Dashboards for Critical Infrastructure Protection & Risk Management

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Declaration

I hereby declare that the work presented in this thesis has not been submitted for any other degree or professional qualification, and that it is the result of my own independent work.

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10th March 2020

Date

Abstract

Visualisation is among the effective ways of data and information representation and has been employed in many fields. The emerging big data and the growing number of data sources have supported the use of visualisation in domains such as risk and protection of infrastructure. The use of Data Visualization Dashboards can support decision makers and experts in identifying and mitigating risks in Critical Infrastructures Protection.

The use of modern visualisation techniques has increased in the business domain and the same principles can be employed and improved in the presentation of Critical Infrastructure Sector (CIS) data for Protection and Risk Management. This motivated the study of the use of dashboards and data visualisation to improve decision support in critical infrastructure protection and risk management.

We reviewed various visualisation techniques in order to find out their effective use in CIS data visualisation. We explored the use of bar charts, dials, spatial, text and other visualisation representations in order achieve the goals of the study. Use of colour, size, centrality and shape was also explored as they effectively achieved information comparison, emphasis, summarisation, exploration and data storytelling.

Usability testing was done using expert interviews to find out the overall dashboard layout, the use of visualisation and information representation, collaboration and the general dashboard layout. We are confident the work will trigger more interest to further develop the topic.

Acknowledgements

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I would like to dedicate this work to my family members especially my parents Mr. and Mrs Omari and my siblings Reuben, Bernard and Loyce Vera for understanding my long absence from my home country in order to fulfil the requirements for my studies.

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Chapter 1: Introduction

1.1 Background

Data visualisation has been successful in supporting management in decision making in the business domain. Salesforce, an American cloud-based software company dealing with customer relation management did a survey in 2015 concluding that 73% of high performers acknowledge that analytics supports gaining insights from data. (salesforce, 2015). Dashboards as a visualisation tool, supports a full view of the subject of study or a phenomenon being analysed by providing a summary of combined charts and tables. (Rizzi, et al, 2019).

A critical infrastructure is an asset, system or network necessary for the proper functioning of a society and economy whether virtual or physical (McCue, 2015). In this work we apply data visualisation techniques to for critical infrastructure sector with the aim of supporting decision makers.

We implemented visualisation reports into dashboards to support decision makers using Microsoft ® Power BI, a business Intelligence software to create a decision support dashboard. We identified important attributes used in the data visualisation domain and how best they can be useful in the infrastructure protection sector.

Finally, a usability testing with infrastructure sector domain experts to determine usefulness of the implementations was carried out and findings presented to support our hypothesis (Sub Section 1.1.1)

1.1.1 Hypothesis

Use of Data Visualization Dashboards supports decision makers and experts in Critical Infrastructure Protection.

1.2 Dashboard Features

I. The dashboard supports the collection of data and protection assessment in addition to investigation of different hypothesis.

II. Different levels of details of the current situation of Critical infrastructure protection and the most effective ways to improve the situation.

III. Extra features for the dashboard include modelling dependency and the ability to add further critical infrastructure types of sectors.

1.3 Thesis structure

The study introduces the discussion topic with emphasis on the use of visualisation on critical infrastructure sector (CIS). The literature review section explores the history of visualisation, sample scenario, various use and a detailed discussion on critical infrastructure sector (CIS). It also contains; literature selection criteria, data visualisation techniques and the problem statement.

The methodology section introduces the key items of discussion in critical infrastructure protection, which includes; interdependencies, risk assessment, resiliency, threat and vulnerability assessment. Visualisation principles are discussed in the chapter.

Findings and conclusions incorporate implementation of the study, dashboard design guidelines, building a cascading failures and interdependency in critical infrastructure protection and a discussion on usability testing on the implemented dashboards and the findings.

Chapter 2: Literature review

2.1 Introduction

2.1.1 Data Visualization

Visualisation has been in use since the early ages of mankind, from the cave hunting drawings and paintings during the stone age period to complex data visualization in the height of the big data age of the 21^{st} century. Visualization is the use of graphical images to represent an idea, communicate an abstract or concrete message and simplify complex representation.

Data, normally referred to as a raw entity, often an observation or measurement (Cooper, 2010) of either a clinical, research or scientific study, a simple transaction processing system or any other source, needs to be turned into information which is data coupled with a context to give meaning (Cooper, 2010) and presented in a way that can be understood by its consumers or users. For example, it will be meaningful to present aggregated annual sales to company executives than give them the raw, daily sales entry of each product or services sold. The aggregated sales will be easy to interpret and help in quick decision making for the executives in line with a business performance.

Data visualization is the use of graphical representation to represent information and covey data. This will allow users and experts to recognize and detect patterns and insights in the information. Data visualization supports fast and efficient understanding of relationships in data. The objective of data visualization is to support in effective, efficient, accurate and relevant information presentation of data.

Rizzi et al describes dashboards as a visualization tool that groups multiple graphical representations like charts and tables, with the goal of providing a 360° view of the items being analysed (Rizzi et al., 2019) which will help in giving insights at a glance.

A 360° view gives an overview of the most important insights representing a particular sector for example in the following dashboard development sketch guide (figure 1). In a critical infrastructure sector, a dashboard can show the following key items:

- Critical Sectors
- Critical Sectors running Status
- Active Critical Sectors
- Overview of all Critical Sectors
- Most Affected or Sectors that are not active

Visual Analytics, leveraging on computation and analytical reasoning is a structured reasoning process that allows experts to gain insights and evidence in data in a particular problem domain or sector (Sacha et al., 2014). Data visualization has been around for a while and has been used in the conveying of statistical data to help in understanding and deriving meaning. In 1858 Statisticians and medical reformer

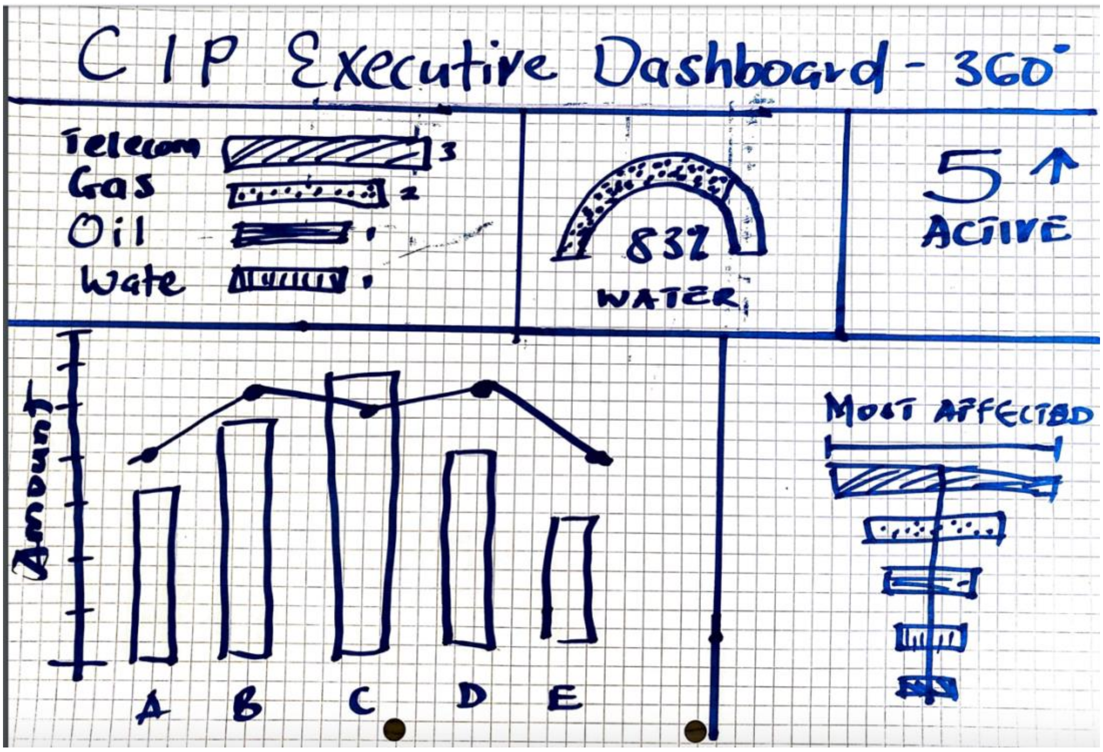

Figure 1. A sketch diagram showing a 360° Dashboard

Florence Nightingale published the famous Nightingale rose diagram, polar diagram or the coxcomb diagram (Cohen, 1984), she tried to explain the causes of British soldiers' deaths during the Crimean war.

