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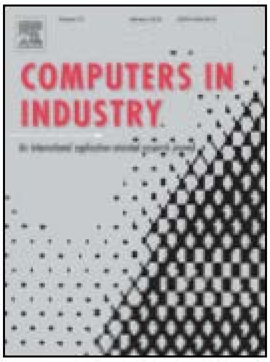

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A Multi-agent System for Minimizing Energy Costs in Cement Production

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Abstract

A cement production planning system is expected to minimize energy costs. Further, such a system needs to be as autonomous as possible to decrease time loss during the communication between related departments of the plant. Hence, in this paper, we present a multi-agent system (MAS) in which software agents work collaboratively in order to assist production, planning and sales departments of a cement plant for the generation of cost-effective cement production plans. Implemented system was deployed and actively used inside one of the plants of a leading cement company in Turkey. Evaluation result shows that the utilization of the proposed system caused a significant energy cost saving. Moreover, workers in the planning department of the cement plant saved approximately 75% of their working hour by using the system. Total workload of the employees (including all departments) decreased to its half.

Keywords: software agent, multi-agent system, mobile agent, production planning, cement production

1. Introduction

Decreasing energy costs, which constitute a big part of cement plants' overall costs, is very important for a cement company while competing in the market. A specific cement production planning system, which decreases energy costs, is necessary when we consider the effect of energy costs on profitability. Furthermore, such a cement production planning system needs to be as autonomous (with minimum human intervention) as possible to decrease time loss during the communication between related departments of the plant. In

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order to produce the best production plan that covers the minimum production cost, required software system should also include the desired computation capability to create this best plan.

We believe that a system, based on the software agents (Wooldridge and Jennings, 1995) with autonomous and reactive behavior capability, may provide an appropriate option to meet the aforementioned requirements of cost-effective cement production planning. Hence, in this paper, we present a multi-agent system (MAS) in which software agents work collaboratively to assist production, planning and sales departments of a cement plant for the generation of the cement production plans. During the cement production plan generation, agents especially take into account minimizing energy costs. Moreover, agents employed in cement sales are implemented as mobile autonomous software entities and deployed on cellular phones of sales representatives; such that these agents can remotely communicate and collaborate with production and planning agents in order to support sales representatives in determination of the best (and at the same time cost-effective) product delivery offer while representatives visit the customers. Proposed MAS was deployed and actively used inside one of the plants of a leading cement company in Turkey. Evaluation of the proposed system within the context of this real-life application is also given in this paper.

The rest of the paper is organized as follows: Related work is given in Section 2. Section 3 includes a discussion of the domain and gives the motivation behind our study. Section 4 discusses the internals of the proposed agent planners. The implementation of the designed MAS is given in Section 5. Section 6 includes the practical evaluation of the system. Section 7 concludes the paper.

2. Related Work

Production planning in cement industry is relatively very new research field. Mostly researchers gave importance to other areas like sales forecasting and supply chain management instead of production planning. Originating from the idea of forecasting cement demands accurately, Ramani and Dholakia (Ramani and Dholakia, 1999) propose a decision support system (DSS) to forecast sales by using time series and econometric methodology. In (Aliev et al., 2011), the application of a fuzzy inference system is introduced for the cement production time series forecasting.

Recent work in (Padhan, 2012) covers the application of various univariate time series forecasting models and proposes that seasonal autoregressive integrated moving average (SARIMA) model is the best performer for cement demand forecasting. Derks and Spieksma (Derks and Spieksma, 1996) introduce a DSS for cement industry even before aforementioned studies. However, their study only considers locating cement plants and aims to bring a solution to the ordinary routing problem.

Following cement demand/sales forecasting studies, a noteworthy work (Spyridakos et al., 2009) is about an inventory control DSS. The system uses a model that helps to minimize total variable cost caused by orders and inventory. (Sahoo et al., 2010) includes a DSS for supply chain planning in cement production. The outputs of the system are production mix, production plan and routing plan. In (Hvam et al., 2006), assessment of a procedure for building product models was realized inside a cement factory. Proposed system optimizes the cement factories with respect to both an increased use of the company's components and the use of previously manufactured components.

The study, conducted within Heidelberg Cement Factory in 2011, presents a real life implementation of a DSS for a cement company (JDA, 2011). Deciding the whereabouts of a new facility or warehouse can be performed more accurately by using this system while minimizing the transportation costs. Most recent work (Mahdavi et al., 2013) on increasing the performance of the cement plant takes into account improving the quality of cement processes by controlling the process correction. Our approach and Mahdavi et al.'s work have similarity in the use of agents during the cement production processes. Mahdavi et al.'s system is noteworthy since the method based on intelligent agents also enables to estimate the cost saving in the plants using cement data and the price of cement. Similar to their work, our work also aims at decreasing production costs by employing a MAS. However, our approach mainly focuses on minimizing energy consumption costs and lightening the workload of the departments inside the plant.

As we can see above, there exist significant studies about improving decision support and/or supply chain management for cement plants. Our study contributes to these efforts by presenting an autonomous software system for the cement production planning while it differs from these studies by concentrating specifically on minimizing the energy consumption during the cement production. Another contribution of the introduced system in this paper is to provide the agent-based derivation of alternative production plans in addition to the main generated plan.

