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Valuable insights into the aesthetic visualisation of uncertainty in data as a means to navigating business risks and making better strategic decisions

Abstract:

The COVID-19 pandemic has changed the global business landscape, with many companies now faced with an entirely new set of challenges and an uncertain future. As a result of this we need to consider how we identify and present critical areas of uncertainty to help businesses navigate risk and make better strategic decisions that steer them towards sustainable sources of growth and profit.

This paper will explore the practice and use of uncertainty visualisations by documenting a series of interviews highlighting the experiences of people from an array of different sectors and organisations (i.e. medical, business, environmental, civil service etc.). These diverse participants/ organisations have been strategically selected in order to provide a more holistic insight into how the application of uncertainty visualisations can/ has aided the planning and decision making of each organisation. The authors are interested in how the participants dealt with and designed the visualisation of uncertain data and if/ how they changed their strategies in accordance to the data presented and finally, the impacts it may have had on them and their organisation. Interview questions were designed to allow participants to express how they approach visualising uncertainty and the influences it presents on their decision-making process.

The findings display the true influence uncertainty visualisation had on an organisations ability to plan for future events. Interestingly, the interviews highlighted how the positive opinions of depicting uncertainty in data visualisations from a data scientist perspective differed from reality of the visualisations produced. Participants expressed their responsibility to portray data in a format that could be easily interpreted by executives or be used to reinforce a decision that had already been made. This research supplements the existing research highlighting the ignorance displayed by many executives who are reluctant to engage in data-drive decisions despite the proven profitable influence for future planning.

Introduction:

Following the sudden and rapid changes caused by the global pandemic businesses were required to alter their operations and to seek alternative methods to plan and prepare for future unexpected events. Businesses with little to no contingency plans were strained to rethink years of strategic planning in order to 'stay afloat' amidst the unforeseen circumstances. In order to confront the new challenges faced and navigate the uncertain future businesses must explore alternative methods of contingency planning and adopt the change from solely basin decision on gut instinct to data driven analytical decisions or a hybrid combination. Businesses have the potential to plan for unforeseen events through utilising historic data and accepting possibilities of uncertainties occurring. As discussed by Oliver & Parrett (2018), the changing dynamics in the business world can present uncertainties which can make it difficult for executives to envision such long-term planning. Moreover, the prospects of planning for events in a market that has not yet emerged can create a burdensome challenge for businesses. However, despite the time-consuming and troublesome tasks presented, the implementation of contingency planning can allow a business to quickly address problems which could halt the operations and can allow the business to plan for not only successes but failures (Milano, 2019).

The research presented in this paper explores the use of aesthetics in uncertainty visualisations to influence the decision-making process. In doing so, it aims to support contingency planning and hence the strategic decision making for businesses growth. In detail, the paper will discuss the findings from a set of semi-structured interviews which explored participants experiences when applying uncertainty visualisation and aesthetic design to benefit their strategic decision making and future planning. These interviews provide a snapshot of how the introduction of uncertainty visualisation across different sectors can influence and support the decision-making processes for future events.

Business Strategy, Technology and Uncertainty:

COVID-19 has caused businesses around the world to face significant uncertainties from multiple sources, e.g. market, regulations, technology, and finance (De Lessio et al., 2015). In terms of technology, the pandemic has caused a massive economic disruption and has led many companies to fast track to a digital transformation of delivery and service. According to a McKinsey Global Survey of executives (2020), their companies have accelerated the digitization of their customer and supply-chain interactions and of their internal operations by three to four years (McKinsey & Company, 2020). This rapid transition to the digital has meant many companies have had to take a new approach to their business strategy and several adjustments and changes have had to be made to maintain a smooth flow of working operations. In many ways, companies have been thrown into the world of IT service management (ITSM) without formally realising it (i.e. they are needing to manage their new IT environments in order to provide value for their customer whilst also being cost effective and competitive). For many of these companies, a good set of IT services will be the new normal (and necessity) and will be the strategic driver for their business value. Without a doubt, it will be organisations with a strong IT service management capability that will form the successes of the future.

