

Goal Directed Supplier Selection Model: An Agent-Based Architecture

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Abstract: *The aim of this study is to develop a supplier selection model on the basis of an Agent Based System in order to assure that the pre-defined goals are fulfilled. To develop the proposed supplier model with measurement capability, primarily a Supplier Agent Architecture was designed, and integration between raw materials and suppliers were assured in accordance with this architecture. The model is formulated by means of a Mathematical Model with a set of weights determined according to Analytic Hierarchy Process. Finally, proposed model is employed in JAVA-based software environment. For the case study, data were taken from real cabinet manufacturing company in Turkey. The results of the implementation clearly indicated that the purchasing costs are decreased. In addition, the result of the study highlighted that the ability to measure of pre-defined goals are possible.*

Keywords: *Agent, Agent-based Systems, Supplier Selection, Manufacturing Systems*

1. Introduction

Supplier selection is a key operational task of the most crucial logistics decision in any Supply Chain Management System. Choosing the right suppliers significantly increases the corporate competitiveness, while significantly reducing the purchasing costs.

De Boer et al. [1] described the supplier selection process as a selection of most suitable suppliers which can deliver the most suitable products at the right time with right quality and in the right price. Various approaches have been used to find right suppliers among various alternatives according to set criteria such as cost, quality, delivery time or similar ones. These are highly dependent on the specific requirements of product, management strategy of company and organizational behavior of the system.

For this reason, the determination of criteria requires analysis, judgment and assessment by domain experts. Note that, there is a need for software programs to collect and analyze data for determining the most important criteria. This software should also be designed to provide information flow between supplier and companies in order to create the most suitable supplier evaluation mechanism. This capability can be ensured using an agent based architecture with intelligent capabilities. Since, intelligent and autonomous systems are considered to be well known for their capability to provide solutions to any kind of selection and assessment, this study aimed utilizing intelligent agents in supplier selection problem with related requirements.

Wooldridge and Jennings [2] defined an agent as: ‘a computer system that is situated in some environment, in which it is capable of autonomous action, in order to meet its predefined objectives’. Multi agent systems (MASs),

on the other hand, can be defined as highly interactive agents working collectively through collaboration or competition to solve problems by using their individual capabilities [3].

The use of intelligent software agents for supply chain management has been studied by several researchers [see for examples, Swaminathan et al., [4] ; Caridi et al., [5]; Chan and Chan, [6]; Nissen et al., [7]]. The MASs are alternative technologies for automated decisions and coordination in supply networks because of the certain features such as distribution, collaboration, autonomy, and intelligence [8].

Considering the agent based architectures in supplier selection, the literature also provides a wide variety of research including Kim and Cho, [9]; Wang et al., [10]; Wang, Wong, and Wang, [11]; Wong and Fang, [12]. Some studies concentrates especially on adaptive negotiation strategy (see for examples, Fang & Wong, [13]; Wang et al., [14]; Yu et al., [15]).

Moreover, He et al [16] studied an agent based retail model, Russ and Walz [17] purposed the multi-agent supply chain simulation framework MACSIMA, Akanle and Zhang [18] showed an iterative bidding mechanism in order to satisfy optimum resource combination.

In this study new shed light on agent-based computational experiment for supplier selection mechanism, and a case study are proposed. The contribution of this paper to supplier knowledge is a well-defined goal based selection process which is measurable and adaptable. Chapter II introduces the proposed model. The application of the proposed model is given in Chapter III. The paper ends with a conclusion including future work.

2. Proposed Model

This model is designed to handle relationship between supplier and raw materials in a certain manufacturing system in order to support the assessment with respect to whether pre-defined goals are satisfied or not. Main motivations behind the proposed model are;

1. Ability to integrate (Specific Purpose - integrating the raw materials to the related suppliers)
2. Ability to measure (Specific Purpose – measuring the performance of the purchased raw materials)
3. Ability to self-organize (Reactiveness - ability to establish basic rules for the interactions between the Supplier model and the system)
4. Ability to adapt (Social Ability - ability to adapt over time in response to changes in the environment of the Supplier Model)
5. Ability to control (Autonomy - ability to control of supplier selection mechanism of the system to purchase needed raw materials)

2.1. Proposed Agent Architecture

In order to establish the Supplier Model with the capability to measure, a Supplier Agent Architecture is designed as shown in Figure 1. Note that the Supplier Model with related agents is a part of an integrated manufacturing environment including product, quality, machine, and accounting agents. This paper focuses the attention only on the supplier agents as explained below.

