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ESTABLISHING INFORMATION VALUING CHARACTERISTICS FOR ENGINEERING DESIGN INFORMATION

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ABSTRACT

Throughout the engineering design process engineers make decisions based on information from various sources. Most of time they do so without formally analysing quality and without making a formal judgement on what they think of its value. There are some methods or assigning 'value' to information in a number of fields and it is a general concept that is widely accepted. However with a range of information characteristics, which can be critical to assess information, the question to ask is, "is it possible to establish metrics to theoretically assess the value of information within the context of engineering design and in relation to the engineering design process?"

This paper starts to address this question. It first makes a brief review of the work that has been undertaken that is related to assigning "value" to information and then focuses on analysing the existing information valuing methodologies. In addition, the characteristics that are involved in the models and methodologies are also investigated and summarized. Based on the results, the key information characteristics that are critical to information value have been identified. Finally the paper introduces a theoretical set of metrics that use information characteristics as the assessment criteria to judge the value of information.

Keywords: Information Value; Information Quality; Information Characteristics

1 INTRODUCTION

Modern industries are becoming more dynamic in nature due to the diversity and complexity of work tasks, trading relationships, environments, as well as the temporary and transitory nature of workplaces and workforces. Information can be viewed either as a tangible or an intangible asset of a corporate body. In addition, the acquisition, maintenance, application and delivery of information has a significant impact on engineering design and engineers' performance.

Value is an idea broadly used in almost any business; likewise information is predominantly regarded as an intangible asset in most business organizations. There are some existing tools and methodologies for valuing intangible assets in engineering, project management, financial, accounting and many other fields, however these methods do not address fully the issues associated with valuing information.

There are a number of issues associated with managing information in engineering organizations in particular the problems associated with the ever-increasing volumes of information, the continuously changing nature of information and in particular the wide variety of uses of even the same technical information. It has been recognized that an effective methodology is required to be established to evaluate information in order to prevent information overload, to retain the right information for reuse, and to somehow identify and record the history or context to give information subsequent meaning for a wide variety of users. It is hoped that by assessing a number of current tools and techniques which attempt to evaluate the 'value' of information, an assessment or filter mechanism for information can be developed.

There is some work that attempts to define and measure the value of information in different fields, such as supply chain management, Value of Information (VOI) in network risk analysis, decision making support in management, finance and accounting, and in the library field. The approaches have been analysed and seen to have both merits and limitations when being used in the context of engineering design. They also show some potential for supporting various information activities within the design process.

In addition, the characteristics that make information a high quality asset are also critical to support the evaluation process so that the information can be regarded as highly valued. Therefore it is likely that information characteristics can be regarded as a basis of the criteria to judge either the information quality or information value. The research about using characteristics to build information quality criteria already exist, so it is easy to match the existing common characteristics against the information attributes that are involved in the research on information value to do some form of statistical analysis, through which the ranking of key information characteristics could be established. These will be used as the basis of a variety of information assessment approaches

The paper is organized as follow: in Section 2 is a review of information overload, value and value of information research; then in Section 3, the information characteristics discussed in those researches are analysed and distinguished; Section 4 discusses the key characteristics and a preliminary decision model of information evaluation; then finally in Section 5, this paper concludes by discussing the establishment of methods and the requirements for support tools for valuing information in engineering design.

2 INFORMATION VALUE

The information overload problem is significant and is exacerbated when through-life activities – which generate huge amounts of information and knowledge – are considered. This information overload problem has been a topic of discussion for a very long time and various solutions have been proposed like concurrency management, new push technology, intelligent agents, and so on [12]. Putting value on information to help to judge what to retain and what to discard is also an obvious solution; previous work on this will be discussed in later sections.

2.1 Information overload

Modern industries are becoming more dynamic in nature due to the diverse and complex nature of work tasks, trading relationships, environments, as well as the temporary and transitory nature of workplaces and workforces. Information can be viewed as an asset of a corporate body, whilst at an operational level appropriate and timely information is very important to the success of a project or a design. In particular, the acquisition of information, maintenance of information, application of information and the ability to deliver information, have ultimately improved operational performance. If, as it is widely believed, information and knowledge are commodities then it is truism for both the individual and the corporate body that they can only afford to acquire and maintain so much. This is not solely for the obvious financial reason, but because of the limits of storage capacity and restricted processing capabilities.

