Decision Support Systems 79 (2015) 24–32

Contents lists available at ScienceDirect

Decision Support Systems

journal homepage: www.elsevier.com/locate/dss

A Bayesian approach for incorporating expert opinions into decision support systems: A case study of online consumer-satisfaction detection

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ARTICLE INFO

Article history:
Received 29 December 2014
Received in revised form 18 June 2015
Accepted 17 July 2015
Available online 26 July 2015

Keywords:
Knowledge fusion
Expert system
Domain knowledge
Classification
Bayes
Text mining

ABSTRACT

Interest in the use of (big) company data and data-mining models to guide decisions exploded in recent years. In many domains there are human experts whose knowledge is essential in building, interpreting and applying these models. However, the impact of integrating expert opinions into the decision-making process has not been sufficiently investigated. This research gap deserves attention because the triangulation of information sources is critical for the success of analytical projects. This paper contributes to the decision-making literature by (a) detailing the natural advantages of the Bayesian framework for fusing multiple information sources into one decision support system (DSS), (b) confirming the necessity for adjusted methods in this data-explosion era, and (c) opening the path to future applications of Bayesian DSSs in other organizational research contexts. In concrete, we propose a Bayesian decision support framework that formally fuses subjective human expert opinions with more objective organizational information. We empirically test the proposed Bayesian fusion approach in the context of a customer-satisfaction prediction study and show how it improves the prediction performance of the human experts and a data-mining model ignoring expert information.

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1. Introduction

Organizational decision making often relies on a collection of *intangible* capabilities, which are invisible, subjective human-driven phenomena that include organizational routines and employee learning, and *tangible* capabilities in the form of procedural knowledge systems [1]. With the advent of (statistical) data-mining tools and computing power, the tangible capabilities for organizational decision making have become more important. In recent years this process has accelerated as a result of the exponential growth of electronically stored information, which is available to companies, organizations, and individuals. The literature on decision support systems highlights several application domains that have been significantly affected by this trend, including credit risk [2,3], bankruptcy prediction [4], customer relationship management [5,6], and fraud detection [7].

Typically, procedural knowledge systems take the form of statistical techniques that are incorporated into a data-mining system (DMS). In line with [8], we define a DMS as the "complete" system — the database or data warehouse, software for mining and analysis, the knowledge derived from these, and the part of the system that supports managerial decision making in a business setting. Traditional DMSs take information about resolved problems and their solutions as input. They then extract rules from that data and use those rules to predict likely outcomes of other cases.

By uncovering patterns or knowledge in the data itself, a DMS obviates the need to elicit knowledge from human experts [9]. To some extent, this is desirable, as expert knowledge might not be available or easily formalized in some industries. In addition, expert knowledge tends to be less objective in nature, and human experts cannot always be relied on to give accurate assessments given their limited reasoning capacities [10]. In contrast, DMSs are labor-saving, intelligent, cognition-based systems that offer the consistency and efficiency that a human expert may lack [11].

However, in many domains, human experts who have developed their expertise over an extended period of time possess important intangible information. Throughout this paper, we refer to such information as an expert system (ES). Despite the existence of well-performing DMSs, human expertise remains dominant in the decision making process [8]. Traditional DMSs do not leave much room for the intangible capabilities of the organization, as they have not been developed to account for non-data based or subjective information. At present, ESs and DMSs basically remain separate types of information and decision systems. Nevertheless, while findings regarding whether ESs make more accurate and efficient judgments than DMSs are inconclusive [12], one might wonder whether a combination of the two types of systems would result in better overall judgments than a reliance on one or the other.

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http://dx.doi.org/10.1016/j.dss.2015.07.006
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This paper makes three key contributions to the decision-making literature. First, we provide insight into the natural advantages of the Bayesian philosophy for fusing multiple information sources into one decision support system (DSS). Second, we confirm the necessity of the continuing search for new or revised methods in this multi-angle information era. Third, we open the path to future applications of Bayesian DSSs in other organizational research contexts. To accomplish the above, we introduce a Bayesian framework that is ideally suited for fusing ESs with DMSs, and we show its beneficial impact on improved decision support. We refer to this fusion of information sources as *fused decision support system* (FDSS). Our approach is based on a blend of recent modeling developments introduced by researchers in the medical [13] and engineering sciences [14]. We empirically benchmark our Bayesian FDSS against an ES and a DMS, both of which use single-source information, in an online setting aimed at detecting consumer satisfaction. This case-study context serves as an ideal test bed because many organizations increasingly focus on online consumer reviews, using web-scraping techniques and advanced big-data analytics to estimate customer satisfaction with the company's product/service strategy. In this regard, organizations rely on internal or external human assessors, who make judgements regarding consumers' satisfaction. The question is whether this expensive expert-labeling strategy (ES) is effective relative to the more efficient DMSs, which automatically detect the satisfaction level by text mining the content of the consumer reviews, or whether it is crucial for decision makers to fuse all available information sources into a Bayesian FDSS.