Note that, the proposed Supplier Model consist of four agents, namely; Material Requirements Agent, Procurement Agent, Buyer Agent, and Order Organizer Agent.

2.1.1. Order Organizer Agent

It is responsible to check the order list. If there is any update on the list, this agent calculates the total number of products to be produced and sends them to Material Requirement Agent for planning the required material.

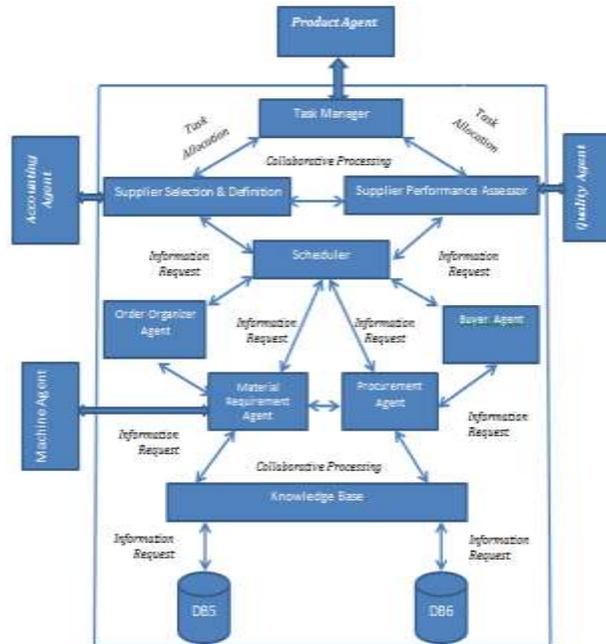


Fig. 1: Proposed Agent Architecture

2.1.2. Material Requirement Agent

It calculates material requirements in accordance with the bill of materials (BOM) and list of the products. It then searches for the available suppliers of those. After identifying the characteristics of possible suppliers, this agent prepares a purchase order for the Procurement Agent. Available suppliers are those which can deliver in the raw materials before the time of manufacturing (lead time). The following formula has been used to make this decision.

$$ASq = T_{i,o} - (T_t + T_{r,q} + T_{i,m}) \quad (1)$$

Where;

AS_q is Available Supplier q

$T_{i,o}$ is due date of product i of order o

T_t is current time

$T_{r,q}$ is delivery time of raw materials r from supplier q

$T_{i,m}$ is manufacturing time m of product i

2.1.3. Procurement Agent

It searches possible suppliers for each units of raw materials and select one of them. It eliminates the suppliers which could not deliver the products on time. Note that each available supplier has a positive idle time value calculate as;

$$Idle\ Time = Order\ date - (processing\ time + delivery\ time) \quad (2)$$

The main objective of this agent is to avoid the manufacturing delay caused by the shortcoming of goods. If none of the suppliers is not able to provide the material on time, than the agent sends a message to the user to search for a new supplier or a compromise strategy is implemented. Once the lists of available suppliers are generated, then the agent starts a selection process by the following process. Note that, if there is only a single supplier on the list, then no selection is employed. The supplier in the list is directly recommended.

For performing the selection, **the procurement agent calculates a quality value** for each available supplier depending on 3 main criteria;

- correct raw material percentage,
- correct received unit percentage and
- correct shipment percentage.

These percentage values of suppliers are provided by the Quality Agent and average quality value of each supplier is calculated as the following;

From the Accounting Agent, the supplier price and payment terms are requested. Weights of the selection criteria is defined for the goods to be purchased using Analytical Hierarchy Process (AHP) which is one of the well-known and most commonly used decision making approach to determination of priority and grading of entities. The basic structure of AHP is shown in Figure 2. A generic form of AHP matrix is given in Figure 3, where w denotes the weight of each criteria. 1-5 scales were used in this study (see Taha, 2007).

