SDI Paper Template Version 1.6 Date 11.10.2012

An Olive Oil Tank Farm Management and Optimum Blend System

Petros-Alexis Kofakis*

TEKMIX Ltd., Athens – Greece

.

ABSTRACT

This paper presents an integrated solution for olive oil tank farm management and optimum oil blending that has been designed specifically for the olive oil sector.
The working scenarios are analyzed to define functional requirements and procedures for an integrated industrial automation solution, tailored to be used in a traditional sector that in most cases lacks the technological background and expertise to operate and support complex automation systems.
The system makes an intelligent and cost effective integration of hardware and software components into a distributed architecture, thus ensuring maximum reliability. It allows olive oil enterprises to exploit their oil stock in an optimum way, ensuring constant quality, cost and total execution time optimization, quick response to the needs of each customer and safety through traceability, taking into consideration the requirements of all relevant EU regulations like (EC) 1989/2003 or 702/2007. The cost and total execution time optimization problem is solved by successive use of Linear Programming and Graph Search optimization.

Keywords: automation, blending optimization, tank farm management, traceability, olive oil

1. INTRODUCTION

Olive oil companies operating at medium or large scale often face the problem of having to provide the market with a high quality of olive oil constantly, although olive oil batches from a big number of suppliers featuring different quality characteristics are used.
At each phase of the production process the olive oil quality and characteristics are measured [1], [2] in order to control the quality and the conformance to customer requirements and specific trade and legislation standards. The need of an oil tank farm management and optimum oil mixing system that is designed specifically for the olive oil sector and enables olive oil enterprises to exploit their oil stock in an optimum way, ensuring constant quality, cost optimization and quick response to their customers is crucial. A similar problem but at a larger and more complex scale is faced in the petroleum industry and many methodologies have been presented from the early ‘50s [3]. Complex systems that face the blending [4], [5], short-term scheduling and planning [6], [7] are in operation at large petroleum refineries worldwide.

* Tel.: +30 211 8000108; fax: +30 211 8000134.
E-mail address: kofakis@gmail.com.

2. REQUIREMENTS

2.1. Working Scenarios

The working scenarios vary from complex to simple ones. We present 2 sample working scenarios and a short description of the daily operation and the relevant processes it can be separated.

2.1.1 Scenario 1 - Olive oil refinery (complexity: 60+ tanks)

Operation/Process - *Reception*: Tanker trucks deliver olive oil. This is immediately directed to specific tanks that are built for the storage of virgin or extra virgin olive oil, and/or the lower quality (lampante, industrial) olive oils. These lower quality oils are then forwarded to the refinement unit to reduce their acidity or remove unpleasant odors. The process involves the selection of destination tanks.
System requirement: The system should give a detailed view of the status of different tanks (capacity, volume of the existing olive oil) to assist decision making for the selection of destination tanks and enable the input of data that describes a specific reception (chemical analysis and other olive oil characteristics).

Operation/Process - *Production*: As much as 25 tons of olive oil is passed through the refinement unit every day to improve the chemical and physical characteristics of the olive oil. Oil to be refined undergoes the following treatments: 1. Neutralization - removal of free fatty acids by chemical or physical process; 2. Decolorization - removal of colored substances; 3. Deodorization—removal of bad odors; and 4. Winterization - removal of substances that solidify and ‘cloud’ olive oil when stored at low temperatures. At the end of the process, the refined oil is directed to specific tanks that are built for storing the refined olive oil.
System requirement: The system should enable the acquisition and visualization of sensory data (e.g. temperature, pressure) to control the refinement unit processes.

Operation/Process - *Blending*: Final products are made from different combinations of olive oils in different tanks, according to different trade specifications or customer requests. For example, the refined oil is often blended with a small proportion of extra virgin olive oil.
System requirement: The system should exploit oil stock in an optimum way, ensuring constant quality, cost optimization, and quick response to the needs of each client.

Operation/Process - *Distribution*: Tanker trucks are loaded with olive oils, which will be forwarded to customers.
System requirement: The system should monitor the delivery process measuring the exact quantity of olive oil transferred to the tanker truck and log all output to tanker trucks, producing all the necessary documentation concerning the delivery to the specific customer.

