Developing a management decision-making model based upon a complexity perspective with reference to the Bee Algorithm

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Abstract

Today’s business world is characterized by a complex non-linear environment, non-hierarchical organization structures, multi-country and de-centralized operations, etc. The prominent models of decision-making that were primarily developed with the industrial economy in mind, and that viewed decision-making as a couple of linear sequential steps and “decisions given-and-decisions followed” — might not work too well. Knowledge-based economies call for developing decision-making models that represent the complexity of the present world business. Under such context, we present an alternative approach to studying management decision-making — seeking inspiration from the natural/biological systems. Bees show similar behavior in their foraging activities, as a single objective management decision-making problem. The uniqueness of the developed model lies in its ability to explain the major properties of a complex system, and the value that emergence (of a decision) brings to a company.

Introduction

In a highly competitive business environment, every organization wants to achieve and sustain its business success. Such business success is acquired when the company secures a competitive advantage over its rivals and also sustains it in the long run. In a review of literature on Sustainable Competitive Advantage (SCA), (Hoffman, 2000) tells us that starting from the mid 1930’s when Anderson first indicated at SCA by saying that the objective of a company is to obtain unique characteristics that distinguishes itself from its rivals; many management thinkers have subsequently contributed to the literature of SCA. While some, like Porter, have identified the types of strategies (i.e., low cost or differentiation) that help a firm to achieve SCA; others like Day and Wensley, Barney, Hunt and Morgan have identified the resources and ways by which companies can obtain SCA. Whatever the debate might be regarding the choices (types of strategies, or resources and methods) through which to attain SCA, it is common sense that none of the desired results can be achieved without a definite management decision-making structure. However in well documented literature reviews on management decision-making (Langley, Mintzberg, Pitcher, Posada, & Saint-Macary, 1995; McKenna & Martin-Smith, 2005; Nutt, 2011); researchers opine that the process is fraught with problems. Without delving deep into the specific problems of decision-making at this point of the discussion, we observe that the previous mentioned researchers agree on a particular point. In today’s highly complex business world that manifests non-linear environment and non-hierarchical organization structures, the classical and behavioral models of management decision-making that views decision-making as a couple of linear sequential steps and “decisions given-and-decisions followed” – might not work too well. Stressing importance on complexity from yet another correlated branch of management – strategic leadership, (Boisot, 1995) tells us that in case of high environmental turbulence and low understanding of the environment – the organization should follow the strategy of intraprenuership. In such tumultuous situations, the top management does not have a clear-cut overall organizational strategy, and individual initiative is encouraged. It is also believed that even though at present strategy is useless (because of environmental instability and organizational incapability of understanding it), yet some of the individual initiatives will pay off in the future, and can be used to build an overall organizational strategy.

The present research tries to address the problems of management decision-making by incorporating a complexity perspective. The paper is organized as follows: first we review some of the established models on decision-making and identify their problems; second, analyze a natural system (single objective maximization problem) with similar goals as management decision-making; third, argue why and how the natural system can provide valuable insights into management decision-making, and finally provide a brief overview of emergence of a decision in the management context.

Decision making models

A concise literature review of the models of decision-making

Here we provide a brief overview of the prominent models of organizational decision-making. The decision-making theory can be historically traced back to John Dewey. In citing the 1910 work of Dewey, (Langley *et al.*, 1995) tells that Dewey breaks decision-making into a number of stages and the splitting of the process to stages finally leads to a solution. However the first substantial contribution into decision-making science comes from Herbert Simon in the 1950s (Langley *et al.*, 1995). Simon's model of decision making consists of a structured process of three sequential steps: Intelligence – in which confusing information from the environment helps in structuring and better understanding the problem, Design – in which the alternative solutions of the problem are developed, and Choice – the analysis of the alternative solutions lead to the best solution of the problem.