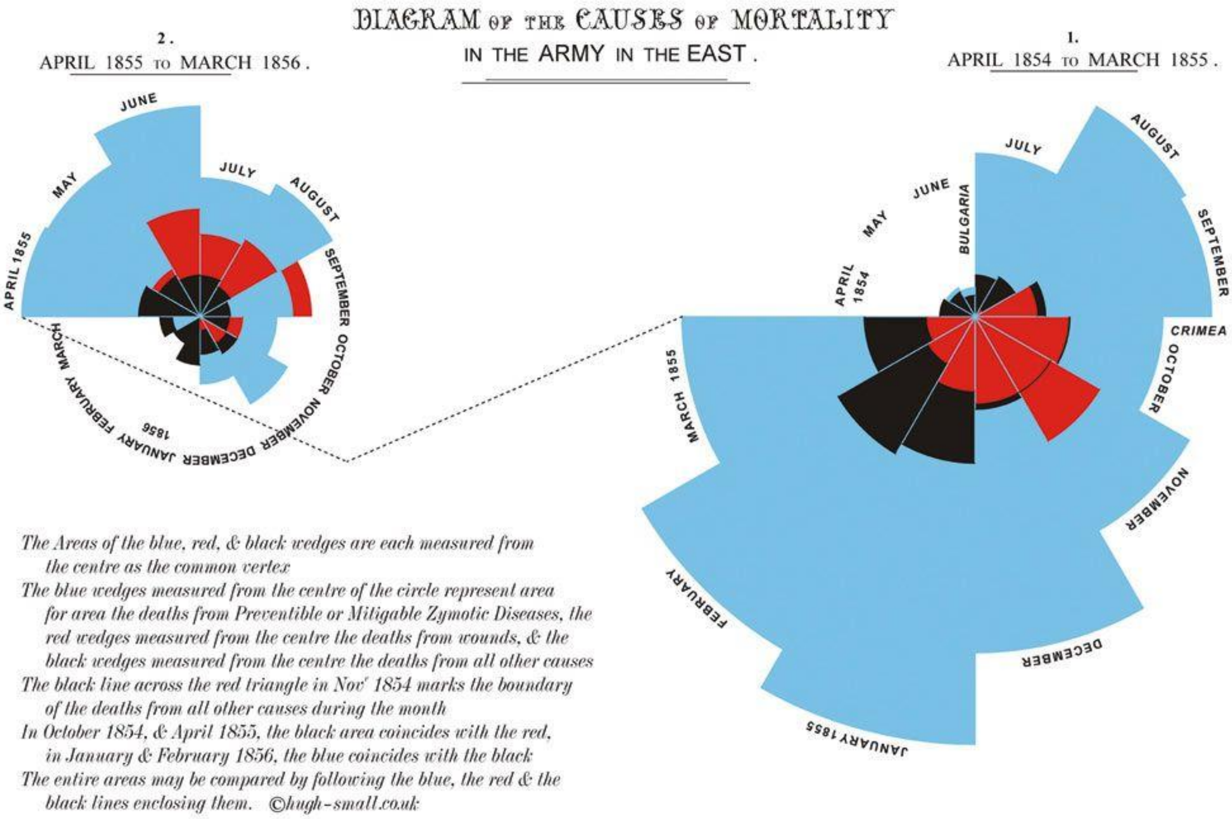

Figure 2. Florence Nightingale's Polar Diagram

Although by current standards her diagram had some flaws like giving more emphasis on the outer parts of the rose diagram, the visualization effectively and efficiently communicated the information and helped in improving public health and sanitation. Many scholars have argued that she could have used a column chart to make her data clearer, but there is an argument that it could not have carried the intended message.

Even though experts use several methods to interpret critical infrastructure protection, visual representation using dashboards is an effective approach in the process of decision making for experts. In this study we will examine the use of data visualisation to help experts and decision makers in identifying and identifying risks

figure 3. A sample dashboard

2.1.2 Critical Infrastructure Protection

Critical Infrastructure Protection (CIP) is a current topic of study and a concern to most government authorities world-wide. Critical Infrastructure includes, "the assets, systems, and networks, whether physical or virtual (McCue, 2015) to any country. Governments are creating policies to help in identification and protection of critical Infrastructure. The United States' Department of Homeland Security (DHS) on February 12th, 2013 released a *Presidential Policy Directive 21 (PPD/21)* (NIPP, 2013) that contains details on identifying and protection of Critical Infrastructure Sector (CIS).

According to the PPD/21 (CISA PPD -21, 2013) there are 16 critical infrastructure sectors whose assets, systems, and networks, whether physical or virtual, are considered so vital to the United States that their incapacitation or destruction would have a debilitating effect on security, national economic security, national public health or safety, or any combination thereof. The CIS are listed below, not in any apparent order.

1. Chemical sector
2. Commercial facilities sector
3. Communications sector
4. Critical manufacturing sector
5. Dams sector
6. Défense industrial base sector
7. Emergency services sector
8. Energy sector
9. Financial services sector
10. Food and agriculture sector
11. Government facilities sector
12. Healthcare and public health sector
13. Information technology sector
14. Nuclear reactors, materials, and waste sector
15. Transportation systems sector
16. Water and wastewater system sector

The European Council's consultations in 2004 came up with the European Programme for Critical Infrastructure Protection (EPCIP) (EU - Directive 2008/114/EC) that endorsed a program for CIP in her EU member states and the wider European Economic Area (EEA). This initiative involved a proposal for developing tools that can be used to carry out vulnerability assessment for European critical infrastructure with the aim of protecting Infrastructure in the EU Member states and the EEA.

The study will assess up to 5 CIS and build a model that can be reused in other CIS to help decision makers in evaluating and managing risks

2.2 Selection of Literature

We applied a thematic literature review protocol (Heer et al., 2010) to undertake the study. The following key words were used in the search, collecting and gathering resources on the following digital scientific libraries.

1. ACM
2. IEEEXplorer
3. Springer
4. Sciencedirect

2.2.1 Key words

1. (“Data visualisation” OR “Information visualisation” OR “Knowledge visualisation”),
2. (“Data visualization” OR “Information visualization” OR “Knowledge visualization”),
3. ((“Data visualisation” OR “Information visualisation” OR “Knowledge visualisation”) AND (“Critical Infrastructure”)),
4. ((“Data visualisation” OR “Information visualisation” OR “Visualisation”))
5. ((“Critical Infrastructures Protection” OR “Critical Infrastructures Sector”))
6. ((“Critical Sectors” OR “Critical Infrastructures”))
7. ((“Visual representation” OR “Design Thinking” OR “User experience” OR” User interface”))

2.2.2 Selection Criteria

Recent papers on critical infrastructure, visualisation and data visualisation where considered for literature selection in order to tap into the latest visualization techniques and research done by scholars. Although we have references of works as old as 1850s, we selected studies between 2010 and 2019 for the visualisation-based papers and related conferences, while on the critical infrastructure topic we referenced 24 papers for this study, this might not be an exhaustive reference but a trigger for further study.

2.2.3 Exclusion Criteria

Exclusion of data visualisation themed papers earlier than 2010 was done in order to accommodate modern techniques and principles of visualisation. An exception of the 'Florence Nightingale polar diagram' (Cohen, 1984) was done to demonstrate the history of visualisation.

We excluded medical and biological visual representation in the study; the visualisation of the scientific phenomenon in 3 or more dimensions of medical, biological and related subjects for visual renderings and representations (Friendly et al, 2008).

