital twin

National Infrastructure is constantly changing. Whether through upgrades, replacements, decommissioning or brand-new additions, each amendment needs careful thought and important decisions made. Infrastructure is not something that is cheap to procure or maintain, so with restricted budgets and limited resources we really need to understand what exists to a level that we know what is critical, what is vulnerable and how they all interface and interact with each other.

To make good decisions, we need all the available relevant information, presented to us in a way we can understand and trust it. This of course is where BIM comes into the equation. If you are still thinking that BIM is 3D pretty pictures or complex schemas, then I'm afraid I am about to burst your bubble! For too long this activity has remained the closely guarded domain of the CAD team, who if you look at the whole lifecycle and the depth of information created, managed and utilised for an asset, is a tiny fraction.

The experiences below aren't based solely on the UK, but lessons learnt from asset owners, major projects and organisations around the world. Over the last 10 years almost 15 thousand individuals have visited me in the Digital Advancement Academy in London to share knowledge, including many from Germany and Europe.

1. A few fundamentals

So, before we look at how we can bring together multiple digital assets into a national digital twin, we need to start with a few fundamentals.

When you were first told about BIM, what did you do? I can bet one of the activities you carried out was to type it into Google and read through a vast array of information, so that you could make your own mind up. Well… you did a very BIM thing! You asked a plain language question into a common interface and that kicked off a search of many different databases, servers and systems to bring you back pages of information to help answer your question. The key difference between this activity and a BIM one, is TRUST. I hope you didn't trust all the information you read from the internet? There are so many pieces of fake news, twisted for commercial or political gain that you need a great deal of caution when reading what the internet serves up for you!

The key thing with BIM is that it isn't just a single piece of unconnected information like a drawing, document, metadata or model, but a whole linked data model of trusted and well managed information that will help you make decisions throughout the lifecycle of your asset portfolio.

Lifecycle is the next fundamental to focus on. When do decisions about our assets start? (Figure 1.0) Information Modelling doesn't start at design or heaven forbid construction! It starts before you even know that something needs to change. You will be monitoring your portfolio of assets to understand how they are performing, if they are delivering the function you need to support your business and also whether they are costing too much to maintain! So, collecting, managing and utilising information starts very early indeed!

