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Comparison of Two Yield Management Strategies for Cloud Service Providers

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Comparison of Two Yield Management Strategies for Cloud Service Providers

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Abstract: Several Cloud computing business models have been developed and implemented, including dynamic pricing schemes. This paper extends the known concepts of revenue management to the specific case of Cloud computing from two perspectives. First, we propose system architecture for Cloud service providers for combining demand-based pricing and scheduling. Second, a comparison of two yield management methods for cloud computing has been compared: Limited Discount Period Algorithm and VM Reservation Level Algorithm. By taking advantage of demand estimation, the two algorithms find the optimum number of VMs that are sold at full price and the optimum time period before the allocation when the prices should change. Simulation results show that both yield management methods outperform static pricing models and the algorithms perform differently considering the deviation of demand.

Keywords: Cloud Computing, Revenue Management, Pricing Strategy, Autonomic Resource Management.

JEL Classification Numbers: C61, C63, D81, L86, M15.

1. Introduction

Cloud service providers (CSPs) face challenges regarding performance and pricing. On the one hand, Cloud service consumers wish to minimize the execution time of their submitted tasks without exceeding a given budget, while, on the other hand, CSPs are keen on maximizing their revenue while keeping customers satisfaction [1]. A real-time view of the Cloud provider's business with respect to revenue and costs becomes essential. Such a system helps to respond in an economically efficient way. Solutions to these issues are provided through business economics [2].

The current problem that CSPs face is that they have to reserve resources (e.g. a specific number of virtual machines) at a particular time upon a given user request. This reservation of resources basically follows the traditional first-come-first-served approach, so that late service requests have to be rejected if resources have already been reserved for earlier service requests, even if these late service requests have a higher value for the CSP. To address this problem, dynamic pricing methods have been successfully applied in many cases [3]. The reservation price can depend on the demand. For instance, an industry that has applied this pricing is the airline sector. Its solutions are based on yield management [4], maximizing revenue.

In the scope of this paper we apply two orthogonal yield management practices for maximizing the revenue. For both yield management practices, the full price and the discount price for VMs will be set. In addition, for the first practice we set the time L, which represents the time when price offerings switch from a discounted to a full price. For the second practice, we set the number of VMs (i.e., the protection level (PL) of VMs) that should be offered at full price. The research questions that will be addressed are how such a dynamic pricing model can be integrated into a scheduling architecture, and how those dynamic pricing models (if they perform differently) can be combined in the architecture through a smart switch.

For answering these research questions, this paper is structured as following: in the next section, an overview about related work is given. Chapter 3 introduces our proposed architecture as well as suggested pricing algorithms. The effectiveness of the work will be evaluated by simulation in Chapter 4 while Chapter 5 concludes the paper.

2. State-of-the-art

2.1. Cloud computing

It has recently become very popular as a new paradigm to shift IT resources and software from locally independent computers to a more collaborative level [4]. Cloud computing refers to not only "the applications delivered as services over the Internet" but also "the infrastructures and systems in the datacenters" [5]. In this work, we follow the definition of Cloud computing of NIST (National Institute of Standards and Technology) [6].

Though Cloud computing has a clear definition and features, there is no clear line of separation with other forms of distributed computing systems like Grid computing. It is no wonder because Cloud not only overlaps with Grid, it has indeed evolved out of Grid and relies on Grid as its backbone and infrastructure support [7]. In this work, the authors compare Cloud and Grids and despite the fact that they have similarity in their vision, architecture and technology, they significantly differ in security, programming model, level of abstraction, compute model, data model, applications, and business model. In case of our work, we have focused on business model differences between those systems. Han [8] believes that the Grid systems are scientific orientated, and are mainly supported by research communities; and compared to that, Cloud computing is profit-orientated and has a much broader user base, including non-IT companies and individuals.

2.2. Revenue management

The idea of revenue management (RM) or yield management is to give the seller the right to set the optimum price. The techniques of RM have been firstly implemented in airline industry, which benefited at $1.4 billion over three years [9]. Other industries, such as hotels, restaurants, and car rental companies, also use RM as a tool for resource allocation and revenue maximization, and this has been studied by a large number of scientists. Following the definitions of yield management presented in [10, 11], the definition of RM that is most suitable for this paper is "a method that helps to sell the VMs to the right consumer, at the most suitable moment, and at the optimum price."

