A Multi-agent MDSS for Supporting New Product Design Decisions

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Abstract Market-driven product design decisions are receiving increasing attention in business practice, complemented by academic research on product design in a variety of disciplines. Mathematical and marketing research models are being integrated into decision-based design frameworks to represent customer behaviors and estimate the demand for design alternatives. The evolution of market structure eventually reshapes customer preference and competition, pushing the designers to rethink their design decision strategies. In this manner, it is necessary to develop decision support tools that would effectively provide support in new product design. In this paper, we argue that a combination of marketing decision support systems (MDSSs), multicriteria and multi-objective methodologies and agent technologies could be a very tool to support decision making in new product design applications. In this work, we propose a multi-agent architecture for a new product design MDSS and describe a system prototype for making new product design decisions.

Keywords Decision support systems and agent technology · New product design · Multi-objective evolutionary algorithms · Multicriteria decision analysis

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1 Introduction

With the globalization of the economy, most modern companies have found a new form of the global competition arena. Marketing managers are faced with a new changing and competitive market environment and are forced to make better decisions to become more competitive (Alexouda 2005). So, the way in which a company could adapt its marketing strategy will have a strong impact on the success or failure of the company's business (Ai et al. 2004).

The product design is one of the most important and expensive marketings' decisions. In the current competitive environment, the efficient development of new products is necessary for the survival of a company. The optimal product design problem is a vital element of the new product development problem and one of the most critical decisions for an enterprise (Alexouda 2005).

According to Matsatsinis et al. (2003), the design and development of new products is one of the most interesting and difficult decision-making cases in modern enterprises. Lei and Moon (2015) indicate that to maintain and improve the level of profitability in a competitive market an enterprise must redesign and reposition frequently its existing products or introduce new ones. At the same time, experts in this field have pointed out the importance of this for the viability of companies. Baril et al. (2012) said that the competitiveness of industries depends, among other things, on their ability to identify the customer's needs and to create products that meet these needs.

In recent years, new products developing is becoming in decentralized work. In this new environment, the task is distributed among different working groups, where the members are separated by discipline. With this, the industries are facing new challenges: (1) designing products in collaboration with distributed environment; (2) designing products that meet customer needs; and (3) reducing product development time and costs (Baril et al. 2012).

Ai et al. (2004) stated that building an MDSS is a valid way to increase the speed and effect of the decision, so as to improve the level of competitiveness of the company. An MDSS is defined as "a coordinated collection of data, models, analytic tools and computing power by which an organization gathers information from the environment and turns it into a basis for action" (Alexouda 2005).

This chapter proposes an MDSS to support new product design based on consumer preferences. The MDSS is developed using software agents, which are capable to respond to the requirements of the software related to the collection, choice, evaluation and utilization of information to support decision makers during the decision process (Matsatsinis and Siskos 2012). The models of MDSS are implemented through multi-objective evolutionary algorithms and are mainly based on the multicriteria ELECTRE III method.

It is believed that this combination will lead to the development of a tool that could effectively support this decision-making process according to the current nature of the new product design activities.

In the remainder of the chapter, it reviewed the existing related research work, the new product design methodology implemented by the software, the proposed multi-agent architecture and the developed prototype of the MDSS.

2 Product Design Decisions, MDSS and Software Agents

The product design process (PDP) in marketing environments "is a knowledge-intensive activity and unstructured decision-making process. In the whole process of product development, designers must make a decision according to a great amount of uncertain information" (Yu and Yan 2006). Modern information system technologies can support marketing managers to manage and take advantage of the large amounts of information currently available through different means.

According to Cassie (1997), MDSSs are "valuable tools to assist in making marketing decisions. MDSS can be used to support, rather than replace, decision makers in the complex, semi- or unstructured situations which are common in marketing problems. They incorporate the personal judgment and experience of the user to improve the effectiveness, rather than the efficiency of decision making."

As we can see in Ai et al. (2004, 1998); Matsatsinis et al. (2003); Banerjee et al. (2002); Liang and Huang (2002); Zha et al. (2003); Vahidov and Fazlollahi (2004); Yu et al. (2009); Morales and Ortega (2010); and Dostatni et al. (2015), many efforts have been made in recent years to develop MDSS to carry out PDP.

An analysis of marketing decision tasks and the characteristics of multi-agent system (MAS) carried out by Ai et al. (2004) showed that:

- Multi-agent technology "makes possible for the system to asynchronously increase or decrease the agent function without influencing other parts of the system" (2004), what is appropriate for an MDSS, which may require smartly increase or decrease according to the change of marketing circumstances.
- In a MAS, the "characteristics of distribution, mobility and self-adaptability help users to get the newest information relevant to the decision task from the network" and "each agent has its own knowledge base, making possible a distributed store of knowledge" (Ai et al. 2004). Both elements are appropriate for current marketing decision's requirements of information.