In the meantime, and in the midst of trying to cope and understand this acceleration but also the fast evolution of the digital, many businesses are finding the making of strategic

decisions and planning much more difficult. They are constantly needing to be responsive and ready to adjust rapidly to changes. As Shah (2020, pg.1) highlights ‘This calls for a complete removal of rigid structures and a shift towards a data-driven, technology-powered enterprise that consists of empowered team members and strong leadership’. In this mix of data, technology and leadership, comes other uncertainties (i.e. COVID-19, Brexit etc). And despite improved data analysis techniques, a lot of market developments are becoming increasingly difficult to predict. This can be a big dilemma for businesses when they have to make strategic decisions based on uncertain information. A key factor here is how businesses handle uncertainty. One thing is clear, as Courtney et al. (2000) highlight ‘underestimating uncertainty can lead to strategies that neither defend against the threats nor take advantage of the opportunities that higher levels of uncertainty may provide’. In their paper, Johansen et al. (2014) adopt the term uncertainty to include both the positive effects (opportunities) and the negative effects (threats).

Defining uncertainty as the lack of certainty about the outcomes of a particular action, where uncertainty occurs at the limits of known knowledge (Wakeham, 2015). Moreover, as the extent in which data can be interpreted as inaccurate or imprecise (Spacey, 2017). In the application of businesses, it is often seen that uncertainty is widely associated with risk. However, it is important to differentiate between the concepts of both uncertainty and risk. In business decision making uncertainty refers to being completely in the dark, that a business does not know what will happen next and cannot see the possible distribution. Risk on the other hand is similar in the sense of not knowing what will happen next, but the business will know what the distributions will look like (Ritholtz, 2012).

To explore the approaches to managing uncertainty in businesses operations we explore the frameworks of uncertainty reduction and uncertainty coping. Uncertainty reduction refers to financial risk management and uncertainty coping refers to strategic management planning (Simangunsong et al., cited in Snizahko 2019). Whilst both uncertainty mitigation methods are critical for businesses consideration, the focus will be on the uncertainty coping framework by Miller (1992). This framework sets out a five-stage approach for coping with the uncertainty, flexibility, imitation, cooperation, control and avoidance (Miller, 1992 cited in snizahko 2019). The focus of this research is surrounding planning and mitigation strategies for businesses and the authors of this paper therefore will focus on the final stage of the Miller framework: avoidance. The avoidance stage will take place when the level of uncertainties within the business is unacceptable to proceed with the risks and unknowns (Snizahko, 2019). It is often found that businesses will delay their operations whilst they analyse the uncertainty and evaluate methods of uncertainty avoidance, this may include waiting until there are viable methods of accurately predicting the uncertainty (Snizahko, 2019). Analysing the approaches that businesses take when managing uncertainty explores further the uncertainty management framework from Miller (1992). However, despite the inherent uncertainties it is important for businesses to find ways to embrace this uncertainty to emerge stronger, more resilient, more flexible and in a better position to make strategic decisions.

Strategic decision making:

Decision making is an essential component in the drive for success (Jankelová, 2017) and can be the most important function of managers in any organisation (Noorai, 2012). Decision-making involves the generation of a setting alternative plans that can be considered and the

approval on the most appropriate to be executed (Bhushan and Rai, 2004). The process of decision making often involves identifying the issue, gathering intelligence, coming to a final conclusion and learning from past experience (Schoemaker and Russo, 2014). Unlike traditional decision making, strategic decision making is associated with the long haul and aimed at pointing the company in the top direction management want to take it (Bondigas, 2019). Strategic decision making is often associate with decisions that are big, risky and hard to reverse, of which will often result in significant long-term effects for a business (Papadakis & Barwise, 1997). These decisions can drastically influence the businesses performance and in drastic times a business's survival. Moreover, strategic decisions are commonly new & complex, it is therefore common these decisions will be primarily handled by the top leadership teams (Selart, 2010), with or without input from department manager or key employees (Bondigas, 2019).

Ackoff (1970) cited in Janczak (2005) categorised strategic decision making as one aspect of the planning procedure. That planning for future business events needed to consider both the strategic and tactical decisions aspects. Highlighting strategic decision are those broad in scope which have long term effects and difficult to reverse. While tactical decisions are concerned with selecting the optimum methods of pursuing the goals set out in the strategic planning stages.

Strategic decision making is imperative for a business to ensure that they can utilise the businesses resources in a way that can improve the competitiveness and maintain a competitive advantage (Haslam, 2012). In the midst of the Covid-19 pandemic it has reinforced that business need to begin to plan for unforeseen events, whether that be with a financial buffer, available facilities or recovery plan strategies (Rigden, 2020). In reality many businesses who did not plan for unforeseen events would have had their strategy slate clean, this will allow businesses to learn from past experience and begin reconfiguring the business planning and decision making for the new reality (Howard, 2020). Moreover, businesses must consider their strategic thinking and the impacts on the business's performance, especially in times of organisational changes due to the need of sustainable development (Dionisio, 2017). In order for a business to plan strategically for future events they must derive insights as a basis of their decision making.

