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Abstract

This paper presents a new formal approach to the modelling of information reuse and integration for innovation. Not all information is useful for innovation, and many ideas do not become profitable. We believe that information resources should not only be available, but also should be capable and compatible with the required information/needs. Use of relevant tools for information management should improve the capacity for effective decision making for innovation. Use of data mining technologies for the extraction of potentially useful information may not always produce the required information. Hidden or previously unknown information may be found in datasets, but the required information for innovation may not be in the datasets. There is a need for the development of techniques to ensure that decision makers are provided with capable and compatible information. Profile Theory is used for the analysis and modelling of reuse and integration of available information.

Author Proof

A Capability and Compatibility Approach to Modelling of Information Reuse and Integration for Innovation

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Abstract. This paper presents a new formal approach to the modelling of information reuse and integration for innovation. Not all information is useful for innovation, and many ideas do not become profitable. We believe that information resources should not only be available, but also should be capable and compatible with the required information/needs. Use of relevant tools for information management should improve the capacity for effective decision making for innovation. Use of data mining technologies for the extraction of potentially useful information may not always produce the required information. Hidden or previously unknown information may be found in datasets, but the required information for innovation may not be in the datasets. There is a need for the development of techniques to ensure that decision makers are provided with capable and compatible information. Profile Theory is used for the analysis and modelling of reuse and integration of available information.

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1 Introduction

Innovation is an important problem in many fields such as business, technology, economics, and engineering. Nowadays innovation is considered as the sustainable basis for organisational growth [6]. There are diverse definitions of innovation [11, 12] that encompass several different perspectives on, and aspects of, innovation. The common aspect, which is addressed in these definitions, is that an idea, a change, a renewal or an improvement is only an innovation when it leads to effective, better, or more profitable outcomes or results. The key point in these definitions is that innovation must bring positive results in the areas where it is implemented.

There are varied degrees of innovation, e.g. radical, incremental, disruptive, etc. The required degree of innovation is defined by the need. Innovation can be considered to be the match between a need and ideas which already exist [17]. Thus, in business, innovation often results from the application of a scientific and/or technical idea in decreasing the gap between the needs or expectations of the customers. In the knowledge-based economy it is important to find a tool which can support innovation.

Innovation is based on the transformation of ideas and relevant information/knowledge into a benefit/need. A benefit may be new, or improved, products, processes or services. In a knowledge-based economy, information is used as a driver for any modern

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business and organisational development. Therefore, use, reuse and integration of information become key tasks for innovation.

In this work we consider innovation from the viewpoint of information reuse and integration, which key parts of information and knowledge management.

Like any management process, information reuse and integration require specific tools to support the capacity of an organisation to innovate, improve, and grow. This paper addresses key aspects in innovation that define a rationale for the proposed formal framework for modelling information reuse and integration.

In this work, Profile Theory [22] is used as a tool for the analysis and modelling of reuse and integration of available information.

2 Key Issues in Innovation

The concept of innovation is discussed by many business disciplines [12, 15] and it has many different definitions that are associated with the relevant and dominant paradigms. Despite the varieties of discussions, theories and approaches, innovation management is still an immature science. The most critical aspect/question is what affects an organisation's ability to innovate. It is recognised that nowadays companies may gain advantage if they can innovate not just through cost reduction, and reengineering. Innovation is a key element in the process of aggressive top-line growth of businesses and organisations [6].

Innovation cannot occur without invention. Invention is a process of creation of new artifacts that are based on ideas and/or scientific research. An invention increases the volume of knowledge. Innovation is a process of implementation of invention to produce practical benefits. An artifact of innovation results from a combination of research, discovery, invention, experimentation, development, engineering, diffusion and management.

The critical task is to define or identify information that direct organisations to a profitable economic outcome. Not all information or knowledge is useful for innovation, and many ideas do not become profitable. In many cases this is not because of failure of the idea. The generation and implementation of new ideas are tasks of equal importance in innovation.

2.1 The Nature of Innovation

The key reason for innovation is growth. The specific nature of innovation is defined by different needs (or objectives, goals, aspirations, expectations) and/or different problems. New needs may involve new problems; and vise verse; new problems may involve new needs. Therefore, we believe that the nature of innovation is different for different needs and the "speed" of change of innovation nature is thus also different.