Based on the above, the nature of software agent technology makes them very suitable for marketing applications.

Some researchers are looking to automate product design-related activities using agent technologies (Ai et al. 2004, 1998; Matsatsinis et al. 2003; Banerjee et al. 2002; Liang and Huang 2002; Zha et al. 2003; Vahidov and Fazlollahi 2004; Yu et al. 2009; Morales and Ortega 2010; Dostatni et al. 2015). Matsatsinis et al. (2003, 1998) presented an MDSS that implements a new consumer-based methodology for product penetration strategy selection. Banerjee et al. (2002) proposed a method to address uncertain in the decisions involved in the new product and technology development and positioning with hybrid intelligent systems. It uses fuzzy inference systems

to model ambiguous conditions and ant colony optimization for searching optimal combined strategy to meet requirements. Liang and Huang (2002) described a collaborative multi-agent system and a procedure to develop modular products. Zha et al. (2003) described a hybrid decision model and a multiagent framework for collaborative decision support in the design process. Ai et al. (2004) designed a layered system architecture composed of decision customer layer, the decision core layer and decision resource layer to develop a distributed MDSS. Vahidov and Fazlollahi (2004) describe a multi-agent architecture for an e-commerce's MDSS a prototype system for making investment decisions. Yu et al. (2009) presented a multi-agent intelligent decision support system (IDSS) based on new product development. The system is composed of eight modules: data collection, data management, statistical analysis, breakeven analysis, risk prediction analysis, resource optimization scheduling, expert system and information exchange. Morales and Ortega (2010) proposed a distributed intelligent system to determine tendencies in customer's preferences from the application of surveys to clients. Dostatni et al. (2015) described the structure of a multi-agent decision support system (DSS) to support the decision-making process of the designers in eco-design.

While these developments in DSS to support new product design are very encouraging, they have the disadvantage that methods implemented in their models not taking into account the parameter of importance that is assigned by a customer to each criterion to evaluate a product, ignoring with it valuable information to model accurately consumer preferences.

3 Customer-Based Multicriteria Methodology for Product Design Decisions

A new product design multicriteria methodology (NPDMM) based on consumer preferences is implemented computationally by the MDSS proposed in this paper. Such methodology has as one of its main characteristics that it models consumer preferences using a more flexible approach than those used currently in the literature and takes into account the importance assigned by a customer to each criterion to evaluate a product. It also considers the preferences of the decision maker, since he is the one who decides what criteria can be approached in the design of the new product based on the actual enterprise condition, capacities and needs of the business. The methodology is based mainly on the multicriteria ELECTRE III method.

4 Relation Between Simon's Decision-Making Process and the NPDMM

The NPDMM is directly related to Simon's decision-making process (SDMP), which includes a choice between alternative plans of action. The choice includes facts and values. Every decision is composed of a logical combination of fact and value propositions. Facts mean existence or occurrence of something tangible and concrete which can be verified. Value is a matter of preference (Simon 1997).

Simon divides the process of decision making into three phases—intelligence: finding occasions calling for decision; design: identifying, developing and analyzing all possible alternative courses of action; and choice: selecting a particular course of action from available choices (Simon 1997).

The NPDMM is structured according to Simon's decision-making process and consists of several stages and tasks that are carried out to design a new product. The main stages and tasks of the methodology are described below:

1. Project Definition: Problem description, criteria, participants, alternatives and evaluation scales are defined.
2. Market Study: Once defined the problem, criteria, alternatives and scales, they will be used to design the survey which will be applied to the consumers to carry out the market study corresponding to the new product to be designed.
3. New Aggregation/Disaggregation Preference Method: It is an ELECTRE III-based method that represents the preferences of the set of consumers from the knowledge stored in the market study.
4. New Market Segmentation Method: It allows to segment the market from a multicriteria analysis point of view using an evolutionary algorithm. It will form classes of consumers similar between them.
5. New Brand Choice Model: It assigns a brand choice model that represents the consumer behavior per consumer preferences generated by the new aggregation/disaggregation preference method. The output of the model is the market share of the new product in a specific market segment.
6. What-If Analysis: It is an iterative process that will allow the decision maker to test different configurations of design of a new product in a specific market segment before being launched. It will give the ranking position of a new product under design with respect to its competitors in a particular market segment.