2.3 Data Visualization Techniques

Various techniques and methods have been used to present insights using data visualisation from standard to more sophisticated and complex techniques that deal with complex data sets (Heer et al., 2010). Simple visualization techniques include but not limited to charts, tables, graphs, maps, infographics and dashboards while complex or sophisticated techniques may include the following;

1. ***complex maps***; choropleth maps, cartographic maps, flow maps and graduated symbol maps. The figure below shows a choropleth map of the household water consumption per day for the members of the European Union in 2014/2015 (European Commissioner, 2016)

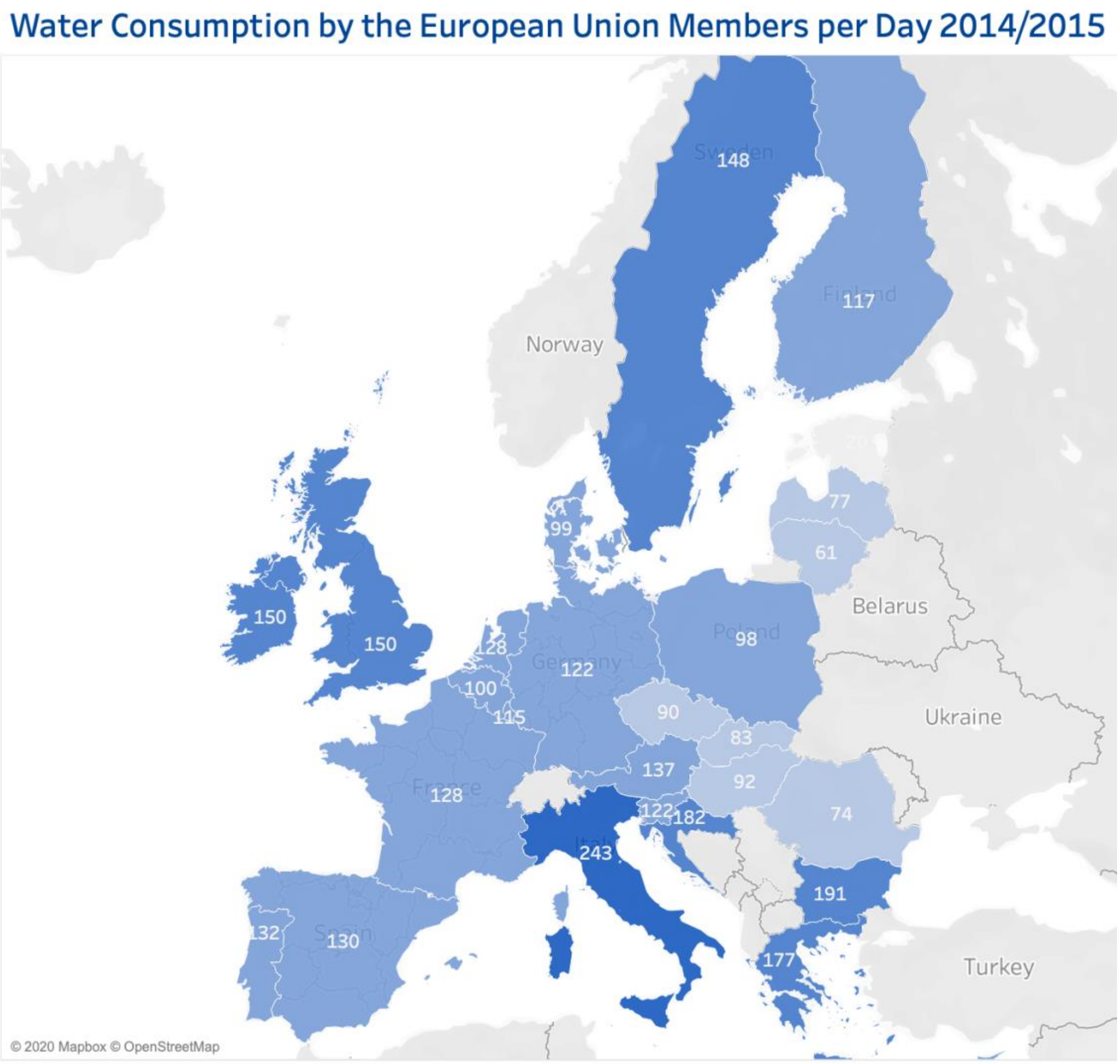

figure 4. Choropleth map showing water consumption in litres per day for the EU members 2015-16

2. ***complex hierarchies***; node link diagrams, adjacency diagrams and enclosure diagrams, example below shows a power plant network diagram showing interconnected infrastructure and the protection mechanism in terms of barriers backup or both

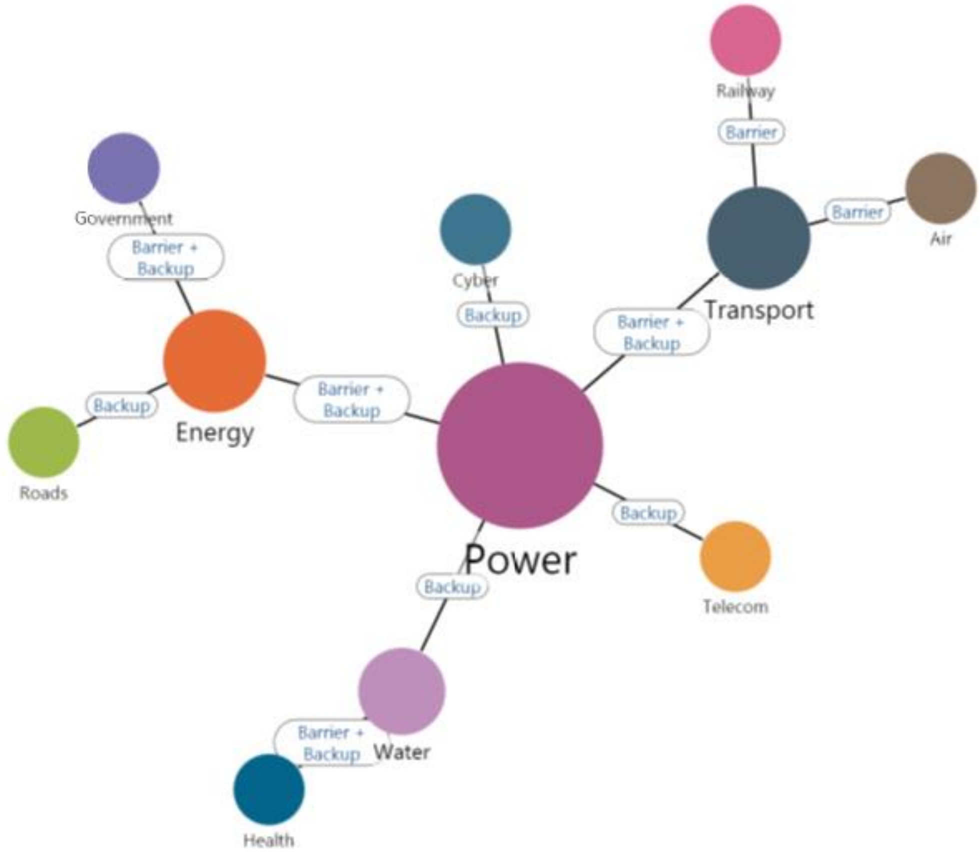

Figure 5. A power plant network node diagram

In recent years, an increase use of data visualization especially in Journalism has given rise to what is commonly termed as data storytelling. According to Seger & Heer, Data visualization is regularly promoted for its ability to reveal stories within data (Yusta et al., 2011). While most researchers and scholars did not agree on what the definition of data storytelling is, many scholars have centred on how the use of visual charts and narratives can support communication and insights (Lee et al., 2015). Edward Segel and Jeffrey Heer used the terms narrative and visualisation to refer to Data storytelling with a chain of events coupled with visual charts. (Heer et al., 2010)

Our definition of data storytelling is the use of data visualization with supporting narratives to deliver better insights from data. Other cognitive techniques like choice of colour, shape, size and other visualization aspects have been employed to increase insights and deliver a clear message to consumers.

2.4 Problem Statement

Scattered information processed by experts cognitively demands increased collaboration. Visual representation through the use of dashboards is effective in supporting experts. This work explores several visualisation principles and techniques and the use of dashboards to present information relevant to a critical infrastructure Sector/site information for the purpose of sector protection and risk management

2.5 Conclusion

The use of data visualization for critical infrastructure protection is a relatively new area of research and we take this opportunity to spur interest to other scholars and researchers in exploring the topic and the benefits it can bring to experts and decision makers. This study explores critical infrastructure protection, data visualisation and data storytelling and their benefits. In the next chapter we will explore methodology and findings after creating dashboards for critical infrastructure protection. Because of the reusable nature of the model we give attention to a set of important critical infrastructure types that can be selected from the following: power plants, water networks, dams, key governmental offices, nuclear facilities, and cyber/information infrastructure. While the choice does not place the mentioned critical infrastructure sector as more important than the others, different countries have placed different sectors as key due to the fact that failure or disruption will have a great impact on the lives of their population. Rehak gives the following list of examples in his study, emergency or primary medical care services, electricity, water supply, oil and gas and telecommunications (Rehak, 2020). The model can be reused with other set of critical infrastructures types not mentioned in this section with minimal changes. In the next chapters we will a model to verify our hypothesis (section 1.1.1) and findings.