On the other hand, there are lots of studies about the development of (mobile) agent systems also considering their industrial applications, e.g. development of Internet applications (Chunlin et al., 2002), network management (Satoh, 2003), supporting survivability and fault tolerance (Lyu et al., 2004), control of intelligent surveillance systems (Pavon et al., 2007), assisting a factory to find suitable outsourcers for customer orders (Cheng and Wang, 2008), dynamic deployment of tasks in automation systems (Nestinger et al., 2010), detection and following of humans (Gascuena and Fernandez-Caballero, 2011), document management (Pesovic et al., 2011) and concurrent supply chain negotiations (Wang et al., 2013). Although all of these studies include valuable efforts on agent-based software development for various industrial domains, none of them takes into account design and implementation for production planning in cement industry.

Finally, it is worth indicating that methods based on the computer-integrated manufacturing (CIM), DSS, neural networks (NN) or holonic systems can also be applied for the production planning and/or energy conservation in various industrial domains. As its name already depicts, all production processes are controlled by using computers inside a CIM (Kalpakjian and Schmid, 2013). Production planning can be automatized via computers, e.g. operators in the production are replaced with the automation technologies and hence the efficiency and reliability of the planning may be enriched. In addition to those benefits, traditional control, brought by the CIM, also represents a top-down and centralized solution for each individual control function. CIM systems are also more efficient for the production with high volume and low variability as reported in (Leitao, 2009). However, CIMs own mostly static architectures comparing with the flexible and dynamic architectures of agent-based solutions. Moreover, intelligence is centered in the top levels of a CIM while it is distributed by the control levels in an agent-based manufacturing. Leitao (Leitao, 2009) also states that CIMs have weak response to disturbance comparing with the MAS.

Likewise, DSS are used for business or organizational decision-making activities over a computer-based information system. Specifically, a decision-making software, which can be considered as one type of DSS, supports the decision analysis involved in decision-making processes most commonly based on the multi-criteria decision making (Wallenius et al., 2008). In general, utilization of DSS enables the automation of managerial processes, quickens the decision making and provides ranking, sorting or choosing from among alternatives. For instance, McKay and Wiers (McKay and Wiers, 2003) discuss the design of an integrated planner which is based on decision support and realizes planning, scheduling and dispatching tasks for a field site. Further, while discussing the related work on cement production planning in the above, we have already exemplified the use of DSS for sales forecasting (Ramani and Dholakia, 1999), routing between the plants (Derks and Spieksma, 1996) and inventory control (Spyridakos et al., 2009) in the cement industry. But, as remarked in (Power, 2009), DSS can overemphasize decision making and the managers may use them inappropriately in many situations. A poorly designed DSS also increases information load. Comparing with MAS, autonomy brought by DSS would be limited since human intervention is much more required.

In addition to above techniques, use of artificial NNs are proposed by many researchers in order to manage a wide variety of industrial tasks (e.g. process monitoring, process control), which are hard to manage using ordinary rule-based programming. For example, Yu et al. (Yu et al., 2008) show that the integration of a knowledge-based artificial NN with a genetic algorithm-based rule extraction can improve the product quality, save manufacturing costs and optimize the manufacturing process by helping the operators during system monitoring. Use of NN for business optimization is discussed in (Groza et al., 2008). Specifically, Groza et al. discuss how NN-based approach provides the automatic optimization of the strategic management decision making required for enterprise resource planning. Although NN-based solutions have the potential for improving industrial processes, difficulties can be encountered during the real application of such systems. Lennox et al. (Lennox et al., 2001) discuss a 2-year industrial investigation into the practical application of NN in the area of process monitoring and control. Based on the findings, they indicate that the insufficient volume of data, irrelevant data transformation and over-fitting and over-training NN models are some of the issues that prevent the justification of NN usage in wide-range of industrial application domains.

Employing holonic systems is another emerging approach for the development of complex industrial and business systems. Holonic systems research has primarily focused on intelligent manufacturing systems and has been organized around the international Holonic Manufacturing Systems (HMS) consortium (Brennan, 2001). Specifically, HMS can also be utilized for flexible process planning and scheduling (Sugimura et al., 2003). Composition of self-reliant units with behavior capability makes HMS appropriate for integrating wide range of manufacturing activities in various industrial domains. However, the implementation of holonic manufacturing is usually realized by already using the agent technology (Shen et al., 2006) due to the agent's natural support in autonomy, cooperation and distributed intelligence (Leitao, 2009). Hence, a holon in a HMS can be considered as a special type of agent that populates a system where there is no high-level distinction between hardware and software (Brennan, 2001).