However, until recently, the approach of many organisations has been to gather all information regardless of the cost, which leads to what can be thought of as information waste and a cost burden. A recent survey [24] revealed that 80 percent of information filed has never been used. Furthermore, it has been widely reported that the performance of an individual or an organisation can be detrimentally affected by too much information or information overload [3] [14].

The problem of information overload is becoming crucial as new technological developments are fast growing [15]. Also information burdens including personal loading, organisational loading and customer loading [12] can have many side effects on people and the organisation such as low productivity and stress leading to “information fatigue syndrome” [28] [33].

Organisations are already aware that these problems generate some fundamental questions such as: how much information does an organisation need? – which pieces of information does an organisation need? – And when does the organisation need them? [14]. In particular, there can be a failure to learn from previous experience because the information has not been captured or it is not readily retrievable in a meaningful context. The latter problem may well be compounded by being lost amongst all the data.

Finding answers to these questions is important for any organisation operating in any business sector. However, in the highly competitive global engineering markets the resolution of these issues is particularly critical. This is because of the information-intensive nature of engineering and construction processes, and in particular the design process. Typically, a design process uses as well as generates vast amounts of information during its execution [38]. In addition answering these questions is made more complicated by the fact that there is a combination of creative processes, with team activities, and also internal and external organisations undertaking large aspects of the activity. In the construction engineering sector context, information can be easily captured but relevant information that may be ready for reuse for the next project or next generation is highly dynamic as the nature of construction.

2.2 Value

Value is a widely used but poorly defined term. In the abstract sense value encapsulates the core beliefs, morals, and ideals of individuals and is reflected in their attitudes and behaviour in society. Kohler said that "At the bottom of all human activities are values, the conviction that some things 'ought to be'" [25]. Although value, or the process of valuation, is common when people make judgment or assessment with regard to their beliefs and expectations therefore the concepts, definition of value and the methodologies of valuation are very different in various fields.

From a philosophical view, Dent stated that value comprised "…three connected issues: first, on what sort of property or characteristic 'having value' or 'being of value' is; second, on whether having value is an objective or subjective matter, whether values repose in the object of is a matter of how we feel towards it; third on trying to say what things have value" [10].

When assessing an object, people make judgment with regard to their beliefs and expectation such as the 'users' values, their goals, and the product the associated services, uses, and the situation being encountered [43]. From this social point of view, value is a perception and it is not measurable. Despite its subjective nature, objective interpretations of value are commonplace and are widely adopted in most fields and typically expressed as a price.

In the manufacturing sector, Miles suggested that the definition of value varies with the purpose, viewpoint and intent of the person who defines it. He identified four forms of value: use value, esteem value, cost value and exchange value [31]. Fowler [19] too recognized that for a product, value is how it fulfils a user's need so that

$$Value = \frac{Worth}{Cost} \tag{1}$$

However he also recognized the difficulty of measuring the worth and suggested an alternative expression with a more subjective view:

$$Value = \frac{users\ initial\ impression + satisfaction\ in\ use}{first\ cost + follow\ on\ costs} \tag{2}$$

From a management perspective, Dell'Isola reflected the objective view in the definition [8]:

$$Value = \frac{Function + Quality}{Cost} \tag{3}$$

Before that, Walters and Lancaster also introduced the notion of value taking various interpretations, and more specifically in connection with the co-ordination of customer satisfaction [40]. It shows that the traditional value chain begins with the company's core competences, whereas evidence suggests that modern value chain analysis reverses this approach and uses customers as its starting point.

Thomson pointed out that a common terminology is very important to find the common interest or limitation between stakeholders and customers [38]. The design quality indicator has also been used to deliver the huge stakeholder value in the design stage. They defined the following value definition:

$$Value = \frac{Benefits\ (what\ you\ get)}{Sacrifices\ (what\ you\ give)} \qquad (4)$$

In the economic, financial, and accounting world, value is an extremely popular topic and it is always connected with pricing or costing systems. In these systems, the “what you get” part and the “what you sacrifice” part are both always measured with price, cost, investment levels or any other financial topic. There are all kinds of approaches, from a simple balance sheet to complicated professional analysis tools for the accounting and financial assessment to help value tangible, or sometimes intangible objects.