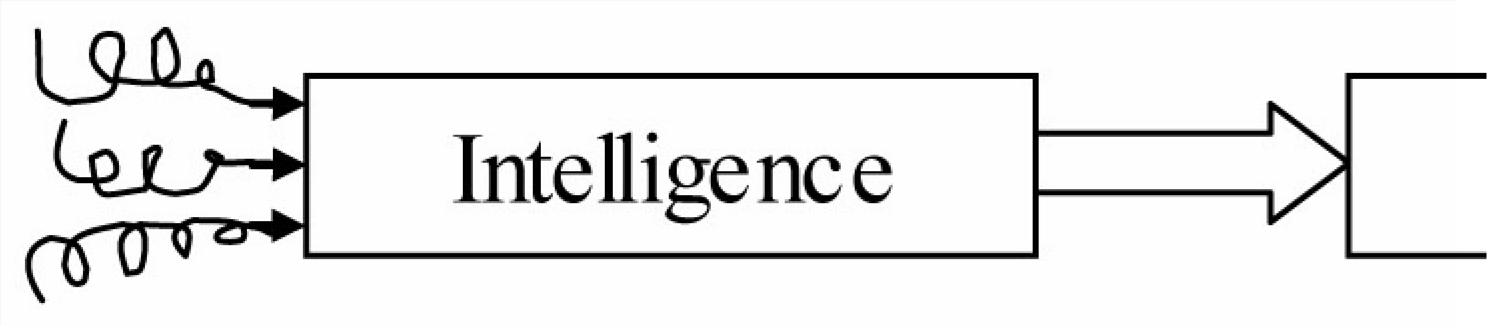

Fig. 1: Simon's sequential model of decision-making

(Adopted from Langley *et al.*, 1995)

Perhaps the greatest contribution of Simon comes from his formulation of the "Administrative man" against the "Economic man". He tells us that in case of decision making under uncertainty and imperfect competition, coupled with the limited cognitive and computational capacity of man and computers; the economist's classical approach of choosing the alternative that has the highest utility will not work (Simon, 1978). Hence in a framework of "bounded rationality", the concept of "economic rationality" gets substituted by "cerebral rationality" – where decisions taken are based more upon cognitive aspects of human intelligence than utility theories of economics (Miller, 1989; Langley *et al*. 1995).

In the complete opposite end of the spectrum of Simon's sequential model, lie the anarchical model of March and his colleagues (1970s). In reviewing their work, researchers like (Langley *et al*. 1995) and (Nutt, 2011) tell us that the organizational system here is composed of smaller loosely attached sub-units that have their own standard operating procedures, and the system is chaotic. The entailed complexity of the situation causes decision to emanate from the system without following any definite system or procedure. However this decision has the property of being "conspicuous and have the support of the right people" in the organization (Nutt, 2011: 7). Thus in this model we see the effect of coalition, politics, bargaining etc. that are absent in Simon's model.

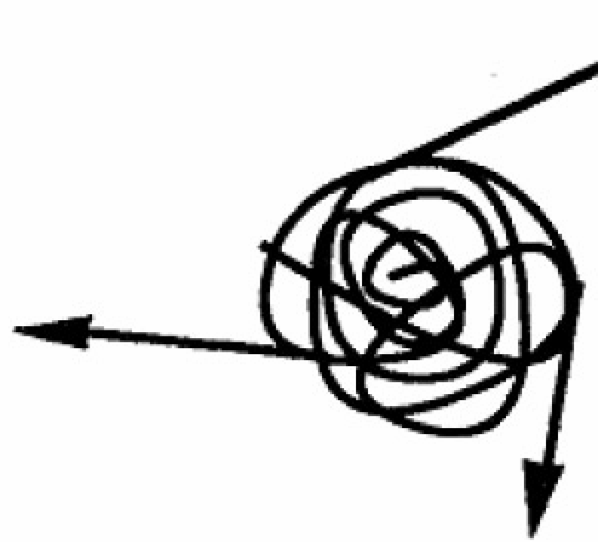

Fig. 2: March and colleagues' Anarchical model of decision-making

(Adopted from Langley *et al*., 1995)

However in between the above two extreme ends of the spectrum, most researchers prefer a middle path for defining/understanding decision-making (an iterative model). In referring to the work of Mintzberg, Raisinghani & Theoret (1976; Langley *et al*., 1995) tells us that their model combines the elements of both the sequential and the anarchical model. Thus while the decision makers start with a definite set of ideas – a specific problem to be solved, alternative solutions to be considered, a final choice from the possible set of alternatives to be chosen as a solution, etc (implying a well defined sequential process); the decision making process falls in jeopardy when the chaotic elements of the complex environment and the conflicting interests of the involved parties are introduced into the model (implying anarchy). Depending upon the strength the opposing forces – decision making transforms accordingly, i.e., if the chaotic forces are strong – decision emanates from the anarchical model through bargaining, coalition etc; and if the chaotic forces can be subdued to restore order – then decision-making comes through the sequential model.