Taking into account the above discussion of other alternative methods/technologies and benefits of using MAS which are exhibited as the result of the individual comparisons with those alternatives, we believe that an agent-based solution best matches with the requirements of the distributed and autonomous production planning. Studies such as (Shen et al., 2006) and (Leitao, 2009) review the fruitful industrial applications of MAS and hence support our assessment within this context. Further, we think that the use of MAS facilitates the implementation of our software design into action specifically for the cement production and energy conservation. As will be discussed in the following sections, use of agents enables to cope with sophisticated interaction among production, planning and sales departments in a cement plant. Also, mobility feature provided by the sales agents in our system enhances the determination of optimal production planning plan with including minimum energy consumption while receiving sales demands from the customers outside the plant. We think that it is crucial for such cement production processes and software agents provide the best way for the implementation of the required mobile autonomy.

3. Saving Energy Cost during Cement Production

For an ordinary cement plant[2], Energy Cost is nearly 25% of all Variable Costs and it is the next biggest item after Thermal Cost. Decrease in Thermal Cost is very difficult since it requires expensive investments like changing some part of rotary kilns. On the other hand, we examine that energy cost (covering Consumed Energy Amount and Energy Price) can be changed without big investments. Change in Consumed Energy Amount is very hard since again it requires some important investments or process changes. However, with a proper production plan, we can definitely make optimization related to the Energy Price. Total

[2] Although a cement production company may consist of many plants geographically distributed over a country (or even over the world), for the sake of simplicity, we prefer to discuss on a company as if it only has one plant. Hence, the terms "cement company" and "cement plant" representing the company are used interchangeably throughout of the paper.

Energy Price is calculated as Fix Costs plus the multiplying of Energy Price of each time zone and Usage Ratio at each time zone. Energy Price of each time zone is constant and set by the electricity company from which the cement plant purchases. Hence, Usage Ratio is the most suitable item for us to work on. It can be changed by planning the production and shifting working hours. To be more specific, we can divide production time into three time zones: Day, Night and Peak. “Night” is the zone between 10:00 P.M. and 6:00 A.M. while “Day” covers the duration between 6:00 A.M. and 5:00 P.M.. Finally, “Peak” represents the remaining zone (between 5:00 P.M. and 10:00 P.M.).

Based on the average energy tariff of Turkey, peak time price is approximately 2 times higher than day time price and 4 times higher than night time price. Hence, if we can shift some peak time work hours of the cement plant to other time zones, our costs can significantly drop. We could argue whether this change/shift worths trying. A simple calculation of the change in the invoice covering the energy expenses helps us for this purpose. We had the chance to obtain approximate energy usage ratios of Çimentaş (Çimentaş, 2014), a leading cement company in Turkey. For example, in 2011, Peak Time usage ratio is 15.55% and the roughly calculated invoice costs approximately 12,400,000 €. If we could shift that 1% peak hour usage into the night hour working, then we would receive an invoice that costs 12,250,000 € and that amount is 150.000 € smaller than the actual invoice paid by the cement company. We believe that software agent plans, which cover the required tasks for workload calculation and above time zone shifting, can be capable of organizing the optimal cement production plan in an autonomous manner.

Generally, in a cement company, the production department collects production data and updates them for the planning department. On the other hand, the sales department collects sale requests and asks the planning department for the chance of realizing these sales. The planning department creates a possible plan by combining both information came from the production and sales departments and returns this plan to these departments. Required connections and communications between these departments are usually too slow and ineligible for customers in many situations. For instance, sales department’s representative may be in a meeting with the customer outside the cement plant and needs a quick response from the planning department. Hence, a mobile production planning software (e.g. an agent in our system) can help them to give a quick reply to customers about the availability of that specific sale. In addition to support quick response to the customer, the planning department should also consider minimizing the energy usage ratio while creating the production plan.

4. Proposed MAS for Cement Production

In this section, we first discuss knowledge and/or constraints that software agents consider during planning within the proposed MAS. Later, internals of agent plans are discussed.

4.1. Knowledge for cement production planning

Agents, who will be employed for the task of generating the best production plan, should take into account following knowledge and/or constraints:

(i) ***Sales plan*** covers the future sales planned according to the customer orders. For example, it can be stated such that 5000 tons of cement "CEM II A-W" should be loaded on a ship by the end of July 13, 2013. Sales plan is prepared by the sales agents in our system.

(ii) ***Minimum inventory*** is the least inventory amount of a specific product at any time. In our proposed system, it is set by the agents working on behalf of the production department.

(iii) ***Stoppage plan*** is the list of stoppages determined for a production period. It includes planned stoppages of cement mills plus some percentage of time for unexpected stoppages. Stoppage dates should be considered while calculating available working hours of each cement mill. Creation of this plan is the task of the production agent in the proposed MAS.

(iv) ***Capacity*** is the volume (i.e. tons) of a specific cement type that each mill can produce during a period of an hour.

A cement plant might have different priorities for different products and mills. For example, a product may not be produced at all cement mills or a product might be desired to be produced at a specific cement mill.

Agent planners have naturally inputs and outputs. Some of them are the constraints which we have mentioned above. We can separate them as:

Inputs: Sales plan, stoppage plan, minimum inventory, transfer inventory, capacity, energy consumption and price

Outputs: Daily production plan for each cement mill, total cost and cost for using additional capacity

All inputs except energy consumption and price are considered as constraints. In here, *Energy* represents the amount of electricity (kwh) that each cement mill consumes while producing one ton of cement. On the other hand, *Price* is also very important information for our goal because it is the main part of the energy cost. The price of electricity is different during different parts of the day as discussed in the previous section of the paper. It is clear that the agent planner should execute in a way that the agent minimizes the peak time workload and maximizes night time workload. The other important point is that all constraints should be covered while adjusting the time zones.

