# Semantic De-biased Associations (SDA) Model to Improve Ill-Structured Decision Support

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**Abstract.** Decision makers are subject to rely upon their *biased* mental models to solve ill-structured decision problems. While mental models prove to be very helpful in understanding and solving ill-structured problems, the inherent biases often lead to poor decision making. This study deals with the issue of *biases* by proposing *Semantic De-biased Associations (SDA) model*. SDA model assists user to make more informed decisions by providing *de-biased*, and *validated* domain knowledge. It employs techniques to mitigate *biases* from mental models; and incorporates *semantics* to automate the integration of mental models. The effectiveness of SDA model in solving ill-structured decision problems is illustrated in this paper through a case study.

**Keywords:** Cognitive DSS, cognitive biases, ill-structured decision support, semantic mental model representation.

## 1 Introduction

Current decision support systems (DSS) lack adequate support for ill-structured problems due to the fact that the solutions to such problems mainly rely upon the cognitive abilities of the decision maker, rather than standard procedures [1, 2]. To support ill-structured decision making, it is essential for a DSS to support the decision maker's cognition [3] . Cognitive decision support systems (CDSS) have been proposed for such problems, using mental models (also called cognitive maps) [4, 5]. Mental models are assumptions and beliefs, generated through experience [6]. During the mental model generation, cognitive biases - which are inclinations towards or against certain ideas/entities - are also introduced based on the circumstances surrounding an experience [7]. While mental models are a fundamental tool for solving ill-structured problems [8], the inherent biases become a barrier to attaining an optimal solution [9–11].

This study proposes semantic de-biased association (SDA) model, which incorporates de-biasing techniques and semantics to improve ill-structured decision support. This paper is organized as follows. Section 2 presents a literature review on *biases in DSS*. In Section 3, the proposed SDA model is described in detail. Section 4 contains the case study to analyse the effectiveness of SDA, followed by conclusions and future directions.

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## 2 Literature Review

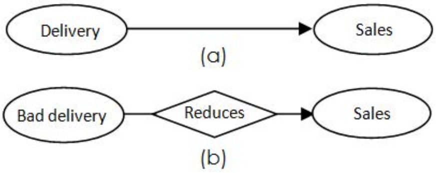


**Fig. 1.** (a)Conventional representation; (b) SDA representation

Early CDSS systems such SPRINT [12] and "Cognitive Lens Support System" [13], offered limited support to decision makers' cognition. Later, Chen and Lee [4] designed a CDSS, which they claimed reduces availability, anchoring, overconfidence and blind-spot biases. The claim was not validated by them. The shortcomings of their approach were: a) no mechanism to de-bias or validate knowledge input; b) different users' cognitive maps remain un-integrated, thus biased; c) increasing size of cognitive maps may become an issue. Li Niu et al. [5] proposed FACETS to support a manager's *situation awareness (SA)*. The key shortcoming of FACETS was slow process to access relevant knowledge, since the output is in the form of lengthy reports and tables. FACETS does not deal with cognitive biases in decision making.

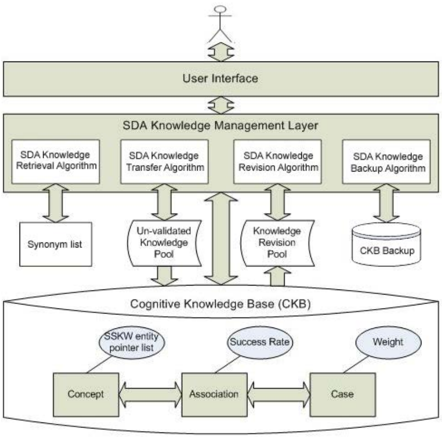


**Fig. 2.** The architecture of SDA Model

The issue of *biases* in mental models hinders optimal decision making. It arises from factors such as inadequate number of decision alternatives (availability bias) [14], lack of contextual information (contextual bias) [15, 16], and misleading problem presentation (framing) [17]. Human mind is inclined to solve problems in terms of recent experiences, which constitutes availability bias [18]. Contextual bias results from environmental factors surrounding an experience [16]. The mind tends to store the mental models of an *experience*, while forgets surrounding contextual information that caused positive/negative assumptions [19]. When such mental models are used later for same type of problem, with different contextual information, they lead to poor decision making [16]. Framing refers to the inclinations created by the way a decision situation is presented [17]. Another bias, which organisations suffer from, is group bias. It refers to the collective biases of a team or group with similar backgrounds, jobs, experiences, and goals [20, 21].