Insight:

Insight is concerned with the sudden interpretation of a solution to a particular problem with which the answer comes into conscious awareness or may seem obvious, it is common that this sudden expression of realizing the answer can trigger an emotional experience (Kaplan & Simon, 1990 cited in Steenburgh et al., 2012). Not only can insight be concerned with the "eureka" moment but also the progressive and incremental increase in understanding a topic in which there is a discovery of new connections or inconsistencies (Black, 2019; Klein, 2013). Insight intrinsically relates to the moment of the 'aha' which is the sudden realisation of an answer or having an unexpected understanding of a problem (Webb et al., 2016). The sudden realisation to a problem can guide the viewer to make a decision in which they believe is correct. However, it is important to consider that the sudden realisation of a solution may be obstructed by the viewers subjective overwhelming impulse of deriving what they believe is the correct solution, when in fact the solution may still be inaccurate. Moreover, the sudden light-bulb moment of 'aha' feeling may in fact accompany ideas which turn out to be incorrect (Webb et al., 2016).

Although insight has been shown to relate to the ‘aha’ experience, in business the term insight can also be delineated as: “A thought, fact, combination of facts, data and/or analysis of data that induces meaning and furthers understanding of a situation or issues that has potential of benefiting the business or re-directing the thinking about that situation or issue which then in turn has the potential of benefiting the business” (Vriens & Verhulst, 2008, p.13). Indeed, the data and analytics can be used to provide a business with a better understanding of situations in which strategic, tactical or operational decisions may need to be made. Insights in business allows the decision maker to base a decision on more than just gut-instinct by reviewing the facts, data or analysis to derive a more meaningful and thorough understanding to problems and situations. Similarly jumping to the conclusion of attaining the correct answer on a single insight is discouraged, a business should review a broader set of insights to ensure a definitive positive correlation before making their decisions (Vriens & Verhulst, 2008).

In the business world it is important to adapt to the rapidly changing environment and planning for future events. Businesses can begin to accomplish this through data analysis with predictive methods such as regression analysis, this will allow the business to begin to harness the full potential insights the data holds (Ergle et al., 2017). New and innovative analytical technique can allow a business to grow and plan exponentially through fuelling discovery and innovations, data analytics can enable business to make faster and more evidence-based decisions (Henke et al., 2016).

However, despite the reasoning to trust data/analytics to provide insight for better decision making, it is reported that in a study of 2190 business executives only 35% admitted to having a high level of confidence in trusting data and analytics (Violino, 2018). Moreover, this untrusting relationship with data has drawn many executives to rely solely on their gut-instinct for decision making.

Gut instinct & Data driven decisions

Strategic business decisions are traditionally based on one of two decision making processes; intuition-based decisions that rely on ‘gut feelings’ or data-based decisions relying on advanced analytics (Deloitte, 2015). However, the vast majority of business executives were found to solely rely on their gut instinct for decisions (business.com, 2020), despite the proven benefit of providing insight that data-based decisions have shown (Kavale, 2021). The debate of gut instinct vs data driven creates a divide between those who prefer to ‘trust their gut’ and those technology-minded individuals who want to see the data before any decision (Brook, 2020). Whilst most organisations acknowledge the benefits data and analytics have to offer, still many organisations struggle to reap the full benefits of data-based decisions and heavily rely on gut-feeling and consensus decision making (Delotte, 2015).

The authors of this paper do not dispute the sheer benefits of trusting your gut to make decisions, an executive with years of experience will have ample knowledge and expertise in their field to make a decision. However, the authors want to convey the risk and disadvantages that sole gut-instinct decisions bring to a business. Moreover, there is significant power in utilising a person’s heuristics, individual knowledge, interpretations and memories (Stevenson & Hicks, 2016) , but coupled with factual data-based knowledge can significantly improve the quality of the decision made (Williams, 2012). A report written by The Economist intelligence Unit found that executives were constrained more by their ability to analyse data than by

accessing it (EIU, 2014). As a method to facilitate executives understanding of data, they may seek to utilise the power of data visualisations to derive insight.