As the output of the agent planner, we expect to see a daily production plan, total cost information and an alternative capacity usage plan. A daily production plan includes the information of how much hours worked and how much cement produced for each time zone, each cement type and each cement mill. For example, Cement Mill No. 4 should work for 4 hours during day time and produce 400 tons of cement type "CEM I 42,5 R". Daily production plan is the extended version of this example to all time zones, cement types and cement mills. The other output that we expect is the total cost. The last output is an alternate plan. Our former plan is based on daily figures[3]. An alternative plan can be crucial for a decision because we can choose to work at the hours left from previous days instead of peak time of that day. For example, a daily plan can consist of 5 hours day time work, 4 hours night time work and 2 hours peak time work. Instead of 2 hours of peak time work, we can work 2 hours at night time of a previous (past) day. This decision can cause side effects (e.g. inventory problems or decision on supplements) but the choice is up to the user (e.g. sales department's representative). The user can choose between two alternatives that software agents generate.

4.2. Agent plans and collaborations between the agents

In our MAS, planning agent collects data from both production and sales agents. Then, daily and alternative plans are prepared. General flow of planning process is shown in Figure 1. As soon as it starts, production agent's duty is to send production figures (data) to planning agent.

[3] Since collected data from the execution of plant mills and/or information pertaining to the operation of the departments in the cement industry are all named with the term "figure", we prefer to keep using this term throughout the paper to refer such kind of data or information.

Everyday production figures should be updated by the production agent because working conditions can be changed. When the production figures are sent, the planning agent is ready for calculations. Remaining figures are about the sales. Sales agent can connect to the planning system anytime. When it connects, it sends sales information to the planning agent. After the planning agent gets sales information, it executes its plan and generates daily production plan and alternative of it. Finally, the sales agent is informed about these plans.

Tasks inside the overall agent planning system are based on reducing peak time working and increasing night time working. Whole behavior model of the planning agent, consisting of those tasks, can be represented with a function that we call ***Prodcalc()***. In the following pseudocode listings for Prodcalc(), "**i**" represents cement mill numbers, "**j**" represents three time zones (and takes value 1 for night, 2 for day and 3 for peak) and "**t**" represents cement types.

The first task (step) of the planning agent's plan is calculating the production volume. According to sales figures and inventory levels, daily production requirements of a specific cement type can be easily determined. The volume that will be produced must be the difference between sales volume and inventory level. While doing that, minimum inventory level should also be covered. Calculation of these figures for each cement type inside the agent planner is shown in Listing 1. Let $\boldsymbol{z}$ be the total number of cement types that can be produced in the cement plant. $\boldsymbol{rprod_t}$ is the required production volume for cement type $\boldsymbol{t}$. $\boldsymbol{sale_t}$ is the possible sale volume of cement type $\boldsymbol{t}$. $\boldsymbol{inv_t}$ and $\boldsymbol{minv_t}$ are the inventory and minimum inventory levels of product type $\boldsymbol{t}$.

```
for t=1 to z
        rprod_t ← sale_t – (inv_t - minv_t)
```