Several reports discuss the nature of innovations [4, 13]. "Innovation is the main lever for a more competitive national economy" [13]; and the notion of innovation is changing radically and rapidly:

"The nature of innovation is changing dramatically in the 21st century. Proprietary invention in search of purpose is out. Open, collaborative and multi-disciplinary approaches to innovation are taking center stage in the shaping of new ideas and creation of tangible value for business, individuals, and the world." [16].

Each period of time in a real-life situation defines specific aspirations and demands. Therefore, major contribution of this work is that it identifies milestones for current events and defines the most important aspects and relevant needs.

2.2 Innovation: Methodologies and Information Reuse and Integration

The following components reflect key aspects of innovation:

- *Wisdom* is a starting point in the innovation process; i.e. we need to identify needs (why?) and a rationale for information and knowledge management.
- *Information* is an essential resource for innovation which involves definitions, descriptions, directions (what/who/where/when?) that can be used for accomplishment of needs.
- *Knowledge* comprises/relates to "tools" (how?); e.g. methods, approaches, strategies, frameworks, for transformation of relevant information to useful results.
- *Idea* is a rational conception which defines possible courses of action and is relevant to something new; i.e. method, procedure, strategy, resources, market, new or improved products.
- *Various processes* (e.g. management including RDD - Research, Development, Diffusion) are involved in supporting the innovation process.
- *Performance measures* (e.g. cost, time, resources, better market, more sales turnover; profit) are used for the measurement of improvement(s) of system performance (e.g. business).

The initial task for innovation is the identification of problem followed by the development of a solution to the identified problem via research and the generation of creative ideas. These first and key steps involve the creation of new knowledge. There are several discussions of different ways for the creation of new knowledge. It is noticed [2, 9] that new knowledge can be created by combining old and new knowledge in an innovative way. Learning processes are considered as key contributors to the production of new and economically useful knowledge [9, 19]. That is, it is recognised that research and development, search and experimentation, learning, data mining and imitation are sources of new knowledge.

Many leading methodologies are used for innovation processes. Some well-known approaches are Brainstorming [21], Brainwriting [14], Delphi Method [3, 12], Heuristic Redefinition Process, Transformation of Ideal Solution Elements with Associations and Commonalities (TILMAG) [24], and Theory of Inventive Problem Solving (TRIZ) [1]. Innovation methodologies are mainly derived from the objectives and expectations of the main stakeholders.

If we closely analyse these methodologies we find that the key tasks are relevant to information and knowledge management and, in particular, to information reuse and integration. In general, these qualitative methods involve information reuse and integration tasks.

2.3 Information Management vs. Knowledge Management in Innovation

Knowledge creation, and the translation of this knowledge into products and services is a key determinant of economic success. It is recognised that knowledge becomes the most important economic recourse in the knowledge society [10, 18]. It leads to a new focus on the role of information, technology and learning in economic performance. In a knowledge-based economy it is important to find a tool which can support innovation. The term "knowledge-based economy" is used to confirm that knowledge management plays an important role in modern economies [10].

Traditionally information management is considered as a process which is about the collection, storage, retrieval, classification, security and distribution/diffusion of data.

Knowledge management is about the use of information which involves modelling of real-life systems, management and application of relevant information, critical evaluation of its application results and decision making. It leads to the creation of new information or knowledge. Knowledge creation is, in fact, a process of value addition to previous knowledge through innovation [8, 20].

It is important to note that innovation is not just about any new knowledge, i.e. not any new knowledge leads to innovation. An innovation generates new knowledge, which is unique since it leads to innovation.

Information management and knowledge management are interrelated and are of equal importance. Information management nurtures knowledge management and knowledge management is used for information management.

The key contributors to volume and quality of knowledge are individuals who are knowledge creators, developers, carriers, and users [5]. Information is an input and people translate/transfer this information into outputs. Knowledge cannot be explicitly managed because it resides in a person's mind. The same information can produce different outputs.

Thus, knowledge involves the link between information and its potential applications. People/stakeholders and the use of information technology define the quality of this link. Information/knowledge management technologies provide stakeholders with decision making support, i.e. allocate the relevant information to the right problem, at the right time for the right request. It increases and improves the capacity for effective decision making/actions for innovation. Note that irrelevant information makes decision making difficult, leads to confusion, affects performance, and reduces the opportunity for innovation.

Therefore, information can be identified as the critical resource for decision making for innovation; and management can be considered as an information-intensive activity. It is crucial for managers to be aware of what information they require, what the quality of this information is; and how to get best/optimal benefits from the use of it in order to survive in the modern knowledge-based economy. Information and knowledge management are key management processes in innovation, and information reuse and integration is an important part of these processes.