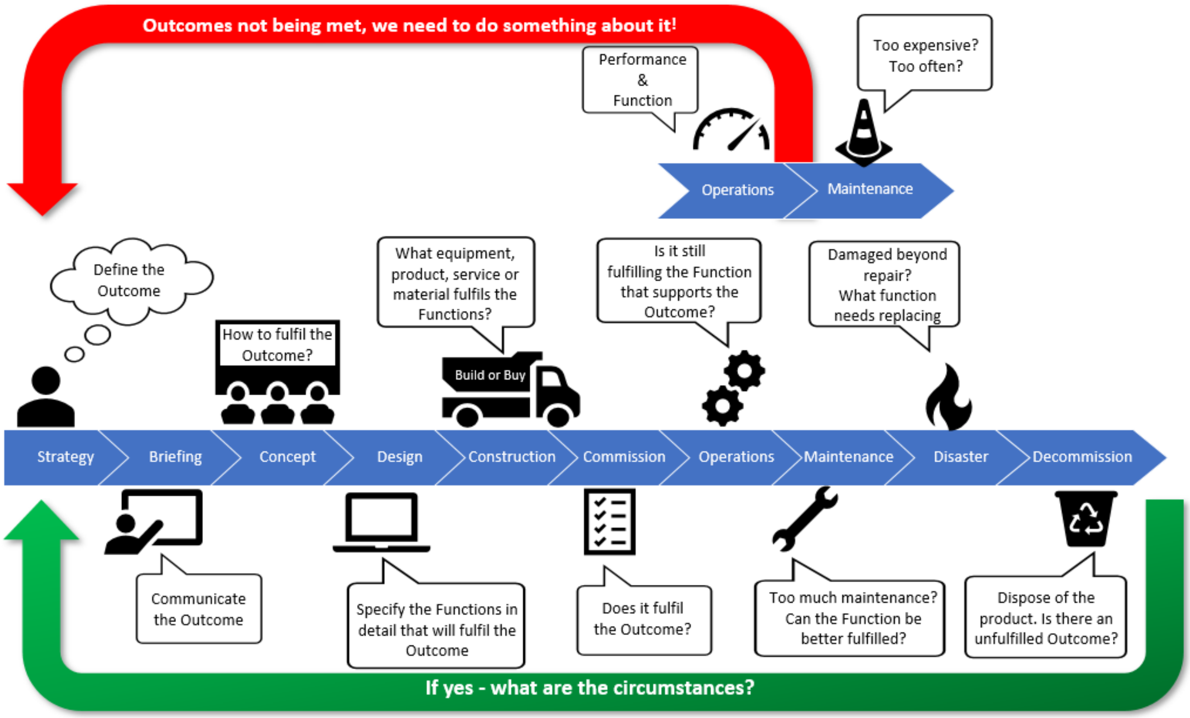

Figure 1.0

1.1 Existing Infrastructure

A high proportion of infrastructure has been operational for decades and in some cases centuries! Over time those assets have changed ownership, been upgraded, become obsolete, have been buried or uncovered. What is common however is the lack of recording what is there and where exactly is it! Whether this is through inaccurate as built records, or simply non-existent records, this absence of knowledge around what we currently own is a massive risk to future growth. Even when we have accurate records, they are held by different owners in different organisations, stored in different formats that will never be able to be read by others.

The problem with infrastructure, is that it is deeply connected and interconnected. Meaning that it is wholly reliant on others for it to function. Yet these dependencies are rarely mapped or understood to any significant detail.

So how can we plan for a better future without understanding what we already have, not only in each individual owner's portfolio, but across all sectors so we can deliver a truly joined up national strategy for future generations?

1.2 Digital Twins

If your original definition of BIM was limited to pretty 3D pictures, then you have a massive leap to take to get to a digital twin. However, if you followed the smart advice and created a solid asset information model with trusted, well managed and valuable data that can be accessed by those that need it to make good quality decisions, then the next step is a simple one of connecting your physical asset to your digital one in both directions. (Figure 1.2)

1.2.1 Sensors and Actuators

One of those key components for a Digital Twin is the connectivity between the physical and the digital enabling the passage of data between the two. This data is not just from Sensors embedded in the Physical Asset that will update information in the Digital Asset, but also actuators that are controlled by the digital asset that can change things in the physical. This is a concept spoken mostly about when looking at the Internet of Everything.

The automotive racing industry has been linking the physical and digital together in a live environment for many years. I am proud to have been an ambassador for the original Bloodhound Super Sonic Car team. Many parts of the car, from its engines, steering, brakes and electrics have a Digital Twin that is both monitored and tweaked remotely when required to ensure the car achieves the outcome set by the team, to reach 1005mph and survive the attempt!

The current thinking with sensors is that they and data storage are relatively cheap, so we should be proliferate in their deployment. The data we collect today may have little value, but when looked at in the future and in relation with other interconnected data then it may flag up some very valuable trends showing any weaknesses in the systems and root causes for operational or maintenance issues.

As our Digital Twins get smarter and we add in artificial intelligence to help predict future issues, the ability for the Digital Twin to tweak and control elements of the physical asset will become more valuable allowing a much more efficient operation. Taking that a step further and linking it to the supply chain systems whether that is for products or skilled people, then either the Digital Twin can start ordering its own parts when they are cheapest or advising agencies about the type of skilled worker needed in the next 6 months to conduct repairs or maintenance tasks!

Whether you see this as an extension of BIM, a leap into Digital Twins or just good practice it is essential that you get the strategy right, not only to suit your current portfolio of assets, but looking into the future as to what will be the outcomes demanded by your end users over the next 50 years.

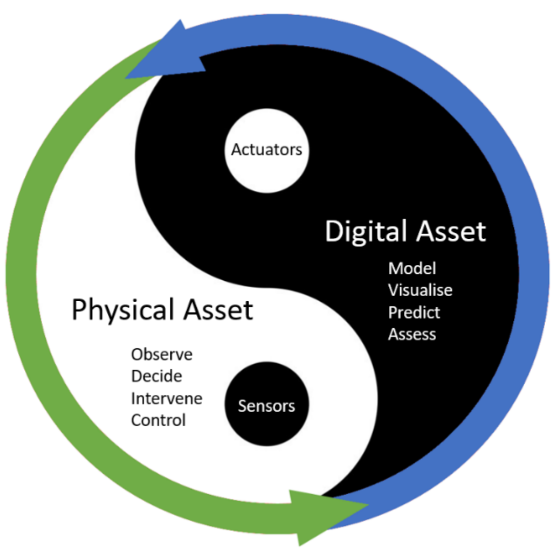

Figure 1.2

1.2.2 Open Standards

No technology vendor can possibly satisfy the vast array of authoring requirements for all the information that will make a Digital Twin. The only way that a true twin of the world we see around us delivering everything from social, economic and environmental modelling to structural, transport, health and industrial modelling is through ensuring the information they create is delivered in an open approach, so that the old risks of interoperability, translations and conversions don't tarnish the long term vision.