Table 1 summarizes the link between Simon's problem-solving model and the NPDMM described in this work.

The next section describes the proposed architecture for the MDSS that implements the NPDMM previously explained.

Table 1 Link between Simon's problem-solving model and the new product design multicriteria methodology

SDMP stages	NPDMM	Comments
Intelligence	Project definition	Finding occasions calling for a decision. Product idea/opportunity discovery. Problem description/design specifications: criteria, scales/identify participants
Design	Market studies, aggregation/disaggregation method, market segmentation method, brand choice model	Identifying, developing and analyzing all possible alternatives. Generate and evaluate rough design layouts/preliminary specifications of the layout. Get consumer preferences and market segments
Choice	Optimal product recommendation and what-if analysis	Selecting from the available choices. Get the specification of production from an optimal recommendation or what-if analysis

5 Architecture of Multi-agent MDSS

Vahidov and Fazlollahi (2004) stated that "agent technologies offer the highest-ever level of abstraction in computer science. This allows the designers to devise the overall architecture of a multi-agent system without specifying the implementation details" (Vahidov and Fazlollahi 2004).

The architecture design in Fig. 1 is based on a combination of the well-known proposal of agent types presented in Sycara et al. (1996) and the component integration based on Simon's decision-making process presented in Vahidov and Fazlollahi (2004).

First, agents are considered according to three different types (Sycara et al. 1996):

1. Information agents provide access to information sources. Their goal is to provide information from the system's general database or other agents. MDSS architecture has the following information agents: project, monitor and market study data manager.
2. Task agents support decision making by formulating problem-solving plans and interacting with other software agents to carry them out. The architecture shows the following task agents: initialization manager, aggregation/disaggregation preferences, market segmentation, automatic optimal recommendation and brand choice.
3. The interface agents interact with the user by receiving user input and showing results. Decision maker and facilitator are interface agents in the MDSS architecture.

As in Vahidov and Fazlollahi (2004), components of the architecture include intelligence team, design team and choice team. Its name corresponds to the phases