## 3 Semantic De-biased Associations (SDA) Model

We propose SDA model, which offers improved representation of *mental models* by incorporating *semantics* (Fig.1). The semantic representation functions as the basis to employ de-biasing techniques. The architecture of SDA model is described as follows.

### 3.1 SDA Architecture

The main components of SDA model are *cognitive knowledge base (CKB), SDA knowledge management (KM) layer* and *user interface* (Fig.2). *CKB* is the core component of SDA model, and is managed by the *KM layer*. It stores *Concepts, Associations, Cases, Success rate* and *Weights*. They are fomally defined as follows. The knowledge in CKB is a collection of mental models about several *problem domains*. A *problem domain (PD)* in SDA model can be defined as:

$$PD = \{A_1, A_2, \ldots, A_n\} \tag{1}$$

where, A is an *association* defined by an ordered set, i.e:

$$A = \{p_a, r, p_b\} \tag{2}$$

Here, $p_a$ is pre-concept; $r$ is semantically-defined causal relationship; and $p_b$ is post-concept. $p_a$ and $p_b$ belong to the set of all concepts in the *problem domain*, denoted as P, i.e:

$$P = \{p_1, p_2, \ldots, p_n\} \tag{3}$$

Whereas, r belongs to the set of relationship labels (verbs), denoted as R; i.e:

$$R = \{r_1, r_2, \ldots, r_n\} \tag{4}$$

An *association* may have none or many *cases* attached to it. *Cases* are the past decision situations appended to an *association*, which assist in understanding the role of the *association* in solving those *cases*. The set of cases is defined as $C = \{c_1, c_2, \ldots, c_n\}$. An association Ai has a *success rate* $S_i$, which is the average of all $s_{ij}$ assigned to cases $c_j$ for the association $A_i$; i.e:

$$\langle S_i \rangle = \sum_{j=0}^{n} s_{ij} \tag{5}$$

where, $s_{ij}$ is the *success factor* of association $A_i$ for case $c_j$ (Fig.3).

Conversely, there may be more than one association (decision alternatives) involved in solving a case. To measure the contribution of each association, a *weight* is assigned to each one of them with respect to the case (Fig.4). A *weight* can be defined as:

$$w_{ij} : (A_i, c_j) \tag{6}$$

where A is association i; and c is case j. The sum of all $w_{ij}$ for a *case* is:

$$W_j = \sum_{i=1}^{n} w_{ij} \tag{7}$$

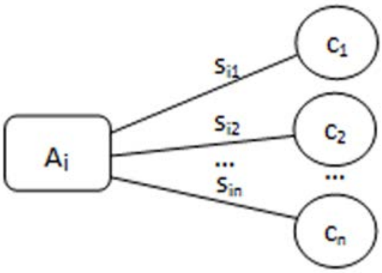


**Fig. 3.** Success rate of an association regarding the cases attached

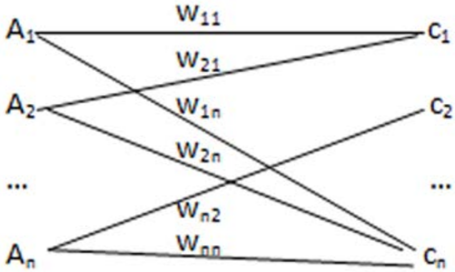


**Fig. 4.** Weight distribution among associations for a case

Where, $W_j$ indicates the sum of *weights* of all contributing associations, (i = 1 to n), in solving $c_j$. The sum is always equal to 1.

The *KM layer* facilitates the *retrieval, transfer, validation, revision*, and *backup* of mental models stored in CKB. A user can query in natural language. Then *SDA knowledge retrieval algorithm* fetches knowledge from CKB accordingly, and outputs in graphical format. The *SDA knowledge transfer algorithm* lets user to input experiences, which go to the *un-validated knowledge pool*, and forwarded to CKB once verified. The *SDA knowledge revision algorithm* updates/deletes out-dated knowledge. *SDA knowledge backup algorithm* copies the de-biased knowledge from CKB to the CKB backup.

### 3.2 Bias Mitigation in SDA

SDA model addresses availability, contextual, framing and group biases. Following is an account of the way these biases are mitigated in SDA model.