2.1.1 Scenario 2 - Olive oil mill (complexity: 5-10 tanks)

We have a similar scenario at an olive oil-mill that produces extra virgin olive oil from olive batches of different origin and/or different producers.

Operation/Process - *Production*: The oil-mill produces extra virgin olive oil from olive batches of different origin and/or different producers. Consequently, the produced olive oil acidity varies from batch to batch. Our objective is to group extra virgin olive oil of similar acidity; thus, we have different tanks that contain olive oil of similar acidity. The produced olive oil is first transferred to a buffer tank. The acidity of the extra virgin olive oil in the buffer tank is measured regularly.

System requirement: The system should route automatically the required olive oil quantities from the buffer tank to the corresponding destination tank, thus making possible an optimum grouping of olive oil according to acidity and optimizes the allocation of tanks.

3. ARCHITECTURE

Our objective was to design a system that will meet the requirements of medium and small sized companies such as the olive oil industries that in most cases lack the technological background and expertise to operate and support complex systems found in petroleum refineries.

The system suitable for the olive oil industries should comply with the following technical requirements:

- Support fully automated and manual control of all motorized valves and pumps.
- Have integrated Supervisory Control And Data Acquisition (SCADA) system for the acquisition and visualization of data from other sensors (e.g. temperature, pressure) and the control of other plant processes, using the Object Linking and Embedding (OLE) for Process Control (OPC) standard.
- Run under Microsoft Windows operating systems and allow Client/Server operation and networking with other PC or computer systems.
- Have Windows-based graphical Human Machine Interface (HMI) providing graphical representation of the complete tank farm, valves, pumps and other sensors, with full user interaction and control.
- Support remote clients / workstations over the internet (e.g. chemical lab, or customer workstation).
- Allow multiple user access security levels and privileges.
- Support connectivity with external databases and other factory and office systems, using Extensible Markup Language (XML) technology.
- Be capable for event messaging via email and SMS.
- Have open system architecture.

The system features a simple and user-friendly MS Windows interface from which the user can have full control of the olive oil tanks. The system can also assist decision making by calculating the cost corresponding to each customer order. Audit and traceability of the olive oil used throughout the tank farm is also provided by the system. The system can be installed in new plants or it can be tailored to meet the specifications of existing storage tanks and instruments.

The system is comprised by hardware and software components. We use a distributed architecture using Programmable Logic Controllers (PLCs) that are responsible to handle all input from low level sensors and control valves, pumps and other machinery devices, thus ensuring maximum reliability. Below we give a description of all the functional subsystems.

3.1 INVENTORY Control Subsystem

This sub system enables the user to monitor (mimic diagram, graphics and tables) the status of olive oil tanks (level, volume and detailed chemical characteristics) and inventory of the enterprise. It supports the automatic export of data to office applications or other enterprise information systems (data bases, accountancy systems etc). The software communicates via network with the Measurement & Control PLC sub system. The system has different levels of user access (authorization) in various operations, with complete recording (logging) of all the activities. The system has an extensive capability to generate reports for plant planning, quality control, financial analysis, accounting purposes and decision making and enables full management of suppliers / customers and olive oil deliveries.

3.2 Recipes & Mix Subsystem

This sub system calculates automatically and proposes mixing recipes, and plans the daily production depending on the existing orders in accordance with the specifications of each specific customer order and in conformance to the olive oil (Marketing Standards) regulations. The system maintains in his database an inventory of standard olive categories and customized recipes. After the automated calculation the optimal mixing sequences are executed automatically.
The software runs under Microsoft Windows operating systems and allows Client/Server operation and networking with other PC or computer systems. During the mix process the user can monitor the process in a dual screen graphic interface, view the progress and interact with the transfer process (Pause, Resume, and Stop). The background execution of multiple transfer and mixing plans is also possible.

3.3 Production Control Subsystem

This sub system enables the user to monitor the production process (mimic diagram, graphics and tables). The system also displays critical parameters (temperature, pressure etc) of the production process and alerts the user when these parameters are not within correct limits. The user has also the capability to issue directly commands and control various instruments, pumps and valves when this is required. The software runs under Microsoft Windows operating systems and communicates with the Production Control PLC subsystem.

