Multiple Criteria Decision Making Methods for Business-to-Business Electronic Commerce

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Abstract. The objective of this thesis is to develop appropriate methods and tools to deal with decision making problems arising in business-to-business electronic commerce. In this context, we propose MCDM methods for the problem of supplier selection and the problem of customer evaluation for order acceptance aiming to tackle effectively and efficiently issues of complexity and uncertainty which are inherent in the respective decision processes. Regarding supplier selection, we present a novel evaluation method with two stages. A satisficing technique is used in the first stage of this method for the prequalification of the suppliers. The final evaluation of suppliers is performed in the second stage through the use of a fuzzy AHP technique. As far as customer evaluation is concerned, we present a novel class of methods extending TOPSIS. On the one hand, the proposed class of methods tackles the issue of uncertainty of the decision maker preferences through the use of linguistic variables and their representation as fuzzy numbers. On the other hand, the proposed class of methods may be parameterized according to the behavioral pattern of the decision maker towards risk. Moreover, a simulation experiment is designed and executed in order to analyze and study the proposed class of methods. The results of the simulation experiment show that it is adequate to distinguish three instances of the proposed class of methods that correspond respectively to risk-averse decision makers, to risk-neutral decision makers, and to risk-seeking decision makers. Finally, we present a novel agent-based DSS architecture for flexible electronic marketplaces. This architecture is employed for the implementation of a Decision Support System incorporating an application for supplier selection which is based on the proposed decision method.

1 Introduction

The objective of this thesis is to develop appropriate methods and tools in order to deal with decision making problems pertaining to business-to-business electronic commerce. Business-to-business electronic commerce constitutes a rapidly changing business environment that is characterized by the constant invention of innovative methods to conduct business operations and transactions, by the formation of new organizational structures as well as by the emergence of new avenues for the exploitation of an abundance of information [1-2]. In this context, decision makers have to

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deal with a number of semi-structured or unstructured difficult decision problems, which underlines the need for efficient and effective decision methods and tools [3].

Business-to-business electronic commerce decisions can be classified into two broad categories: **configuration** (design-oriented) decisions that relate to the basic infrastructure on which the transactions are executed, and **coordination** (execution-oriented) decisions that relate to the actual execution of the transactions [4]. According to [4], configuration-level decisions include the following topics: *procurement and supplier decisions*; *production decisions*; *distribution decisions*; *information support decisions*. Furthermore, coordination-level decisions include the following topics: *material flow decisions*; *information flow decisions*; *cash flow decisions*.

In this thesis we focus on the problem of supplier selection as well as on the problem of customer evaluation for order selection since these problems are especially important for the following reasons:

- As far as supplier selection is concerned, interest about the respective decision process has been continuously growing because reliable suppliers enable the reduction of inventory costs and the improvement of product quality [5]. Modern industries have to adapt to a market environment that is characterized by openness to global competition. Therefore, companies are under pressure to rationalize their expenses, to reduce their production costs. Instrumental to this is the reduction of the purchasing costs through the selection of the appropriate suppliers [6]. Moreover, modern production systems such as Just-In-Time production and mass customization manufacturing presume the prompt supply of raw materials and outsourced parts in the expected quantity and with the expected quality [7].
- As far as customer evaluation for order selection is concerned, the environment of business-to-business electronic commerce is characterized by competitive prices and lean profits and, as a consequence, suppliers are forced to hold limited stocks in order to reduce their storage and financing expenses [8]. Moreover, suppliers gain a competitive advantage when they are able to fill customer orders quickly and when they offer products customized to the needs of their customers [9]. Hence, suppliers are driven to shift their production from make-to-stock (MTS) to make-to-order (MTO) production systems [10]. Under these conditions a supplier is usually able to address only part of the orders placed by customers since the demand may surpass the supply quantity for the specific production capacity of the supplier [11]. Therefore, the problem is to determine good order acceptance strategies in connection with appropriate production planning and scheduling mechanisms in order to minimize the damage from the rejection of received orders [12]. Some studies [9, 11, 13] have identified assessment of customers' importance according to multiple qualitative and quantitative criteria as a distinct stage or part of the order acceptance process as it has been shown that not all customers are equally profitable for a company and, therefore, a supplier should select appropriate customers in order to allocate its resources optimally and prioritize orders accordingly.