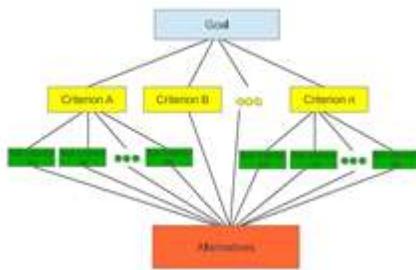


Fig. 2: A Generic Hierarchy of AHP (Klutho, 2013)

$$A = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \dots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \dots & w_2/w_n \\ \vdots & \vdots & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & \dots & w_n/w_n \end{bmatrix}$$

Fig 3: A generic Matrices of AHP (Klutho, 2013)

The weight values obtained is placed in a utility function to find the best supplier that satisfies the desired purpose. In this study, the utility function is named as PQPT value (P: Payment Q: Quality and PT: Payment Term) is designed as given in Equation 3. The utility value of the each supplier is recorded them in information system. Suppose P_q^r represents the unit price of raw material r of supplier q, Q_q^r denotes the quality value for raw material r of supplier q, PT_q is payment term of supplier q. Then the Supplier Utility function is;

$$PQPT_{q,r=1} / P_q^r * w_1 + Q_q^r * w_2 + PT_q * w_3 \quad (3)$$

In this study, payment terms are assumed to be equal for each product which is supplied by the same supplier. Structural frame code of supplier measurement function $f_{q,rs,t}^{SPM}$ is designed as given in Figure 4.

```
public float calculatePQPTbyRM(RawMaterial rawMaterial) {
    float pqpt;
    // calculate pqpt
    return pqpt;
}
public class PQPT {
    public RawMaterial RawMaterial;
    public float Price;
    public float QualityValue;
    public float PaymentTerm;
    public float calculate() {
    }
}
```

Fig. 4: Structural frame code of supplier measurement

After calculating PQPT values of all available suppliers, this information is sent to the Buyer Agent.

2.1.4. Buyer Agent

It receives the supplier opportunity cost report from Supplier Performance Assessor and suppliers PQPT list. It starts the bargaining process between suppliers. The following rules are implemented.

1. For suppliers with equal payment term value, the Buyer Agent selects the supplier which has highest PQPT value;
2. For the different payment terms then the agent selects the supplier which has the highest Opportunity cost which is explained below and provided by the Supplier Performance Assessor
3. It selects most appropriate supplier for the Purchasing and the agent sends a report to Supplier Performance Assessor.

After the agent architecture of the model is created, then design architecture of the proposed model is developed to satisfy the motivation of the proposed model.

2.2. Design Architecture of the Proposed Model

In order to satisfy model motivations listed above, the following components are generated within the architecture.

2.2.1. Supplier Selection and Definition

Module primarily creates a “supplier card” for each supplier and stores the related information of each raw material supplied.

```
public class Supplier {
    public void addSupplierCard(String name, String code,
        ContactInformation supplier, List<RawMaterial> materials, List<PQPT>
        pqpt, List<SupplierParameter> supplierParameters) {
        SupplierCard suppliercard = new SupplierCard(name, code, supplier,
            materials, pqpt, supplierParameters);
            this.saveSupplierCard(suppliercard);
        }
    private void saveSupplierCard(SupplierCard suppliercard) {
        }
    }
    public class SupplierCard {
        public String Name;
        public String Code;
        public ContactInformation Supplier;
        public List<RawMaterial> Materials;
        public List<PQPT> PQPT;
        public List<SupplierParameter> supplierParameters;
        public SupplierCard(String name2, String code2, ContactInformation
            supplier2, List<RawMaterial> materials2,
                List<PQPT> pqpt2, List<SupplierParameter>
            supplierParameters2) {
        }
        public float calculatePQPTbyRM(RawMaterial rawMaterial) {
            float pqpt;
            // calculate pqpt
            return pqpt;
        }
    }
    public class SupplierParameter {
        public RawMaterial RawMaterial;
        public String Shipment;
        public float DeliveryTime;
        public float TotalCapacity;
        public float UsedCapacity;
        public float calculateAvailable() {
        }
    }
}
```

Fig. 5: Structural frame code of the Supplier Card

This is required for the sake of sustaining the integration. The content of the supplier card is provided in Appendix A. In other words, integration between raw materials and suppliers are satisfied by means of supplier cards. The Structural frame code of the Supplier Card function which is denoted as $f_{p,ts,t}^{PrD}$ is given Figure 5.