3.4 Measurement & Control PLC

This sub system is structured with PLCs and communicates via network with the Inventory Control Subsystem. For the measurement of olive oil volume in each tank, special ultrasound level sensors are used. The system also controls the motorized valves and the pumps during the process of olive oil mix.

3.5 Production Control PLC

This sub system is structured with PLCs and communicates via network with the Production Control Subsystem. It collects and transmits critical parameters (temperature, pressure etc) for specific machinery of the production process. It accepts also commands for direct control of low level instruments, pumps and valves, when this is required.

4. OPTIMAL BLEND PROCESS

4.1 Mix Model

The focus of the system is the blending process. The olive oil quality and characteristics of each tank are measured [1], [2] and are used in the optimum blend procedure. Taking into account that most parameters are expressed as a percentage and that the resulting blends do not stay for long periods in the mixing tanks we consider a linear mix model that simplifies the modeling of the blending process. Linearity means that if we mix two volumes of oil V_1 and V_2 then the value of parameter *I,* $P_{result,i}$ of the resulting mix will be:

$$p_{result,i} = \frac{P_{1,i} * V_1 + P_{2,i} * V_2}{V_1 + V_2} \qquad (1)$$

Preliminary experimental results have verified that such a model is correct. The analysis of the blending result from a limited set of two or three olive oil batches of different origin, indicated that the difference $P_{\max} = \max(|\, p_{estimated} - p_{measured} \,|)$ between the estimated value that has been calculated using the linear mix model and the actual (measured) value for the most common and easily measured parameters (*acidity, peroxide value*) is uniformly distributed and less that 5% for all the above parameters.

During the optimal blend process the user after he enters the details of an order (quantity and quality), selects the tanks that can contribute in the order preparation. The program calculates automatically the optimal (lowest cost) blend, which satisfies the quality criteria of the order. For the calculation of the quality criteria the program takes into consideration the EU Commission Regulation (EC) No 1989/2003 of 06/11/2003 "*amending Regulation (EEC) No 2568/91 on the characteristics of olive oil and olive-pomace oil*" which lays down methods of assessing these characteristics, and/or updated amendments like Commission Regulation (EC) No 702/2007.

EU Commission [1], and international regulations and standards [8], [9] define very clearly the physical, chemical and organoleptic characteristics of olive oils for specific categories that are:

1. Extra virgin olive oil
2. Virgin olive oil
3. Lampante olive oil
4. Refined olive oil
5. Blended olive oil composed of refined olive oils & virgin olive oils
6. Crude olive-pomace oil
7. Refined olive-pomace oil

Table 1. The olive oil characteristics used by the system

Characteristic
• Acidity
• Peroxide value
• Waxes
• Saturated acids in 2-position of the triglyceride
• Stigmastadienes
• Diff. between HPLC ECN42 and theor. ECN42
• K232 *
• K270 *
• Δ-K
• Fatty acids content
Myristic
Linolenic
Arachidic
Eicosenoic
Behenic
Lignoceric
• Sum of transoleic isomers
• Sum of translinoleic and translinolenic isomers

- Sterols composition
  - Cholesterol
  - Brassicasterol
  - Campesterol
  - Stigmasterol
  - Betasitosterol
  - Δ-7-Stigmasterol
- Total sterols
- Erythrodiol and uvaol
- Organoleptic assessment Median of defects (Md)
- Organoleptic assessment Median of fruity (Mf)

*<u>Note</u>: *K232, K270* and *Δ-K* do not follow the linear mixing model, they are used only for informational purposes.

4.2 Linear Programming

The optimum blending problem can be formulated as a Linear Programming (LP) problem. Linear programming [10], [11], [12] is widely used in order to compute optimal (i.e. the best) solutions and is formulated as the problem of maximizing or minimizing a linear function subject to linear equality and linear inequality constraints.

Our problem can be formulated as follows:

> *What are the optimal blend mixes that will maximize the profit and meet the requested order volumes and quality specs subject to specific tanks availability*?