Visualisation, Uncertainty Visualisation and Aesthetics:

As the information age continues to grow, the requirements for businesses to transition their operations online causes an overwhelming consignment of data. To ensure businesses harness the full potential held within the data, it is critical to correctly interpret the data to go onto making informed decisions (Robert & Laramee, 2018). A common method of interpreting data is through the use of transforming the data into a visualisation. A visualisation offers a business the ability to view data in a graphical form, which can transform large and complex datasets into a form easily understandable (Sadiku et al., 2016). Visualisations capture a business's data in order to assist with communication, improved information seeking, data analysis and improved decision support (Zheng, 2017). Visualisations offer a strong method that can be used to systemically uncover hidden trends and patterns which might have gone undetected by the viewer (Uyan Dur, 2014). Moreover, humans gather more information through visuals than any other methods as visuals provided the highest bandwidth for communication between human and computer (Ware, 2004), this can speed up the ability to gather insight and understanding from data.

Making use of visualisations can benefit a business hugely if done accurately. Data within a visualisation is often to be said has more 'meaning' as it can allow a business to easily explore patterns and areas of significance, whilst helping the businesses to focus on specific areas of the data that require attention (Saranya, 2019). However, it is critical to consider that a data point represented on a visualisation does not always represent the true data value, when actually the data point may actually fall elsewhere on the visualisation (Wilke, 2019). Furthermore, the visualisation of predictive data runs the risk of portraying what is deemed the 'most likely' event or the one with the highest probability when uncertainty is not visualised.

The visualisation of uncertainty is relating to the representation of data alongside an additional dimension which will signify the probability, confidence, accuracy or errors which can go on to influence the interpretations and decisions based on the data (Boukhelifa and Duke, 2009). The visualisation of uncertainty can provide the viewer with an enhanced and in-depth understanding of what the data shows, this strengthening of understanding has been found to improve the decision-making performance and quality in specific tasks (Chung and Wark, 2016).

"Decision-making quality is improved from understanding the uncertainty in the data and information being used. Categorising uncertainty is a preliminary step towards reorganising and dealing with uncertainty in the decision-making process." (Kleineberg et al., 2019, pg.4-5). Through accurately depicting uncertainty, decision makers are able to have a better understanding of what the data is showing them. Whilst most business decision makers acknowledge there are uncertainties present, it is essential they visualise these uncertainties to strengthen their decisions.

It is important to consider that there is no optimal method of visualising uncertainty, and a business must review the data case-by-case in order to represent the uncertainty effectively (Levontin et al., 2020). Two of the most commonly representations of uncertainty in a visualisation are error bars and confidence bands, however, it is said for a lay audience these

are not favorable (Wilke, 2019). In order to effectively represent uncertainty into a visualisation we may need to turn to aesthetics to give a competitive advantage to the non-specialist audience.

Aesthetics

The term aesthetics is often associated with the description of the appreciation of beauty within the field of art, regarding something that invigorated both the body and mind and awakens the senses (Cwthon and Vande-Moere, 2007). The applications of applying aesthetics in a visualisation is more than manipulating a visual variable. It is often believed applying aesthetics to a visualisation is the process of making a visualisation ‘beautiful’, when it actually has a practical aim of revealing underlying meanings and structures (Bennett et al., 2007). Applying aesthetic designs to a visualisation can encourage the creation of associations and meanings through feelings, intuitions, thoughts and memories (Carroll, 2010). The application of aesthetics in a visualisation can harness the power of both forms of decision making, data driven decisions through the visualisation and gut-instinct supported by the aesthetic design.

Aesthetic designs play a vital role in everyday life and are a significant influence on our decision-making process (Bhaduria, 2016), therefore, it is important to consider the effects of aesthetics design on decision making in a visualisation. Triggering an emotional response through the use of aesthetic design can create a powerful and persuasive driver on the decision-making process (Lerner et al., 2015). However, it is important to consider the influence caused by aesthetics designs which may introduce bias into the decision made from the subjectivity of the visualisation designer. The visualisation designer’s interpretation and influence on the aesthetic modifications may differ from the decision makers. However, Quispel, Maes and Schilperoord (2018), state that subjectivity does not mean that the viewers are being forced to swallow the designer’s opinions regarding the data. That the visualisation designer feels the need to add the aesthetic elements in order to enable the viewers to arrive at their own adequate interpretation of the data.

The challenges faced through the visualisation of uncertainty may start to modulate with the use of aesthetic designs. The visualisation designer has a duty to not introduce subjectivity into their designs but instead guide the viewer to statistical outliers or areas of interest. Moreover, the use of design elements and aesthetic design must help explain what the visualisation is showing and not be placed redundantly, such as the use of colour could be used to direct a viewer to what is important within the visualisation (Yau, 2011).