The remainder of this paper is structured as follows. First, we revisit ESs and DMSs in organizational decision making, and we discuss how their relative importance has shifted over time. Second, we also describe the quantification of expert opinions and their incorporation into an FDSS. Third, we benchmark the predictive performance of the ES, the DMS, and our novel Bayesian FDSS approach in a real-life case study of customer-satisfaction modeling using online product reviews. Finally, we discuss the implications of using an FDSS for combining human experts' opinions with statistical predictions, before we present our conclusions.

2. Human expert systems, data-mining systems and information fusion: an overview

An expert — the sub-unit of an ES — is someone who has knowledge, and who is capable of efficiently and effectively communicating and using that knowledge during a decision-making process [15]. In the past, human experts often played a monocratic role in managerial decision making. The status of expert is granted on the basis of the individual's professional characteristics and track record, and intuition has been shown to play a critical role in expert decision making [16].

However, experts are not completely free of biases in their judgments of a situation. Potential differences in cognitive styles in terms of what experts think and how they think may lead them to incorrect or biased conclusions [17,18].

Organizational decision-making processes have undergone a tremendous shift in the last twenty years. DMSs which merely interpret data and make automated decisions regarding the best solution to a problem are becoming very popular. The popularity of DMSs is attributable, in part, to the objectivity and, in part, to the explosion of internal company data collected through recent developments in information technology. The limited information-processing capabilities of human experts means that machines are necessary for coping with the exponential growth in data availability. This massive collection of data, which is often referred to as "big data" [19] offers tremendous opportunities for information systems (IS) researchers and managers, who can incorporate new technologies into DMSs [20]. For instance, in their bibliometric study, Chen et al. [21] report a steep increase in academic publications related to DMSs using big data and business analytics. *Decision Support Systems* ranks as leading IS journal for this type of publication. Moreover, the *IBM Tech Trends Report* [22] identifies business analytics, which is an inherent part of DMSs, as one of the major technology trends of this decade based on a survey of more than 1200 decision makers from 16 different industries and 13 countries spanning both mature and growth markets.

McAfee and Brynjolfsson [23] estimate that 2.5 billion gigabytes of company data are created every month, and that this number will double every 40 months. The need to effectively and efficiently manage the inflow of company data and the necessity of converting the underlying data patterns into relevant company insights have led to the ever-growing popularity of DMSs. However, despite the initial intention to use DMSs to replicate and replace the decisions of ESs [24], DMSs have limited decision-making abilities because they are best suited for solving problems that have clear boundaries. Moreover, they have limited reasoning capacity [25].

A number of studies look into information fusion for decision support. They find that the inclusion of expert knowledge in DMSs adds value along two dimensions [26,27]. First, the opinion of the expert is valuable in the independent variable definition phase and when deciding which variables should go into the DMS. In fact, prior studies investigate how domain knowledge helps to define additional, high-level independent variables that are usable by the DMS [28,29]. Weiss et al. [30] build a DMS using only expert knowledge as input data to predict promising sales leads. Sinha and Zhao [9] combine expert knowledge with a DMS in the context of credit ratings. To improve the predictive performance of the DMS, these authors ask domain experts to make educated guesses about the credit rating based on characteristics of the applicant and the loan. To test the effects of the inclusion of domain knowledge, the expert predictions are then used as additional inputs for the DMS. The authors find a substantial increase in model performance, which leads them to conclude that fusion of ES and DMS results in substantial monetary benefits for the company. While these studies clearly show the importance of the interplay between an ES and DMS, they limit the role of the domain experts to defining and shaping inputs used in the DMS.

Second, domain experts can contribute to making DMS output consistent with the extant domain knowledge [31]. Previous research primarily operationalizes this aspect by introducing monotonicity constraints on the link between the independent variable(s) and the dependent variable [31]. Therefore, the ES can interact with the DMS during pre-processing [32], classification model building [33] or post-processing [34]. For instance, Lima et al. [33] propose that when the sign of the parameter of an independent variable is the opposite of the sign the expert expects, it should not be incorporated into the analysis. Other authors describe rule-set extraction methods as a valuable approach to bringing domain knowledge into the DMS. See [35] for an overview and comparison of rule-extraction methods in the context of customer churn prediction.

Our Bayesian FDSS method proposes four improvements over the existing methods. First, our method does not only rely on expert opinions in the DSS (e.g., [30]). Moreover it overcomes the drawbacks of Sinha and Zhao [9]'s approach in which domain experts have to evaluate every unit of analysis. For instance, if the goal is to assign a credit score for 1000 potential lenders, the expert(s) have to manually evaluate each applicant. In many real-life contexts, this procedure is too time consuming and expensive given the large number of cases that have to be screened on a daily basis.

Second, previously used knowledge-fusion approaches impose monotonicity constraints to verify whether the link between the independent variables and the dependent variable is line with the domain expectations. This is a difficult, yet necessary, exercise [31]. More specifically, this means that these methods assume that: (i) the independent variables are interpretable, (ii) the model parameters/output that serve as the bridge between the independent variables and the dependent variable are intuitive enough for domain experts to evaluate,

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