2.4 Data Mining vs. Information Reuse and Integration

According to a recent study [7], one of the leading topics in information reuse and integration is data mining and knowledge discovery, acquisition and management.

Data mining technologies are widely used for the extraction of potentially useful information from datasets. Data mining gives information that would not be otherwise available. Data Mining is concerned with the extraction of hidden information. Hidden or previously unknown information can be found in datasets, but the required information may not be in the dataset. If it does not exist (i.e. if it is not there) we cannot extract the required information.

The outcome of the applications of a data mining technique is information, which becomes available for decision making. However, this information may not satisfy the required need. Therefore, there is a need for reuse and integration of information in order to reduce the gap between required and available information. If hidden or unknown information is available the next step is that it should be used/reused, and integrated with other elements of available information to ensure that the required information is allocated to the needs/tasks. Therefore, the following important problems must be addressed in the process of information reuse and integration: how relevant the information is, and how well it satisfies a required need.

That is, information resources should not be only available; but should also be capable and compatible with the required information/needs for innovation. Therefore, there is a need for the development of techniques to ensure that decision makers are provided with capable and compatible information.

Innovation requires new knowledge which uses available information. Data mining technology can be used for the extraction of potentially *useful information* from datasets; but for innovation it may be not enough since we are interested in potentially *utile information.* We define *utile/innovative information* as (profitable) information, when is used, leads to benefits/innovation.

2.5 The Need for Formal Modelling of Information Reuse and Integration

As discussed, information reuse and integration are a part of information and knowledge management. It is important to note that innovation can be identified after it has occurred. Modelling is a tool that supports decision making for innovation. Information nurtures knowledge through models. A model with the relevant (i.e. capable and compatible) information is used for decision making, analysis, explanations, and developments. The quality of information is a crucial factor for model performance. Therefore, modelling of information reuse and integration is one of the most important tasks in decision making. The integration of descriptive, normative and learning models contributes to the quality of decision making for innovation. It is recognised that innovation is a fundamental determinant of organisational performance. Since innovation has to provide effective, better and more profitable results, normative and learning models for information reuse and integration become "must have" tools that can contribute to effective development of innovation.

3 Profile Theory: Brief Introduction

In this work, Profile Theory is used as a tool for the analysis and modelling of reuse and integration of available information where information capability and compatibility problems are addressed. Profile Theory [22, 23] is designed to address an important class of problems, which are not addressed by traditional theories (i.e. including complex systems theories), in which the central issues relate to capability and compatibility problems of complex systems and/or their elements; and determination of complex system structures. The importance of Profile Theory derives from the fact that in the real world such problems are the norm rather than the exception. Key research issues include: the analysis and modelling of complex systems where capabilities and compatibilities of their elements are critical factors.

We define the information resource *integration problem* as a problem of allocation of capable and compatible information resources to tasks in order to provide information resource utilisation at the desired performance and technology levels. Thus, the determination of information resource capabilities and compatibilities is a focus of an integration problem. In order to provide information resource integration, we determine an *allocation strategy*, which is used for the allocation of capable information resources to the tasks, and then an *integration strategy*, which is applied for the allocation of compatible information resources. Analysis and reuse of available information is considered as a key task in the information integration process.

3.1 Profile Definition

In Profile Theory an object is described by its internal characteristics. That is, an object is described by a set of factors, and in turn each factor may be defined by multiple characteristics. A set of such factors forms a profile. More factors are used for an object description, and more explicit identification and definition of object is provided. We represent a factor by qualitative and quantitative information. A quantitative description of the ith profile factor is defined by an indicator characteristic ε_i, property v_i, and weight w_i[1]. In particular,

- ε_i - is the indicator characteristic, that indicates and expresses, by factor presence in the object description, the existence of certain conditions. In particular,
  1. ε_i may be defined as a time characteristic of the ith factor $\varepsilon_i = \varepsilon_i(t)$:

$$\varepsilon_i\text{:T} \rightarrow \text{E}_i \text{ or } \text{T} \times \text{E}_i = \{(t, \varepsilon_i),\ t \in \text{T and } \varepsilon_i \in \text{E}_i\}$$

     where T is a set of time characteristics; E_i is a set of possible indicator characteristics of the ith factor.