The resolution of the specific problems includes an analysis of the respective decision processes, the determination of the criteria which guide them, and a treatment of the special requirements which stem from their nature. In this context, we confronted the issue of *complexity* pertaining to information search, processing and exploitation because of the "information overload effect" which is related on the one hand with the existence of a large number of alternatives and on the other hand with the incongruity and the large number of the decision criteria. Equally important is the issue of *uncertainty* which stems from the preference structure of the decision makers and the existence of qualitative criteria.

Since the ranking order of the alternatives is not dependent only on one criterion on attribute, the following issues arise: (1) the combination of multiple and possibly conflicting criteria in a common evaluation model and (2) the fact that the decision maker plays an active part since the analysis and the coherent representation of his/her preferences is necessary [14].

Multiple Criteria Decision Making (MCDM) involves the development and implementation of methodologies, methods and tools to support decisions involving multiple and possibly conflicting criteria or goals. MCMD methods are classified into three broad categories with regard to the operational approach for the aggregation of the criteria: (1) use of a single synthesizing criterion without incomparabilities; (2) synthesis by outranking with incomparabilities; (3) interactive local judgments with trial-and-error iterations [15].

The operational approach that we followed for the aggregation of criteria in the proposed MCDM methods belongs to the first category since no issue of criteria incomparability has been raised in both supplier selection and customer evaluation for order selection according to the conducted literature review [5–9, 11, 13]. Furthermore, in order to deal with the issue of uncertainty we use fuzzy set theory as a theoretical and methodological basis. Apart from its use as a language to model appropriately problems and situations which contain fuzzy phenomena or relationships, fuzzy set theory can be used also as a tool to analyze such models in order to get a better insight into structures of problems and models and as an algorithmic tool to make solution procedures more stable or faster [16].

Contributions. The main contributions of this thesis are the following:

- A decision method is proposed for the problem of supplier selection consisting of two phases. In the first phase of the method, which corresponds to supplier prequalification, the supplier selection search space is pruned through the use of a satisficing technique with the application of hard constraints on the selection criteria. In this manner, the "information overload effect" is alleviated and the complexity of the problem is reduced. Moreover, the capturing and representation of the decision maker's preference structure is facilitated with the introduction of a rating scale with five evaluation levels. In the second phase of the proposed method, a Fuzzy Preference Programming method is employed for the final evaluation and ranking of suppliers, which extends rating scale Analytic Hierarchy Process. This approach has both the advantages of the usual rating scale AHP approach and of the FPP method: it overcomes the explosion in the number of pairwise comparisons when the number of alternatives is large, it reduces the computational complexity in terms of the linear programs to be solved and at the same time resolves the problem of inconsistent and uncertain human preference models by using interval values for preference relations.
- A novel class of fuzzy methods is proposed for the problem of customer evaluation for order selection. This class of methods is devised by modifying the aggregation function of TOPSIS method through the use of fuzzy set theory in order to model the risk attitude of the decision maker. Moreover, the issue of uncertainty of human

preference models and qualitative criteria is dealt with through the use of linguistic variables and their representation as fuzzy numbers. The proposed class of methods is analyzed through the design and execution of a simulation experiment. The results of the simulation show that one the one hand there is no direct correspondence between an instance of the proposed class of method and the original TOPSIS method, and on the other hand that it is adequate to distinguish three instances of the class of methods which correspond to risk-averse, risk-neutral and risk-seeking decision makers respectively.

- A novel agent-based Decision Support System (DSS) architecture for the provision of decision support in electronic marketplaces is proposed. This architecture is used for the implementation of a DSS incorporating an application for supplier selection which is based on the proposed method.
- Our work constitutes an autonomous contribution in the broader field of decision making since the proposed methods may be also used in a variety of other selection/evaluation problems.
- On the whole, the performed research constitutes a full-fledged approach to tackle decision making problems arising in business-to-business electronic commerce as it includes a combination and improvement of decision methods as well as their integration in a DSS for electronic marketplaces.