Listing 1: Calculation of the required production figures for each cement type

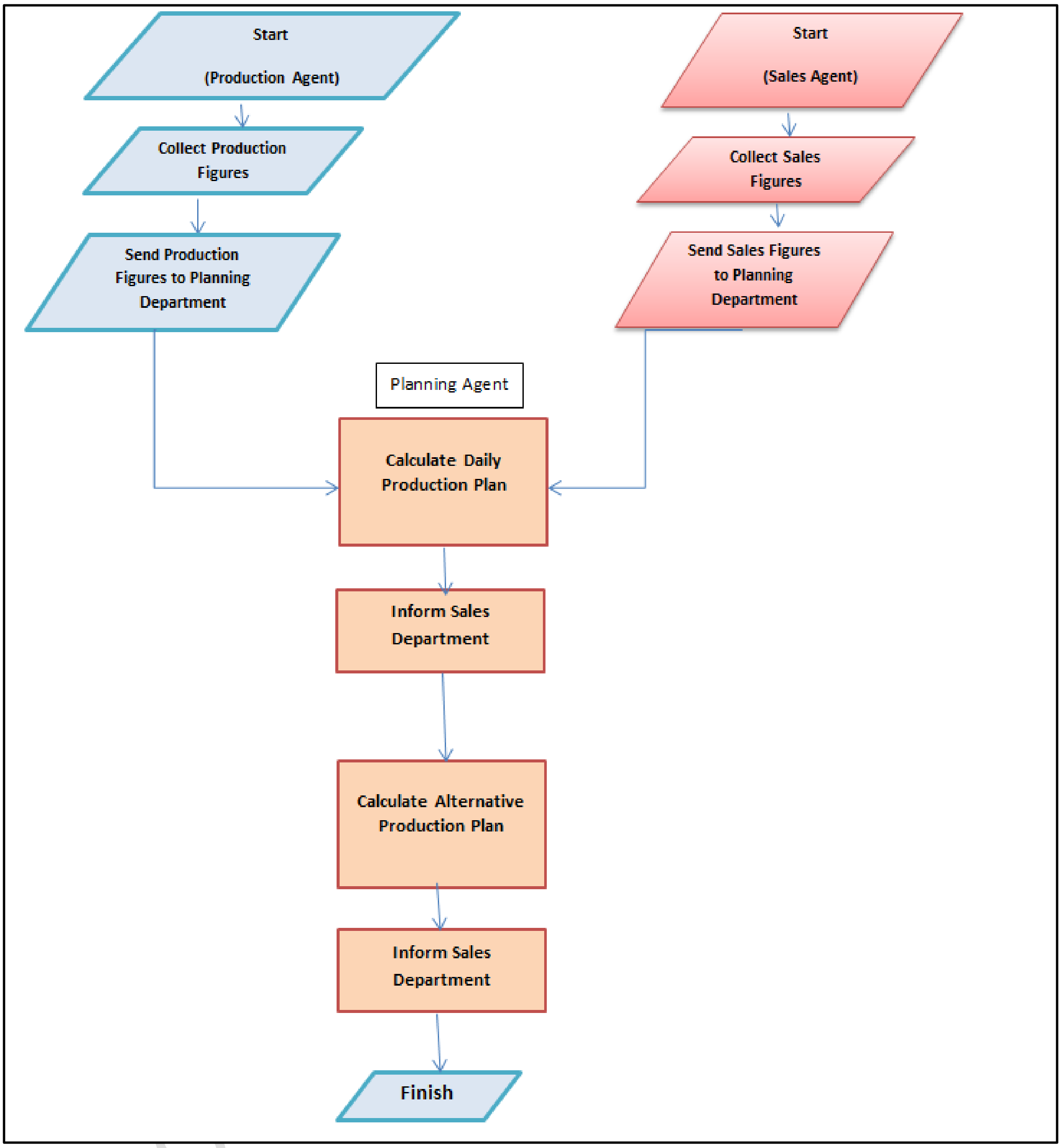


Figure 1: General information flow between agents

After calculating how much to produce, now it is time for the preparation of the detailed plan. As it is mentioned above, the main goal is minimizing the energy cost while covering all constraints. Energy cost is the multiplication of energy price (€/kwh), production volume (ton) and energy consumption (kwh/ton). Production volume cannot be decreased because it is necessary to cover demands. So, our agent's aim is to decrease the energy price. Of course, the unit price cannot be changed but as it is discussed above, different time zones have different prices. Choosing night time work is the most logical decision because it is the cheapest. Listing 2 shows the related agent plan in which agent generates optimal cement production plan based on the available zones and inventory. ***AT_{ij}*** is the available time for cement mill ***i*** at time zone ***j***. ***ton_{ti}*** is the tonnage of product type ***t*** at cement mill ***i***. ***WH_{tij}*** is the working hour of cement mill **i** for product type **t** at time zone **j**. ***$aprod_t$*** is the actual production volume for cement type ***t***. ***$Eprice_j$*** is the price of electricity at time zone ***j***. Price is the total real price. ***kwh_i*** is the energy consumption of cement mill ***i*** while producing 1 ton of cement. ***$capacity_t$*** is the production capacity which can be used for product ***t***. ***pastcap*** is the total past time capacity that can be used. ***$calcprod_t$*** is the volume of product ***t*** which can be produced. Within the same iterative approach, planning agent determines the best production plan for all requested product types and computes the cost of applying each plan.

```
capacity_1,2…z ← 0
calcprod_1,2…,z ← 0
price ← 0
for t=1 to z
        pastcap ← 0
        for i=1 to x
                for j=1 to y
                        capacity_t ← capacity_t + (AT_ij * ton_ti)
                        if   capacity_t < rprod_t    then
                                WH_tij ← AT_ij
                                AT_ij ← 0
                                calcprod_t ← calcprod_t +(WH_tij * ton_ti)
                                pastcap ← pastcap + (PAT_ij * ton_ti)
                                price ← price +(WH_tij * ton_ti * Eprice_j * kwh_i)

                                if   i=x and j=y  then
                                        capacity_t ← capacity_t + pastcap
                                        if   capacity_t >= rprod_t   then
                                             warn for PAST TIME CAPACITY USAGE
                                             exit from the loop
                                        else if  capacity_t < rprod_t   then
                                             warn for NOT ENOUGH CAPACITY
                                             exit from the loop

                        else if  capacity_t >= rprod_t   then
                                WH_tij ← (rprod_t – calcprod_t) / ton_ti
                                AT_ij ← AT_ij - WH_tij
                                aprod_t ← calcprod_t + (ton_ti * WH_tij)
                                inv_t ← inv_t + aprod_t – sale_t
                                price ← price + (WH_tij * ton_ti * Eprice_j * kwh_i)
                                exit from the loop
```

Listing 2: Product planning and determination of minimum costs for producing each requested cement type

Above computations of the agent are enough for planning a day in detail. If an alternative plan is needed, then peak time hours should be replaced with past days' hours. Details of creating the alternative plan (in which the agent makes related computations in the same manner with the above given plan) are not given in this paper due to space limitations. As the result, agents in the system prepare and recommend both production plans and the staff, who makes decisions, prefers one of them.