Or

> *For all the blends in a certain time period: Minimize the cost of the final blend.*
> *Subject to: (the total oil volume = requested volume) AND*
> *(all chemical analysis parameters fall between certain minimum and maximum values)*

Nomenclature:

T	the set of tanks (indices t)
P	the set of chemical analysis parameters including virtual parameters (indices p)
O	the set of orders (indices o)
$cost_t$	unit cost of the oil in each tank t
$sell\_price_o$	unit sell price of order k
x_{to}	unknown oil volume from each tank t and for each order o
$param_{pt}$	value of chemical analysis parameter p in tank t
min_param_p	minimum required value for parameter $param_{pt}$
max_param_p	maximum required value for parameter $param_{pt}$
min_vol_t	minimum desired volume we can take from tank t
max_vol_t	maximum volume we can take from tank t

Objective function (maximize net profit)

The main objective of the problem is to maximize the net profit which is defined as:

$$\max \sum_{o}^{O} \sum_{t}^{T} (sell\_price_o - cost_o) * x_{to} \qquad (3)$$

Subject to:

$$\min\_param_p < \sum_t^T param_{pt} * x_t < \max\_param_p \quad (4) \text{ and}$$

$$\min\_vol_t < \sum_o^O x_{to} < \max\_vol_t \text{ for each tank } t \quad (5)$$

The ”cost” or objective is a difficult feature to define in practice. The most important and with the greater weight is the contribution of the economic cost. The use of LP and the formulation of the objective function should be viewed as a practical method to describe and obtain a solution to a complex decision making problem [13], [14], [15]. LP does not make any judgments. In our implementation the cost is a function of:

- *Economic profit*: we try to minimize the economic cost of the result blend by taking into account the unit cost (price per litter) of each tank that can contribute to the blend. The unit cost is based on statistical and actual market data. This is equivalent to the maximization of the value of the final blend, and consequently the profit.
- *Rarity*: we try to minimize quantity of tanks that contain olive oils that are rare (i.e. a tank that contains olive oil with Protected Designation of Origin (PDO)).
- *Near empty tank levels*: we try not to leave small quantities of oil at the origin tanks. I.e. we try to minimize the number of near empty tanks.