Based on "expected marginal seat revenue" (EMSR) technique developed by Belobaba [12], airline companies make decisions about how many seats to sell for each price class they have. The same algorithm has been implemented in the hotel industry [13-15]. Hotels have different prices for the same quality of rooms. To separate two guest segments, the hotel introduces a protection level (PL) that divides the total capacity of rooms into two parts. The protected rooms will not be sold at a discount price because of the possibility that some customers might buy the same rooms at a full price later. Furthermore, the booking limit (BL) is the number of rooms that may be sold at the discount price.

In [10, 16, 17], the possibility of using RM in telecommunication industry and specifically in Grid was studied in detail. Arun Anandasivam et al. overviewed RM how this concepts can be deployed to Grid. He compared the Grid computing domain with other common areas for RM showing that even there are notable differences, RM is applicable on Grid. Anthony Sulistio et al. went deeper and presented the model using RM and simulation for two Virtual Organizations (VOs) with broker between users and Grid to determine pricing of reservations. Both of these works outlined the requirements for applying RM to the Grid and showed how the RM tools can be effectively exercised. But their architecture does not give consumer any possibility to use other allocation method that could be more applicable on consumer's need.

2.3. Resource Management

Existing studies of the internet and media workloads indicate that client demands are highly variable ("peak-to-mean" ratios may be an order of magnitude or more), and it is not economical to overprovision the system using "peak" demands [18], [19]. Gmach has presented results that illustrate the peak-to-mean behavior for 139 enterprise application workloads. He has shown that an understanding of burstiness for enterprise workloads can help in choosing the right tradeoff between the application quality of service and the resource pool capacity requirements. The ability to plan and operate at the most cost-effective capacity is a critical competitive advantage [20].

Van et al. presented an autonomic resource management system, which has the ability to automate the dynamic provisioning and placement of VMs. For this, they have taken into account both the application-level service level agreements and resource exploitation costs with high-level handles for the administrator to specify trade-offs between the two [21].

3. System architecture and algorithms

For the sake of maximizing the revenue of a CSP, we propose the system architecture as shown in Fig. 1.

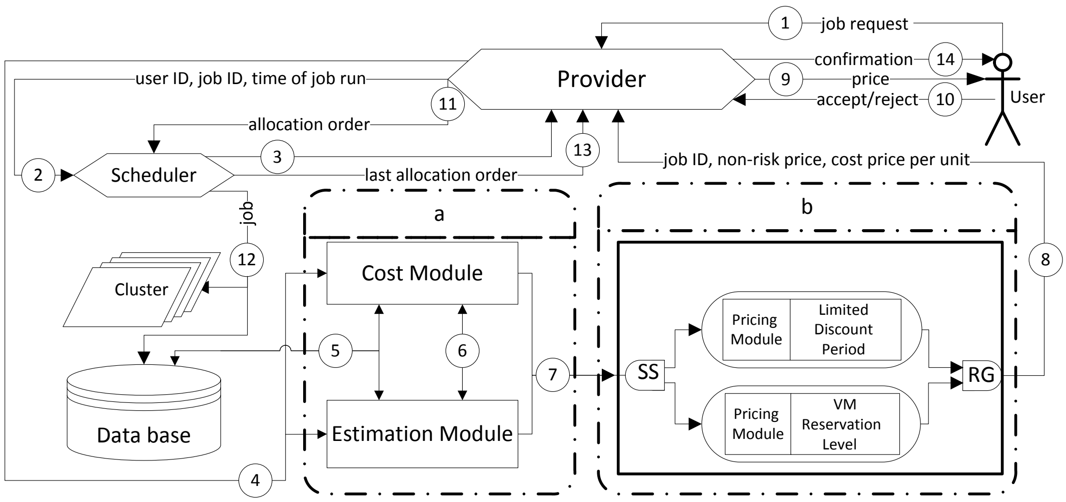

Figure 1. Proposed architecture for pricing and resource allocation in a CSP.