5. Implementation of the System

Proposed MAS for the cement production planning was implemented by using Jade MAS development framework (Bellifemine et al., 2007) and its add-on called Jade for Android (Jade-Android, 2012). Jade (Java Agent DEvelopment Framework) is a well-known software framework fully implemented in Java language (Bellifemine et al., 2001). It simplifies the implementation of MAS through a middleware that complies with the specifications determined by IEEE Foundation for Intelligent Physical Agents (FIPA) (FIPA, 2002).

Three agent classes, that extend Jade Agent class, were prepared for the implementation. They are Production, Planning and Sales agent as expected. The communication of the departments in real life is now supplied by the messaging system of Jade agents. Agent internals discussed in the previous section were implemented by using the behavior library of Jade API.

Production and planning agents were created with Jade's desktop distribution while sales agents were designed and implemented as mobile agents. Therefore, they were created by Jade's add-on for Android instead of Jade's desktop distribution. A different interface was built for our sales agent on Android (Android, 2012). A sales agent collects sale figures from the user on a mobile device and connects to other agents remotely.

The computer, used for the main container of the product and planner agents, includes Intel Core i5 2.50 Ghz CPU, 6 GB RAM and Microsoft Windows 7 64-bit OS. The version of Android which we use for the mobile device is 2.3.3 (Gingerbread). Device used for deploying mobile agents is Samsung Galaxy S i9000. It has 1 Ghz CPU, 2 GB user memory and 4.0” display (Samsung, 2012). Jade’s version 4.2.0 was used in this study.

To give some flavor of the implementation, collaboration among the system agents and interaction of sales agents with human sales representatives are discussed below. Production planning concerning only two cement mills and two cement types is exemplified for the sake of simplicity.

Figure 2 shows that production agent sends production figures to planning agent as soon as the connection between these two agents has been established. Available time, inventory level, energy consumption figures and energy price are sent to planning agent by production agent. For example, available day time for cement mill 1 is 11 hours and the transfer inventory of CEM II is 1000 tons. Unit electricity price for each time zone is given in Turkish Liras (TL)[4]. When planning agent gets all these information, a confirmation message is sent back. As can be seen from the message at the bottom of the screenshot, all production figures are now available and the planning agent is ready to get contacted with mobile sales agent(s) to receive sale figures and make proper decisions.

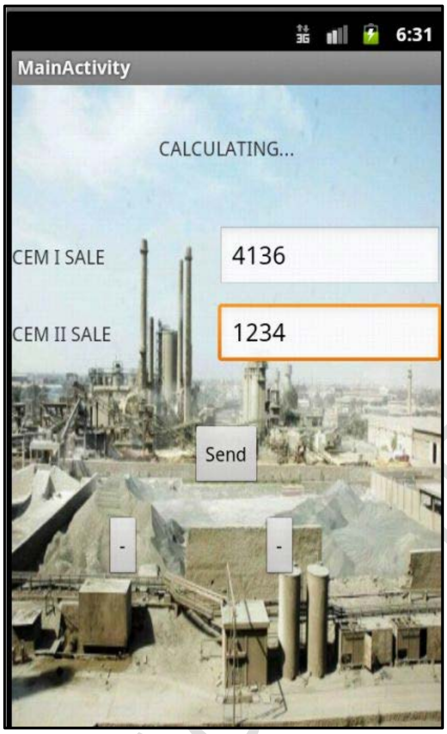
```
Agent container Main-Container@192.168.2.5 is ready.
--------------------------------------------
Transferring Stock Levels...
Transferring Tonnages...
Transferring Energy Figures...
Transferring Enery Prices...

Available Working Hours were transferred!
Tonnages were transferred!
Energy Figures were transferred!
Enery Prices were transferred!
Stock Levels were transferred!

Transfer COMPLETE!

PRODUCTION FIGURES

Day Time Mill 1 = 11 h --- Night Time Mill 1 = 8 h --- Peak Time Mill 1 = 5 h
Day Time Mill 2 = 11 h --- Night Time Mill 2 = 8 h --- Peak Time Mill 2 = 5 h

Devir Stok CEM I = 2000 ton --- Min. Stok CEM I = 1000 ton
Devir Stok CEM II = 1000 ton --- Min. Stok CEM II = 1000 ton

Tonnage of CEM I at Mill 1 = 200 t/h --- Tonnage of CEM II at Mill 1 = 100 t/h
Tonnage of CEM I at Mill 2 = 100 t/h --- Tonnage of CEM II at Mill 2 = 50 t/h

Electricity cons. of Mill 1 = 35 kwh/t --- Electricity cons. of Mill 2 = 30 kwh/t

Elec. Day Price = 2 TL --- Elec. Night Price = --- 3 TL Elec. Peak Price = --- 7 TL

THE SYSTEM IS READY FOR CALCULATION!
```