2.2.2. Supplier Performance Assessor

Module is designed for measuring the purchasing performance using a mathematical model. This provides the ability to measure the goodness of the suppliers. Suppose;

$f(SA) =$

$\{P_t^S, A_q^S, Q_{q,dr}^S, f_{q,ts,t}^{SD}, f_{q,ts,t}^{SPm}, SSS_q, \epsilon_q^S\}$

denotes the function set of the Supplier Model,

where;

- P_t^S set of percept of supplier q,
- A_q^S set of actions of supplier q,
- $Q_{q,dr}^S$ set of defect rate dr of supplier q,
- $f_{q,ts,t}^{SD}$ denotes the Supplier card definition function task ts of supplier q, at time t,
- $f_{q,ts,t}^{SPm}$ is performance measurement function task ts of supplier q, at time t,
- SSS_q denotes the system states of the Supplier Agent and
- ϵ_q^S defines set of environmental states of the Supplier Agent,

Total success factor of the suppliers (indicated by Z) is calculated as;

$$\text{Max } Z_s = \text{avg}(\sum_{q,rm}^S (RM_{q,rm,pqpt})) \quad (4)$$

where, $RM_{rm,pqpt}$ refers the PQPT value of raw material rm purchased from supplier q. And average, PQPT value is assumed as success rate of supplier q. In similar way, equation 5 is designed for the negotiation process between PQPT value and Opportunity Cost.

$$OC_{r,q} = P_q^r * TQ_r * [1 + (\text{interest rate}/100)]t \quad (5)$$

where;

- P_q^r represents the unit price of raw material r of supplier q
- TQ_r denotes the total need of the raw material r
- t refers the payment term
- $OC_{r,q}$ is opportunity cost for raw material r to be purchased from that supplier q

This calculation is especially important for making selections among the suppliers with equal P values. As keeping the cash capital for a while provides extra profit. Structural frame code of supplier measurement function $f_{q,ts,t}^{SPm}$ is provided in Figure 6.

```
public float calculateZbyQ(RawMaterial rawMaterial) {
    float z;
    // calculate z
    Return z;
}
public class Z {
    public float OpportunityCost;
    public float calculate() {
    }
}
```

Fig. 6: Structural frame code of Supplier performance Assessor

After calculating the Opportunity Cost, this information is sent to the Buyer Agent to decide on necessary procurement. When there is a new purchase, the related new supplier success value is recorded in Database.

2.2.3. Task Manager

It is designed to allocate the tasks. It enables system administrators to update the related information which includes system dynamics (beliefs, desires, rules, etc.). These dynamics give the model an ability to establish basic rules for the interactions and satisfy self-organizing capability.

In order to establish self-organizing capability; the business rules, which will ensure information flow was created. The information flow between agents is shown in Figure 7.

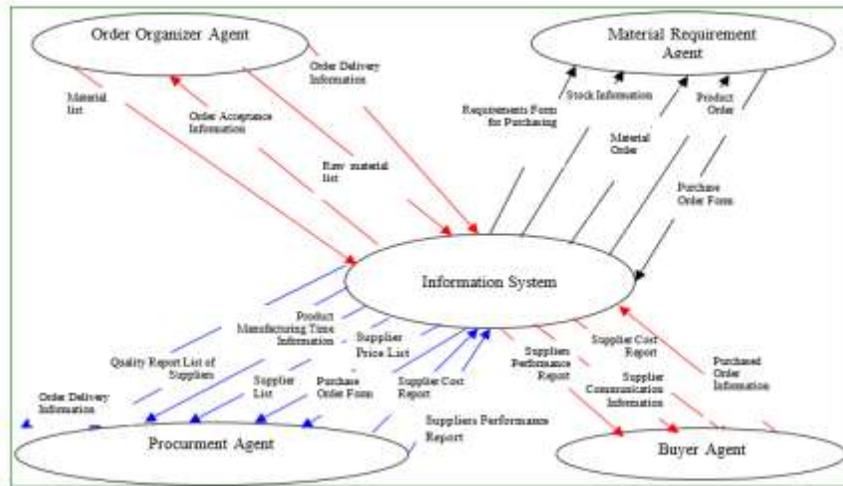


Fig. 7: Proposed Supplier Model Information Flow

```

<envelop>
  <from>
    TM
  </from>
  <to>
    SPA
  </to>
  <Supplier>
    <Supplier>
      RMSG1
    </Supplier>
    <Supplier>
      RMSG5
    </Supplier>
    <Supplier>
      RMSG6
    </Supplier>
  </Supplier>
  <requestType>
    successValue
  </requestType>
</envelop>