5. SYSTEM OPERATION

5.1. Process Steps

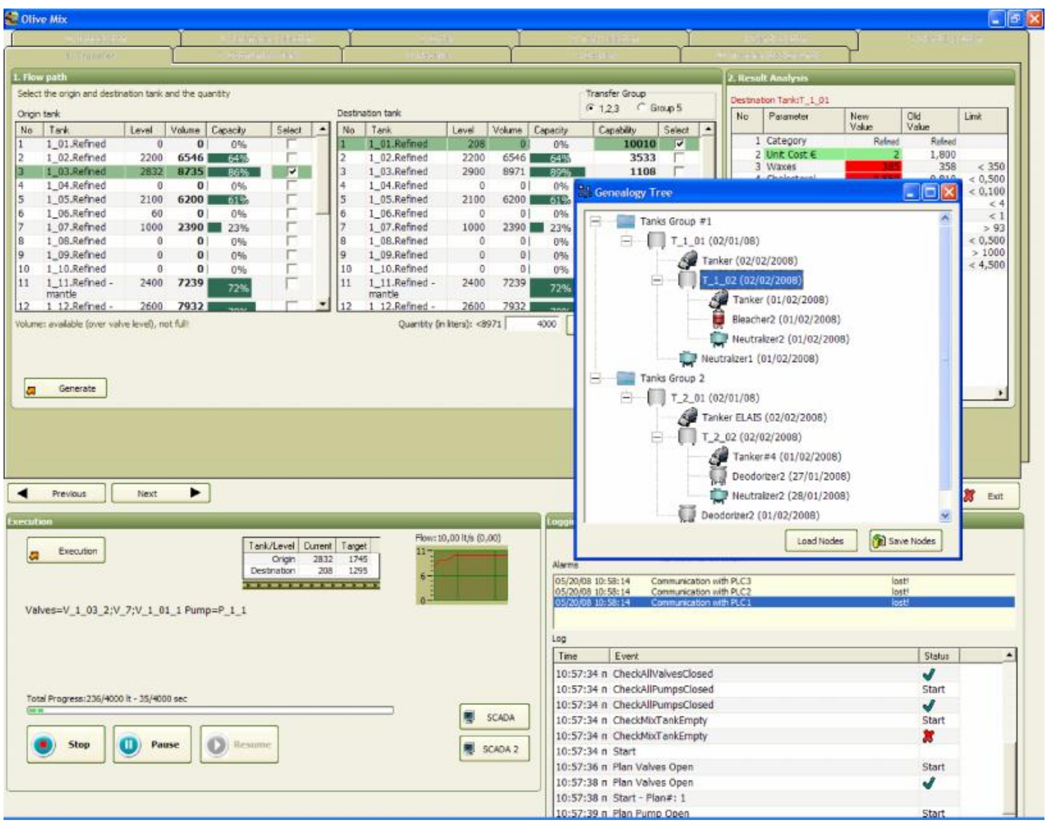

Fig. 1. Left screen of the system

The use of the system by operators is the key to a successful blending system. After we have analyzed the requirements of the user who operates the system, we designed a very clean and easy to use layout of the user interface and a sequence of displays that are the steps of the blend process.

The system uses two screens: the left screen (Figure 1) which is used for all the data input, selection of parameters, display of tank inventory, calculation and review of optimal blend solution, and execution of blend sequences and the right screen (Figure 2) which displays a mimic diagram of all the tanks, valves, pumps, and sensors that are controlled by the system. It enables the direct control of pumps and valves.

The ease of use is considered in the design of the user interface displays. During the optimal mix process, the user enters the order data (quantity and quality) and selects the tanks that can contribute in the formation (mix) of the order. The program automatically calculates the optimal (with the lowest cost) mix that satisfies the quality criteria of the order. For the relevant quality criteria, the program takes into consideration the existing EU Commission Regulation. The implementation of the operation is a sequential process that allows the easy operation by the nonspecialized users. The system executes a series of successive steps that are presented in successive cards (tabs) of the user interface.

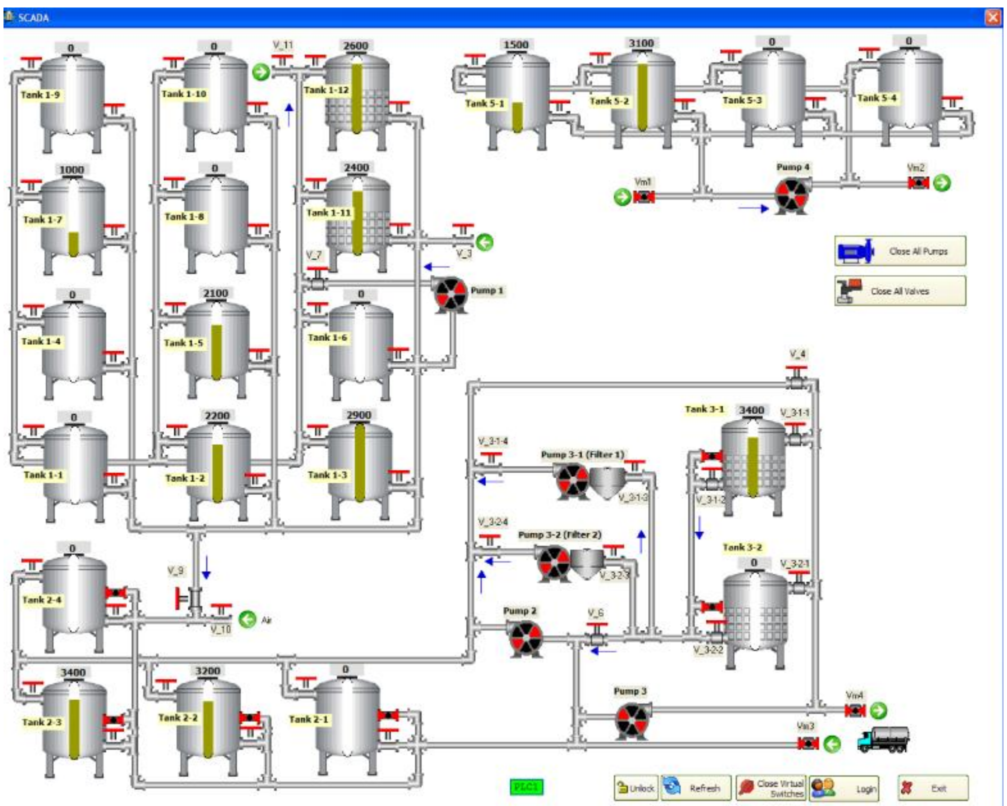

Fig. 2. Right screen of the system

<u>Step 1) Choice of Parameters</u>
In this step, we select the parameters (chemical analysis of the olive oil) that will be used by the program for the automatic calculation of the optimal (with the lower cost) mix that satisfies the quality criteria of the order.