The proposed architecture for the CSP includes information about demand and the system cost [see a) in Fig. 1], the business support framework (BSF) [see b) in Fig. 1], the provider and the scheduler. The sequence is as explained here: In order to manage the requests, user interacts (1) with a component, namely, the provider. The provider manages requests based on First-Come-First-Served. It sends (2) job information to the scheduler to check the technical feasibility of the job (e.g. are sufficient resources of requested quality available). The scheduler will report (3) the feasibility to the provider. In case of being feasible, an order from provider will be sent (4) to block ‘a’ of Fig. 1, which means start demand estimation and cost calculation. Hence, the cost module and the estimation module request and get (5) needed data from data base to calculate the estimated demand by which (6) total cost is computed. The results are input (7) for BSF. The outcome of BSF processes will be sent (8) to provider. Based on the proposed data, the provider is able to negotiate with the user to finalize the deal (9, 10). Finally the provider orders (11) the scheduler to allocate proper VM on the requested time to the job. The scheduler will assign the VM to the job as per order (12), and send a confirmation notice back to the provider (13). Finally, the user will be informed of the confirmed deal (14). Yet, all information regarding the jobs goes to the database to keep the historical records. This data helps the CSP to set the prices that reflect the risk of losing opportunity cost and to estimate the near future demand.

3.1. Demand estimation module

Forecasting is often considered the most critical part of revenue management. The quality of decisions, such as pricing and capacity control, depends on an accurate forecast [22]. The data used in a demand estimation module is based on the historical data of requests and submitted jobs in the full price class. In designing the estimation module, such inputs should be available due to our modeling. Required inputs include historical data of demand (number of jobs requested at full price), application (VM) category, type of VM, e.g., in the case of Amazon: EC2, S3, etc. The module performs the analytical calculations and returns the estimated future trends, i.e., the demand for the full price. The module takes advantage of a heuristic method to estimate the demand of VM. More specifically, based on the past experience of the Cloud vendor, particular application categories, such as web server, game server, online-shopping server, e-learning server, etc., are required before going through the details of trend estimation since the module categorizes data based on its application category. This helps to obtain a better prediction for each category.

For simplicity, we assumed that the curves are of a monotonic function, modeling an overall upward or downward change in demand. We further assumed that all demand traces have a cyclic behavior. To perform the abovementioned prediction, four major processes are considered: extracting patterns, calculation of the pattern, deviation calculation and classification. Based on the estimation, two trends are generated, i.e., the demand for the full and the discount price to be used by the pricing module.

3.2. Cost module

For any kind of service pricing, one should be aware of total cost of the service; so that price setting won't make any loss for the service provider. Hence in the proposed architecture all of the BSF processes are based on the calculated cost of the service. To calculate the overall costs of a VM, a detailed cost model has been proposed in [23] in which fixed and variable costs should be calculated. For fixed cost (FC) the proposed formula accounts all of the initial costs: server purchase, network device purchase, cost of software licenses, cost of facility space, the cost for cabling and preparation of data center. Then all variable cost factors should be extracted and calculated. Items as listed in [23] are cost of electricity, the cost for Internet usage and the cost of maintaining labor. Finally total cost is gained based on total fixed cost and total variable cost; which will be inputs for pricing module.

3.3. Business Support Framework

First step of is that the Smart Switch (SS) checks the demand situation and recommends algorithms performing superior for the respective time span. Then the selected algorithm(s) use provided information by step 7 for setting full and discount prices. The BSF is able to run various economic-based algorithms. By now we have pro-posed two algorithms namely, Limited Discount Period (L algorithm) and VM protection Level (PL algorithm) as shown in b) of Fig. 1. Both of the algorithms need pro-posed prices, so the pricing module is embedded in them. This module, being dependent on demand level, generates on-time prices for the allocation algorithms of the BSF. In the L algorithm, the prices of VMs depend on how many days in advance the request is made, while the PL algorithm sets prices according to the PL of resources. Then Report Generator (RG) will merge the results of algorithm(s).