Study Design:

This qualitative study was conducted through a series of semi-structured interviews with participants from an array of industries (private sector, natural resources, civil service, medical). The study was designed in order to allow participants to expand on their own experiences with uncertainty visualisation and decision making within their respected fields. The questions were devised to enable the authors to probe the level of understanding participants had for uncertainty visualisation and their methods of applying it to real world data problems. The semi-structured interviews lasted between forty-five minutes and one hour. The interviews were conducted through video conference (i.e. Microsoft Teams & Zoom meeting).

The questions were strategically designed with a logical flow. The first question prompted/probed participants for their definitions of uncertainty visualisations and aesthetic design. This

enabled the authors to immediately establish participants understanding of the terminology. The remaining questions were then designed to draw from participants past experiences within their respective industries. These questions included; ***“Have you ever been in a situation where you found it difficult to visualise data in a way that portrays it accurately?”***, ***“In your job role have you come across visualisations that attempt to show you the confidence level, the reliability or the multiple outcomes of the data?”*** & ***“Have you ever attempted when portraying data (either in visualisations or not) to give an ‘in depth picture’ and provide details on the confidence, reliability and potential outcomes of the predictive data?”***. These questions aimed to elicit an in-depth picture of the use of uncertainty visualisation and the importance of providing the decision makers with an ‘in-depth’ picture of what the data affords/shows. The questions encouraged participants to provide examples of where they were required to display confidence levels, reliability and probabilities in order to allow for data-driven decisions.

Not only were questions aimed at deciphering the participant’s experience with depicting uncertainty, a range of questions focused on the design and how participants utilised aesthetics in their visualisations. These questions were focused on understanding the level of thought that participants put into the aesthetic design of their visualisations and how these modifications may affect decision making. These questions included ***“What role do you feel design aspects play with presenting data?”*** & ***“When you design your visualisations (or when presenting data) do you consider the influence and sensory perceptions you cause? E.g. triggering an emotional or affective response?”***. The motivation behind these questions was to start to understand how different industries may consider the design of their visualisations and whether this influenced their decision making. By understanding how different industries contemplated the use of aesthetics in their visualisations, the authors believed it would provide a more holistic insight into the thought processes of displaying data for data-driven decision making.

Research Participants:

The main aim of this study was to explore how uncertainty visualisations and aesthetics design can influence participants decision making in a range of industries. Participants were strategically selected in order to provide a comprehensive understanding of how different industries utilise uncertainty visualisations for their decision making. Moreover, participants were selected through purposive sampling in order to allow the authors to control the number of participants from each industry. This method of sampling allowed the authors to control who was interviewed, on the condition that the participant consented to providing information (Tongco, 2007).

The selective nature of determining appropriate participants only considered the industry and job role in which the participant was affiliated with. Once an industry had been selected only participants who deal with data science, data visualisations or decision making were contacted. Participants were contacted directly inquiring their involvement in the study. No other parameters were assigned when selected participants which could introduce bias into the study.

A total of five participants were recruited, interviewed from five distinct industries. Participants consisted of two males and three females, all over the age of 18 years and all resided in the United Kingdom. A full breakdown of the demographic of participants:

Participant:	Gender:	Age:	Industry:
Participant 1	Female	22-35	Public sector-Bioinformatician
Participant 2	Male	36-50	Public-sector-Natural Resources
Participant 3	Female	51-60	Public sector-Census engagement
Participant 4	Female	22-35	Public Sector-Civil Service
Participant 5	Male	22-35	Private sector-Insurance

Table 1: Demographic of participants involved in the study.

Analysis:

The qualitative research method was selected for its ability to gain insight into specific situations and meanings through the subjective experiences of the participants (Palmer & Bolderston, 2006). All interviews were recorded to enable the researcher to transcribe the information into an exact text replication. A thematic analysis of the results allowed the researcher to begin to interpret the data. In order to assist in the data analysis, the software NVivo was used to determine trends and patterns in the qualitative results. In addition, to support the thematic analysis vignettes will be generated by the authors as a means to probe specific questions about uncertainty and decision-making.

Vignettes

Vignettes will be used to present the results as they encourage articulation of perceptions, beliefs, attitudes and opinions from a set of participants as they responds to particular scenarios of situations (Azam & Mahadhir, 2017). Moreover, vignettes allow the authors to explore and gather insights from authentic experiences and attitudes of participants. Vignettes allow the reader to determine their understanding of the participants experiences through their own personal opinions or attitudes towards the vignette (Erfanian et al., 2020).