[1] It should, however, be pointed out that each profile factor may be described by an N-dimensional tuple [22].

Domain constraints may define bounds, i.e. $\varepsilon_i^b \leq \varepsilon_i \leq \varepsilon_i^u$, where $\varepsilon_i^b \geq 0$, $\varepsilon_i^u \geq 0$ represent bottom (lower) and top (upper) values of the *i*th factor time range, respectively.
The time characteristic can represent the duration (or length) of experience or factor utilisation.

2. ε_i may also represent a number of times of factor utilisation (e.g. a number of projects (or tasks) where a particular knowledge/skill was utilised)
3. ε_i may also represent a binary case. For instance, factor existence $\varepsilon_i = 1$ or non-existence $\varepsilon_i = 0$; Boolean variable: $\varepsilon_i = 1$ if factor is true or $\varepsilon_i = 0$ if factor is false.

- v_i - is the property of the *i*th factor (e.g. depth, range, complexity, capability, degree, grade of compatibility or level of a factor): $v_i \geq 0$. Since a property may change with time, v_i can be defined as a function of time $v_i = v_i(t)$:

$$v_i\colon \mathrm{T} \to \mathrm{V}_i \text{ or } \mathrm{T} \times \mathrm{V}_i = \left\{(t, v_i),\ t \in \mathrm{T} \text{ and } v_i \in \mathrm{V}_i\right\}$$

where V_i is a set of property characteristics of the *i*th factor.

Domain constraints may define bounds, i.e. $v_i^b \leq v_i \leq v_i^u$, where $v_i^b \geq 0$, $v_i^u \geq 0$ represent bottom (lower) and top (upper) values of the *i*th factor property range, respectively.

- w_i - is the weight of a factor which defines either the factor importance or the factor priority: $w_i \geq 0$. Factor weights can vary, and therefore, w_i can also be considered as a function of time $w_i = w_i(t)$:

$$w_i\colon \mathrm{T} \to \mathrm{W}_i \text{ or } \mathrm{T} \times \mathrm{W}_i = \left\{(t, w_i),\ t \in \mathrm{T} \text{ and } w_i \in \mathrm{W}_i\right\}$$

where W_i is a set of possible weights of the *i*th factor.

4 Information Modelling

The strategic management of information capabilities *via* analysis, comparison and management of the information resource capabilities and their compatibilities is an important component in innovation. Thus, tasks are to analyse, reuse and integrate available information profiles in such a way that provides *innovative information*, i.e. information which is used for innovation. Let us consider a set of information profiles as a topological space. We need to find among available information profiles, a profile or a set of profiles that cover(s) the required information profile for a given task.

Let us semantically define a set of information profiles as a set of N available information profiles: $E = \left\{b^{(j)}, j = \overline{1, N}\right\}$ and B as a subset of the available information profiles of E for a given task: $B = \left\{b^{(j)}\colon b^{(j)} \in E,\ j \in \{1, 2, \ldots, N\}\right\}$.

For information space modelling we define the information profile space as a topological space (E, B), where the family B is a *topology* in the set E. The subsets B are the collections of the available information profiles for a given task that are the open sets of E.

In order to select all combinations of the available information profiles, that satisfy the required one, we represent the information profile space as a metric space. The concept of a metric is used to define a notion of distance on the information profile space and carries with it a certain structure. A metric space approach to information profile space modelling provides both the modelling of combination of the individual information profiles and the determination of a number of the viable alternative combinations of information profiles.

4.1 Information Profile Space as a Metric Space

In order to define a metric on a set E of the available information profiles of the information space, we need to define the distance from the information profile $b^{(i)}$ to the information profile $b^{(j)}$ [2].

A "deviation" of the available information profile $b \in E$ from a required information profile $b^{(0)}$ can be measured by the covered power index [22]:

$$\rho(b) = \rho(b, b^{(0)}) = \frac{m}{n},\ 0 \le \rho(b) \le 1$$

where m is a covered power of b; n is the required information profile power.

The distance $d(b^{(i)}, b^{(j)}) = |\rho(b^{(i)}) - \rho(b^{(j)})|$ between two covered power indices can be considered as the distance between the available information profiles $b^{(i)}$ and $b^{(j)}$ (or as a compatibility-length metric) [22].