The remainder of this dissertation summary is organized as follows. Section 2 briefly discusses the proposed method for supplier selection. The intent of Section 3 is to present the class of methods devised for the problem of customer evaluation for order selection. In Section 4 we describe the DSS architecture that we have designed for the provision of decision support in electronic marketplaces. Finally, Section 5 summarizes the conclusions of our research.

2 Supplier selection using satisficing and fuzzy AHP

Supplier selection is defined in [17] as the "process of finding the suppliers being able to provide the buyer with the right quality products and/or services at the right price, at the right quantities and at the right time". This process is generally described in the literature to consist of five stages: (1) Identification of the need for a new supplier; (2) Identification and elaboration of selection criteria; (3) Initial screening of potential suppliers from a large set; (4) Final supplier selection; and (5) Continuous evaluation and assessment of selected suppliers [18].

Therefore, supplier selection initially requires the identification and elaboration of decision criteria that will guide the decision making process (stage 2). Different organizations may choose different decision criteria for supplier selection according to several factors, the most important one being the size of the buyer organization [19]. Several studies have identified a number of qualitative and quantitative factors identifying factors of cost, quality, delivery, etc [7].

The stages of the initial screening and of the final selection of suppliers involve the application of decision methods and algorithms. The Analytic Hierarchy Process has been identified in a significant number of studies as a useful, practical and systematic method for supplier selection [20]. However, the AHP method has been criticized for not taking into account issues of complexity, risk and uncertainty in supplier assessment [20].

The proposed method is a synthesis of a satisficing approach with fuzzy AHP. Satisficing is used in the first stage of the supplier selection process in order to prune the suppliers' search space whereas fuzzy AHP is utilized in the final stage of the supplier selection process in order to produce the final ranking order of suppliers [21]. Moreover, our approach reduces the complexity of the fuzzy AHP method in terms of pairwise comparisons (i.e. user input) and in terms of the linear programs to be solved (computational complexity).

2.1 Criteria hierarchy

Since the proposed approach is based on the Analytic Hierarchy Process the problem is structured hierarchically, i.e. the decision maker defines the criteria hierarchy structure. The hierarchy structure includes goals, criteria, sub-criteria, rating scales and alternatives.

2.2 Supplier pre-qualification

The buyers in an e-marketplace have to evaluate a very large number of suppliers in order to make a choice. Given the fact that specialized decision methods for supplier evaluation are time consuming and require considerable computational power and user input, it is reasonable to prune the supplier search space and focus on the most suitable alternatives. In this context, we propose the application of hard constraints on the selection criteria for the initial pre-qualification of the suppliers based on a satisficing technique. It must be noted that satisficing has long been used as such a technique because of its strong intuitive appeal as well as because it is an accurate indication of what actually transpires during the initial screening of alternatives [22].

The pay-off function is then modeled as a vector function $V(s)$, where V has several components $V_1, V_2,...$ corresponding to the sub-criteria considered by the buyer organization at the lowest level of the criteria hierarchy. The components of the pay-off function take values for the alternative suppliers according the method proposed by Liberatore [23]: absolute values for the quantitative criteria (e.g. price) and information about the qualitative criteria will be rated by each customer from a scale of 1 to 5 (unsatisfactory, below average, average, above average, outstanding) and, thus, rating levels for each criterion as well as the corresponding hard constraints will be established. The use of a five-grade rating scale to map different evaluation standards for qualitative criteria and absolute values for quantitative criteria has been employed in various problems with success and can be found in various studies [23]. It must be noted that this formulation of the pay-off function will help in the next step of the supplier selection process as it will be shown in the next subsection 2.3.

2.3 Supplier ranking

A Fuzzy Preference Programming method which is based on the rating scale AHP is used for the stage of final supplier ranking. Initially, we will briefly discuss the AHP method. The AHP divides the decision problem into three main steps: (1) problem structuring; (2) assessment of local priorities; (3) calculation of global priorities.