1.3 National Digital Twin

This is not just an aggregation of all the Digital Twins of all the owners of infrastructure in the nation, that would be a crazy proposition! What this is, is a circuit board that in times of either crisis or national strategy creation, the individual Digital Twins can be plugged in, so they connect to each other and we can see the sum of the whole, rather than just individual parts.

This requires the creation of a universal circuit board, that is interoperable enough to allow each Digital Twin "chip" to plug in and show how they interact and impact on those around them. It also means that a minimum set of common data, defined in a nationwide standard is recorded by each owner against their asset portfolios. (Figure 1.3)

This national digital twin is transient in nature, as each of the DT chips are maintained by the asset owner, kept secure and up to date on their own systems. It is only at a time of national need, such as when a national infrastructure strategy is being written or when there is a crisis, that the affected DT chips are plugged in allowing a cross sector analysis to be made.

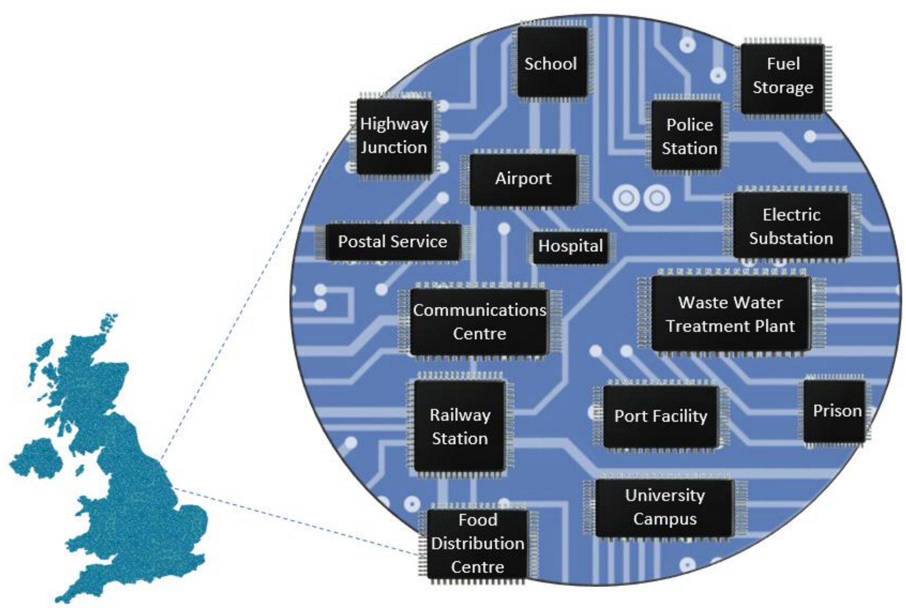

Figure 1.3

Making this circuit board and ensuring the DT Chips can be plugged into it, is not the end of the National Digital Twin effort, but it is a solid foundation data model to build from.

2 Creating this circuit board using proven methodologies

When there is a natural disaster anywhere in the world and aid agencies alongside governments scramble to assist putting that country back on its feet, where do they start? With limited resources and manpower where are their efforts best placed, not only in repairing the damage, but also protecting what survives from aftershocks or human panic?

The Infrastructure Assessment methodology has been utilised for decades doing just that and this same methodology, whilst currently unautomated, could deliver a significant part of this solid foundation data model.

To explain how this method works, lets talk through a disaster scenario:

Figure 1.4

It's not hard to imagine the scene after an earthquake, where buildings and structures have collapsed cutting off power, water and communications to towns and villages across the country. (Figure 1.4)

People are injured and, in the aftermath, the hospital plunges into darkness without power, you have a limited budget and time to get things going. What do you do?

In the military I was always taught to have what is known as a "Condor Moment" rise up above the chaos around you and look at the bigger picture before making your plans! This moment is created by analysing the infrastructure on a cross sector level to truly understand how things impact on each other and where they connect.