The vignettes data analysis methods allows for the systematic review of each industry and to build personas of participants in their respected fields. The vignettes allow the authors to identify and evaluate the perceptions and implementations of the aesthetic depiction of uncertainty in visualisations.

Results:

The results highlight differences in the utilisation of uncertainty visualisations and aesthetic design across the array of chosen industries. It was found a participant's understanding and willingness to visualise uncertainty and include aesthetic designs were strongly influenced by the audience the data was intended for. A common trend through interviews appeared to be that participants acknowledged the benefits of visualising uncertainty, yet the determining factor whether or not to depict uncertainty was affected by who the final visualisation was intended for. Each respective industry had their own standards and stakeholders in which their creative visualisation freedom were constrained by.

One participant (p4) expressed the importance of providing clients with an 'in-depth' picture of what the data shows but often clients only wanted the 'bare-minimum'

"From my perspective, I think it's good to show everything and if the client doesn't ask for that and they just want the minimum that's what you get, they just want basics, showing them a load of information they don't want could have a negative effect on the relationship" (p4)

Another participant (p2) expressed their concerns with providing the in-depth picture:

"Sometimes I think even going too much into the detail almost assumes that it is up for debate still."

Interestingly, the participant (p2) went on to explain that often visualisations are not used in order facilitate the making of data driven decisions, but instead used to reinforce a decision already made. When asked "***How do you think decisions are affected when you give an in-depth picture of what the data shows (i.e. confidence)***" the participant responded with:

"Do they actually want that a visualisation or do they want you to confirm the decision they've already made? So sometimes if you tell them something, and they're not sure, they'll just ignore you. We like to think we're driven by the data, but we're not. So, I think we're asked to produce things after the decision has really already been made.".
(p2)

Through conducting a thematic analysis, a number of key themes arose in which participants could be said to experienced uncertainty visualisation and aesthetic designs in contrasting circumstances. The authors categorised the different experiences to better empathise and understand the situations which accompanied each situations participant found themselves in.

The following sections displays 4 Vignettes that were derived from the interview data which illustrate the different personas of dealing with uncertainty and aesthetics in data visualisations. The personas are broken down into '*The confident but restricted*' , '*The confident and unconfined*' , '*The unconfident and unconfined*' and the '*The cautious visualisation designer*'

Table 2: Vignettes personas.

All participants had past experience in building, designing or using data visualisations in their current positions. The following Vignettes show the differentiation in experiences when dealing with uncertainty and aesthetics in a visualisation for improved decision making.

Vignette 1: The confident but restricted: (Confident to visualise uncertainty in their visualisation but are restricted by what they are allowed to include in a visualisation)

- **What comes to mind when you think of uncertainty in a visualisation?** I think of displaying what the confidence or probabilities are within the data such as providing error bars or ranges for example. I think of a visualisation that shows alternative possibilities for the data to go.
- **How do you feel visualising uncertainty helps a decision maker?** Displaying uncertainty can show the viewer if there are any significant gaps in the research. It allows you to consider all your options because you could go down one route and then realise it's not going to work. I think It is best to consider all the avenues
- **Do you often visualise uncertainty?** I am restricted as to what I can include in my visualisations. My visualisations are passed to executives and decision makers who do not have a good understanding of data analytics and therefore only want the bare minimum. I often question if their decision has already been made before they see the visualisations.
- **How important do you feel design plays in a visualisation?** I think it's critical because I am a visual learner and I can infer quite a lot from a visual instead of text. I also think it makes a visualisation a lot more engaging and interesting.
- **Do you think design can trigger emotional and affective responses?** I think it depends on the person and what they want to take from the data, I do think you need to be cautious you do not add too much bias into the visualisation and consider the type of effect you're trying to achieve.

Vignette 1 – The confident but restricted

Vignette 2: The confident and unconfined: (Confident to visualise uncertainty in their visualisation and has complete freedom as to what they include in their visualisation)

- **What comes to mind when you think of uncertainty in a visualisation?** I would say it would be using coloured bar to represent the confidence intervals and the uncertainty that sits around the data.
- **How do you feel visualising uncertainty helps a decision maker?** I think they allow you to give more evidence for your decision, especially when you're making these bold claims it can show how accurate or the confidence there is in the data.
- **Do you often visualise uncertainty?** In my field we have a particular set way of displaying uncertainty in our visualisations. It has become an industry standard and if we don't display the uncertainty then our work won't be taken any further. The decision makers and viewers in my field understand the ways we display the uncertainty
- **How important do you feel design plays in a visualisation?** The whole point of a visualisation is to display information in a way that is visually pleasing and to save the reader from trawling through loads of text to find an answer.
- **Do you think design can trigger emotional and affective responses?** I would hope that data speaks for itself and a person is not too influencing based solely on the design of the visualisation. However, I suppose it has given me something to think about when I design my visualisations.