2.3 Information Valuing

When information needs to be valued – for example in the calculation of cost and benefits of information – the commonly used evaluation methods are not adequate because of the special characteristic of information compared with other tangible and intangible objects. Existing work on the topic of information valuation mostly focuses on specific kinds of information from specific backgrounds. The following have been chosen for study: supply chain management, Value Of Information (VOI) for risk analysis, project and business management including financial and banking, IT, and others like librarianship.

*2.3.1 **Value of information analysis** in supply chain management*

In the field of supply chain management, some work has been undertaken on valuing the information shared throughout the supply chain using a number of mathematical models. The information flow direction, the inventory information and production plan information is a two-way communication between the downstream and upstream organisations in the supply chain. The sales information and demand forecasting information are the flows from downstream companies to their upstream partners. The order state information is provided by upstream organisations to their downstream partners.

Gavirneni and Kapuscinski established cost models against the yield information (early or late) and lead time (long or short) to measure the value of information in the management of supply chains [21]. Ben-Haim developed a two-part model about the value of the information: It assesses the usefulness of information as a ‘robustness premium’; it then determines a value for information as the added reward that the decision maker can demand without losing robustness when the information is exploited [1]. Dominguez and Lashkari using mathematical models that consist of the costs of labour, labour-hours (regular, increasing, decrease, additional), transportation, raw materials, carrying goods inventory (at manufacturing facilities, in transit, at the distribution centres) and over time [11]. Ferrer and Ketzenberg analysed the value of information in a supply chain in the context of remanufacturing complex products [17].

There are a number of key questions that need answering:

1. Is there any value in information sharing? While almost all researchers revealed value in information sharing, very few argued that information sharing has no value for supply chain management.
2. How much value does information sharing have? Much research has indicated quantitative analysis on this problem. However, the analytical results are significantly different from each other. Li et al. took the possible cost saving by information sharing as an example and pointed out that the most optimistic report is 35 per cent saving, while some others says the saving would not exceed 9 per cent [29].
3. What are the factors that influence the value of information, and in a further step, influence the value of information sharing? How strong could the influence be and what are their trends? It is widely agreed that demand variance, lead time, production capability and cost are the major factors. However other researchers have opinions that the factors have totally different influences. It is clear that the picture is not straightforward

2.3.2 *Value Of Information (VOI) for risk analysis*

In the field of risk analysis or risk management not only for engineering but also for cost, financial, health, and environment, the Value of Information (VOI) analysis provides useful insights. VOI analysis evaluates the benefit of collecting additional information to reduce or eliminate uncertainty in a specific decision making context. As noted in one of the earliest VOI applications: "no theory that involves just the probabilities of outcomes without considering their consequences could possibly be adequate in describing the importance of uncertainty to a decision maker". VOI analysis makes explicit any potential losses from errors in decision making due to the uncertainty and it also identifies the "best" information collection strategy, which leads to the greatest net benefit to the decision maker [44].

For a very long time, unlike other economic analytic methods such as cost benefit analysis and cost effectiveness analysis, very few VOI analysis tools existed. Actually some recent analysis of VOI application shows the tendency of articles to focus on demonstrating the usefulness of VOI approaches rather than on applications to actual management decisions. Among all these solutions, the simplest VOI application for uncertainty is the decision tree. Little work has been done for complex continuous input but Yokota and Thompson give a review of a possible solution of this and suggests that strategies should be generated after the information has been gathered, when dealing with nonlinear continuous information inputs [44]. The Bayesian decision theory plus some more constraints that are relevant to information is mostly used to diagnose the overall system risk. Mussi developed a methodology for building a theory-based VOI sequential decision support system, and a design engine to build step-by-step knowledge-base and the related inference [32].

The VOI analysis is also useful when measuring the risk for uncertain outcomes of economic activities, which are always accompanied by a risk. Cox et al. use the VOI analysis method to develop a decision analytic framework to quantity the potential economic value of tracking Canadian cattle imported in to the United States to minimise the cost of tracking and testing requirements [6]. Pflug presents a concept of risk measures for the uncertain outcomes of economic activities which are based on the notion of the value of full information in stochastic programs, and to explore the management of information and the response of economic activities to such information [35]. They examine sellers' anticipation of buyers' pricing behaviour and whether buyers' prices reflect correct inferences of the disclosure strategy of sellers. Based on traditional Bayesian behaviour, they employ a manual technology and their results show that prices themselves are sensitive to the information environment (full certainty, intermediate certainty and low certainty) in which information asymmetry is manipulated. These techniques rather concentrate on the outcomes rather than the information inputs.

