The Optimal Gasoline Blending into Romanian Refinery
Case Study

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Abstract: The paper presents the research into Romanian industrial in line gasoline blending. The paper is structured in three parts. First part presents an industrial bending system of a Romanian refinery. The second part contents a research of the blending mathematical model for petroleum products. The last part is a case study, regarding an industrial problem of the gasoline blending in a Romanian refinery. The study has reported similitude and differences between the optimal solution calculated by Blend Optimization and Supervisory System (BOSS) and the optimal solution obtained by using the author's model.

1 INTRODUCTION

Refineries are not producing final products according with quality norms, it's producing different components with various chemical specifications from whom is produced the final products. In this category is included the commercial gasoline. The actual technology used to produce a commercial gasoline presents two main processes: tank blending and in line blending.

In order to control these blending processes, the authors detect two types of issues. The first problem is the automation system with which is controlled the blending process. In literature there are presented various automation systems used for petroleum products blending (Hydrocarbon Processing 1987; 1989; 1991; 1995).

The second problem is the blend recipe. This can be determinate based on experiments and is unchangeable, or it can be determinate by calculations, based on a mathematical model. In the second variant, a particular interest it is represented by a test of an optimum blend recipe. The Romanian refineries have automation systems which can provide a control of this blending process, and software system which can determine an optimal recipe to produce commercial gasoline (http://iom.invensys.com).

In this context, authors formed a blending process in order to obtain a commercial gasoline and, by solving this, they could compare the numeric results derived from the blending model purposed with dates generated by the software of the optimization system used in refineries. The validation of this system software is the objective of this article.

2 INDUSTRIAL SYSTEM FOR IN LINE BLENDIG OF PETROLEUM PRODUCTS

The in line blending is a process where the entire components are blended simultaneously, in a common pipeline, and then send in a final product tank. The advantages of this method are (Manescu 1970); (Lambert 2006):

- significant reduction of the blending process time;
- realized the blend in a closed and pressurized system;
- eliminate the blends in other tanks;
- control the blending process during cycle mixing, with on line analyzers characteristics;
- the possibility to obtain batches according with optimum recipes.

Figure 1 presents an industrial system used for in line blending of petroleum products in a refinery from Romania. This system has two subsystems: one subsystem for the automation of the in line blending

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process and the other subsystem used to calculate the optimal blending recipes.

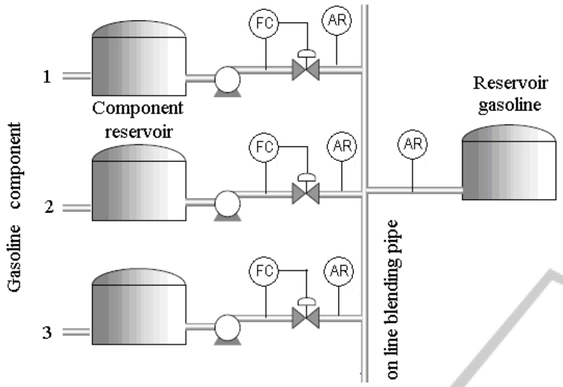

Figure 1: Industrial system for petroleum products in line blending.

2.1 The Industrial Blending Control System

The blending control system includes the following control elements: regulatory control system for flows composed by flow transmitter with outlet pulse and regulatory control valve, temperature and pressure measurement system, components specification measurement system and final product characteristics measurement system. The measurement system used for blending components and final product is related to the NIR analyzer (http://www.unityscientific.com). The NIR analyzers can measure many characteristics, for large petroleum products diversity. Some of characteristics of the NIR analyzer are:

- API density;
- distillation temperature at 10%, 50% and 90% ;
- research octane number (RON) and motor octane number (COM);
- aromatic content;
- Reid pressure vapors;
- benzene and olefins content.

2.2 Optimization Software System

The name of the Optimization subsystem of the in line blending for petroleum products is Blend Optimization and Supervisory System (BOSS) and this is used in the refinery to mix an optimum recipe for crude oil and to obtain optimum recipes for gasoline and diesel products. The optimization system is using a linear programming to make the optimum recipe for gasoline blending.

The main objective is to minimized blend costs and quality giveaway of the final product. The structure of the optimal control system – BOSS is illustrated in figure 2.

3 MATHEMATICAL MODELLING OF THE GASOLINE BLENDING PROCESS

In scope to validate the optimization system BOSS, the authors have studied the mathematical model of the gasoline in line blending process and they have solved the linear optimization problem.