Vignette 2 – The confident and unconfined

Vignette 3: The unconfident and unconfined: (The person is not confident with the visualisation of uncertainty and has complete freedom to include what they want in their visualisation)

- **What comes to mind when you think of uncertainty in a visualisation?**
I am not sure what uncertainty in a visualisation is, but for me a visualisation must just make sense and is not complicated. The term uncertainty makes things sound complicated.
- **How do you feel visualising uncertainty helps a decision maker?**
I think that it could help people share their knowledge and understand it better.
- **Do you often visualise uncertainty?**
We work that once our data goes past a certain threshold, we class it as reliable and do not represent alternative paths. We do consider the uncertainty in our testing data sets before to ensure integrity.
- **How important do you feel design plays in a visualisation?**
A massive importance, I see design as the bridge that links the data together. It's unfortunate that there are often differences in the way a designer would visualise uncertainty and a scientist, they need to look at it from each other's perspectives.
- **Do you think design can trigger emotional and affective responses?**
A visualisation designer has a huge responsibility when it comes to portraying data in a visualisation. The integrity and not introducing bias is in the visualisation designers' hands.

Vignette 3 – The unconfident and unconfined.

Vignette 4: The cautious visualisation designer: (Cautious about the visualisation of uncertainty and the design of a visualisation – Mostly has freedom with what they choose to include)

- **What comes to mind when you think of uncertainty in a visualisation?** Data which might be messy or unclear. Anything where the data just doesn't look obvious straight away.
- **How do you feel visualising uncertainty helps a decision maker?** I think it can make the decision harder for the viewer as you have now made it more real for them. That's the problem with communicating this stuff the person needs to understand it, and well most people don't.
- **Do you often visualise uncertainty?**
I think it comes down to who the data is for, what they are asking me and if uncertainty is needed. I think sometimes it comes down to that people are just bad at understanding uncertainties.
- **How important do you feel design plays in a visualisation?** It is critical to a visualisation but it's unfortunate that it is critical because it should mostly just be about the data not the design. However, I do think it can help a visualisation is done correctly. If a design is bad it can ruin the visualisation completely.
- **Do you think design can trigger emotional and affective responses?** I think you have got to be cautious about the type of effect that you are trying to achieve. I do still think it comes down to the data and who the visualisation is intended for.

Vignette 4 – The Cautious visualisation designer

Discussion:

Through using the vignettes analysis approach the authors have been able to compare and contrast the application of uncertainty and aesthetic visualisation for decision making through the personal experiences of data scientists and visualisation facilitators. It is clear from the research that all participants acknowledge the benefits and constructive use of considering the uncertainties in their visualisations.

A summary presented by one participant (p2) nicely summarised the importance of uncertainty visualisation and providing the viewer with an in-depth picture of what the data shows:

“We know life is uncertainty and really risks, so what do you want to do stumble around in the dark? Or would you like a flashlight to help you see where you’re going? And I feel that a good data visualisation and good analytics is exactly that...It’s like having a flashlight and its helps illuminate where you’re going” (p2).

What is clear from that description is that all understanding of uncertainty in a visualisation is well defined from a statistical perspective from some i.e. *The confident but restricted* , *The cautious visualisation designer* , *The confident and unconfined* and best defined from a user experience or decision maker perspective from others i.e. *The unconfident and unconfined*.

The vignettes portray three sides to the visualisation of uncertainty: the restricted, the unconfined and the cautious visualisation designer. Two of these categories (the restricted and the unconfined) create a divide as to the level of freedom the visualisation designers have when depicting uncertainty in their visualisation. The most common factor causing restrictions was found to be the executives or decision makers ability to understand the additional dimension to the data. This was especially apparent in those industries where the data scientist/visualisation designer acknowledge the true benefits an in-depth picture could have provided.

One participant (p4) detailing the potential affect of a visualisation depicting the probability of an event occurring:

“If you’re being told something is 90% accurate you would be very happy. You probably wouldn’t even worry about that extra 10%. Whereas if you’re showing the effects of that 10% then it might make you look into the other options, bringing those ideas in the back of your mind to light” (p4).