Assessment of local priorities. The term local priority is used both for the weights of the criteria and sub-criteria and for the rating scores of the alternatives. The assessment of local priorities is performed after the decision maker provides his preferences by pairwise comparisons among factors in each level of the hierarchy. Saaty introduced in [24] a nine-point numerical scale to represent the relative degree of importance for two factors, where the value of 1 stands for "equally preferred", the value of 2 stands for "equally to moderately preferred" and so forth up to the value of 9 that stands for "extremely preferred". After the comparisons have been performed, a pairwise comparison matrix A is constructed, in which element of the matrix is the relative importance of the i-th factor with respect to the j-th factor at the same level of the hierarchy. Obviously, the relation $a_{ji} = 1/a_{ij}$ always holds and therefore A is a positive reciprocal matrix:

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix}$$

Then the values of weights of the criteria may be obtained from the comparison matrix by applying a prioritization technique such as the Eigenvector analysis.

The rating scale AHP method is different from the usual AHP method in that a rating scale is assigned to each sub-criterion related to every alternative. Thus, the comparison matrices are constructed through pairwise comparisons among the rating levels for each sub-criterion. The major advantage of the rating scale approach is that it overcomes the explosion in the number of pairwise comparisons when the number of alternatives and/or the number of sub-criteria is large. Thus, even if, prima facie, it seems that the rating of absolute values for quantitative criteria by means of a 5-point scale is unnecessary, it is evident that it can be really helpful in this manner, as the number of comparisons and user input is greatly reduced, the problem of information overload is, to a certain extent, alleviated and the comparison process becomes more comprehensible.

Assessment of global priorities. Then, in the last step of the AHP the global priorities of the alternatives are calculated by a weighted sum of the type: $R_j = \sum_i w_i r_{ij}$. In order for this method to be consistent, then all elements a_{ij} must have perfect values $a_{ij} = \frac{w_i}{w_j}$ and, therefore, $a_{ij} = a_{ik} a_{kj}$ for all i, j, k. Nevertheless, in most of the practical cases, the method is not consistent since evaluations a_{ij} are only estimations of the unknown ratios $\frac{w_i}{w_j}$. This is due to the fact that in real situations the decision makers are generally unsure of their preferences because information about the problem is incomplete and uncertain where as some of the criteria are subjective and qualitative, so the preferences cannot be easily expressed in an exact way.

Modified FPP method. Our approach to face the issues of inconsistency and uncertainty is based on the method proposed by Mikhailov in [25]. If the pairwise comparison matrix A is constructed through the assignment of intervals with lower and upper bounds to its elements $a_{ij} = [l_{ij}, u_{ij}]$ to capture the uncertainty experienced by the decision maker, the problem of the calculation of the weights may be transformed to a fuzzy Linear Programming problem with constraints that correspond to the consistency relations $l_{ij} \tilde{\leq} \frac{w_i}{w_j} \tilde{\leq} u_{ij}$, where $i = 1,2,...,n-1$, $j = 2,3,...,n$, $i < j$ and $\sum_{i=1}^{n} w_i = 1$. The symbol $\tilde{\leq}$ denotes the relation "fuzzy less or equal to". When objectives as well as constraints of a LP-problem are represented by fuzzy sets, a solution to the decision problem has to belong to all fuzzy sets involved. The space of these solutions is also a fuzzy set, which will be called "Decision Fuzzy Set" (DFS). Optimal solutions are those solutions in the DFS for which the maximum value of the membership function of the fuzzy set is reached. By definition, the DFS is the intersection of all fuzzy sets representing constraints and objective functions and, therefore, its membership function is $\mu_{DFS}(x) = \min_i(\mu_i(x))$, where $\mu_i(x)$ are the membership functions of all involved sets. Thus, the best vector of local priorities will be given by $w_o = \max_w \min_k(\mu_k)$.

Thus, to sum up in a few words the advantages of the proposed method for supplier selection, we must note that our approach reduces the complexity of the problem on the one hand through the pre-qualification process and on the other hand through the use of rating scale with five levels which reduces the number of necessary pairwise comparisons and, possibly, the number of the respective linear problems. Moreover, our approach deals with the issue of uncertainty and inconsistency of the preference structure of the decision makers through the use of a fuzzy programming method.

3 Customer evaluation for order selection using a novel class of fuzzy methods

In this section we present our proposal for a method addressing the problem of customer evaluation according to multiple qualitative and quantitative criteria in the context of the order acceptance process of suppliers. The proposed approach is intended to deal with the issues of uncertainty and risk that characterize the specific evaluation problem by introducing a new class of fuzzy methods based on TOPSIS [26, 27].