2.3.3 *Value of information in business management*

Knowledge, coming from 'valuable' information, can be beneficial to a business and even to the overall success of an organisation [40]. Information can be a key asset of a company and is multi-dimensional including product, customer, market, human resource, management, supplier, account, business process and specialist knowledge and information [34]. However, it can be detrimental to the daily and even long-term operation of the company if information is not properly managed or is unavailable. Information is organic (as it has a life cycle of being reused, maintained and updated), mechanic (as it increases productivity and competitiveness of a company) and dynamic (as it is time dependent). The value of information also depends on the context and use. The use of information in turn depends on access, tools and order [4]. Decision-makers are always making subjective judgments of the value of information within restricted time frames, due to information overload and other pressures.

Industries like construction, aerospace, automotive and healthcare are context-dependent and involve proprietary information. Decision-makers may find it difficult to value a piece of information especially if it has no intrinsic value [2] and is highly time-dependent. Methods have been used to assess information value in relation to the profitability of a company. The methods are too simple and ignored the rationale of the decision-makers. Interestingly Pickard and Dixon argued that the rationale will be affected by cognitive, affective and social variables [36]. However, the approaches were not sufficiently comprehensive to cover the intangible assets of the information. Overall this work showed the importance of information value but did not include the detail mechanisms to value individual information assets.

2.3.4 Value of information in IT application

The information evaluation research in the domain of IT has been mainly focused on information search and retrieval. Finding relevant document or information no longer seems to be the major challenge of the state-of-art search engines. Trying to convey information rather than just data seems to be a major concern nowadays. A simple Google-like scoring system for documents is known to be not efficient enough for the large quantities of modern information. There are several approaches that have been attempted to improve on this situation based on valuing both general information and documents.

The Delphi Group proposed the idea of an information value chain, which is a framework for determining how to optimize information resources across an organisation and its many third parties and market connections [9]. Cleveland investigated the potential value that IT can contribute to the engineering management domain [4]. Saygin and Reisman focused their research on data mining and information sharing which have increasingly gained importance in corporate decision making [37]. Mason and Ragowsky undertake some discussion as to the circumstances when tangible benefits from information systems need to be identified [30]. Galzer suggests that the firms that successfully integrate an IT strategy with their business strategies to do so by focusing on the information itself, rather than on technology [20]. Lee more specifically states the value of IT by developing an economic model using the grounded theory approach [27]. Weide and Bommel developed an incremental searcher satisfaction model for information retrieval for information value of documents based on some earlier work [41]. It is clear from this that the value of information is reflected in the affect the information has on the system or business, and there is still lack of information valuing methods for information itself.

2.3.5 Value of information in other fields

There are still some other fields in which the value of information is researched, like for example: the library area. Fenner first gives a general summary about how to place value on information [16]. Weissinger gives a theoretical basis and analysed the materialist, idealist and critical metaphysical theories about the evaluative nature of information [42]. In other domains, there are some other solutions. For example, Oppenheim et al. analysed how to value information as an asset in companies from an accounting point-of-view [34]. After interviewing the accounting and information professionals, they found out that the most acceptable method would be “by reference to an active market”. But the main argument against this is that there is no such market exists for information. Further investigation of theirs shows that the FRS10 (Financial Reporting Standard, Accounting Standards Board, 1997) can possibly be used to value information as an intangible asset although information hardly meets the strict conditions of FRS10. Ladley gives a similar point to use tradition balance sheet or income statement to deal with the information value problem in data management administration departments in companies [26]. Hughes developed a methodology for objectively determining the potential value of information in a decision theoretic context in the absence of any prior information [23]. Coiera uses information economics to analyse the dynamic of information across networked systems like the internet [5].

The above methods represent the state of the art in activities associated with the valuation of information. They cover the issues and the considerations and some of the factors that have to be considered. However none of them give specific techniques that would be directly applicable to engineering design information. It is clear that to undertake an information valuing activity there will have to be some metrics and a process. The metrics will be based on some key characteristics. These will be discussed and evolved in the next section.

3 INFORMATION CHARACTERISTICS

This section start to analyse the characteristics that are involved in the research reviewed in Section 2. The relationship between information quality and information characteristics has been studied in many instances. Davis, S. M. gives a matrix of engineering information quality criteria and the research clearly indicates that sound information characteristics metrics can be established and information quality can be judged through the measurement of those characteristics [7]. Eppler presents the common used characteristics criteria, which can be found in Table 1 [13].