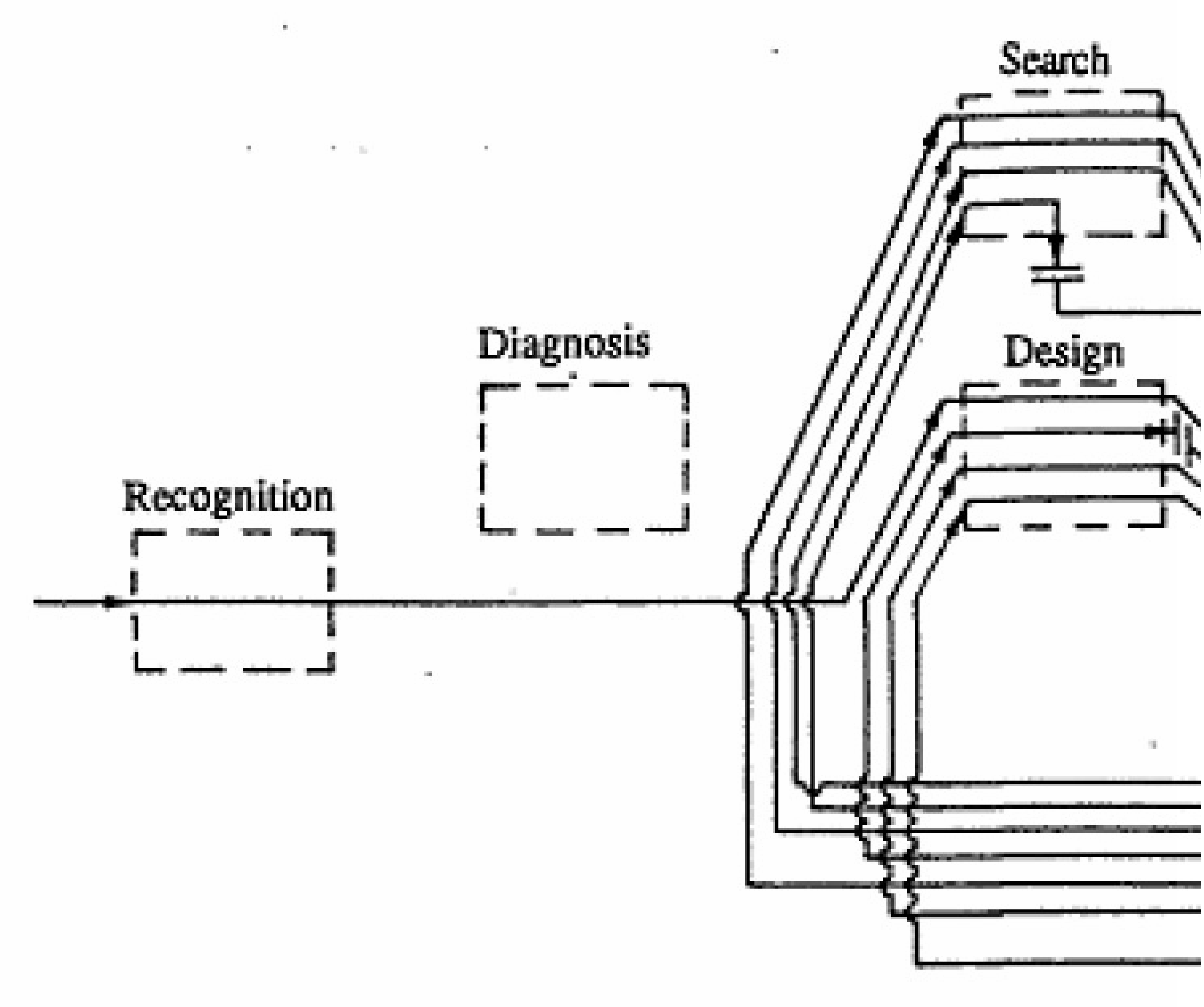

Fig. 3: Mintzberg et al.'s iterative model of decision-making

(Adopted from Langley *et al*., 1995)

However, the salient feature of the model is the incorporation of the "cycling back and time lags" (McKenna & Martin-Smith, 2005: 822) of decision-making. Practical experience of decision-making in organizations tell us that organizational decisions cannot be taken as a "one-shot" process, and constant adjustment between objectives and decisions should come through multiple iterations between them. This cybernetic perspective of feedback of results of past decision in future ones is seminal to cognitive rationality of complex decision-making supported by nature inspired algorithms.