```

Fig. 8: An example request from TM -> SPA (Task Manager to Performance Assessor)

Some of the pre-defined business rules are listed below;

- Supplier success defines the intervention of the decrease in performance of the supplier by means of the supplier success.
- A relationship between raw-material/material with Supplier is to be set
- To prevent shortcoming of the goods, idle time calculation is to be done
- By using AHP, weights of the each criteria (price, quality, and odor measurement) is to be defined

- Supplier PQPT (price, quality and payment) value of each Supplier (read Procurement agent working principle) is to be calculated.
- For the equal PQPT values, opportunity cost value is to be calculated to select most appropriate supplier
- The supplier s the most appropriate on when PQPT value or opportunity cost is the most suitable
- After each new procurement, new success level of each supplier is to be calculated

Similarly, the *KQML* message standard and XML is selected for Agent Communication Language. One of the applied XML structure is illustrated in Figure 8 for the Supplier success measurement task event of Supplier 1.

2.2.4. The Scheduler

It responsible for both satisfying the adaptation of the model-based intelligent design system, and control of the activities within the model. These are being explained respectively.

Ability to adapt: An example adaptation rule of the Supplier Agent is pre-defined and given in Figure 9.

```

//Supplier selection
public SupplierCard supplierSelection(RawMaterial rm){
SupplierCard supplier;
float pqpt = 0;
for(SupplierCard sc : SupplierCardList){
if(sc.Materials.contains(rm)){
if(sc.calculatePQPTbyRM(rm) > pqpt){
supplier = sc;
}
}
}
return supplier;
}

```

Fig. 9: An example rule for adaptation

After every production process completed, when the stock level of any raw material being used is decreased below the minimum stock level, the process of supplier selection is started. It takes process information from the system, checks for needs and sends this information to Material Requirement Agent. In addition, this model controls the activities in the model by means of a precedence relation given Figure 10 below.

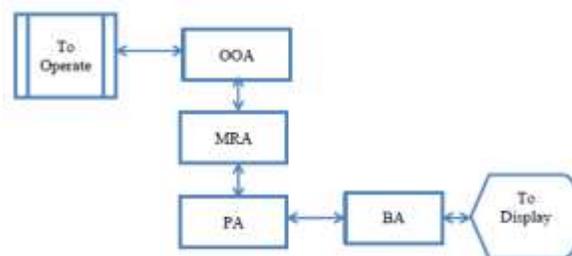


Fig. 10: Precedence rule in the proposed model.

3. Case Study

A prototype case study is implemented in a real manufacturing company located in Istanbul, Turkey. It manufactures cabin products and markets these products to many different countries of the world. Due to the sensitivity of the information used and the competitiveness, the name of the company is intentionally named as ABC. The applying the proposed system in ABC is explained step by step below.

Step 1: The data about the suppliers of the company were collected in order to generate respective supplier cards (see Appendix A). Then, weights of each criteria are determined by the experts using AHP (see Table 1)

TABLE 1: AHP matrix (P-price, Q-quality, and PT- payment term)

	P	Q	PT
P	1	4	3
Q	0.25	1	3
PT	0.33	0.33	1

A normalized matrix was built and relative weights are gathered as shown in Table II.

TABLE II: AHP normalized matrix

	P	Q	PT	W
P	0.63	0.75	0.43	0.60
Q	0.16	0.19	0.43	0.26
PT	0.21	0.06	0.14	0.14

For the detail information on calculation of normalized matrix see Taha [19].