Chapter 3: Methodology

3.1 Introduction

In this chapter we will briefly explain the methods of our study and the key items that we considered in order to satisfy our hypothesis. We used a qualitative method in this study. We will explain the items to focus on CIS and the visualisation principles that will guide us in the research. We used data from available literature.

3.2 Critical Infrastructure key items of research

We investigated CIS Interdependency, risk assessment, threat assessment, vulnerability assessment and resiliency of CIS. This will help in visualising the risks associated with CIP. (Sabrina, 2019)

3.2.1 CIS interdependencies

The term interdependency means the bidirectional connection between two CIS agents whereby there is a relationship or correlation between the CIS. Interdependency of CIS is also described as disruption and the spread of a complex and interconnected infrastructure system (Consolini, 2009). Different scholars have suggested different types of interdependencies, (Rinalidi et al., 2001), mentions the following types

- Physical interdependency
- Geographical interdependency
- Cyber interdependency
- Logical interdependency (Sabrina, 2019)

3.2.2 CIS Risk Assessment

Risk Assessment are popular in decision analysis and are used to determine losses if a risk occurs. According to Banks, Organisations perform risk assessment by;

1. Identifying disruptive events
2. Assessing the probability of occurrence
3. Assessing the cost conditional on the occurrence of disruptive events (Banks, et al 2015)

By using the above parameters, it is possible to determine risks in a CIS by visualisation of the events and probability of occurrence

3.2.3 CIS Threat Assessment

Threats are possible hazards to CIS that might exploit vulnerabilities and cause a destruction or damage to CIS. Assessment of threats help

3.3 Effective Visualization Principles

There are several attributes that increase a visual representation's effectiveness in crafting a message or improving decision making for experts. Such values or principles have been and are still being explored by scholars. In this work we will explore several previously discussed principles the reasons for being an effective method of improving decision making through visualization. This is just a guide to the study rather than a full explorative research of effective data visualisation principles.

According to Sabrina, the following are some characteristics of visualization attributes that define some of the visualization techniques; structural restrictiveness, content modifiability, outcome clarity, visual appeal and directed focus (Sabrina, 2019)

Even as we discuss all these techniques, we must understand that too much of anything is not good, it is important to have the right mix and balance of the visualisation techniques and principles.

Most of the effective principles have the characteristics described by Sabrina, 2019, for example;

i. ***Simplicity*** – making a visual representation simple and easy to understand borrows heavily on structural restrictedness and outcome clarity, for a data visualization, chart or dashboard to be effective it should be simple and easy to understand

ii. ***Comparison*** – a visualisation should be able to present an easier way to compare items and hence improve decision making. By using directed focus characteristic on the item's importance, i.e. emphasizing the main items of a discussion helps visually project to comparative items and greatly improve decision making.

iii. ***Exploratory*** - a visualization that can easily lead to new insights has an exploratory principle. Visuals that make experts discover new items improve decision making. Modifiable characteristics is the ability to dynamically change the items of a visualisation this greatly enhances the exploratory effectiveness of a visualisation representation.

iv. ***Collaboration*** - When more than one expert contributes in a visualisation in order to improve understanding of a phenomenon or data under investigation, then collaboration visualisation is achieved. (Isenberg, et al 2011)

v. ***Coherency*** - the reason why we use data visualisation is to make large data sets clear or sensible or coherent. Visualisation should be able to make any large data set articulate and clear and hence improve decision making. Outcome clarity characteristics better explains the principle of coherency.

vi. ***Balance and proportion*** - a balanced visual representation is visually appealing. On the contrary balanced and proportional visual representation alone without other mentioned visual design/representation principles alone cannot improve decision making but an all-round designed visual representation including this principle will improve decision making

vii. ***Emphasis*** - projecting dominance of the item in question by use of colour, size, shape etc, as described by Sabrina 2019, as the use directed focus visualisation characteristic helps in quickly discerning the item in question. For example, a map showing the city of New York as having a larger population than other cities in the US by use of a deeper colour saturation and larger circle puts emphasis on the case.

viii. ***Storytelling*** – As discussed in section 2.3 Data storytelling is the use of Data visualization with supporting narratives to deliver better insights from data. This is an emerging technique to be explored in creating compelling visuals with stories to better communicate insights. Dashboards and charts portray what is happening, but narratives show why something is happening

3.3.1 Guide to chart selection

Figure 6. gives a guide on what type of visual charts to use with what kind of data and expected insights. For instance, to give a better comparison of two datasets column charts tend to represent the information better and gives a quick overview for the comparison. (Abela, 2009)

For example, as stated in the diagram below the column chart

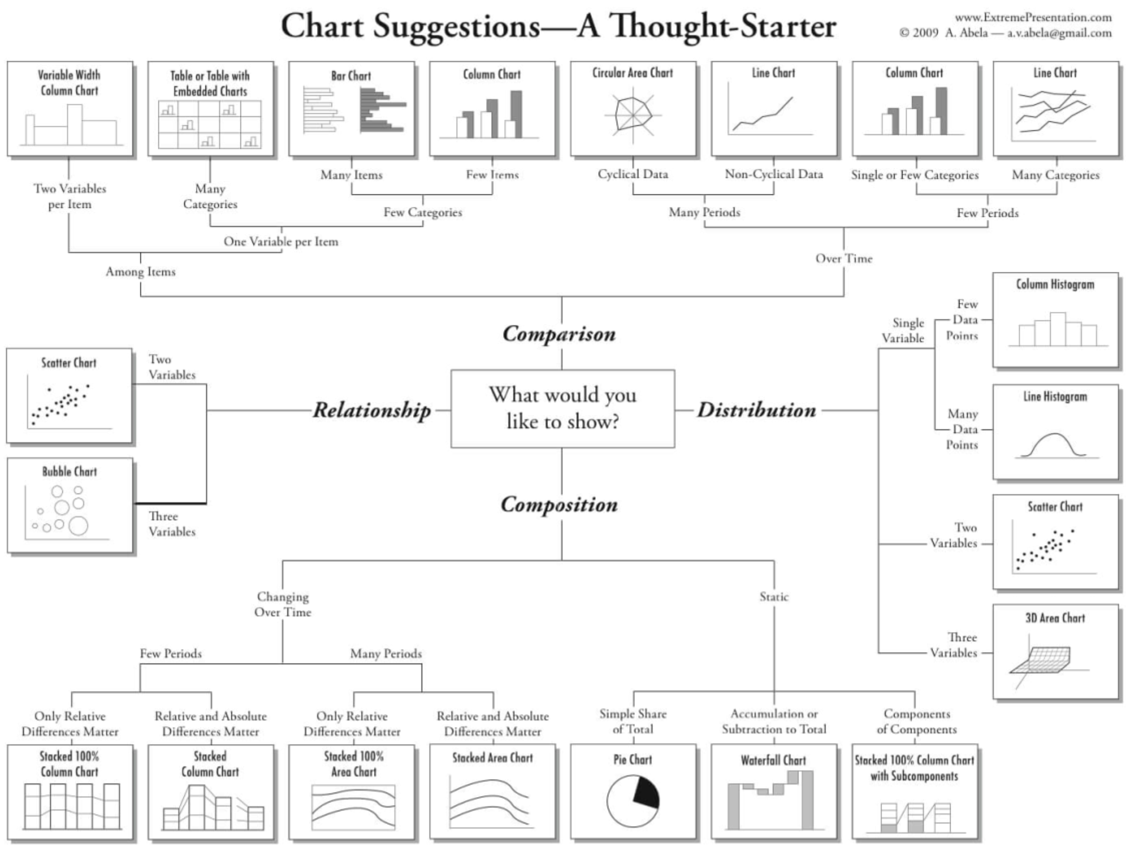

Figure 6. Chart selection guide

3.4 Conclusion

We aim to discuss further on how the risks associated with CIS can be presented visually and using discussed visualisation techniques and principles, implement a data visualisation dashboard. Different parameters have been used to determine the effectiveness of the data visualization in aiding experts in decision making.