Problems of the models of decision-making

Like all branches of management studies, decision-making is also burdened with problems. Langley*et al*. (1995) argue that the specific problems of the above models are: Reification – even though decision-making is an abstract concept, efforts are carried to visualize it as a physical or real process and "there is that moment of “choice”” (Langley et al. 1995: 264) in the course of decision making actions. This in effect helps in viewing organizations as “mechanistic and bureaucratic” (Langley *et al*., 1995: 264) entities – which may not always be true. Dehumanization – in stressing upon “cerebral rationality”, researchers tend to forget the impact of insight, inspiration etc that affect decision-making process, in addition to the rational intelligence and logic. Isolation – in case of multiple decisions-making processes being simultaneously operational in the organization, the models seem to imply that each particular process is independent of the others. An extension of the argument would mean that tracing back particular choices, independent and separate decision-making process can be identified upon which the environment of the organization would have no effect. However we know that in complex organizational environment, this is not true.

In addition, a close look at the time of development of the above models shows that these models were all formulated in the last century. However, in the recent past, business environment have seen dramatic changes in the form of single country operation to globalization, hierarchical to flat organization structure with de-centralized operations, stable environment with linear thinking to complex environment manifesting non-linear dynamics etc (McKenna & Martin-Smith, 2005). In addition we opine that the transformation of the global economy from the industrial to the more knowledge-based one would have considerable impact on management decision-making. In reviewing the works of various other authors, (Rogers, 2001) tells us that compared to the industrial workers, the knowledge professionals have (i) a higher level of domain specific knowledge and hence education, (ii) a strong inclination for independence in work place and (iii) a more professional rather than an organizational orientation. Similar opinions are shared by Drucker when he says that knowledge workers are “associates” and not “subordinates”; challenge in work is equally important as their pay, and it’s more important to lead the knowledge workers than manage them (Drucker, 2001). Thus the above models that were primarily developed with the industrial economy in mind, might not work too well in the present knowledge-based economy – a kind of economy in which collaboration and competition are pivotal behavior aiming at valuable information.

The Bee algorithm

In view of the above problems, we present an alternative approach to studying management decision-making – seeking inspiration from the natural/biological systems. Mimicry of behavior of birds and fishes (Particle Swarm Optimization), ants (Swarm Intelligence), cuckoo (Cuckoo Search) etc. have been extensively applied in solving problems related to engineering, mining and search of data, computer animation, etc. (for details refer to Nanvala & Awari, 2011; Dorigo, Birattari, & Stutzle, 2006). In addition, the principles entailed in these algorithms have been recently used to study problems in business management – such as logistics and supply chain (Bell & Griffis, 2010), vendor selection (Chen & Cao, 2009), business strategy (Terano & Naitoh, 2004), market analysis (Darley & Outkin, 2007), appropriate decisions (Caldas, Pita & Lima Neto, 2007) etc. With such a back ground of previous research, we were motivated towards examining the foraging behavior of bees to study the problem of management decision-making as both have similar objectives.

A brief description

Recently there has been a growing interest in the studies of bees, their colonies and their interaction with the environment. The actions of the bees, as represented in their foraging, information sharing, learning, memorization, reproduction etc have been widely used in solving problems related to large scale precise navigation, telecommunication, economic power dispatch, water resource management, etc. (for a detailed review of applications –refer Baykasoğlu, Özbakır, & Tapkan, 2007). In this section we look at the foraging behavior of honey bees through the Bee Algorithm (Pham *et al*., 2006; Pham, Darwish, & Eldukhri, 2009).

During the food harvesting season, a bee colony deploys its scout bees randomly in multiple directions at distances that can range upto 10 kilometers, to search for potential food patches (Von Frisch, 1976; Seeley, 1996; cited in Pham *et al*., 2006). The aim of the colony is to find food patches that have ample quantity of nectar or pollen and would require less effort in exploration – to be visited by more bees, and those that contain less nectar or pollen – to be visited by less number of bees. After searching randomly from one patch to another, those scout bees that have found a food source that have food content higher than the specified minimum standard (fitness parameter – measured by the content of sugar) deposit the nectar, go to the dance floor and so do what is known as waggle dance (Seeley, 1996; cited in Pham, Pham, Ghanbarzadeh, & Castellani, 2008). This dance consists of three important pieces of information – the direction at which the food source lie, the food's distance from the hive, and the quality or fitness of the food source (Camazine*et al*., 2003; Von Frisch, 1976; cited in Pham *et al*., 2006). Based on the information exhibited in the dance, the colony decides upon the number of follower bees to be sent with the scout bee to collect the nectar. The more the food content in a food patch, the greater is the number of follower bees sent to collect food. Once the bees return, the waggle dance takes place once again to evaluate the food content of the patches visited. It is to be noted that as more follower bees visit a particular patch, the food content of the patch decreases. If the decrease is below the fitness parameter – the patch is abandoned, and more scout bees are sent to random newer locations for searching newer food sources. Again through the process of waggle dance, newer areas to be foraged and the process continues. The process ends when the whole area is exhausted, i.e., food content in all patches fall below the fitness parameter.