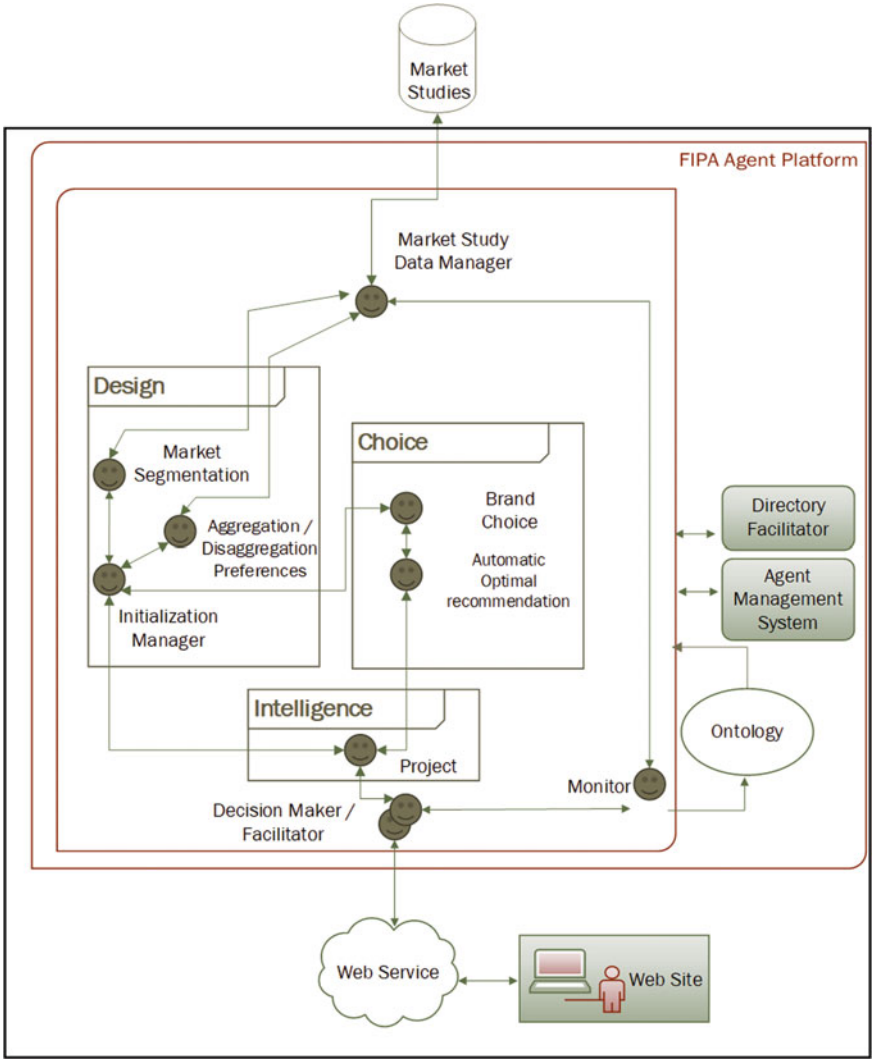

Fig. 1 MDSS multi-agent architecture

of Simon's decision-making stage that the corresponding agents aim to support (Vahidov and Fazlollahi 2004).

- The intelligence team has one information agent: the project agent. Its responsibilities are to define the decision problem and identify criteria to evaluate new product and alternatives of an existing product in the market.
- The design team incorporates information and task agents: initialization manager, aggregation/disaggregation preference agent and market segmentation agent. Its main responsibilities include the initialization of the environment for the new

product design. It obtains consumer behavior through multi-objective evolutionary algorithms based on ELECTRE III multicriteria method incorporated in the aggregation/disaggregation preference agent. Consumer characteristics are obtained by multi-objective optimization based on the non-dominated sorting genetic algorithm II (NSGA II). The output of both elements is used as input for the brand choice agent.

- The choice team also consists of information and task agents: automatic optimal recommendation agent and brand choice agent. Its main responsibility is to generate an optimal recommendation of the new product under study. The output of choice team agents will tell the position of a new product under design with respect to its competitors in a particular market segment. The recommendation is generated automatically from an evolutionary algorithm based on linear programming that determines the optimal configuration of a product with respect to the group of competitors in a specified market segment. Here can be carried out a what-if analysis. It is an iterative process that obtains the position of a new product under design with respect to its competitors in a market segment.

6 Multi-agent MDSS Prototype for Product Design Decisions

In order to show our proposal, we have developed an MDSS prototype to support new product design decisions. The interface is a PHP Web site that provides interaction between the user and MDSS multi-agent platform to show information, perform calculations and what-if analysis and carry out other related tasks. The models, data and user interface are traditional DSS components. Data are collected from applied surveys of market studies and are stored in a relational Microsoft SQL Server database. At this moment, the prototype incorporates the agents of intelligence, design and choice teams which was described above. The decision maker (DM) or facilitator (F) can accept it or go to evaluate different configurations until it finds a satisfactory one. Below are some sample screens of the prototype user interface.

Figure 2 shows a dashboard that is presented once the user logs in the system. Here, the list of projects in which the user participates is displayed. In this window, it is possible to create a new project by pressing the <Design New Product> button, or manage an existing one by clicking on the name of the desired project.

Figure 3 shows the automatic recommendation screen for the *Corn Oils* project, which is divided into three sections: *Setting Grid*—in this section are displayed the optimal values for each attribute of the new product in a grid format; *Market Share Grid*—in this section, the market share obtained for the new product is shown regarding the products evaluated by consumers in grid format; *Expected Market Share*—it shows the same information from the Market Share Grid section but in pie chart format in which the market share of the new product can be observed visually in relation to the products evaluated.