Step 2: The payment dates of the company were categorized in accordance with the view of experts as the following:

- i. “0” for suppliers who demand cash on delivery
- ii. “1” for suppliers who demand payment after 30 days from delivery
- iii. “2” for suppliers who demand payment after 60 days from delivery
- iv. “3” for suppliers who demand payment after 90 days from delivery

For calculating the utility function; $PQPT_{6,1}$ denotes the utility function value of supplier 6 for raw material say,

h_1

- i. Price / Lot (TL) of h_1 is 1.3 TL (TL: Turkish Lira)
- ii. Quality value of Supplier 6 is 59% (can be seen in Table 3)
- iii. Payment Term of the Supplier 6 is 3.
- iv. Total need (from production order) is assumed as 350

Utility Function of supplier 6 for the raw material type h_1 is calculated as;

$$(PQPT_{6,1}) = (1/(0.63*1.3)) + 0.26*59 + 0.14*3 = 17.04$$

Step 3: A database for the quality levels of the suppliers of the company was created and defined in the software. Table III shows a part of the table prepared to measure suppliers' quality levels. The table shows that the quality success levels of suppliers which can supply h_1 .

TABLE III: A part of quality success levels of suppliers

Suppliers	Number of Raw Material Type	Number of fault Raw Material Type	Correct Raw material percentage	Received Raw Material	Fault Raw Material	Correct Received unit percentage	Number of Shipment	Number of Fault Shipment	Correct shipment percentage	Average Quality Success level
S1	22	9	59.09%	2169	520	76.03%	13	5	61.54%	65.55%
S2	21	2	90.48%	169000	27402	83.79%	43	2	95.35%	89.87%
S3	11	1	90.91%	12834	540	95.79%	7	1	85.71%	90.81%
S4	28	5	82.14%	167033	14980	91.03%	40	6	85.00%	86.06%
S5	71	7	90.14%	2203477	242724	88.98%	79	7	91.14%	90.09%
S6	1	1	0.00%	176000	16000	90.91%	8	1	87.50%	59.47%

Step 4: The software is executed to analyze the available suppliers. For the demonstration of the model, two orders for product 069007Q00 are created; o1 and o5. The program was run for the selection of a suitable supplier for another raw material h2 which is required to produce 069007Q00.

As explained earlier, Order Organizer Agent receives the new orders from the user and sends this information to the Material Requirement Agent by means of software communication.

There were two different orders for product 069007Q00. Requested units in o1 are 150, and requested units in o5 are 200. The information that a total of 350 products will be produced reaches Material Requirements Agent. Agent calculates the required units of raw materials. For this product, the order amount is equal to 350 units, depend on the bill of material list, required h2 units are calculated by the software. Then, Agent searches for the available suppliers for the related raw materials depend on the zero stock assumption.

There is one more important decision here, two orders have different due dates, agent considers the order which has minimum due date for the select available supplier (see equation 2). There are 7 suppliers available for supplying h2 as shown in Table IV.

TABLE IV: Searching for Available Supplier for h2

1	Order = o1 Order = o5, Product = 069007Q00, Material = h2, Supplier = s1 , Supply Time = 11.0
2	Order = o1, Order = o5, Product = 069007Q00, Material = h2, Supplier = s3 , Supply Time = 3.0
3	Order = o1, Order = o5, Product = 069007Q00, Material = h2 Supplier = s4 , Supply Time = 5.0
4	Order = o1, Order = o5, Product = 069007Q00, Material = h2, Supplier = s5 , Supply Time = 4.0
5	Order = o1, Order = o5 Product = 069007Q00 Material = h2 Supplier = s8 , Supply Time = 8.0
6	Order = o1, Order = o5, Product = 069007Q00, Material = h2, Supplier = s9 , Supply Time = 5.0
7	Order = o1, Order = o5, Product = 069007Q00, Material = h2, Supplier = s10 Supply Time = 8.0

TABLE V: Supplier Information for Material h2 with PQPT

1	Order = o1, Order = o5, Product = 069007Q00 Material = h2, Supplier = s1, Supply Time = 11.0, Cost = 76.0, Quality = 20.0, Payment Term = 3.0, PQPT = 5.64
2	Order = o1, Order = o5, Product = 069007Q00 Material = h2, Supplier = s3, Supply Time = 3.0, Cost = 121.59, Quality = 90.0, Payment Term = 0.0, PQPT = 23.41
3	Order = o1, Order = o5, Product = 069007Q00 Material = h2, Supplier = s4, Supply Time = 5.0, Cost = 197.6, Quality = 90.0, Payment Term = 1.0, PQPT = 23.54
4	Order = o1, Order = o5, Product = 069007Q00, Material = h2, Supplier = s5, Supply Time = 4.0, Cost = 380.0, Quality = 85.0, Payment Term = 2.0, PQPT = 23.68
5	Order = o1, Order = o5, Product = 069007Q00, Material = h2, Supplier = s8, Supply Time = 8.0, Cost = 167.19, Quality = 90.0, Payment Term = 1.0, PQPT = 23.54
6	Order = o1, Order = o5, Product = 069007Q00, Material = h2, Supplier = s9, Supply Time = 5.0, Cost = 273.6, Quality = 80.0, Payment Term = 1.0, PQPT = 20.94
7	Order = o1, Order = o5, Product = 069007Q00, Material = h2, Supplier = s10, Supply Time = 8.0, Cost = 170.24, Quality = 90.0, Payment Term = 0.0, PQPT = 23.4