Chapter 4: Findings and Conclusion

4.1 Implementations

We considered the following principles in our study in order to test how effective they were in aiding experts in decision making for CIP. Often, there is no individual best or superior visualisation, (Börne, et al., 2019) but psychology and cognitive scholars have aimed to identify mental processes for analysing visualisations and the confusing factors that make interpretations difficult, some graph visualisation are difficult to interpret and others are easier according to Pinker in his “graph difficulty theory” (Pinker, et al., 1990). The mentioned principles and respective elements are not exhaustive but a representation of the principles currently in use in the business and scientific documents in aiding decision making by use of visual representation.

The following table lists the visualisation principles we decided to test/ design for, related elements scientific reference, use case scenarios and dashboard features. The choice is due to available and selected literature for the study. Our dashboard will aim to depict some of the visualisation techniques and their use case scenarios

Table 1. The use of Data Visualization and Dashboards to interpret and prevent risks in critical infrastructure protection

	Visualization	**Element**	**Reference**	**Use case Scenario**	**Dashboard Feature**
a)	Emphasis	Colour, Shape, Size, Labels	Isenberg et al. (2011)	Bar charts	Interdependency of CIS
b)	Comparison	Colour, Shape, Size, Labels	(Nagy, 2020)	Centrality on network graphs	Risk Protection in CIS
c)	Exploratory	Hide & Seek, Pyramids, drill-down story	(Nagy, 2020)	Cascading failure decomposing tree	Cascading failures in CIS
d)	collaboration	Chats, Comments, email, face to face meetings	Isenberg et al. (2011)	Comments chats and face to face meetings	Experts comments
e)	Data Storytelling	Text, Numbers, Narratives, Shapes, Sizes, drill-down story	Heer et al. (2010)	Narratives & explanation	CIS protection and CIS Status

4.2 Dashboard design guidelines

4.2.1 Choice of dashboard development tool

While most data visualisation and analytics tools can help in creating dashboards, a number of market leaders like Tableau, Power BI, 3DS, plotly dominate the scenes. Although we implemented our model using Microsoft Power BI, it's evident that any visualisation tool supports implementation and presents the user with a number of techniques to best present their data.

The choice of tool, however, does not imply superiority of one tool over another or an and endorsement of a visualisation tool. Power Bi was selected because of the following support features.

1. Seamless integration with Microsoft software platforms especially Microsoft office.
2. Collaboration between experts using tools like comments and chats
3. Live connections to Microsoft Azure cloud database which makes it easier for decision makes who want real time data especially in critical infrastructure sector.

4.2.2 Choice of Colour

Many multi varied factors including culture influence colour meanings (Mikellides et al., 2017) but it is widely accepted that some colours have a universal meaning influenced the choice of colours in the design of the dashboards. For example, the figure below from the dashboard shows a normal running level using colour green, a warning level using orange or amber colour and a critical level in red. These colours have been used in traffic lights in major cultures and city and their implied meaning tend to be the same in western cultures. This guideline was also tested with expert's usability perceptions.

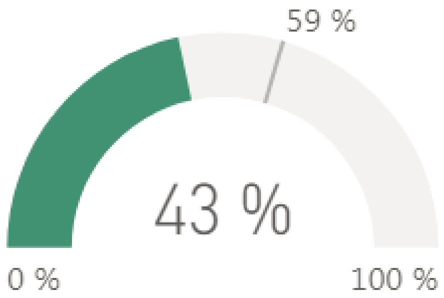

Figure 7. Green dashboard meter gauge

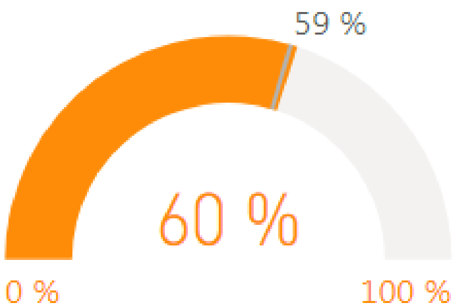

Figure 8. Amber dashboard meter gauge

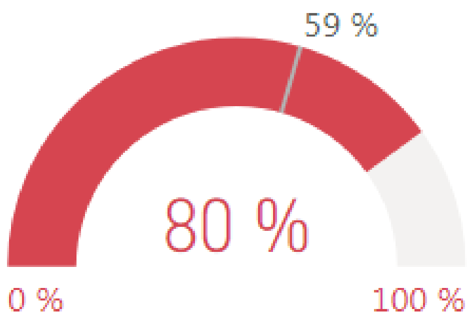

Figure 9. Red dashboard meter gauge

4.2.3 Choice of visualisation for chart selection

Abela describes better on what chart to use with type of data in his "Guide to Chart Selection" Figure 2. (Abela, 2009). For comparison and distribution, bar and column charts were used. For cascading failures, a decomposition tree was used as it provided a better drill down and expansion capability. Network graph diagrams were used to illustrate interconnection of CIS. Although this is not a simulation but a visualisation guide, this opens for more study into the topic.

4.3 Building an interdependency network for CIP

We created the following interdependent network according to (Ouyang et al., 2014) and we will use it to show how critical infrastructure protection can be achieved using visualisation. We considered the following critical infrastructure sector; Power Plant, Energy, Water, Transport, Telecommunication and Government Offices. All this are Interconnected in various ways and hence the interdependency.

For example, outages in power systems on a physical, logical, geographical or cyber interdependency network caused transport network disruption, interruption of water supply pumping stations, interruption of communication services, damaged utility systems and emergency services, interruption of government and health facilities among other critical infrastructure sector.

Various assumptions have been made in order to come up with this visualization and the following is a visualisation based on the literature from Ouyang M 2014.

The following image is an example of an interdependency network of CIP (Ouyang et al., 2014)

Dashboard Section showing Interdependency network

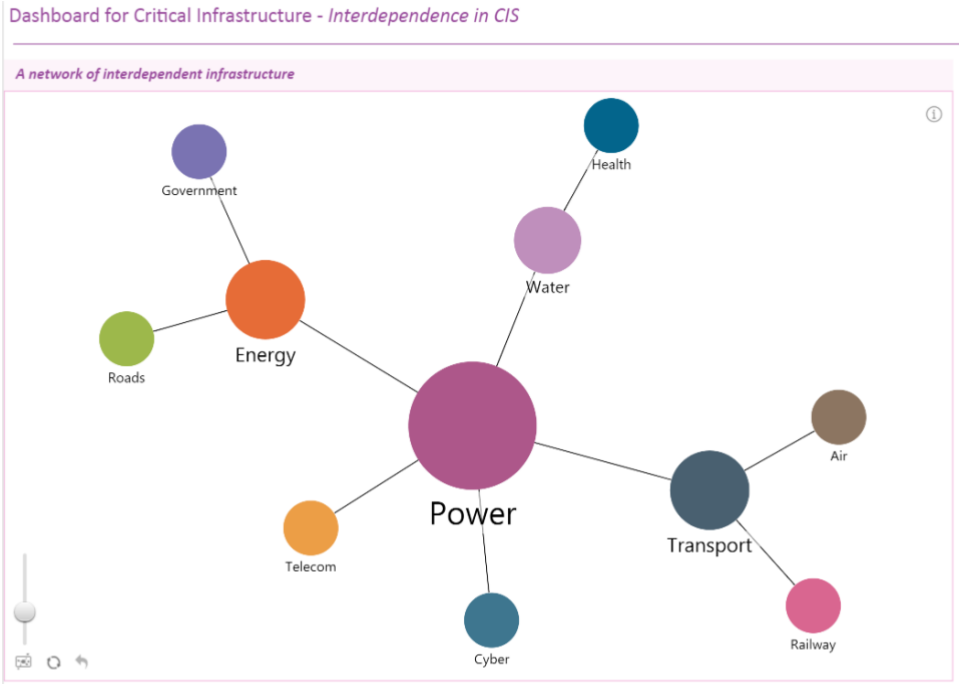

Figure 10. Network graph diagram

4.4 Cascading failures in CIP

Because of the coupling effect of CIS, a failure in one Sector may cause subsequent failures in other interconnected CIS, normally referred to as cascading failures. (Rinaldi et al., 2001). We designed the following dashboard to illustrate cascading failures, affected CIS and percentage of failure to affected CIS, although the data used was a mere illustration, a real-world scenario allows expert to input their data and adjust items like warning levels which Power Bi allows.