TOPSIS (Technique for Order Preference by Similarity to the Ideal Solution) method was first developed by Hwang and Yoon [28] and ranks the alternatives according to their distances from the ideal and the negative ideal solution, i.e. the best alternative has simultaneously the shortest distance from the ideal solution **and** the farthest distance from the negative ideal solution. The ideal solution is identified with a hypothetical alternative that has the best values for all considered criteria whereas the negative ideal solution is identified with a hypothetical alternative that has the worst criteria values. However, the TOPSIS method suffers from two important disadvantages. Firstly, it presupposes that the evaluations of the alternatives with regard to each criterion and the weights of the criteria are crisply defined whereas the customer evaluation problem is characterized by uncertainty with regard to the preference structure of the decision makers and the existence of qualitative criteria. Moreover, the aggregating function of the TOPSIS method does not produce results such that the highest ranked alternative is simultaneously the closest to the ideal solution and the furthest from the negative ideal solution since these criteria can be conflicting.

The proposed method deals with the issue of uncertainty through the use of linguistic variables and their representation as fuzzy numbers. Simultaneously, we propose the use of a new model for the definition of the aggregating function that is based on a fuzzy set representation of the closeness to the ideal and the negative ideal solution in order to deal with the contradictory nature of the TOPSIS principle of compromise. Therefore, the aggregating function is modeled as the membership function of the intersection of two fuzzy sets, i.e. the fuzzy set of alternatives that have "the shortest distance from the ideal solution" and the fuzzy set of alternatives that have "the farthest distance from the negative ideal solution". In the next sections it will be shown that this definition permits modeling of the risk attitude of the decision maker.

Linguistic variables. The concept of linguistic variables is very useful in complex or poorly defined to be reasonably described in conventional quantitative expressions evaluation problems. For example, the ratings of alternatives on qualitative criteria could be expressed using a linguistic variable with values such as "good", "poor", etc. Thus, the weights of criteria and the ratings of qualitative criteria are expressed as linguistic variables. Such linguistic values can be represented using positive triangular fuzzy numbers.

Triangular fuzzy number representation. A triangular fuzzy number $\tilde{m}$ is defined by a triplet *(a, b, c)*. The membership function μ_m of $\tilde{m}$ is given by

$$\mu_{\tilde{m}}(x) = \begin{cases} \frac{x-a}{b-a} (a \le x \le b) \\ \frac{c-x}{c-b} (b \le x \le c) \end{cases}$$

Since calculations and comparisons of fuzzy numbers is a complicated procedure, the transformation of triangular fuzzy numbers into crisp numbers proposed by Yong [29] is followed. This approach employs the graded mean integration representation of triangular fuzzy numbers and the canonical representation of addition and multiplication on triangular fuzzy numbers.

TOPSIS. The procedure of the TOPSIS method consists of the following steps: *Step 1: Construct the normalized decision matrix. Step 2: Construct the weighted normalized decision matrix. Step 3: Determine the ideal and the negative ideal solutions. Step 4: Measure the separation of alternatives from the "ideal" solutions. Step 5: Calculate the "relative closeness" of each alternative to the ideal solution and the final ranking according to the equation* $C_i^+ = \frac{S_i^-}{S_i^- + S_i^+}$ *, where* S_i^- *and* S_i^+ *are the separations of an alternative i from the ideal and the negative ideal solutions*. The definition of the "relative closeness" demonstrates that the aggregation function used by TOPSIS models the closeness of an alternative to the ideal solution **in relation** with the closeness to the negative ideal solution, i.e. if an alternative is closer to A^+ than to A^- then C_i^+ approaches 1 whereas if an alternative is closer to A^- than to A^+ then C_i^+ approaches 0. Therefore, it is evident that the notion of "relative closeness" does not correspond to the principle of compromise that the best alternative should simultaneously have the shortest distance from the ideal solution **and** the farthest distance from the negative ideal solution but only in a relative sense.

Fuzzy set representation model. Thus, we propose the use of the model proposed by Zimmerman and Zysno [30] to represent the closeness to the ideal and the negative ideal solutions. According to this model, the memberships of the of the fuzzy sets of alternatives that have the shortest and the farthest distance from the ideal and the negative ideal solutions respectively are defined as a function of the distances S_i^+ and S_i^- between a given alternative i and the ideal/negative ideal solution: $\mu^+ = \frac{1}{1+S_i^+}, \mu^- = \frac{S_i^-}{1+S_i^-}$.