Step 2) Order

In this step, we enter the order quantity and select the desirable quality.

Step 3) Choice of tanks

In this step, we select the tanks that can contribute in a blend and that will be used by the program for the automatic calculation of the optimal (with the lower “cost”) blend, which satisfies the quality criteria of the order.

Step 4) Optimal Blend Calculation

In this step, the optimal (with the lower cost) blend that satisfies the quality criteria of the order is calculated. The user can modify the optimal solution that has been suggested by the system by entering values (volume for each tank) of his choice. For each modified solution, the system calculates and displays the estimated mix result, i.e. the new chemical analysis (parameters) of the olive oil in the destination tank that will result from the mix.

Step 5) Optimal Mix Tank Selection

In installations with many tanks -where we have considerable pipe lengths- the position of the mix tank can drastically increase the total time for the execution of the mix plans / transfers.

To minimize the duration time of blend process and the quantity of the oil that remains in the pipelines after the transfers, the system calculates and proposes the best choice for the mix tank for which the time for the execution of the mix plans / transfers will me minimal, taking into consideration possible “contamination” of pipes from olive oil of low quality.

This problem is managed using a graph search. The Nodes of the graph are the valves, tanks, pumps, and pipeline junction points, and the weighted edges are the pipelines. The edge weight is proportional to the pipe pressure drop.

The problem can be formulated as follows:

Find the mix tank that minimizes the total pipe pressure drop

$$\min \sum_{c}^{C} pd_{cm} \tag{7}$$

Where:

M the set of available mix tanks (indices m)

C the set of available component tanks i.e. the solution of step 4 (indices c)

pd_{cm} the pressure drop for the pipe path from tank c to tank m

Step 6) Mix Execution

The process is a series of individual olive oil transfers that have been calculated in steps 4) and 5), from an origin tank into the destination mix tank. For each transfer, the system executes a transfer cycle that is executed sequentially by the PLCs that control the motorized valves and pumps that should be activated for the implementation of individual transfer.

5.2. Other functionalities

The use the system has also displays/tabs that facilitate other operations such as:

Tank-to-Tank Transfer

After we select the origin tank and the destination tank, we enter the quantity (in liters) that we need to transfer. The system indicates the largest value for the quantity. The system calculates and displays the mix result, i.e. the estimation of the new chemical analysis (parameters) of the olive oil in the destination tank that will result from the mix.

Receipt

In this card, we plan and control the process of olive oil receipt from tanker trucks. We select the quality and the supplier (from the supplier data base) and enter the quantity as well as the unit price and the values of the olive oil sample characteristics (chemical analysis).

Delivery

In this card, we plan and control the process of olive oil delivery to the tanker trucks.

SCADA

The Supervisory Control And Data Acquisition (SCADA) window opens on the right screen (Figure 2) and displays a mimic diagram of all the tanks, valves, pumps, and sensors that are controlled by the system. It enables the direct control of pumps and valves. If the symbol of a tank is clicked, a new form that displays all the relevant information for the particular tank (volume, capacity, level and complete chemical analysis parameters) opens. Accordingly, for clicking a pump or valve, a virtual switch is presented, which enables the direct control (on-off) of the corresponding pump or valve.

5.3 Traceability

Traceability in the food industry is a very important issue that has become mandatory in all EU countries [16]. The traceability shall be established at all stages of production, processing, and distribution. Traceability enables quality control, optimum plant operation, detection and tracing of problems during the production process.
By default, the system logs all the information related to every oil transfer and processing and monitors logs every change of the tanks status. This enables the accurate trace of olive oil flow from the moment it enters the plant premises to the moment it leaves to be forwarded to the customers.
The system enables forward and backward trace (Fig. 1, ‘Genealogy Tree’ subwindow) and tracks the complete genealogy of all tanks, providing both forward and backward trace, even in complex blends. In “backward trace” the system finds and displays every tank or input that went into a tank or customer batch. In “forward trace” the system finds and displays the status of every tank or customer batch made from a certain input or tank. The system can also generate a “traceability tree,” a graphical representation of traceability, showing the flow of oil from one tank to the next.