Pricing module. Since the approach of this work is YM method, the prices for the services of the CSP should be differentiated. The pricing module generates two prices: the full price (A) and the discount price (B), which are directly linked to demand. The key principle of the price strategy used by pricing module is that, if the probability of selling the product is very high then there is no need to offer a low price to sell it. Hence, the prices will be set using the full-cost method (or cost-plus) [24]. This method is very easy to explain, and the structure of the price is clear. The gross profit margin (GPM) in this method is set manually. To minimize human intervention in the price setting procedure in this work instead of the GPM other values that are directly tied to demand has been used as explained in equations 1 and 2.

$$A = \left(1 + \frac{q^{max}}{C_{full} + q^{max}}\right) * \frac{TC}{q_{avg}} \qquad (1)$$

$$B = \left(1 + \frac{q^{min}}{C_{full} + q^{min}}\right) * \frac{TC}{q_{avg}} \qquad (2)$$

In the proposed formula, where TC is the total cost, C_{full} means the total capacity of the CSP. Therefore, the full price is set based on the highest demand point (q^{max}), and the lowest demand point (q^{min}) determines the discount price. An average demand within the same accounting period is q_{avg}.

The Limited Discount Period algorithm (L algorithm). The objective of the first algorithm is to define the time duration, L, before the “job-start-time” so that when it occurs, the price changes from discount price to full price [25]. The idea of starting from the discount price and then switching to the full price is selected for two reasons. First, a low price attracts more customers, and it reduces the risk of not covering the production cost. Second, the practice of buying services in advance contributes to forecasting and resource allocation planning. In this case, the discount price is seen as an incentive for customers.

Hence, we use a breakeven analysis as a simple and easily understandable method of examining the relationship between the fixed cost, the variable cost, the volume, and the price [26]. The breakeven sales quantity helps to assess the number of products that must be sold to generate a contribution equal to the total cost.

$$BEQ = \frac{FC}{p - VC(q)} \qquad (3)$$

Where BEQ is the breakeven sales quantity, FC is the fixed cost, VC is the variable cost per unit, and p is the price per unit.

The calculation of point L starts with the breakeven analysis. Equation (3) helps to find the point where the sales revenue covers all the costs exactly, i.e., the profit is zero.

Only when the next unit is sold, the CSP realizes any profit. Therefore, the CSP starts to receive requests taking into account the time of request, t_r, and the job-start-time, t_s. Having ascertained the BEQ and the outcome of the estimation module, the CSP can calculate how many days are needed, L, to cover the production cost.

Steps of the algorithm are: 1) First assess system's parameters C_i and p_i; 2) After receiving a request, set $j = t_s - t_r$ and $L = t$ where $t + 1$ until $\sum d_t = BEQ$; 3) If $j \geq L$, and $p_i = B$, let $C_i = C_i + 1$, otherwise, $p_i = A$ and let $C_i = C_i + 1$; 4) Calculate the total capacity. If $\sum C_i \geq C_{full}$, go to the last step, otherwise start from the beginning; 5) The calculation stops with summing the total revenue $\sum(p_i * C_i)$.

The VM reservation level algorithm (PL algorithm). Since the CSP must decide the quantity of VMs to sell at the full price, the CSP must determine the protection level (PL) that divides the CSP's total capacity into two parts: the protected VMs and the VMs at discount price [15].

To explain mathematically, we refer to the EMSR technique [12]. We define $F_i(d_i)$ to be the probability density function for the total number of reservations requests, d_i, for VMs in price class i. The number of VMs allocated to a particular price class, C_i, in case of rejection may not exceed the number of actual requests for that price class.

$$F_i(C_i) = \int_0^{C_i} F_i(d_i)\, \partial d_i \qquad (4)$$

The optimal protection level, PL, for the business class is the value of C_i that satisfies the condition:

$$A * F_1(C_1) = B * F_2(C_2) \qquad (5)$$

$$F_1(PL^*) = \frac{A - B}{A} \qquad (6)$$

Steps of the protection level algorithm are as follows: 1) After assessing the system's parameters C_i and p_i, calculate Q^* and find from the table of cumulative probability the smallest cumulative value greater than or equal to PL^*; 2) Calculate $BL = C_{full} - PL$; 3) Receive a request and, if $C_i < BL$, accept the order and let $C_i = C_i + 1$ and $p_i = B$; 4) Otherwise switch the price so that $C_i = C_i + 1$ and $p_i = A$; 5) Then calculate the total capacity. If $\sum C_i \geq C_{full}$, go to last step, otherwise go to beginning; 6) Calculate the total revenue $\sum(p_i * C_i)$, then stop.