Drawing insight from the Bee algorithm to frame a model of management decision-making

In reflecting upon decision theories from a philosophical perspective, Over (2004) tells that while the normative theories of cognition show how we should ideally think and make decisions; the descriptive theories of psychology tell us how we actually think and make decisions. The difference between these two are caused by epistemic rationality ("rational belief and rational inference" – based on theoretical considerations) and rationality of actions (based on practical individual goals). Also based upon the principles of unbounded rationality – the normative theories are inadequate for practical considerations because there exists imperfect information in the real world and the cognitive and computational capacities of human beings and computers are limited. On the other hand our beliefs and judgments, upon which the descriptive theories are based – often may be poor and hence the best decisions are not taken. In order to avoid the above mentioned impasse, Baron (2000) suggests a prescriptive rule approach to decision-making. The advantage of the approach lies in the fact that it utilizes heuristics – that are bounded, satisficing, applied relatively fast without wastage of much time and energy, and their usage lead us closer to the normative theory.

In a detailed analysis of the decision-making models from the management perspective, Nutt (2011) tells us they suffer from the problem of either being descriptive or prescriptive, i.e., while some study decision-making from the context of the organizational factors, external and internal environmental factors, personal attributes of the decision maker, etc; others study the procedures of decision making – how good/efficient the procedures are.

Below we present a single objective management decision-making model (Fig. 4), that draws certain insights from the bee algorithm. The novelty of the research lies in creating a model that shows the properties of Complexity. Also we show how (1) the use of heuristics helps us in getting closer to the normative decision-making model, and (2) it can simultaneously incorporate the descriptive and the prescriptive components of decision-making.

Based upon real world analogy with business organizations, we make certain additions in the model that are absent in the bee algorithm. First, since the departments of a business organization are constrained by an overall limited financial budget of the company, so one's prosperity would mean the poverty of the other. In this sense all the departments of an organization are dependent to one another. This is not seen in the bee algorithm, where the food sources are independent. Second, we assume that in successive search iterations, a business organization can adjust its fitness parameters, depending upon the overall internal and/or external conditions. Thus in a particular year of robust economy, a company would target at more profit, and hence would have a higher value of the fitness parameter. Conversely in a year of financial slump, the company would downgrade its profit expectations, and hence a lower value of the fitness parameter. To our knowledge, the literature on bee algorithm is silent of this issue.

The setting of the model is as such: a business organization is faced with a long term decision making problem, for example: how to increase its profit to (say) 25% in the end of five years from now. It starts its journey at the beginning of the first year by deciding upon increasing its profit in the ongoing year by 5%.

The concepts used in the model are as follows. Short term profit value (a number) is indicated by PV. PV is similar to the fitness parameter of the bee algorithm. Similar to the fitness parameter that gives an idea of the minimum amount of sugar that food should contain; PV gives an idea of the minimum profit to be generated by the company. After the PV has been determined, a subsequent search in the individual departments for generating the profit leads us to the possible business strategies. For each of these departments, the possible business strategies are denoted by Potential Solutions (PSs). Comparisons between the PSs and PV then lead us to the actual departments to be exploited (to generate profit). The profit generating strategies of these actual departments are indicated by Actual Solutions (ASs). Finally the actual profit generated from following a specific strategy, and the cost incurred in following the strategy are denoted by PRO and C, respectively. For a detailed sequence of the steps through which the decisions are taken in a particular year, refer to the flowchart. Also the same iteration process continues for the next four years.