If you have this information, then you will know that rushing to the hospital and supplying electricians is a waste of time. What you actually need to do, is to fix the railway bridge, which has collapsed, stopping the trains with the fuel supply from reaching the power station, therefore causing the blackout.

This analysis can help to make our infrastructure assets more resilient in future disasters, but what do we mean by resilience?

Resilience is made up of four areas:

• Resistance: Concerns direct physical protection (e.g. the erection of flood defences). Resistance is ensured by preventing damage or disruption through the protection of Infrastructure against threats and hazards. This includes reducing vulnerability through physical, personnel and cyber security measures.

• Reliability: The capability of Infrastructure to maintain operations under a range of conditions to mitigate damage from an event (e.g. by ensuring that electrical cabling is able to operate in extremes of heat and cold).

• Redundancy: The adaptability of an asset or network to ensure the availability of backup installations, systems or processes or spare capacity (e.g. back-up data centres).

• Response and Recovery: An organisation's ability to rapidly and effectively respond to and recover from disruptive events.

2.1 Infrastructure Assessment methodology.

When doing this assessment, you will always work with what you have, so in a country where you own or have friendly relations with the owners of the asset information, it is greatly simplified. In other cases, for example third world locations, there might be no information of existing assets, so the methodology takes this into account right from the start. How do you eat an elephant this large? One piece at a time!

Each sector; road, rail, power, comms, water, fuels, medical etc is firstly analysed on its own and then brought together into a single cross sector network (such as we require for the foundation data model in a national digital twin)

A primary decision before you start is to decide to what level of detail you want to take this analysis to. My suggestion is that you start at Facility level and if you require more granular answers then conduct the same analysis at Primary Functional Unit and Functional Unit level. This is normally called an Asset Breakdown Structure. (Table 1.0 and Figure 1.5)

Asset Level	
Complex	In Infrastructure this is the complete network encompassing all connected assets.
Facility	In infrastructure complexes these are both Hubs and Connectors. For example, a facility could be a motorway junction or the road between them. A hospital, a reservoir, a railway line or a gas pipeline could all be labelled as a facility.
Primary Functional Unit (PFU)	These are the primary systems that make up a facility. On a motorway this could be a bridge, a gantry system or even an earthwork.
Functional Unit (FU)	These are the supporting systems inside the PFU. In a highways example these could be a speed camera system, the wearing course or traffic light system which is part of a bigger junction control signal PFU.
Element	This is the lowest level and is down to the level of value or in simple terms the maintainable level.

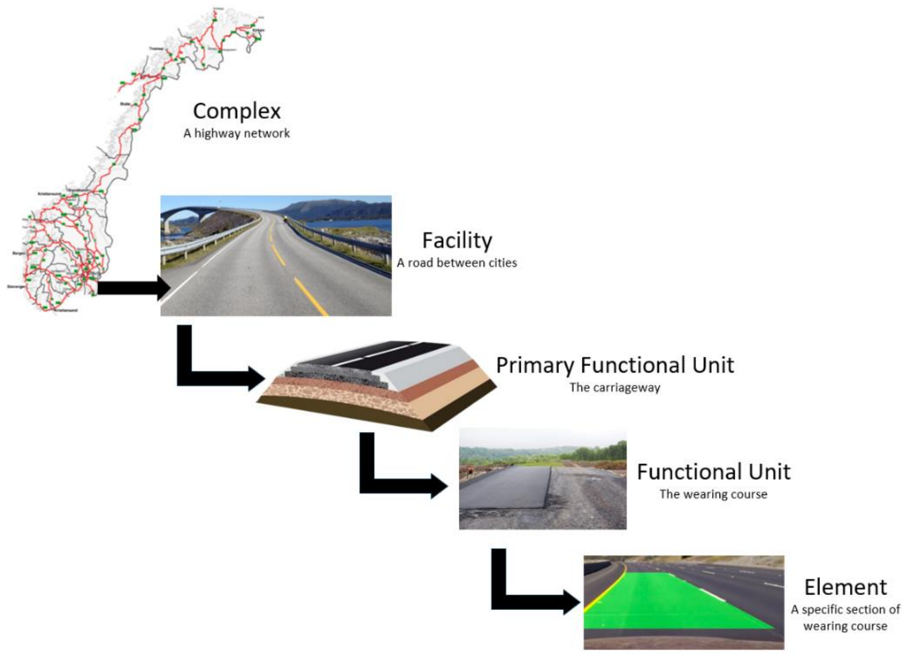

Figure 1.5

Where to start the assessment? If you have access to the functional network diagrams of your sector asset owner, that's great. If not, you are going to have to get a sector subject matter expert to put together their "best guess" with whatever information can be gleaned from open sources.