Similarly, another participant (p5) expressed the benefits of depicting uncertainty and providing an in-depth picture:

“It can help build users general confidence in a visualisation”

Despite participants expressing their preference to visualise uncertainty and provide an in-depth picture they also told the story of how this additional data was either never asked for, never wanted or could never be understood. Participants touched upon how the visualisation of uncertainty or providing the viewer with a more thorough picture would in some cases act as more of an obstacle than tool in decision making.

Consistently participants would express their concerns or reasoning behind not visualising uncertainty. Statements such as “I think if they’ve already made the decision, you can only use the data to prove it or to give them more evidences. Rather than to influence their decision.” (p2), depict circumstances where the visualisation is not used to influence decision and mostly

evident that the design elements used in the visualisations were simply to distinguish data or to make it visually pleasing.

One participant spoke how they can be influenced on their selection of colours and designs based on previous experiences and that they “can't really pinpoint an emotional or more of a though provoking response I'd be looking for in the viewer.” (p1). Another participant similarly said “No, I never thought that deep into it if I'm honest...I'm aware you can make things worse like using reds...but it's not something I've come across myself” (p5). These statements raise a question of whether more can be done by the visualisation designer in order to aid the executives and decision makers through the additional dimension of data.

Conclusion:

The quality study reported in this paper has preliminarily investigated the experiences and thought-processes around the visualisation of uncertainty and aesthetic design to improve decision making. Through combing a thematic analysis with the use of Vignettes, the authors have analysed the key characteristics present in situations participants found themselves in. Moreover, the experiences provided details in which accentuated the actions participants took when faced with these situations.

What is of particular interest is the limited ability for data scientists to portray visualisations with an in-depth picture to improve decision making. On numerous accounts the data scientists/ visualisation facilitator has acknowledge the benefit uncertainty visualisation can provide through enabling a data driven, fact driven and evidence-based decision. However, the executives/ decision makers ability to make use of this additional dimension in the visualisation is severally hindrance by their lack of skill to understand the extra data.

Nevertheless, not all blame can be pinned on the business executives leisurely approaching to learning about data analysis. As one participant (p3) explaining, **the visualisation designer has a huge responsibility with cannot be underestimated to display data in a way that can be understood by everyone.** This raises the question of whether the visualisation designer is doing enough in order to help and guide the business executives or decision makers to utilise the full potential of their data analysis. This research provides evidence that the visualisation designers interviewed acknowledge the benefits of uncertainty visualisation and design yet can be inattentive to the messages and influences caused by their design choices.

Two core assertions can be derived from the findings of the study.

1) Business executives do not utilise the full potential of data and data visualisations because they do not have an extensive understanding. Therefore, business executives and decision makers rely on their gut instinct to make important strategic decisions.

2) Visualisation designers acknowledge the benefits of uncertainty visualisation to provide the decision maker with an in-depth picture of what the data shows. However, they do not utilise or think about how design can be used in order to depict uncertainty. Moreover, that design is often used redundantly in order to make a visualisation more appealing and not more comprehensible.

Evaluation & Future Work

The authors of this paper suggest that visualisation designers should be encouraged to use aesthetic visualisations in order to depict uncertainty and provide an in-depth picture of what the data shows. The aesthetic visualisations will allow the visualisation designer to depict their data both visually pleasing but also have an underlying consideration of how the combination of design elements may enhance the viewers understanding and messages derived from the data. The visualisation designer must have an understanding of how the designs they select may have an influence and/or cause an affective response to their participants.

The focus on this paper has been the intersection of data scientist and the visualisation designer, moving forward the authors feel that it will be important to further explore the rationalisation of gut-instinct versus data driven decision from the executives or decision makers' perspectives. This, will enable them to gain the perspectives of the executives/decision makers and draw a more in-depth understanding as to why the adoption of data driven decisions are frowned upon in the business world. Although the authors acknowledge the benefits of relying on gut instinct to make low level or short period decisions, strategic long-term decisions we maintain should be steered by data-driven or at least a combination of gut-instinct and data-driven decision making (a hybrid method).

As a means to address the visualisations designer's ability to depict uncertainty through the use of aesthetic design, one author's PhD work is aiming to address this problem. The author's PhD work is - to address how different aesthetic designs may be used to target different situations in which uncertainty is present in a visualisation. An uncertainty visualisation framework will be constructed to help guide the visualisation designer to select aesthetic combinations (both design elements and principles) in order to best represent their data. This proposed framework will provide the visualisation designer with a comprehensive understanding of the level of effect they can typically expect from their aesthetically depicted visualisations.

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