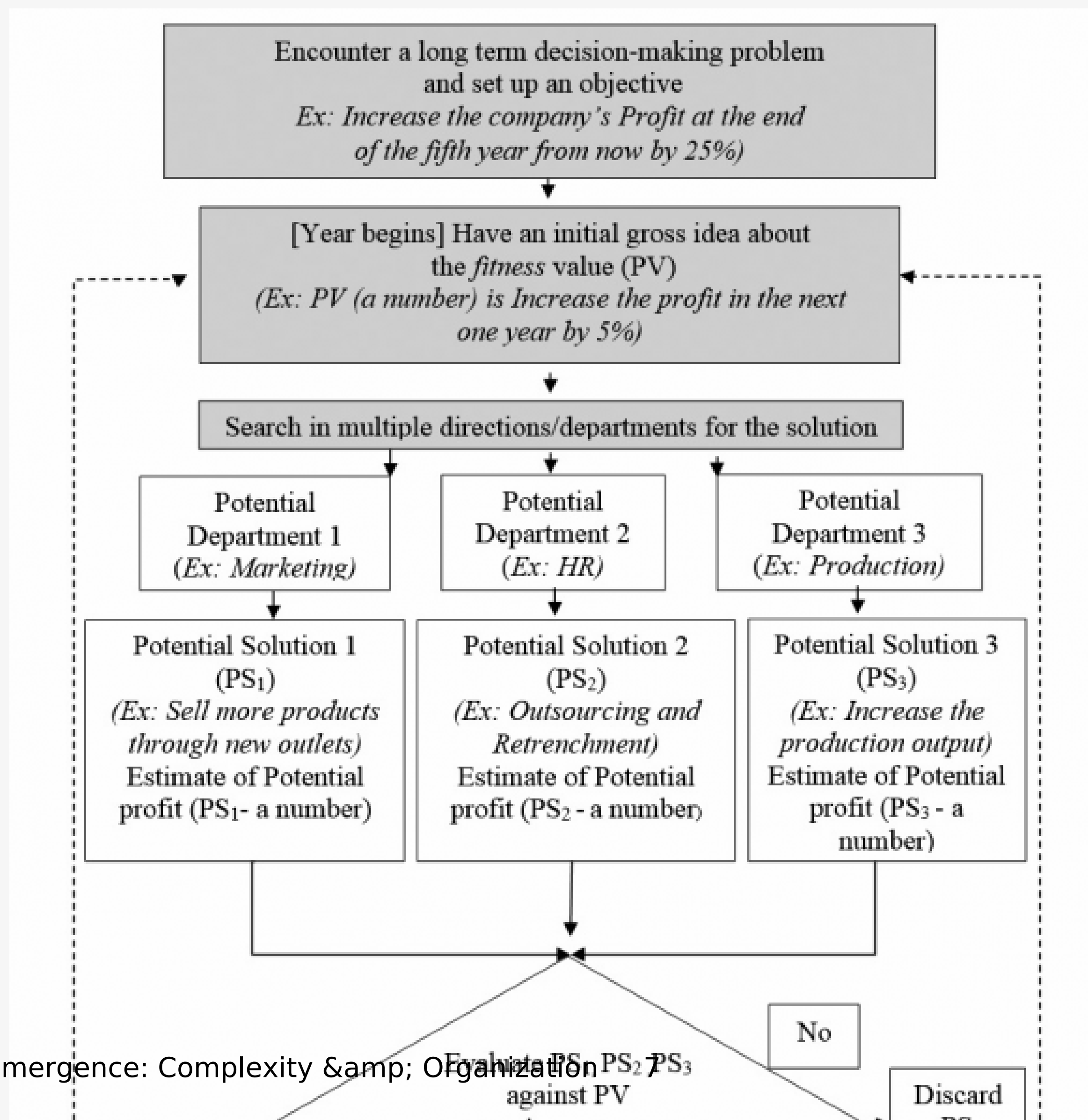

Fig. 4: A single objective management decision-making model, based upon the Bee Algorithm

The flowchart is inspired by the bee algorithm. During the waggle dance, the bees evaluate the sugar content of the food patches (that have previously been searched by the scout bees) and select the ones that are above the fitness parameter. In the same way, here departments are selected that have PS value above the PV. In addition, similarity exists between the allocation of the follower bees and the ASs. In the same way as more follower bees are allocated to the patch with greater food, more resources are allocated to the department with greater value of AS. Lastly, in the bee algorithm as the fitness value decreases, newer areas are found – effectively meaning the start of a new iteration. In the same way, in our flowchart, as the value of [PRO/C] decrease below PV, a new iteration loop starts.