Table 1. Information characteristics criteria. [13]

1. Comprehensiveness 2. Accuracy 3. Clarity 4. Applicability 5. Conciseness 6. Consistency 7. Correctness 8. Currency 9. Convenience 10. Timeliness 11. Traceability 12. Interactivity 13. Accessibility 14. Security 15. Maintainability 16. Speed 17. Obejctivity 18. Attribute-ability 19. Value-added 20. Reputation (Source) 21. Ease-of-use 22. Precision 23. Comprehensibility	27. Verifiability 28. Testability 29. Provability 30. Performance 31. Ethics/ ethical 32. Privacy 33. Helpfulness 34. Neutrality 35. Ease of Manipulation 36. Validity 37. Relevance 38. Coherence 39. Interpretability 40. Completeness 41. Learn-ability 42. Exclusivity 43. Right Amount 44. Existence of meta information 45. Appropriateness of meta information 46. Target group orientation	48. Response time 49. Believability 50. Availability 51. Consistent Representation 52. Ability to represent null values 53. Semantic Consistency 54. Concise representation 55. Obtainability 56. Stimulating 57. Attribute granularity 58. Flexibility 59. Reflexivity 60. Robustness 61. Equivalence of redundant 62. Concurrency of redundant 63. Non-duplication 64. Essentialness 65. Rightness 66. Usability 67. Cost 68. Ordering 69. Browsing
24. Trustworthiness (Source) 25. Reliability 26. Price	47. Reduction of complexity	70. Error rate

This is an initial and useful list, and the next step is to feed in the characteristics from the analysis of the value literature in Section 2. Table 2 shows the result of the summary of the information characteristics from this analysis.

Table 2. Information characteristics analysis.

Info characteristics	***Relevance of the literatures***		
	High (4)	**Medium(18)**	**Low(6)**
Accessibility	100.00%	33.33%	33.33%
Accuracy	25.00%	11.11%	33.33%
Acquisition		5.56%	16.67%
Appropriateness		5.56%	
Availability	25.00%	16.67%	
Classification		5.56%	
Coherence	25.00%	5.56%	
Completeness			16.67%
Complexity		5.56%	
Comprehensiveness		11.11%	
Confidence/Trustworthiness		11.11%	
Consistent		5.56%	
Context	25.00%	22.22%	16.67%
Density		5.56%	
Dependency	25.00%	11.11%	

Distribution		5.56%	
Divisibility		5.56%	
Meaningfulness		5.56%	
Monotonicity	25.00%	5.56%	
Navigation		5.56%	
Periodicity		5.56%	
Relevance	25.00%	16.67%	
Reliability		5.56%	
Representation		5.56%	
Scarcity		5.56%	16.67%
Search		5.56%	
Secondary sources		5.56%	
Standardization		5.56%	
Structure		22.22%	
Timeliness	50.00%	11.11%	16.67%
Traceability		5.56%	
Transaction		22.22%	33.33%
Uncertainty		5.56%	
Usability	50.00%	27.78%	16.67%
Validity		5.56%	

There were 28 papers that were analysed in the review. These were assessed in terms of their direct relevance to the overall goal of the research, namely, valuing engineering information. It can be seen that only 4 were considered of high relevance (Table2)

The next stage was to extract the major characteristics identified by the researches, 28 in all from *accessibility* to *validity* and then identify their occurrence in the relevance related papers. So accessibility occurs in all 4 high relevance papers and in a third of the medium relevance papers (6 in total) (Table 2)

After identifying the information characteristics involved in each item of literature and the relevance level of each, it is necessary to appoint a weight for each involvement level of the information characteristic in Table 2. The weighting system, and hence the weight value, could be very different according to the content of the research. Considering the nature of the research the weight system is as:

- High relevance involvement characteristic = 1.0
- Medium relevance involvement characteristic = 0.75
- Low relevance involvement characteristic = 0.35

Through this weight system, the characteristic involvement parameter in Table 2 can be reorganized and they rank differently. This result can be found in Figure 1.

A sensitive study has also been conducted through putting different value on Medium (=0.65; 0.55; 0.5) and Low (=0.25; 0.2; 0.15) relevance involvement characteristics. All though there are some variations critically the top eight characteristics stay the same.