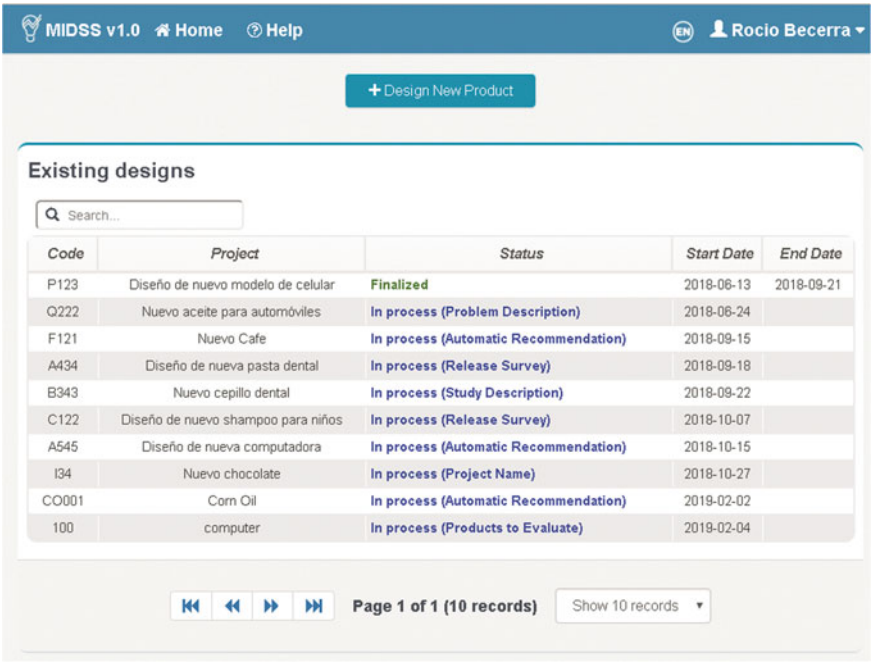

Fig. 2 MDSS new product design screenshot

7 Discussion and Conclusions

This paper presented a multi-agent architecture for a new decision support system to support new product design decision process in a real-world context. It is argued that a combination of DSS, agent technologies and multi-objective evolutionary algorithms based on multicriteria ELECTRE III methods to support decision making in marketing applications will prove to be a powerful tool. It described a multi-agent architecture for a novel MDSS which implements a new methodology for designing new products based on consumer preferences. Such methodology is substantiated on Simon's decision model. Their models are based on ELECTRE III multicriteria method and were built in the software through multi-objective evolutionary algorithms. Unlike other approaches in the literature, consumer preferences are modeled in the methodology using a more flexible approach which allows taking into account the importance assigned by a customer to each criterion to evaluate a product with what is intended to model more appropriately consumer preferences than in the current proposals.

The MDSS is built using a generic reusable multi-agent architecture which has three different agent types: interface agents, task agents and information agents. The major components of the architecture also reflect the phases of decision-making stage of Simon and include intelligence team, design team and choice team. Intelligent

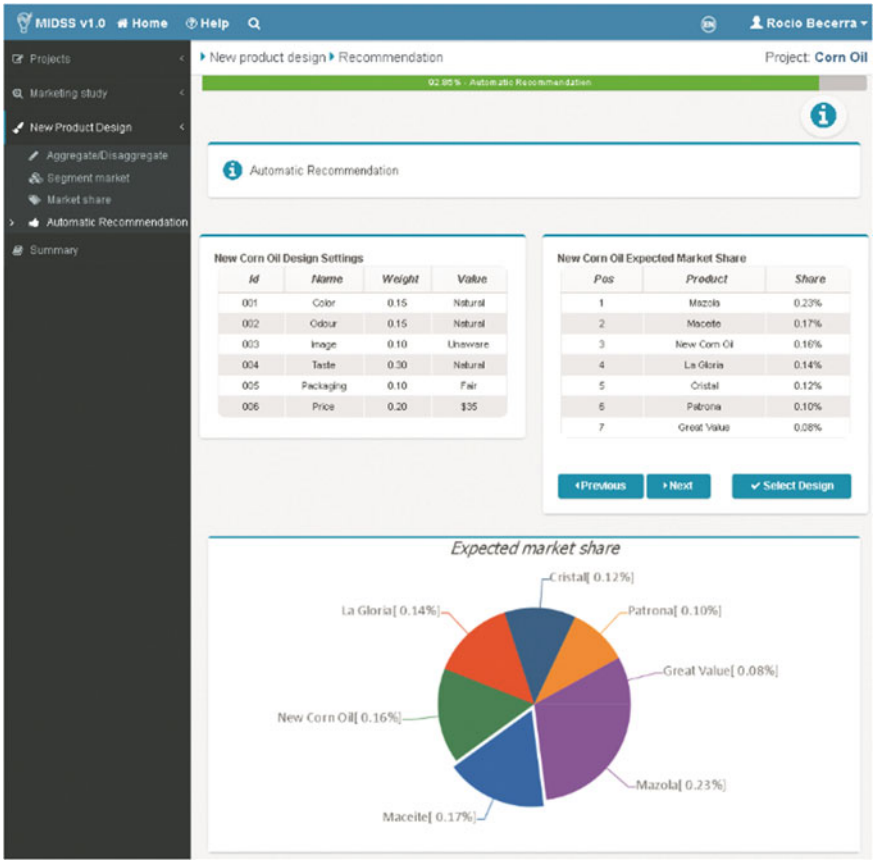

Fig. 3 MDSS automatic recommendation screenshot

software agents are capable to respond exactly to the requirements of collection, choice, evaluation and utilization of information to support decision makers during the product design process in distributed marketing environments. They allow to have a distributed store of knowledge, a flexible increase or decrease of the system without influencing other parts of software and a close cooperation between each intelligent agent for task's decomposing.

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