An analysis of the above model of decision-making shows that it has the following major properties of a complex system:

1. Inter-dependence of agents and non-linearity – The network of agents of a complex system are always ready to act proactively and re-actively with the other agents in its vicinity by simple localized rules. In the flowchart above, the region marked 1 shows the interdependence of agents (in our case the departments of the organization). It is to be noted that the overall financial resources of an organization is limited. So a policy of hiring new marketing personnel (that involves the cost to the organization due to recruitment, training, remuneration etc) might hinder the process of retrenching older workers from other departments (that involves a cost to the company due to their severance package). Thus one cost may have an effect on the other. This shows the interdependence of the departments (agents) in the decision-making process. Also the distribution of cost to the various departments may not often be based upon purely mathematical considerations of what may be good for the company. As an enterprise consisting of human beings, we might expect vested interests of various groups coming into play in distribution of financial resources. Since these interactions between the individuals of various departments are rich and dynamic, it is not possible to predict with absolute certainty how the final sharing of resources might look like – unless the various departments actually interact and share the resources (Cilliers, 2000). Also instances of small bickering among the competing departments might have big intra organization turmoil or vice-versa. All these shows that the system is non-linear.
2. Highly decentralized distributed control – System behavior is not governed by any single centralized control mechanism, but is rather determined by the collective cooperative and competitive activities of the agents. Senge terms this as property localness (Senge, 1990). From the above flowchart it can be noted that no figurative head/top management decides which department would contribute/not contribute to increase the profit margin of the company. Multiple iterations and random searches for the potential departments that might have the potential to contribute, and the successive decisions (marked by 2 in the flowchart) shows the property localness of the system.
3. Feedback loops – As the agents interact with one another – the resultant changes in the particular part of the system get transmitted via its boundaries to the other parts of the system. Based upon the nature of the changes, the recipient agents may respond in a particular manner. These secondary changes or reactions of the second group of agents get transmitted to the first group of agents causing it to change. Cilliers tells us that these feedbacks may be either “positive (enhancing, stimulating) or negative (detracting, inhibiting)” (Cilliers, 2002: 4), and both are necessary. Feedback loops are marked as 3 in the flowchart. It is evident from the flowcharts that at the end of a particular iteration, the feedback send regarding the value of secondary change: PRO/C against PV (from flowchart) would help in re-configuring the choice of the departments (the primary change). In choice of the departments would again influence the value of PRO/C, and the iteration process continues. Also it is to be noted that the feedback information pertaining to a particular department might give the indication to the organization regarding adjustments to be made to the fitness value in the subsequent period, when other departments will be considered. For

example certain departments might have more potential in contributing to the company's profit than the others. Now if we consider one such department at the end of a particular iteration process, the feedback it might send would mean that in the next iteration – the organization might have to reduce the fitness value or profit expectation because it will not have this high profit generating department in its choice space. Such a feedback is negative that inhibits the activity of a system. Conversely, a department with low profit generating potential might send a signal that interprets as – the organization will have higher profit generating departments in its choice space in the subsequent iterations. This means a positive feedback that accentuates the activity of the organization.

4. Change and Adaptability– In anticipating the future, the agents of a complex system are always interacting with one another in its immediate vicinity. Richardson terms this autonomy of interaction of the agents as their local memory (Richardson, 2008). As the agents with local memory constantly learn from their newer experiences, re-organize themselves in accordance with the changing environment; the complex system changes constantly, and gets adaptable to new, unexpected conditions (Zimmerman, Lindberg, & Plsek, 1998). In our case, although uncertainty affects each step of the flowchart, specific instances of its effects are marked by the shared regions. In the long-term setting objective which further gives rise to the long-term decision problem, the uncertainties are due to governmental policies, competitive environment in the industry, predicted changes in technology and customer preferences, etc. In the next step, i.e., the short-term objective setting phase, the uncertainties can arise from such phenomenon as rivalry from competitors, the current debt structure of the firm, etc. In the next step, organizational uncertainties might play a major role and affect the choice space (of the departments). And lastly, in the allocation of resources, uncertainty can arise due to the internal political conflicts of the departments involved; regarding allocation of resources to cover the involved costs (refer to the diagram to see the costs). Under such uncertainties, the system constantly changes and adapts itself by taking the decisions, as noted by the decision boxes. The above discussion shows that the decision-making model contains the major characteristics of a complex system. In the following paragraphs we show why it is an improvement over the existing models of management decision-making.