As it is shown in Figure 1 from the far right end, the key information characteristics from the analysis are:

- *Accessibility*
- *Usability*
- *Timeliness*
- *Context*
- *Accuracy*
- *Availability*
- *Relevance*

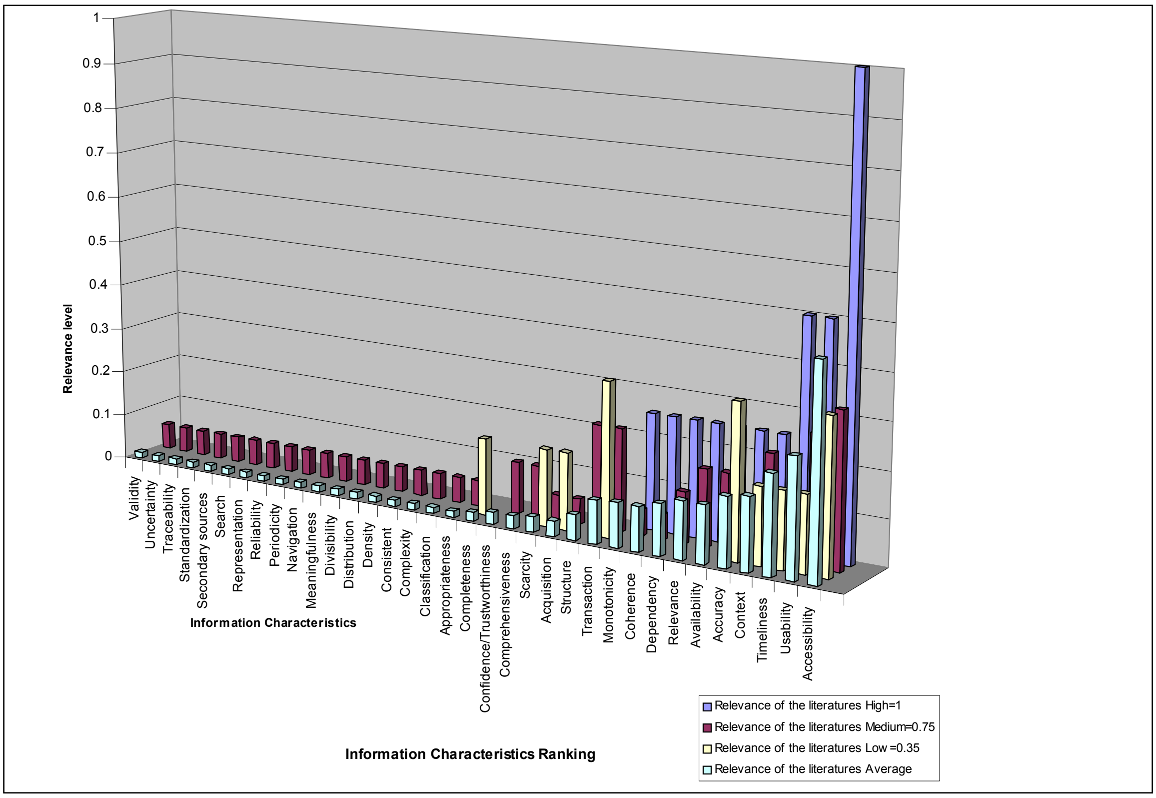

Figure 1. Information characteristic ranking

These are the key characteristics, however it is very hard to consider context to be a characteristic. Nevertheless it does illustrate the importance of the context to the value of information, that is, the value of a piece of information is very context-oriented and same piece of information can have a different value in different context. This is particular relevant to what the authors call Personal Value.

4 INFORMATION VALUING MODEL

In this Section, the key characteristics that have been identified in the above analysis are further analysed and a preliminary Bayesian net decision model is introduced using these information characteristics as the decision nodes

Although *Context* is difficult to think about as an information characteristic, the corollary it is *relevance*, which is, of course dictated by context. Eppler counts *Relevance* amongst the elements that define the *Context*. In the literature reviewed different terms are often used for similar concepts [13]. For example *Availability* and *Accessibility* are closely related, as are *Timeliness* and *Currency*. Amongst the information characteristics most often mentioned in conversation with those in industry during this research is the *Trust* level that can be ascribed to a piece of information.. These considerations have led to a list of key information characteristics as follow:

- *Accessibility*
- *Usability*
- *Currency*
- *Accuracy*
- *Trust*
- *Relevance*

From this start point, all of those information characteristics, plus that of *Cost* (derived from the definition of value in Section 2.2) can be used to build a Bayesian Network and each of the characteristics can be regarded as a node. With the support of probability parameter and the network structure, a decision model can be established as it is shown in Figure 2.