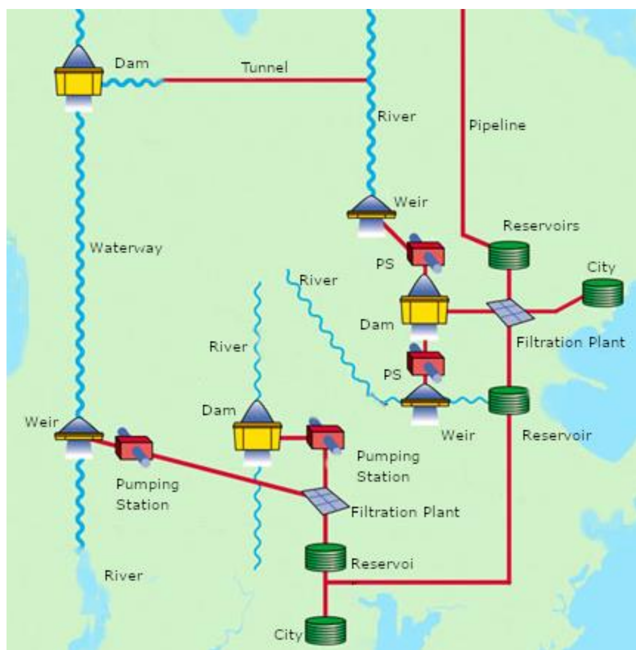

Figure 1.6

This Functional Network Diagram is important to ensure nothing is left out and we know what we are looking for on the ground because some assets might be buried or contained inside anonymous buildings. (Figure 1.6)

It is important at this stage to get an understanding as to whether there is a dependency with other sectors and to identify what that is. Does this asset need power, communications, fuels, transportation or any other feed? Secondary is to note down if one of the assets delivers a function to another sector.

The next stage is to identify all the elements on the ground and their connectors. This will deliver a Physical Network Diagram. Some infrastructure may not functionally connect, but they will be in the same physical location and so will impact on each other if there is a problem. (Figure 1.7)

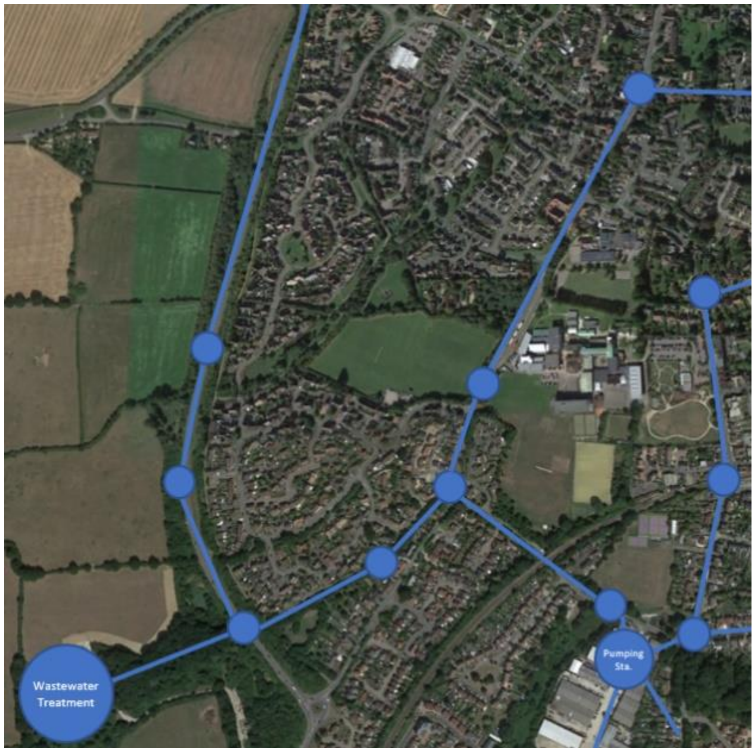

Figure 1.7

Now you have a physical network diagram, the next stage is to create a Dependency Matrix. This is currently a very manual process at the time of writing this article, but I'm sure there is systems and software to make it easier!

The Dependency Matrix shows the links between different assets, each of these is essentially a hub in the network with connectors between them.