6. CONCLUSIONS

The system makes an intelligent and cost effective application of techniques and methodologies from the oil and gas sector and applies them to a traditional sector dominated by Small and Medium Entreprises (SMEs) and end users with little automation systems experience. The use of the system has demonstrated the following benefits:

1. Constant Quality. Production of olive oil batches according to required specifications and characteristics.
2. Decision-making support. That is, whether we can satisfy an order and what is the cost?
3. Security. Multiple safety conditions are checked before the activation of any motorized valve or pump motor.
4. Quick response. Shorter mix execution and transfer cycles, leading to shorter delivery times.
5. Ease of use. Absolutely serial process of implementation that allows the operation by the nonspecialized users.

6. Optimization of final product cost and use of tanks.
7. Audit and traceability of all tank transfers and mixing operations.
8. Drastic reduction of labor cost.
9. Enforcement of good practices. The major benefit of the system is that it enforces the users to follow specific procedures that are difficult to override manually.

Application to other food industries/sectors, including all edible oil industries and industries that have tank farm management and blending applications, such as the dairy industry is straight forward.

Future improvements include the development of short-term scheduling of the optimal blend process as an integrated process. Short-term scheduling within an integrated approach becomes necessary. The optimal blending analysis should also investigate the short and long term chemical interaction of olive oil ingredients during a mix and also address non linear mixing models (*K232, K270* and *Δ-K* parameters) for improved accuracy.

REFERENCES

1. Commission Regulation (EC) No 1989/2003 of 6 November 2003 amending Regulation (EEC) No 2568/91, *On the characteristics of olive oil and olive-pomace oil and on the relevant methods of analysis*, Official Journal L 295 , 13/11/2003; pp. 0057–0077.
2. Aparicio R, Harwood J. Handbook of Olive Oil: Analysis and Properties. 2000; 620 pages, Aspen Publishers.
3. Charnes A, Cooper WW, Mellon B. Blending aviation gasolines. Apr. 1952; Econometrica 20; 135-159.
4. Gill G. Blending petroleum products at NZ Refining Company. 33rd ORSNZ (Operational Research Society of New Zealand) Conference, 30th August - 1 September, 1998; p59.
5. Sasaki S, Sugawara H, Ishiguri A, Kubo K. Blending Optimization System, Yokogawa Technical Report English Edition, No. 24; 1997.
6. Joly M, Moro LFL, Pinto JM. Planning and Scheduling for Petroleum Refineries Using Mathematical Programming. Braz. J. Chem. Eng. 2002, vol.19, n.2; pp. 207-228.
7. Marques CN, Matos HA, Relvas S. Inventory Management for Multi-product Tank Farm Systems using a MILP Model with Rolling Horizon. Computer Aided Chemical Engineering, Elsevier, Volume 30, Pages 472-476, 2012.
8. FAO (Food and Agriculture Organization of the United Nations). Codex Standard for Olive Oil, Virgin and Refined and for Refined Olive-Pomace Oil *(*CODEX STAN 33-1981, Rev. 1-1989).
9. International Olive Oil Council. Trade Standard Applying to Olive Oils and Olive-Pomace Oils, COI/T.15/NC no. 3/Rev. 1, 5 December 2003.
10. Vanderbei RJ. Linear Programming: Foundations and Extensions, Kluwer Academic Publishers, Boston, 2001.
11. Dantzig G. Linear Programming and Extensions, Princeton University Press, 1963.
12. Nash S, Sofer A. Linear and Nonlinear Programming, McGraw-Hill. 1996.
13. Williams HP. Model Building in Mathematical Programming. Wiley 1993, 3rd edition.
14. Sahdev MK, Jain KK, Srivastava P. Petroleum Refinery Planning and Optimization Using Linear Programming*. Accessed* 2010.
    Available: http://www.cheresources.com/content/articles/energy/refinery-planning-and-optimization
15. Barsamian A. Genetic Algorithm Optimizers for Blend Planning Applications. Refinery Automation Institute, LLC; Accessed 2010. Available: http://www.refautom.com/
16. Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002, *laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety*.