Dashboard Section showing Cascading Failures in a network

The visualisation below shows a count of critical infrastructure sector affected by a power failure and corresponding cascading effects due to the failure. For example, when there is a power failure, gas supply sector will failure which in turn will lead to cogeneration failure and an oil production failure.

The limitation on this visualisation is practical modelling was not used but rather a rendering of the cascading effects on failure in a critical infrastructure sector.

This has been modelled from a fault tree analysis where a tree diagram is adopted and failure of an infrastructure sector is organically linked to the failure of the next linked infrastructure sector (Li et al., 2019)

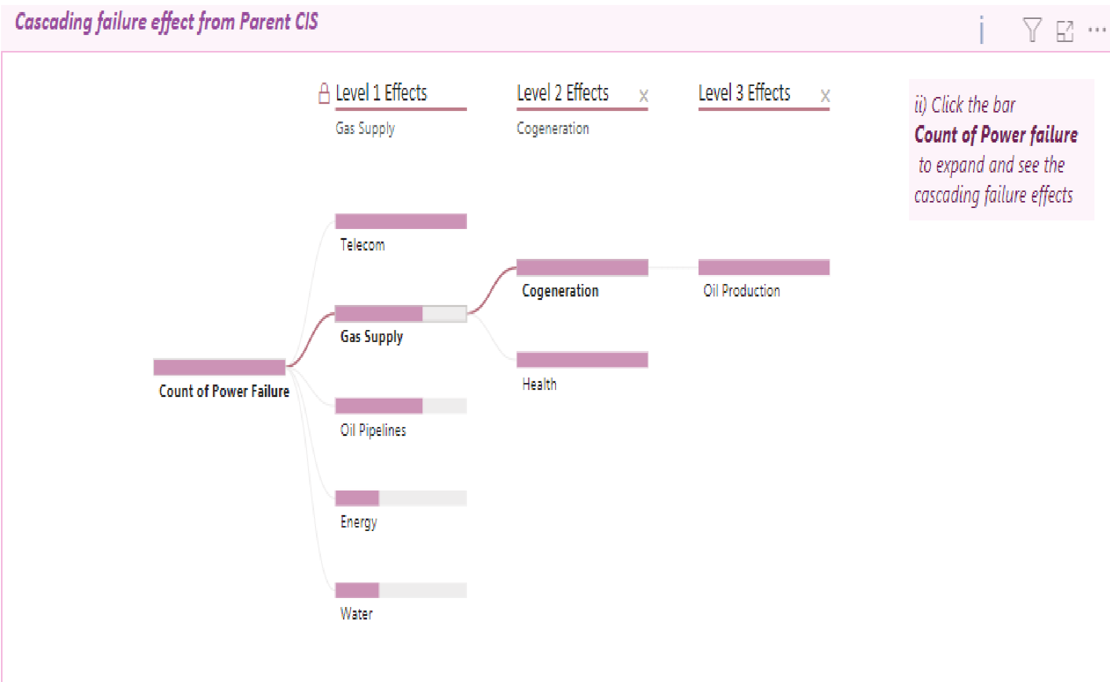

Figure 11. Decomposition tree illustrating Cascading failures in critical infrastructure sector

4.5 Risk Analysis, reduction and resilience in CIP

NIPP identifies various CIS of interest and key initiatives with a framework of critical infrastructure and key resources by relevant authorities (US Dept of Home Security, 2003).When assessing Risks in CIS, a number of factors have to be considered like, identifying of critical assets of a particular sector, putting in place protection measures and a feedback mechanism for future improvements.

Critical infrastructure protection involves management of risks by minimizing consequences, vulnerabilities mitigation and deterring of threats. The measures can range from physical barriers, back up initiatives to particular sectors e.g. electricity back up in a nuclear plant to enable continuous cooling in case of failures and other prescribed measures as determined by sector experts.

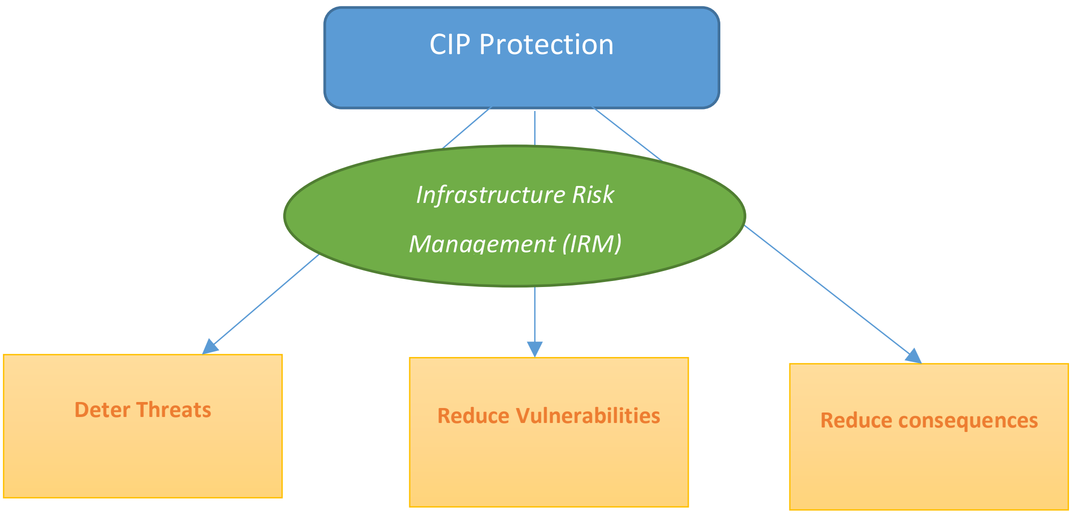

Figure 12. Risk management in CIS

In the visualisation diagram we demonstrate barriers (BA) and back up (BU) put in place between interconnected network to avert the risk of cascading failure and reduce the effect on the next sector. The most common and effective protection mechanism for example in government and power facilities is putting barriers to effectively deter physical threats – this is demonstrated in the visualisation as protection mechanism for Critical infrastructure. To protect an infrastructure a visualisation will show whether there are effective barriers and backup in place to deter threats, reduce consequence and vulnerabilities in case of an infrastructure failure, interruption or attack.

The illustration below shows a critical sector interconnected network with protection mechanism. The Government and Roads infrastructure sectors depends on energy sector and if a disruption or failure on the energy sector occurs, it will lead to a cascading failure on both the roads and government sector. To protect these sectors a barrier or backup or both is needed. For example, a backup energy will supply government sector with power until the disruption is resolved.

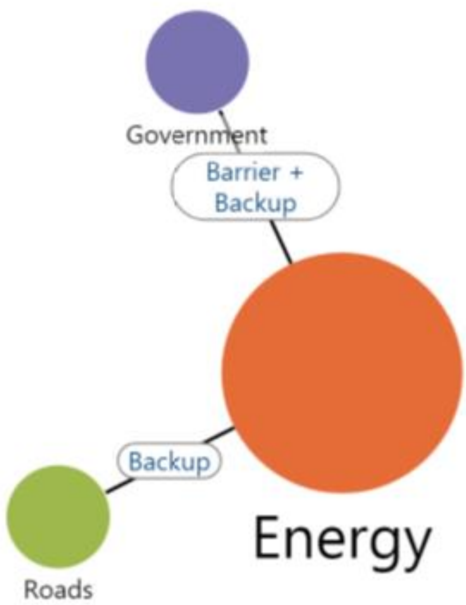

Figure 13. Protection between Sectors – Barriers and Backup

4.6 Finding and discussion

4.6.1 Dashboard visualisation usability testing

The main aim of usability is to produce products that provide maximum ease of users to users (Ghasemifard et al., 2015). To find out if the visualisation techniques and principles meet the required or intended purpose, we did a usability testing by interviewing experts and intended users of the dashboards.