Availability bias can be reduced by providing users with a wide range of *decision alternatives*, to assist them in drawing maximum relevant knowledge from *long-term memory* to *working memory* [14]. SDA model allows multiple users to input their mental models. SDA automatically integrates these mental models, and provides them to the users at decision making time to assist them in exploring maximum decision alternatives.

To reduce *contextual bias*, it is essential to preserve the *contextual information* surrounding an experience [15]. SDA model achieves this by storing *contextual information* behind every *decision alternative* in the form of *cases* as references to past decision situations. *Framing bias* can be avoided by drawing or studying causal maps of a solution to a decision problem [22]; or by having access to extensive contextual information about the current decision situation [16]. SDA model handles framing in two ways: a) it represents the *decision alternatives* graphically, b) it fetches relevant information about current decision situation from the backend according to the produced *decision alternatives.* The *Group biases* can be removed by letting users from different backgrounds review each other experiences (recommendations) [21].For this reason, the users of SDA-based system are selected from three different backgrounds, having dissimilar skills and experiences. They are *domain experts, managers* and *employees.* Users are a vital part of *knowledge validation process*, as bias in a user's mental model is neutralized during this process, by users from other groups.

### 3.3 Semantics in SDA

In order to incorporate de-biasing techniques, it was essential to first integrate the mental models of various users. For this purpose, we have chosen to apply *semantics* in SDA. The advantages of employing *Semantics* are three-fold; a) it automates the integration of mental models from various users in a meaningful way; b) it facilitates the access to relevant knowledge faster and reliable; c) it offers an improvement on conventional mental model representation (Fig.1).

### 3.4 SDA Knowledge Cycle

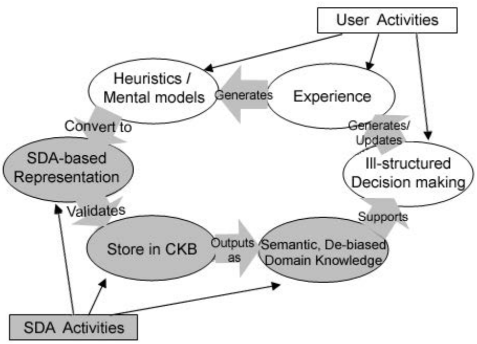


**Fig. 5.** Knowledge Cycle created by SDA Model

SDA model creates a knowledge cycle between the user and the system. A user holds mental models in their mind, generated from experience. SDA model allows the user to input these mental models according to the specified format, which facilitates the mitigation of inherent biases. These mental models are then validated and stored in CKB. At decision making time, user is provided with de-biased mental models in graphical format. The user, while employing this knowledge to resolve the current decision situation, might learn or synthesize new knowledge, or discover a new pattern. This will augment their knowledge, consequently generating new mental models. At this point, the user may decide to add this recently acquired knowledge to the system, thus continuing the SDA knowledge cycle (Fig.5).

## 4 Case Study

For the case study, we use a decision problem based on Adventure Works, a fictitious business organisation. The decision situation is: *"Why the sales of bike (BK-M82S-38) have dropped over the past 2 weeks?"*

Adventure Works (AW) has been dominating the market for a long time, however, recently the sales of their newly released bike model (BK-M82S-38) have dropped over 40%. Using SDA-based CDSS, how can the CEO resolve the situation?

Below is the process of getting to the core of the problem and solving it with SDA. As the first step, the CEO inputs the query: *"Why have the sales* *of our product BK-M82S-38 been dropping for the past two weeks?"* The system parses the main contents according to its vocabulary; that is *sales*, along with the verb *dropping*, and any business object labels, in this case *BK-M82S-38*. The associations containing *sales* are fetched, and stored as an intermediate result. Next, synonyms for the verb *dropping* are retrieved, and all the records with occurrence of any of the synonyms are obtained from the intermediate result. Since no other concepts are stated in the query, the system outputs the mental models about *dropping sales*, in graphical format (Fig.6). The object name *BK-M82S-38* is used to fetch its current status from the back-end, which is mapped to the associations in the graph produced. Clicking on an *association* opens a window containing two reports: one about the *association* and *cases* attached, the other containing the current status regarding the *concepts* in the *association*. For example, clicking on the *bad delivery reduces sales* opens a window containing information such as *problem domain, success rate* and *cases*; as well as current delivery status of *BK-M82S-38* obtained from the back-end (Fig.7).