Then it is possible to model the aggregating function of the TOPSIS method as the membership function of the intersection of the fuzzy sets defined above. The most common definition for the intersection of fuzzy sets is the one proposed originally by Zadeh: if + is the set of the alternatives that have the "shortest distance from the ideal solution" and – is the set of alternatives that have the "farthest distance from the negative ideal solution", the membership function of $+\cap-$ is given by: $\mu^{+\cap-} = min(\mu^+, \mu^-)$. This definition corresponds to decision makers that take into account only the worst characterization of an alternative with regard to the grade of membership in the above fuzzy sets. Consequently, we propose the use of the class of intersection connectives proposed by Yager [31], which includes Zadeh's minimum connective as a special case, permits modeling of the relative importance of membership values as well as modeling of the "strength" of the intersection connective: $C = \mu^{+\cap-} = 1 - min[1,[(1-\mu^+)^p + (1-\mu^-)^p]^{1/p}$ for $p \geq 1$.

Actually, the parameter p is a measure of the strength of the intersection, i.e. a measure of the simultaneous satisfaction of the two conditions of the TOPSIS principle of compromise. In particular, the parameter p is inversely related to the strength of the intersection. Moreover, as parameter $p \to \infty$ alternatives' ratings depend only on the minimum value of the degrees of membership, i.e. the worst characterization of an alternative. Conversely, as p decreases, ratings are becoming more dependent on the magnitude of the best characterization of an alternative. In other words, the proposed method includes an extreme instance ($p \to \infty$) that corresponds to pessimist decision makers whereas lower values of parameter p correspond to increasingly optimist decision makers.

The results of the conducted simulation experiment show that it is adequate to distinguish three levels of "optimism" or else three levels of risk attitude. The instance og the class $p \to \infty$ corresponds to risk-averse decision makers, the instance $p = 2$ corresponds to risk-neutral decision makers, and the instance $p = 1$ corresponds to risk-seeking decision makers. Therefore, the decision maker may choose the appropriate value of parameter p according to his/her risk attitude.

Summing up, we must note that, apart from covering a gap in the literature concerning customer evaluation for order acceptance as far as modeling of risk attitudes is concerned the proposed method has a wider scope and potential for further applications.

4 DSS for electronic marketplaces

As we have already mentioned in Section 1, the environment of electronic marketplaces is characterized by high requirements pertaining to information search, retrieval and processing as well as pertaining to capturing and representation of the users' preferences. In this context, we propose the use of software agents as "building blocks" of the DSS architecture, which intervene proactively in all phases of the decision processes. Software agents facilitate both the exploitation of information and the capturing of the preferences of the users. In particular, we propose a DSS architecture that incorporates: an information agent that acts as a sensor in the environment of the electronic marketplace to gather information about the suppliers and the buyers as well as an interface agent that utilizes appropriate methods of human computer interaction to capture the preference structure of the decision makers [32].

The DSS that has been implemented according to this architecture incorporates an application supporting supplier selection. The decision maker is guided by an interface agent in all the stages of the decision process.

5 Conclusions

A key finding of the literature review was that decision making in business-to-business electronic commerce is characterized by complexity and uncertainty. In this context, we developed a supplier selection method consisting of two phases. In the first phase of the method the supplier search space is pruned through the use of a satisficing technique. In the second phase of the method, the final ranking of the suppliers is produced through the use of a Fuzzy Preference Programming method which tackles complexity as well as uncertainty and inconsistency of the preferences of the decision makers. Furthermore, we developed a class of methods for the problem of customer evaluation for order selection which on the one hand deals with uncertainty through the use of linguistic variables and fuzzy numbers and on the other hand extends TOPSIS method in order to model the risk attitudes of decision makers. The proposed class of methods was investigated through a simulation experiment which showed that it is adequate to distinguish three instances of the class of methods corresponding to risk-averse, risk-neutral and risk-seeking decision makers respectively. Lastly, a DSS for electronic marketplaces was designed and implemented utilizing the functionality of software agents and incorporating a supplier selection application.

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