The above flowchart is an example of the operation of the dual process theories of the mind. In referring to the works of (Fodor, 1983; Evans & Over, 1996; Sloman, 1996; Stanovich, 1999; Stanovich & West, 2000; Kahneman & Frederick, 2002); (Oven, 2004) tells us that human mind take decisions through two mental processes – System 1: running of content specific heuristics in domain specific modules; and System 2: conscious, explicit rules are followed that are based upon the normative theories of decision-making. In our present flowchart, the shaded regions are points that follow System 2. As discussed above, activities such as setting of long and short term objectives is based upon multiple external and internal organizational factors. At this points, the decisions are explicit based upon certain formal rules pertaining to maximization of organizational utility function (in our case: maximizing of company profit) – thus hinting at normative decision-making. However, the rest of the steps of the flowchart (specifically the decision boxes) are based upon System 1, which follows simple and evident heuristics. Thus we see that the flowchart is a simultaneous combination of the normative and prescriptive theories of decision-making. In addition, if we consider the problem of cost allocation – as it often happens in organizations – distribution of cost might be based upon a lot of factors (such as political dynamics within the organization) that are hard to quantify and based upon imperfect information– thus hinting at unbounded rationality. Solution of such cost allocation problems through the unfolding of the complexity drama (wait and watch) – help us in visualizing application of the descriptive theories of decision-making in our model.

The random search for the departments hints at its gathering information in an uncertain environment. This addresses the descriptive component of decision-making. The successive iterations provide a method for the organization to optimize its allocation of resources. The prescriptive component of decision-making is addressed by the steps of the flowchart/procedure. The procedure (of decision-making) is efficient and effective, because based upon some initial value of the fitness parameter, and multiple decision points – provide a method for an area to be exploited or discarded. Since at a single step of the decision-making procedure, the judgment of continuation or rejection of the search is obtained, the procedure is both efficient and effective. Thus as the descriptive and the prescriptive components of decision-making are handled simultaneously in a single model, we argue that it is an up gradation over the existing models. Also the novelty of the work lies in incorporating complexity into the study. A fair understanding of the impact of various elements of uncertainty on management decision-making, and their interaction with the departments can provide us with a better understanding of complexity in decision-making.

Emergence in the present model

At this point, the question that might arise: what happens after multiple iterations of the above process. In other words, what can the organization implementing the process expect to emerge and how can it benefit from such Emergence at the end of five years. Considering an example of three departments to start of the iteration (as shown in the flowchart) towards the beginning of the year, at the end of the year we can expect two departments to be better effective and efficient towards contributing to company profit, i.e., intra competition between departments help the organization identify some departments that are better than the rest in a particular year (let us call them as the “smartest departments”). In the beginning of the next year, the search space (of the collection of departments) is again reshuffled. The competition among the departments during the year might generate a new choice of the smartest departments at the end of the year. Thus at the end of five years, intra competition between the departments will ultimately help in becoming each of them better in efficiency and effectiveness. Thus overall the organization would become more efficient and effective and this would help it in combating competition from rival organizations.

However it is to be noted that we will not be able to quantify the magnitude of such Emergence in this complex system. In other words we cannot say in exact value terms how much advantage the organization gets from the algorithm. This is because following Cilliers’s logic, in a complex system whose boundaries are open, we cannot completely comprehend and hence incorporate all the elements that affect the system (Cilliers, 2000). Also the non-linearity of the characteristics of the system does not allow us to accurately determine the effect of one agent upon another. This seems particularly true in our case because we are unable to determine the effect of organizational politics, vested interests etc. in sharing of financial resources.

Conclusion and limitations of the model

Firstly, the bees are a group and cannot be conceived as if they were individuals. That is a major advantage as a starting point for a model of decision-making. The rationality debate that lies at the base of much of decision theory starts with individuals and wants to upscale from there. The complexity perspective starts from interaction in unpredictable ways between many different entities defined in their interaction and the feed-back loops that constitute the processes that make up the whole. This means that the description of what happens and the prescription of how decision-making can be better in organizations does not have to separately explain the impact of group dynamics as a secondary issue to the move from rational (normative) to limited rational (descriptive) to remedy (prescriptive) on an individual level and then on a group level but conceives the entire matter in group terms from the start. The second benefit is that complexity forces us to start from the premise that there is a lot happening at the same time, quite a bit of which is really fundamental to the decision-making. The conclusion of (Langley *et al.*, 1995) paper is that decision-making has to be conceived of as a flow. Complexity starts with that as an assumption and the bees help us understand how the many things that are happening include the shifting of parameters in terms of fitness and goals. These are framework advantages that are present in the developed decision-model, based upon the bee algorithm.

The biggest limitation envisaged is that the model does not incorporate the option of multiple objectives. Also the model implicitly assumes that the all the departments would constantly strive for excellence. However as real life situations often show, collusion instead of competition among the departments might break down the functioning of the model.

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