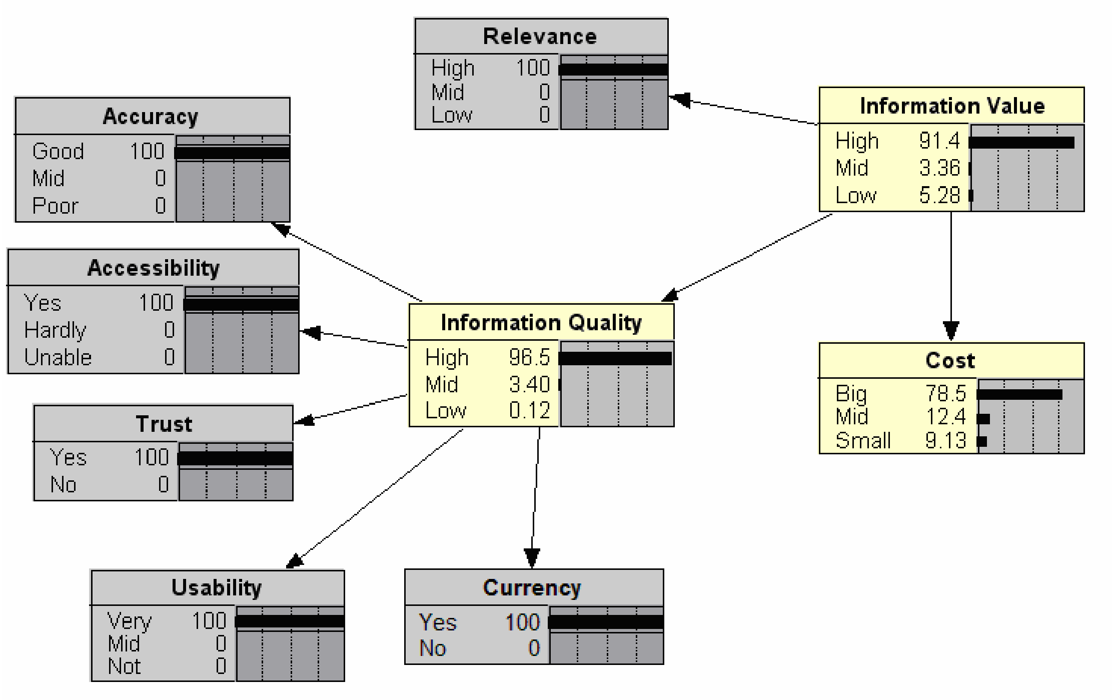

Figure 2. Information value decision using Information characteristic

The model is populated in the manner shown merely to illustrate how the Bayesian approach would be used to combine the various characteristics and their metrics into an overall assessment of quality and then value. Understanding how the probability figures may most usefully be arrived at constitutes future research work. In this illustration it can be seen that when the information evaluator thinks that the accuracy is good, the information can be readily accessed, the information can be trusted, is easily usable and up to date, then the information has a 96.5 per cent probability of being high quality, a 3.4 per cent probability of being mid-quality and 0.12 per cent probability of being low quality. Once the quality of the information has been assessed, the next step is to judge the context. Here, the evaluator estimates that the information is relevant to the context, which gives a 91.4 per cent probability of information being high value, and so on.

5 CONCLUSION

This paper addresses the problem of assigning value to information firstly by reviewing the literature related to the topics of information overload, value in general terms, and value of information in the fields of supply chain management, VOI risk analysis, management decision, IT, and others. Through the review, a set of information characteristics has been derived from the various models and methodologies. Then most importantly, the key information characteristics are identified through ranking using a weighting system. A preliminary Bayesian decision making network model has been developed based on these key information characteristics.

The decision model will rely on historical probability data among each information characteristics to compute final values. Collection of this historical probability data will be a difficult job and will need sufficient statistical work. But when these data are available, an accurate numerical result of information value can be calculated through this model. It is expected that as part of the overall research, methods will be established to collect this type of data automatically.

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