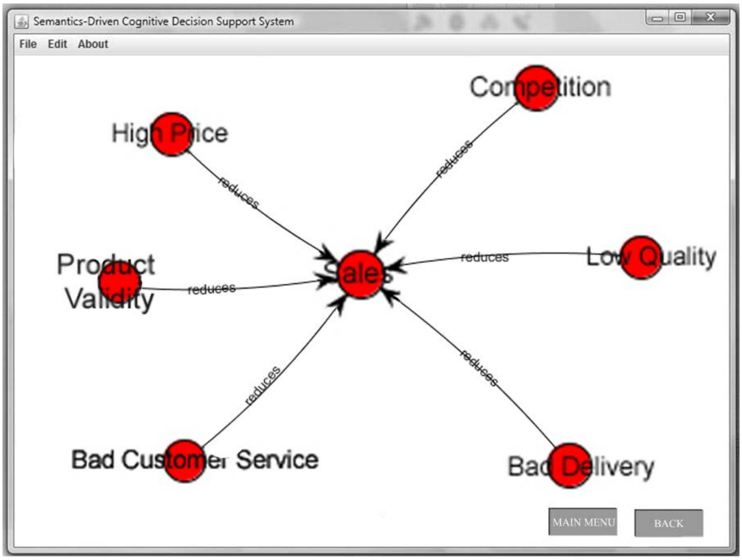


**Fig. 6.** Result of the decision query in the *case study*

The concise and relevant output regarding the decision alternatives in the graph helps the user to clearly see the situation from a less-biased perspective. The user can then compare past *cases* with the current decision situation and, with the help of the vast array of *decision alternatives* and *contextual information* available, make a better-informed decision. In this case study, the user discovers a problem in delivery, which has become slower in the past few weeks. Looking at the status of appointed delivery companies, the CEO decides to end the company contract with *Globex Postal* and *Round World*, as their average delivery times are much longer, which is costing AW its business.

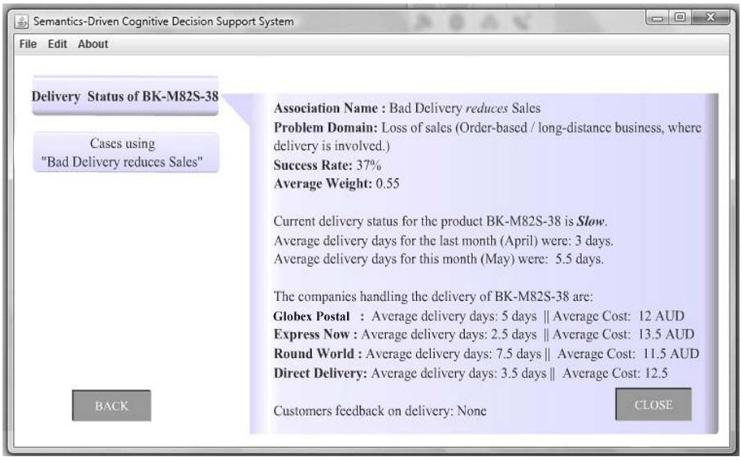


**Fig. 7.** The *de-biased* and *relevant* business knowledge about the delivery status of *BK-M82S-38*

## 5 Analysis of SDA Model

As can be seen from the case study above, the SDA model provides a human-centric design which allows seamless knowledge transfer between the user and the system. It enables the user to query in natural language, and presents the results graphical format. The graphical output helps the user to swiftly perceive the current business situation, in contrast to the lengthy, text-based outputs of previous CDSSs. Semantics makes it possible to extract only relevant and precise knowledge from the system. The most important contribution of the SDA model is the mitigation of bias from mental models. These de-biased mental models assist the user to make better-informed decisions.

There are nevertheless two limitations of the SDA model: a) the degree of de-biasing depends on the number of experts available, and b) a mechanism is needed to measure the weight of an association with respect to a case, rather than allowing a user to allocate it, since a user's perspective may introduce bias.

## 6 Conclusions and Future Work

SDA model mitigates biases, *availability, framing, contextual* and *group biases*, in a decision maker's cognition and improve decision support for ill-structured problems. Semantics in SDA model automate the integration of mental models and make the access to relevant knowledge faster and reliable. Case study shows that SDA model helps user to reach a better informed decision, faster.

Our future work involves devising a mechanism to measure the weight of an *association* with respect to a *case*; as well as developing a *CDSS* based on SDA model and conduct a survey research to assess the significance of SDA model in decision support.

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