Figure 2: Establishment of the connection and transfer of the information between the production agent and the planning agent

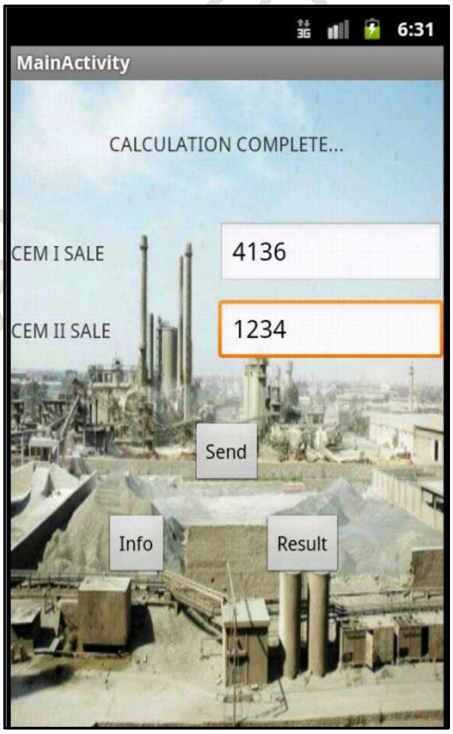
Sales agent is expected to be connected to the MAS from a mobile device. Figure 3 shows the screenshot of the mobile sales agent's interface. When the planning agent receives sales

[4] 1TL is approximately equal to 0.49 USD or 0.37 € at the time of writing this paper.

figures, it prepares the most appropriate and energy cost saving production plan according to agent planning system discussed in the previous section. Before doing this, sales agent needs to get related input from the sales representative and sends them to the planning agent. For instance, Figure 3 (a) includes the screenshot of the sales agent's user interface while it is waiting for the planning agent after sending sales figures. Sales of 4136 tons of cement type CEM I and 1234 tons of cement type CEM II are projected. When the planner agent prepares the plan to cover these figures, that plan is sent to the sales agent. As shown in Figure 3 (b), “Info” and “Result” buttons which were previously inactive, are now available for the representative since the generated plan is ready to be assessed with the customer.



(a)



(b)

Figure 3: Screenshots of the sales agent taken: (a) during the preparation of the production plan (b) when the production plan is available

Pressing the "Info" button shows general information about cement mills received from the production agent. Pressing the "Result" button shows the results of the computations made by the planning agent. There may be three different possible results. First one is normal daily plan and an alternative for it. Second result advises to use of work hours from the previous (past) days while third result is for the situation exceeding the production capacity in which the sale is cancelled and insufficient capacity message is shown to the representative.

Considering the first situation/result, normal daily plan shows production volume and working hour of a cement type for different time zones (Figure 4). For example cement mill 2's day time includes 11 hours of working which produces 550 tons of CEM II. At the bottom of the screen, total cost of the planned production can be seen which is 3540 TL (approximately 1540 €). Figure 5 shows the generated alternate plan. Alternate plan shows peak time working for both cement mills and substitution with past time working figures. Also, peak time and substitution cost of the alternatives can be seen. Alternate plan shows that peak time working of cement mill 1 for CEM II is 4 hours. The alternative solution involves working 3 hours at cement mill 1’s night time and 2 hours at cement mill 2’s night time. Alternate plan has two different prices as shown at the bottom of the screenshot in Figure 5. First price is the cost of working at normal day’s peak hours. The second price is the cost of working at past time instead of normal day’s peak time.