The interviews aimed at testing the following usability best practices guided by discussed visualisation principles and techniques

a. **Dashboard intuitiveness and ease of finding information**

Many dashboard designers follow the approach that the most important or main information should be highlighted in a summary and forms the main part of the dashboard

Table 2. Dashboard design layout guide

Important Summary	**Specific Summary**
Important Information	**Specific and less important information**

The following is an extract from the designed dashboard with the proposed layout design

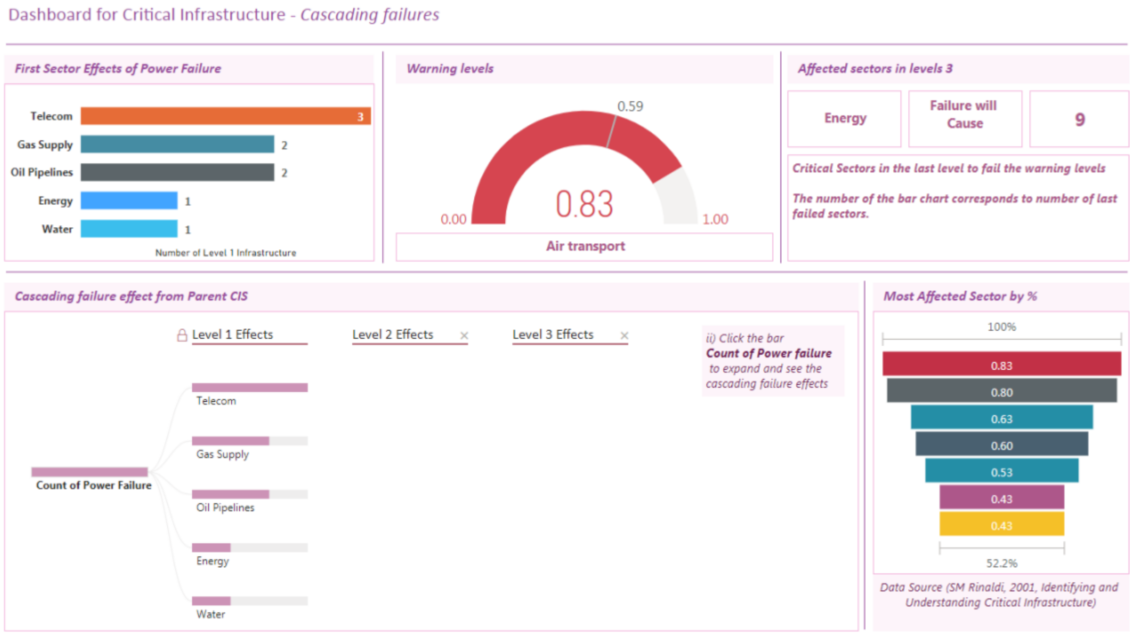

Figure 14. Dashboard Layout

b. <u>Information representation methods</u>

Information can be represented in many ways in a dashboard by use of various charts, graphics, colours, shapes and sizes. A usability testing will be carried out to determine if the use of such methods as colours, shapes, etc. affects how information is perceived by the dashboard's users.

The following representation or visualisations will be tested

a. Colour
b. Shape
c. Size
d. Centrality

c. Relevant use of visualisation

We will test how best and relevant the use of some of the visualisation's techniques to the dashboard users.

1. Charts
2. Dials
3. Text
4. Spatial

4.6.2 Usability qualities of a dashboard or a visualisation

The three mentioned usability visualisations representations are supposed satisfy the common usability qualities to improve or increase ease of use.

1. Learning curve – the ease of users to perform basic intended tasks in a visualisation.
2. Efficiency: How fast are users in getting relevant or required information from the dashboard or visualisation.
3. Ease of remembrance: The ease of returned users to easily and quickly use the tool like or better than the previous use.
4. Satisfaction and Errors, how satisfied are the users with the tool and how often do users make errors while interacting with the tool. (Ghasemifard et al., 2015)

4.6.3 Dashboards and visualisation scenarios for usability testing

Sample Testing Scenarios

Scenario 1.

I am an infrastructure protection specialist and I would like to know the cascading failures visualisation and affected sectors

The following dashboard features will help in this scenario

1. General layout and ease of finding information – *reference figure 14*

2. Visualisation that can help in demonstrating cascading failures and drill down

   Reference figure 11 – Decomposing tree

   Use of colours to show affected sectors status for immediate attention –*Reference figure 7, 8 & 9*

Scenario 2.

I am an infrastructure protection specialist and I would like to know the general location of power plants, their capacity and running health status

The following visualization features will illustrate the scenario

1. Spatial representation of information

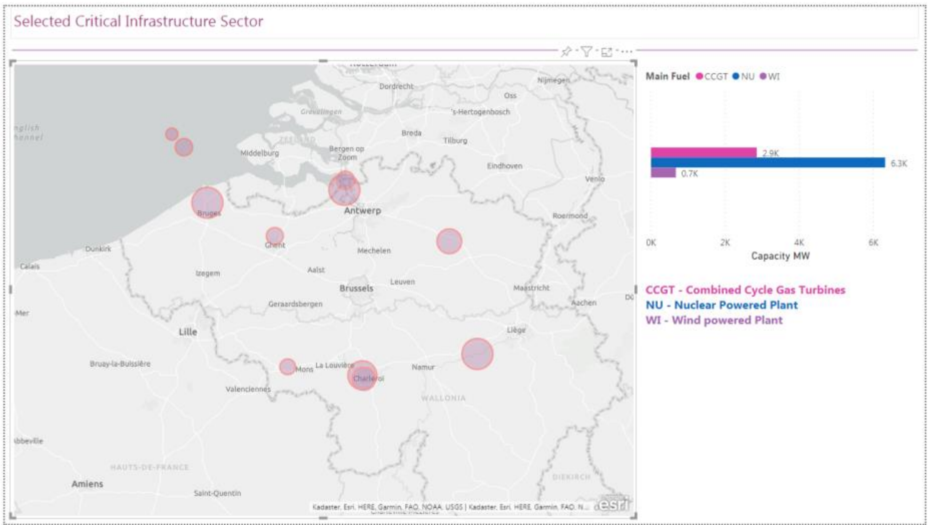

Figure 15. Selected Infrastructure Sector visualisation

2. Information representation using colours and texts to represent the selected infrastructure sector

4.6.4 Usability review feedback

The following is a self-declared narratives and observations from the expert on the usability of the implementation.

From the usability testing we found out that general dashboard layout supported satisfaction and efficiency of use of the visualisation by expert and reduced errors in identifying several Critical infrastructures in a sector.

Information representation on the reports and the dashboards such as the use of colours, size and shapes supported in identifying relevant information in an infrastructure sector of interest.

Collaboration among experts was possible through supported technology such as chats and emails and also the tradition face to face meeting which supported decision making with experts on the sectors of interest in the dashboard visualisation.

4.6.5 Limitations

i) The data used is not synchronous data but a demonstration of a practical scenario, real time data can be used directly connected to a database, real time system integration or real time spreadsheets.

ii) More resources could yield better study of the topic

iii) Usability testing was on a self-declared narrative, this has its limitation on results and feedback

iv) The concept of collaboration is an opportunity for future research as we did not explore it to a further extent.

v) For a better study of colours and cultures, psychology and social studies research well supports the use of colours in different cultural settings and is not covered in this work

4.7 Results and discussion

Critical Infrastructure experts examined the dashboard layout, the use of colour and the visualisation techniques and principles discussed in section 2.3 and section 3.3 and gave a self-declared narrative to support the study. Visualisation of fault tolerance systems modelled using decomposition tree visualisation supported identification of cascading failures in an interconnected network. Experts were able to recognize different critical infrastructure sector and potential failure when a root infrastructure sector is disrupted or fails.

A high level 360° view dashboard layout combined with visualisation techniques assisted experts in overview representation of vital information of a critical infrastructure sector. A spatial representation of critical infrastructure sector in a dashboard assisted experts in geographically evaluating an infrastructure sector.

4.8 Conclusion

We have explored the various visualisation techniques and principles and how they can support decision making. Through our implementations and findings, dashboards and other visualisation techniques can be employed to support expert's decision making in critical infrastructure protection.

Several visualisation principles have showed to support users/expert decision makers by intuitively presenting complex information through the use of charts, colours, shapes, sizes, spatial and text.

This is an open topic to be further explored and discussed to merge modern visualisation techniques and visual thinking into the critical infrastructure sector. We aim to proceed with incorporating risk mitigation in critical infrastructure protection using visual effects in future studies. We are certain future studies will bring more to light and help the scientific community and experts in achieving goals aimed at improving certain sectors and learning.