4. Simulation experiments

4.1. Simulation scenario

In our scenario, a CSP wants to identify optimum prices of VMs in order to maximize revenue. In presented simulations "the future time horizon of the simulation" is considered to be 30 days (but one may set it to other values). For simplicity, group requests are not considered hence one job means one VM for one hour. The Cloud vendor charges the customers two classes of prices: full price and discount price. There are three price-impacting inputs associated with the CSP's production cost: the fixed cost, the variable cost, and the total capacity. The fixed cost and variable cost of the Cloud provider are given as €20 and €1 accordingly. The total capacity of the CSP is assumed to be 100.

Each job request has two timing parameters: the job request time and the job start time. In this step of the work simulation is limited to solve the problem for a particular "job-start-time" (JST), i.e. to find the optimum L and the PL for a particular JST.

4.2. Data generation

In this work, two types of simulations have been performed. First, demand was generated between 1 and 100 based on uniform random distribution. Second, the simulator generated demand based on normal random distributions, for which μ was set to be 25, 50 and 100, while σ was considered to be 1, 10, 20 and 30.

4.3. Simulation results

Based on the generated random data in each simulation, full price and discount price have been calculated using formula 1 and 2. Then, the total revenue of each simulation is counted. Total revenue of both pricing strategies is shown in Fig. 2. The diagram shows a comparison of four pricing methods: the L algorithm, the PL algorithm, fixed high price (A) and fixed low price (B). It shows that the L algorithm often generates more revenue than the PL algorithm. But in some other cases PL algorithm is making more profit; and with this information one can't imply when and under which situation L or PL works better. So another round of simulation has been performed to find out the situation of better revenue by each algorithm.

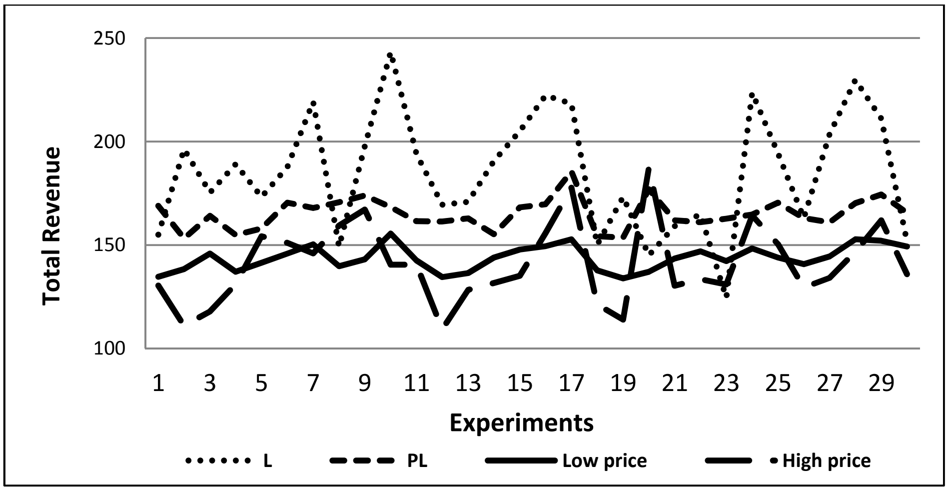

Figure 1. Comparison of the results of the four pricing strategies in first round of simulation.

Then a second round of simulation has been performed. The average results are shown in Table 1 (from 50 simulation runs). Based on those values, the full price and discount price are also calculated (Table 1).

Table 1. Average results for mean μ = 25, 50, 100 and standard deviation σ= 1, 10, 20, 30.

St.Dev	**1**			**10**			**20**			**30**		
Mean	**25**	**50**	**100**	**25**	**50**	**100**	**25**	**50**	**100**	**25**	**50**	**100**
Max demand	27	52	102	46	71	120	68	91	140	87	99	161
Min demand	23	48	98	5	30	80	1	8	57	1	2	39
Avg demand	25	50	100	25	50	100	35	49	99	44	51	100
Full price (A)	2.3	2.1	2.4	2.6	2.4	2.6	2.7	2.7	2.9	2.7	2.8	3.1
Disc price (B)	2.2	2.1	2.4	1.9	1.8	2.2	1.7	1.5	1.9	1	1.4	1.7

The revenues of the L and the PL algorithms have been calculated according to the 3.2.3.2 and 3.2.3.3. The generated revenue ratio of L and PL algorithms is compared in Fig. 3. Moreover, the average total revenue of 50 experiments is depicted in Fig. 4.