As shown in Table IV, available suppliers for raw material h2 are 1, 3, 4, 5, 8, 9, and 10. The agent sends this information to the procurement agent for calculating PQPT values by also using AHP decision tool. Table V includes this information.

As can be seen by this analysis, the best Suppliers by PQPT is s₅ with the following information.

Order = o₁, Order = o₅, Product = 069007Q00, Material = h₂, Supplier = s₅, Supply Time = 4.0, Cost = 380.0, Quality = 90.0, Payment Term = 2.0, PQPT = 23.68

The procurement agent sends this information to the Buyer Agent. It then, sends a request to Supplier Performance Assessor to receive the values of the opportunity costs. Supplier Performance Assessor, on the other hand, calculates the opportunity cost of each purchasing alternative which has more or less the same PQPT values (S₃, S₄, S₅, and S₈). Results of calculation are given in Table VI.

TABLE VI: Opportunity costs of the suppliers for material h₂

1	Order = o1, Order = o5, Product = 069007Q00, Quantity = 350.0, Material = h2, Raw Quantity = 350, Supplier = s3 , Supply Time = 3.0, Cost = 121.59, Quality = 90.0, Payment Term = 0.0, PQPT = 23.41, Opportunity Cost = 0.0
2	Order = o1, Order = o5, Product = 069007Q00, Quantity = 350.0, Material = h2, Raw Quantity = 350, Supplier = s4 , Supply Time = 5.0, Cost = 197.6, Quality = 90.0, Payment Term = 1.0, PQPT = 23.54, Opportunity Cost = 1152.66
3	Order = o1, Order = o5, Product = 069007Q00, Quantity = 350.0, Material = h2, Raw Quantity = 350, Supplier = s5 , Supply Time = 4.0, Cost = 380.0, Quality = 90.0, Payment Term = 2.0, PQPT = 23.68, Opportunity Cost = 4433.33
4	Order = o1, Order = o5, Product = 069007Q00, Quantity = 350.0, Material = h2, Raw Quantity = 350, Supplier = s8 , Supply Time = 8.0, Cost = 167.19, Quality = 90.0, Payment Term = 1.0, PQPT = 23.54, Opportunity Cost = 975.33

S5 is also the best supplier based on opportunity cost calculation;

Order = o₁, Order = o₅, Product = 069007Q00, Quantity = 350.0, Material = h₂, Raw Quantity = 350, Supplier = s₅, Supply Time = 4.0, Cost = 380.0, Quality = 90.0, Payment Term = 2.0, PQPT = 23.68, Opportunity Cost = 4433.33

Supplier Performance Assessor sends this information to the Buyer Agent. All this calculations shows that S5 is the most appropriate supplier to purchase h₂. Buyer agent sends a procurement order to this supplier. The Supplier Performance Assessor also sorts the PQPT values from bigger to smaller using the following classification and records the new success value for h₂ in each supplier card is calculated using the following rules.

- On the supplier's card of Supplier which has the highest PQPT value, change the h₂ success rate to 1,
- On the supplier's card of Supplier which has the second highest PQPT value, change the h₂ success rate to 2 ,
- Go on until all supplier h₂ success values are updated.

The following formula is used to calculate the overall percentage of success for each supplier after new updates.

Overall Success = Sum of all PQPT Sequence values for all materials sold by the supplier / Number of materials sold by the supplier (see last column of Appendix A)

Results of this calculation are interpreted as the following.