Any L_p - metric can also be used as a distance between profiles:

$$\|b - b^{(0)}\|_p = \left[\sum_{i=1}^{n} \left|V_i - V_i^{(0)}\right|^p\right]^{1/p},\ p \in \{1, 2, 3, \ldots\} \cup \{\infty\}$$

or any weighted L_p - metric:

$$\|b - b^{(0)}\|_p^{\lambda} = \left[\sum_{i=1}^{n} \left(\lambda_i \left|V_i - V_i^{(0)}\right|^p\right)\right]^{1/p},\ p \in \{1, 2, 3, \ldots\} \cup \{\infty\}$$

where $\lambda \in R^n$ is a non-negative vector of weights; and V_i is available factor capability with respect to required factor capability and is defined as [22]:

[2] Distance is not always distance in the colloquial sense, for example cost, elapsed time, reliability, compatibility, capability, etc. can also be interpreted as a distance.

$$V_i = V(b_i) = w_i \left(\frac{\varepsilon_i}{\varepsilon_i^{(0)}} \right) \left(\frac{v_i}{v_i^{(0)}} \right)^2$$

Thus, the information profile space is represented by a metric space (E, d) with the metric $d(b^{(i)}, b^{(j)})$. This allows the definition of the metric on the information profile space, which generates the topologies for E, and defines the feasible combinations of information profiles (individual performers) for a given task. The topology for E is generated by metric.

We say, that *feasible combinations* of the information profiles for a given task are generated by metric and represented by the topologies.

A given or required distance we call a *radius* $r = r(b)$.

Thus, we can define a number of the possible *criterions for the acceptance an available* information *profile for a task*. In particular, an available information profile can be accepted for utilisation for a given task, if the distance between an available information profile and a required information profile is less than a given radius r

$$d(b^{(i)}, b^{(0)}) < r,\ r > 0.$$

where r can be represented by any metric or characteristic.

We may define the *ball with radius r and centre* $b^{(0)}$ (required information profile), that is the set of the available information profiles for which the distance from a required information profile $b^{(0)}$ is less than a given radius r [22]:

$$B_r(b^{(0)}) = \{b^{(i)} | b^{(i)} \in E: d(b^{(i)}, b^{(0)}) < r,\ r > 0,\ i \in \{1, 2, \ldots, N\}\}$$

It was theoretically proved that the available information profiles are accepted for a task, if they are elements of the ball with radius r and centre $b^{(0)}$ [22].

For instance, the *covered power distance* between an available information profile and a required information profile is defined as $d(b, b^{(0)}) = |\rho(b) - 1|$. An available information profile b *covers* the required information profile $b^{(0)}$ if the covered power distance is less or equal to the given radius: $d(b, b^{(0)}) \leq r(b)$.

The required information profile may be associated with many alternative available information profiles that may have identical information profiles but are relevant to different performance profiles. We need to find a set of information profiles which gives us optimal or better results for the given problem. An *innovative information profile* is a profile which determines an optimal or better result(s) to the given task/problem. Also it can define an optimal strategy for information reuse and integration for innovation.

5 Conclusion

In this work we consider innovation from the viewpoint of information reuse and integration; which are a key part of information and knowledge management. Information is considered as the critical resource for innovation. That is, information should not be only available but also should be capable and compatible with the required information/

needs, and relevant tools for information management should be provided in order to increase and/or improve the capacity for effective decision making for innovation. The need for a formal modelling approach to information reuse and integration is critically discussed. Data mining technologies may not deliver the required useful information for innovation; since it may not be in the datasets.

Normative and learning models for information reuse and integration are defined as "must have" tools that can identify (capable and compatible) information which could lead to innovation. In this work, Profile Theory is used as a tool for modelling of reuse and integration of available information. A number of metrics for measurement of capability and compatibility of information are introduced. An information profile space modelling provides both the modelling of a combination of individual information profiles and the determination of a number of the viable alternative combinations of information profiles. The required information profile may be associated with many performance profiles and may be introduced by the multiple presentations of alternatives that define the decision making environment for innovation. We define an innovative information profile as a profile which determines optimal or better result(s) to a given problem.

Thus in the proposed approach to modelling information reuse and integration, determination of information resource capabilities and compatibilities is a focus of an integration problem. There are two possible ways for the use of information profile(s) for the task, i.e. use of only one information profile or a combination of information profiles. In order to provide information resource integration, we determine an allocation strategy, which is based on an allocation of capable information resources to the tasks. The proposed formal approach to the modelling of information reuse and integration can be considered as a tool to support the capacities of organisations to innovate, improve, and grow.

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