References

- Banks, D., Aliaga, J., Rios Insua, D. (2016). Adversarial Risk Analysis. New York: Chapman and Hall/CRC, https://doi.org/10.1201/b18653
- Chopade, M. R. M., & Dhavase, N. S. (2017). Agile software development: Positive and negative user stories. 2017 2nd International Conference for Convergence in Technology (I2CT). doi:10.1109/i2ct.2017.8226139
- CISA - Critical Infrastructure Security. (2019, October 23). Retrieved from https://www.dhs.gov/topic/critical-infrastructure-security.
- Cohen, I. B. "Florence Nightingale," Scientific American, 250 (March 1984),128-137.
- Consolini, T., 2009. Regional security assessments: A strategic approach to securing federal facilities. Master Thesis. Naval Postgraduate School.,Monterey—CA (USA). 103p
- Cooper, P. (2010). Data, information and knowledge. Anaesthesia & Intensive Care Medicine, 11(12), 505–506. doi:10.1016/j.mpaic.2010.09.008
- Costantini, V., Graccevaa, F., Markandyaa, A., Vicini, G., 2007. Security of energy supply: Comparing scenarios from a European perspective. Energy Policy 35, 210–226.

- Costantini, V., Graccevaa, F., Markandyaa, A., Vicini, G., 2007. Security of energy supply: Comparing scenarios from a European perspective. Energy Policy 35, 210–226.

- E. Segel and J. Heer, “Narrative Visualization: Telling Stories with Data,” IEEE Trans. Visualization and Computer Graphics, vol. 16, no. 6, 2010, pp. 1139–1148
- European Commissioner, 2016, https://www.europarl.europa.eu/news/en/headlines/society/20181011STO15887/drinking-water-in-the-eu-better-quality-and-access
  Future of Testing, ed Freedle R (L. Erlbaum Associates, Hillsdale, NJ), pp 73–126
- Ghasemifard, Mahboubeh Shamsi, Abol Reza Rasouli Kenari, Vahid Ahmadi, N. (2015). A New View at Usability Test Methods of Interfaces for Human Computer Interaction. Global Journal Of Computer Science And Technology, .

Retrieved from https://computerresearch.org/index.php/computer/article/view/1126

- Heer, J., Bostock, M., & Ogievetsky, V. (2010). A tour through the visualization zoo. *Communications of the ACM*, *53*(6), 59. doi: 10.1145/1743546.1743567
- Isenberg, P., Elmqvist, N., Scholtz, J., Cernea, D., Kwan-Liu Ma, & Hagen, H. (2011). Collaborative visualization: Definition, challenges, and research agenda. Information Visualization, 10(4), 310–326. doi:10.1177/1473871611412817
- K. Börner, A. Bueckle, M. Ginda Data visualization literacy: definitions, conceptual frameworks, exercises, and assessments Proceedings of the national academy of sciences, 116 (6) (2019), pp. 1857-1864, 10.1073/pnas.1807180116
- Lavalle, A., Mate, A., Trujillo, J., & Rizzi, S. (2019). Visualization Requirements for Business Intelligence Analytics: A Goal-Based, Iterative Framework. *2019 IEEE 27th International Requirements Engineering Conference (RE)*. doi: 10.1109/re.2019.00022
- Lee, B., Riche, N. H., Isenberg, P., & Carpendale, S. (2015). More Than Telling a Story: Transforming Data into Visually Shared Stories. IEEE Computer Graphics and Applications, 35(5), 84–90. doi:10.1109/mcg.2015.99
- Lex Access to European Union law. (n.d.). Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=LEGISSUM:jl0013.
- Li, H. W., Ren, Y., & Wang, L. N. (2019). Research on Software Testing Technology Based on Fault Tree Analysis. Procedia Computer Science, 154, 754–758. doi:10.1016/j.procs.2019.06.118
- M. Friendly, & D. Denis, Milestones in the History of Thematic Cartography, Statistical Graphics, and Data Visualisation, Nov. 2006, www.math.yorku.ca/SCS/Gallery/milestone/
- M. R. M. Chopade and N. S. Dhavase, "Agile software development: Positive and negative user stories," 2017 2nd International Conference for Convergence in Technology (I2CT), Mumbai, 2017, pp. 297-299.
- McCue, C. (2015). *Data mining and predictive analysis: intelligence gathering and crime analysis*. doi: 10.1016/C2013-0-00434-3

- Mikellides, B. (2017). Colour psychology. Colour Design, 193–214. doi:10.1016/b978-0-08-101270-3.00008-4
- NIPP Supplemental Tool: Executing a Critical Infrastructure Risk Management Approach https://www.dhs.gov/publication/nipp-2013-ci-risk-management-approach
- Pinker S (1990) A theory of graph comprehension. Artificial Intelligence and the
- Rehak, D. (2020). Assessing and strengthening organisational resilience in a critical infrastructure system: Case study of the Slovak Republic. Safety Science, 123, 104573. doi:10.1016/j.ssci.2019.104573
- S. M. Rinaldi, "Modeling and simulating critical infrastructures and their interdependencies," 37th Annual Hawaii International Conference on System Sciences, 2004. Proceedings of the, Big Island, HI, 2004, pp. 8 pp.-. doi: 10.1109/HICSS.2004.1265180
- S.M. Rinaldi, J. P. Peerenboom and T. K. Kelly, "Identifying, understanding, and analyzing critical infrastructure interdependencies," in IEEE Control Systems Magazine, vol. 21, no. 6, pp. 11-25, Dec. 2001. doi: 10.1109/37.969131
- Sabrina Bresciani, *Visual design thinking: a collaborative dimensions framework to profile visualisations,* Design Studies, Volume 63, 2019, Pages 92-124, ISSN 0142-694X, https://doi.org/10.1016/j.destud.2019.04.001.
- Sacha, D., Stoffel, A., Stoffel, F., Kwon, B. C., Ellis, G., & Keim, D. A. (2014). Knowledge Generation Model for Visual Analytics. *IEEE Transactions on Visualization and Computer Graphics*, *20*(12), 1604–1613. doi: 10.1109/tvcg.2014.2346481
- Salesforce: State of analytics (2015), www.lubbersdejong.nl/wp-content/uploads/2015/10/Salesforce-2015-State-of-Analytics-report.pdf
- Segel, E., & Heer, J. (2010). *Narrative Visualization: Telling Stories with Data*. IEEE Transactions on Visualization and Computer Graphics, 16(6), 1139–1148. doi:10.1109/tvcg.2010.179
- Yusta, Jose M., et al. "Methodologies and Applications for Critical Infrastructure Protection: State-of-the-Art." *Energy Policy*, vol. 39, no. 10, 2011, pp. 6100–6119., doi:10.1016/j.enpol.2011.07.010.

Appendix 1: List of Acronyms

1. BA: Critical infrastructure protection barriers
2. BU: Sector Backup
3. CIP: Critical Infrastructure Protection
4. CIS: Critical Infrastructure Sector
5. DHS: Department of Homeland Security
6. EEA: European Economic Area
7. EU: European union
8. GitHub: An open online software version control tool
9. IRM: Infrastructure Risk Management
10. NIPP: The National Infrastructure Protection Plan
11. US: United States of America

Appendix 2: User Stories

We employed the use of user stories to guide us in dashboard prototyping and development

User stories are a way of guiding developers on requirements from the customer perspective to improve requirements understanding and application development in an agile methodology (Chopade et al., 2017)

i) I am a risk assessment specialist and I would like to know the cascading failures visualisation and affected sectors

ii) I am a risk assessment specialist and I would like to know using dashboards the percentage of total failure of all CIS in case of a total failure of one infrastructure

iii) I am a risk assessment specialist and I would like to know the high-level status of interdependent network and the tolerance level in case of failure,

iv) I am a risk assessment specialist and I would like to know the general location of power plants, their capacity and running health status

Appendix 3: GitHub repositories

Chapter 1: Link to power Bi dashboard repository:

https://github.com/calvoh/dashboards-for-critical-infrastructre

Glossary:

1. Visualisation - A graphical representation of information through tables and charts.
2. Dashboards – A collection of charts and tables with 360 degrees view on a phenomenon subject
3. Data:
4. Critical Infrastructure: An asset, whether physical or virtual that is important to the well-functioning of a society or country.