If overall success=1 then, respective supplier success rate is 100%

If overall success is between 1.01 and 2.00 then, respective supplier success rate is 80%

If overall success is between 2.01 and 3.00 then, respective supplier success rate is 60%

If overall success is between 3.01 and 4.00 then, respective supplier success rate is 40%

If overall success is between 4.01 and 5.00 then, respective supplier success rate is 20%

If overall success is greater than 5.01 then, respective supplier success rate is 0%

Suppose that, three different products are supplied by supplier S5 namely, h₂, h₄ and h₅. After every procurement process, total success value must be recalculated. Total success value can then be calculated based on the classification defined by Supplier Performance Assessor. If;

- success of h₂ calculated as 1 ;
- success of h₄ was 2;
- success of h₅ was 3:

Total success rate of S5 calculated as: $(1+2+3)/3 = 2$

That means, **the success level of s5 is 80%.**

Suppose success level of all suppliers is calculated as the following.

S1: Company A	80.00%
S2: Company B	60.00%
S3: Company C	40.00%
S4: Company D	60.00%
S5: Company E	80.00%
S8: Company F	60.00%
S9: Company G	80.00%
S10: Company H	40.00%

Then, the Average Success Rate of the calculated by the model for all suppliers is 62.5%

Case study results indicate that the company must be improved their Suppliers list. Up to now, execution of the model is explained. The proposed model is also simulated for different pieces and the effect of the results is examined. As can be seen from the Figure 11, the proposed model has provided a significant decrease in procurement cost. Also, it is seen that when the purchased quantity increase, the decrease rate of the model on purchasing cost is increasing.

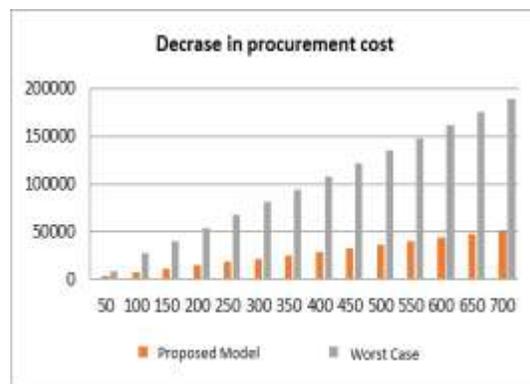


Fig. 11: Some of the simulation results conducted on procurement cost (in terms of \$)

4. Conclusion

In this study, it was focused on possibility of using agent based system for supplier selection problem in order to increase automation and autonomy for the sake of productivity as well as efficient decision making on suppliers. This study differs from previous work in twofold. First, the model takes the payment term into consideration. And second, in addition to the performance measurement of a specific supplier, it gives the ability to measure how well the company selection process is implemented. The results of the case study, clearly indicated that the supplier selection capability of company ABC is increased while the procurement is decreasing.

The study will continue with the following objectives;

- Although agent adaptation and agent learning is stated in the model, a multi-agent learning should be developed in order to increase the level of integration between different modules.
- A more systematic way to define the weight values are to be defined.
- Continue to extend the current prototype to all manufacturing functionalities.
- Integrating the model within the framework of Industry 4.0 is yet to be investigated.

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APPENDIX A. Pre-defined Supplier Card – (for Supplier S5)

SUPPLIER CARD																
Supplier Name		Company B											No:	00001-S2		
Card Code:		S5											Date:	01.01.2014		
Address		Bostanci				City:			Istanbul			Country:		Turkey		
Contact Person		x				Contact Phone:			x			Email:		x		
Material Code	Name	Quality Test Code	Measurement Parameters-1			Technical Parameters				Shipment Type	Delivery Time / Lot	Total Capacity / TMTH	Used Capacity / TMTH	Available Capacity / TMTH	PQPT Measurement	
			Price / Lot (TL)	Quality Value	Payment Term	Width	Height	Thickness	Color						PQPT Value	Sequence in PQPT list
h2	0.8 mm Sheet Metal Gage	T1	1,3	85	2	-	-	0,8	-	ST1	12	500	-	500	23,6	1
h4	1.2 mm Sheet Metal Gage	T1	0,7	89	2	-	-	1,2	-	ST1	12	500	-	500	25,8	2
h5	1.5 mm Sheet Metal Gage	T1	1,2	89	2	-	-	1,5	-	ST1	5	500	-	500	24,8	3
Total Success Value of S2																80%