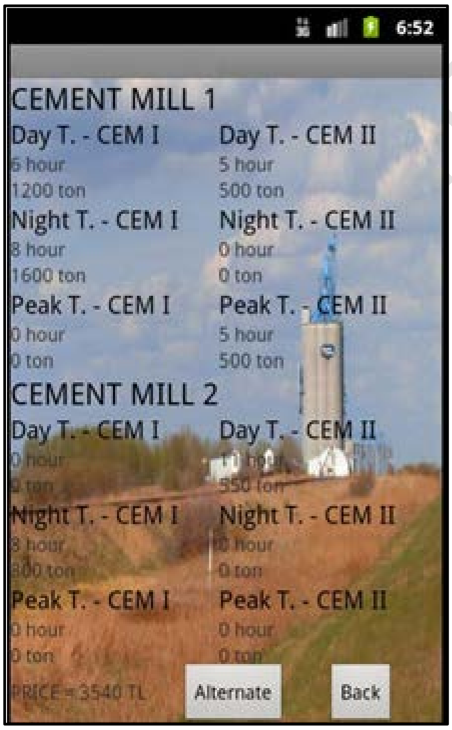


Figure 4: Production Plan

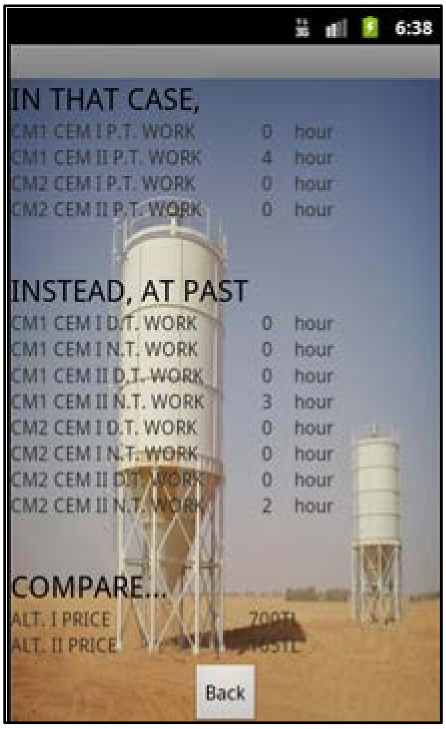


Figure 5: Alternate Plan

6. Evaluation

Developed system was evaluated via its real-life usage inside Çimentaş Cement Company, which is one of the biggest cement production corporations located in Turkey. It was founded as the first cement plant of Aegean Region and currently has 4 different plants, each located in different industrial regions of Turkey (Çimentaş, 2014).

Our MAS was deployed and actively used in Çimentaş's Izmir plant for 1 year. Evaluation results showed that a serious drop in energy costs was provided with the use of the new agent-based software system. Peak time usage was dropped by 0.79%. The system successfully shifted 0.50% of that peak time usage to night time usage and remaining 0.29% to day time usage. The company's planning office compared the total energy cost with the amounts of prior invoices paid by the company. Based on the calculations, they determined that the company can now save approximately 112,000 € in its yearly energy costs.

In addition to the saving in energy costs, use of the system also decreased the workload of employees and hence reduced the number of possible errors caused by human intervention. Based on the information gained from the company employees, production department was working approximately 1 hour/day, planning department was working approximately 2.5 hours/day and sales department was working approximately 1 hour/day during a typical cement production and sale process before the use of the new system. With the support of the new agent-based system, it is examined that each department only needs approximately 0.8 hour/day at most for such a process.

Table 1 lists the tasks performed by each department and elapsed time for each task before and after the use of new MAS. With or without using the new MAS, production department needs same amount of time for collecting production figures and sending them. However, working on the plan with planning department takes less time (0.05 hours) in the new system because the plan is now more precise. Sales department is effected similarly because duration needed for both talking with clients (customers) and preparing sales plan remains the same. On the other hand, working with plan takes less time (0.05 hours). The biggest improvement is observed at the planning department as expected. With the use of the new system, consolidating production and sale figures now takes no time because it is automatized. Time needed for evaluating the production plan remains the same but discussing with other departments takes significantly less time. As the result of all these changes, total daily working hours are reduced from 4.5 hours to 2.25 hours.

Table 1: Workload of the departments before and after the use of new MAS

	Hours needed per day before the use of new MAS	Hours needed per day after the use of new MAS
Production Department		
Collecting production figures daily	0.5	0.5
Sending production figures to Planning Department	0.25	0.25
Contacting Planning Department for Production Plan and working on it	0.25	0.05
Total	**1**	**0.8**
Planning Department		
Consolidating Production and Sales Departments' figures	0.5	0
Making Production Plan	1	0
Evaluating Production Plan	0.25	0.25
Discussing with Production and Sales Departments	0.5	0.15
Re-evaluating and finalizing the plan	0.25	0.25
Total	**2.5**	**0.65**
Sales Department		
Contacting with clients & preparing Sales Plan	0.5	0.5
Sending Sales Plan to Planning Department	0.25	0.25
Contacting Planning Department for Production Plan and working on it	0.25	0.05
Total	**1**	**0.8**
TOTAL	**4.5**	**2.25**

7. Conclusion

A MAS for cement production planning has been discussed in this paper. In the system, software agents for sales, production and planning perform their tasks on behalf of their human users. The autonomous system is capable of deriving cement production plans for energy cost saving by taking into consideration electricity time zones for a plant and workload of the cement mills. Sales agents also serve alternative plans with including their costs to the sales representatives during negotiation with the customers.

Evaluation result of the proposed system within the context of its industrial application showed that the utilization of the system caused a significant energy cost saving. Furthermore, workers in the planning department of the cement plant saved approximately 75% of their working hour by using the system. Total workload of the employees (including all departments) decreased to its half.

We believe that the agent-based production planning approach introduced in this study may also be applied especially for the optimization of time scheduling and/or resource allocation in various domains other than the cement production. For instance, the planning mechanism and collaboration of the autonomous agents within this approach may pave the way of efficient resource management during the production of goods in many manufacturing processes. Efficiency of the production devices can be increased with calculating the workload and directing the most appropriate device in a specific product line based on the coordination between the planning and production agents similar to the one described in this paper. Further, supply chain management for different industries is also possible with the introduced MAS. Specifically, remote communication and coordination required during the movement and storage of raw materials from geographically distributed suppliers can be provided with the employment of the mobile agents similar to our implementation for sales representatives. Inside this system, planning agents may control demand and supply while production agents are employed during the production of goods as expected.

Our next work is to increase automatization level in achieving figures especially taken from the production department during construction of the best cost effective plan. Gathering such kind of data can also be automatized in a way that the production figures are directly transferred from cement mills to the planning agent without any human intervention.

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