Identify those hubs, grouping together those with similar functions. Write them down along the top and down the side of the dependency matrix. If they don't already have one, give them a unique identification number.

Now identify the links between those hubs. If this is being down from on an unknown or unrecorded network, then it will have to be a best guess! You will need to analyse each of those links to better understand what type of connection it has:

> **Low (1)** - There is a relationship or a weak connection of very low importance. Minimal or no disruption would result because of losing the link
>
> **Medium (2**) - There is a definite connection, the loss of which would result in some loss quantifiable of service
>
> **High (3)** - There is a strong link with severe consequences if lost

	Emergency Water	Water Supply	Fire Hydrant	River	**Total Dependencies**	**Weighted Score**
Emergency Water		3		1	**2**	**4**
Water Supply					**0**	**0**
Fire Hydrant	3	2			**2**	**5**
River					**0**	**0**
Total Dependants	**1**	**2**	**0**	**1**		
Weighted Score	**3**	**5**	**0**	**1**		

Table 1.1

In the example above, the emergency water has a strong requirement from the water supply and only has a weak connection from the river. (Table 1.1)

The total scores can be calculated to give the total dependants on the bottom and total dependencies on the right. The weighted scores are also calculated. These can indicate the most important or critical assets (most dependants) and potentially most vulnerable (most dependencies) in the network but network or system redundancy must also be considered.

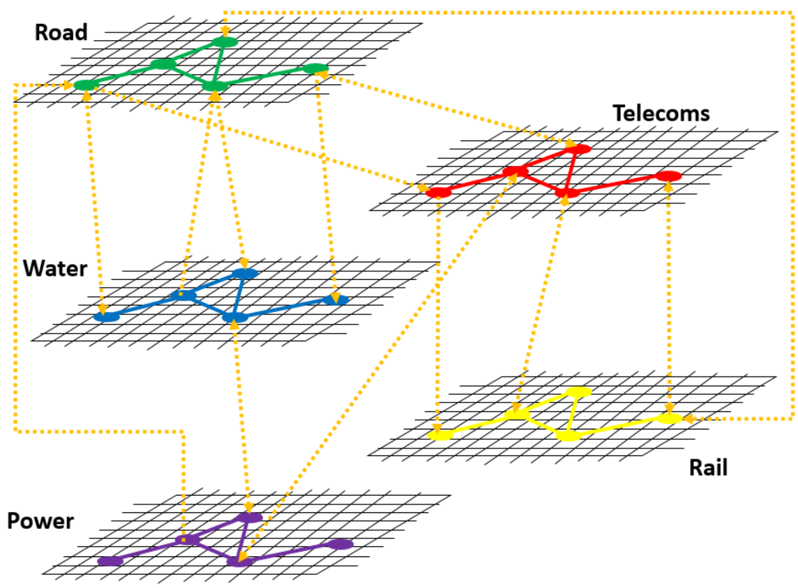

Figure 1.8

You now have a basic data model for a single sector. This process needs to be repeated for every sector that impacts onto our infrastructure that supports our nations and societies. (Figure 1.8 and Table 1.2) If each sector is made responsible for their own, then to bring them together needs a representative from each sector to come together with the others to map the links between them. This team is also used to conduct the CARVER analysis later

Primary Sectors		Secondary Sectors	
National Infrastructure Sector	**Sub Sector**	**National Infrastructure Sector**	**Sub Sector**
Transport	Aviation	Food	-
	Ports/Inland Waterways	Government	-
	Road	Health	-
	Rail	Finance	-
Water	-	Defence	-
Energy	Electricity	Space	-
	Gas	Chemicals	-
	Fuels	Civil Nuclear	-
Communications	Broadcast	Emergency Services	Ambulance
	Telecommunications		Fire and Rescue
	Internet		Marine
	Postal Services		Police

Table 1.2

This analysis comes together in a combined dependency matrix, a daunting task perhaps, but necessary if we are going to understand how each sector impacts, reacts and depends on the others to get a truly national digital twin to use for creating strategy and reacting to a crisis. (Figure 1.9)