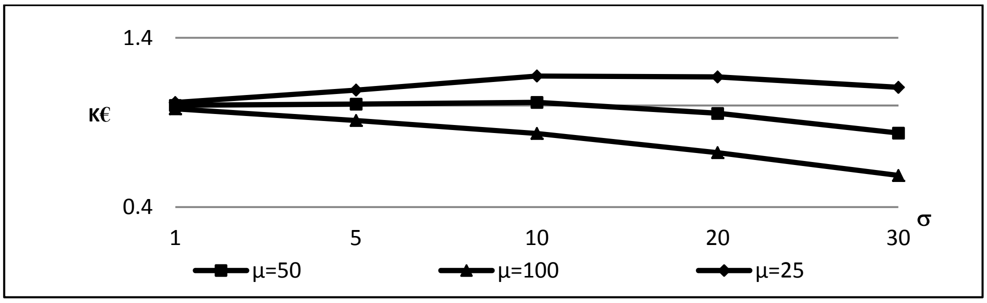

Figure 2. Comparison of the total revenue ratio of L to PL in case of five σ for three different μ.

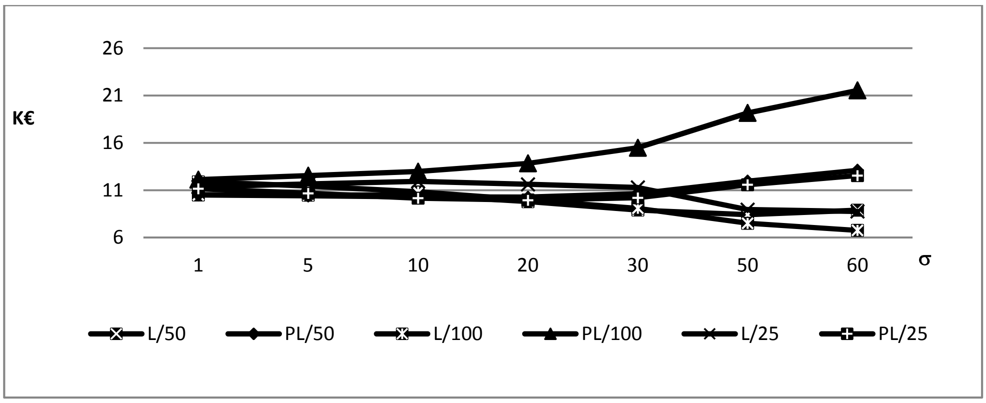

Figure 3. Comparison of the total revenue in seven cases of σ and three means (*25, 50 and 100; unit: K€*).

4.4. Analysis and discussion

The results of the first simulation are not giving meaningful conclusion about which algorithm (i.e., L or PL) is superior. To figure out the conditions, under which it is better to run the L algorithm, some additional simulations have been done. As diagram of Fig. 3 shows as the demand approaches the full capacity (here 100 VMs) revenue ratio is increasing for PL algorithm. The statement is true vice versa, i.e. for the μ=100 the more variation of demand the more revenue of PL algorithm. It can imply that if demand is very near to full capacity, the revenue is better when considering the protected level of VMs than L days prior to the job-start-time. While observing the cases in which the L algorithm made less revenue, it can be concluded that, if demand is low, the L strategy is more applicable. Nevertheless, both of the proposed pricing strategies are more effective than selling the VMs at any fixed price. The conclusion is supported by the Fig. 4 showing in case of PL algorithm as far as getting farther from full capacity revenue decreases, but this is reverse for L algorithm.

In the real world, CSPs may take advantage of the two proposed models to gain greater revenue. A smart switch in BSF as drawn in Fig. 1, can select best method according to demand situation.

5. Conclusion

Within this paper, we described how providers can be supported in price setting decisions. We proposed a system architecture, which included a demand prediction module, a cost module, a pricing module, and a business support framework. The system modules are described in details. In particular, we introduced two different pricing strategies, which follow the yield management method, for selling a Cloud service.

Our simulation results show that the proposed architecture and algorithms can be helpful to set an optimum price that generates maximum revenue. Our future work aims at extending this research so that more complicated cases, which have greater applicability in the real world, are assessed.

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