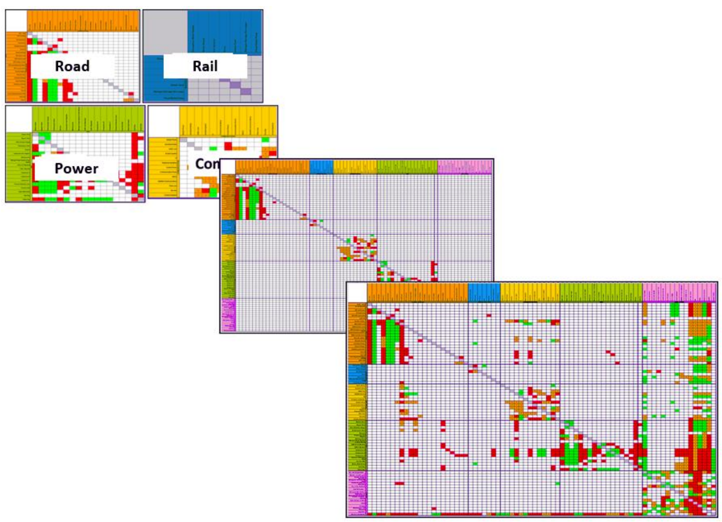

Figure 1.9

The first bit of analysis which will be useful for resilience planning becomes clear quickly by simply summarising how much each sector is dependent on the others. Once completed the Combined Link Matrix can become unwieldy. Even those who have been involved in its production will rapidly lose the ability to assimilate and brief its meaning. A summarised version of the Combined Link Matrix can reduce the physical size of the analysis and highlight the important aspects to the reader (see below) The links can be graded and scored Red=3, Amber=2, Green=1 and the Dependants and Dependencies can be totalled to give an indication of the most vulnerable sector and most important sector. (Table 1.3)

	Road	Rail	Power	Water	Dependencies (Vulnerability)
Road	Key factors and deductions from Road sector analysis	Key reliance of Road on Rail	Key reliance of Road on Power	Key reliance of Road on Water	6
Rail	Key reliance of Rail on Road	Key factors and deductions from Rail sector analysis	Key reliance of Rail on Power	Key reliance of Rail on Water	8
Power	Key reliance of Power on Road	Key reliance of Power on Rail	Key factors and deductions from Power sector analysis	Key reliance of Power on Water	6
Water	Key reliance of Water on Road	Key reliance of Water on Rail	Key reliance of Water on Power	Key factors and deductions from Water sector analysis	4
Dependants (Importance)	7	7	6	4	

Table 1.3

2.2 CARVER

The CARVER analysis methodology has been used since the 1940's to help analyse the importance of assets in conjunction with post war reconstruction. It stands for **C**riticality, **A**ccessibility, **R**ecoverability, Vulnerability, Effect and Recognisability analysis. Each asset is scored out of a possible 5 marks, with 5 being the highest.

For example, when something scores a 5 for Criticality it is defined as follows:

- If it's loss directly impacts on the quality of life of our population. Extended outages would directly result in disease, unrest and the breakdown of society.
- If its reduced functionality would have a significant economic impact
- If its loss or reduced function has a relational impact that could cause loss of life or serious environmental impacts.

Criticality also incorporates the magnitude of impact on a wider number of people and geographical area.

Accessibility looks at how easy it is for people to gain access to the asset for accidental or criminal damage purposes. As well as how easy it is to gain access to fix it!

Recoverability measure how quickly a normal service could be resumed either through physical repair, alternatives or restarting systems. The longer it takes to recover the more critical an asset might be.

Vulnerability understands how easy it is for this asset's function to be disrupted.

Effect covers how if this asset is lost or disrupted, how much of an impact will it have on the bigger picture.

Recognisability is also a double-edged sword, easy to recognise, easy to fix. But also, perhaps easy to recognise the value for it to be stolen or destroyed!

It can be a very subjective analysis but through experience very rapid. This is followed by 2 simple calculations where the scores for Accessibility, Vulnerability and Recognisability are combined to give a Likelihood score and Criticality, Recoverability and Effect are combined to give an Importance score. The total of all of them is the CARVER score, giving you a priority list for your limited resourced relief efforts or your national infrastructure strategy.

The final report identifies areas of concern that are critical to national infrastructure, where vulnerabilities lay and what planning needs to be put in place to increase resilience.

3. Change is coming

Whether that change is political, climate or economical we need infrastructure to support the society which defines our nations. As the world becomes a little less certain and we have to ensure money is well spent making a positive impact on our economy, our environment and our people, we will have to make difficult decisions whilst defining national strategy.

Making our infrastructure more resilient, making decisions easier and more certain through the use of a good quality national digital twin can only be a good thing.