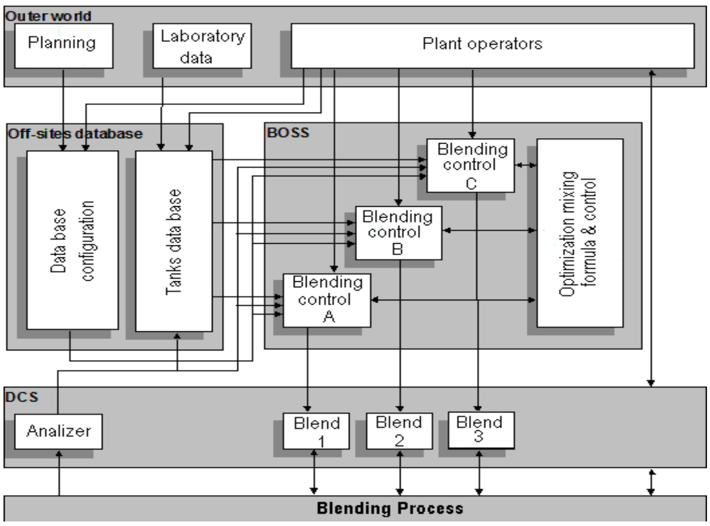

Figure 2: The optimal control system BOSS structure.

3.1 Mathematical Model

The gasoline in line blending is formulated so: a refinery has *n* types of gasoline, $b_i, i = 1,\ldots,n$. Each type of gasoline is characterized by the next properties: research octane number o_i ; density d_i; distillation index r_i and components prices c_i . The scope is to obtain a commercial gasoline with a minimum price, in quantity of $\bar{b}$ tones, with research octane number $\bar{o}$, density $\bar{d}$ and distillation index $\bar{r}$.

The model purpose by the authors contains an objective function and a restriction array. The objective function has a financial order and with a next formula:

$$F = \sum_{i=1}^{n} c_i x_i \tag{1}$$

where x_i represents the quantity from component *i* witch is included in blend.

The restriction array contains the next calculation formulas for estimation and checks the next gasoline blend properties:

- Research octane number

$$\sum_{i=1}^{n} o_i x_i \geq \bar{o} \sum_{i=1}^{n} x_i \tag{2}$$

- distillation index

$$\sum_{i=1}^{n} r_i x_i \geq \bar{r} \sum_{i=1}^{n} x_i \tag{3}$$

- density

$$\sum_{i=1}^{n} \frac{x_i}{d_i} \geq \frac{\sum_{i=1}^{n} x_i}{d_i} \tag{4}$$

- components quantity

$$x_i \leq b_i, \quad i = 1, 2, \ldots, n \tag{5}$$

- available quantity

$$\sum_{i=1}^{n} x_i \geq \bar{b} \tag{6}$$

- non-negativity condition of the variables

$$x_i \geq 0, \; i = 1,2,\ldots,n \tag{7}$$

3.2 The Solving Model

To solve the linear optimization problem, the authors have used the MATLAB function `lp`, function which determines the minimum point for a multivariable objective function, for who, the restriction are presented in a matrix form (Ghinea 1997); (Patrascioiu, 2005). The optimization problem has the next formula:

$$\underset{min}{F}(\boldsymbol{X}) = [c_1\; c_2 \ldots c_n] \times \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix}; \tag{8}$$

$$\begin{bmatrix} a_{11} & a_{12} & \ldots & a_{1n} \\ a_{21} & a_{22} & \ldots & a_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ a_{m1} & a_{m2} & \ldots & a_{mn} \end{bmatrix} \times \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} \leq \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_m \end{bmatrix}; \tag{9}$$

and

$$x_{min,i} \leq x_i \leq x_{max,i} \quad i = 1,\ldots,n \tag{10}$$

From these four variants of the `lp` function utilization, the authors have selected the variant where the restriction array contains equality restrictions and inequality restrictions, subject to have this formula:

```
x=lp(c,a,b,VMI,VMS,x0,k);
```

The description of these variables from this `lp` function is:

`x` - variables row vector;

`c` - row vector coefficients;

`a` - restrictions coefficients matrix;

`b` - row vector of restrictions free element;

`x0` - initial values of variables vector;

`VMI`- $x_{min,i}$ values vector, associated to simple skirts restrictions;

`VMS`- $x_{max,i}$ values vector, associated to simple skirts restrictions;

`k` – equality restrictions number from the restriction array.

4 CASE STUDY

The authors have analyzed the optimal software system BOSS from Invensis Corp. used into Romanian refinery. The case study developers the nest problems:

– the industrial mixing problem;
– the mathematical modeling;

– the comparison between the BOSS results and the author's model results.

The validation of the software system BOSS has been the objective of the case study.

4.1 The Industrial Mixing Problem

The industrial mixing problem is the production of 4000 t commercial gasoline at a minimum price with the next properties:

- Research octane number to be minimum 94.8;
- Density at 15°C to be maximum 0.7673g/cm^3;
- Benzene content to be maximum 0.795 ppm;
- Sulfur content to be maximum 7.4 ppm;
- Final boiling temperature to be maximum 202°C.

To produce this type of commercial gasoline there are available eight components with the properties presented in table 1. The quantity of *i* component which is mixed is x_i

4.2 The Industrial and the Solving Model Problem

The application of the general model presented in the section 3 and in according to the conditions formulated in table 1 conduces to mathematic model of the commercial gasoline production, respectively the relations (11) – (12).

The restrictions used by the authors system have the next components:

- Restriction (2) relates to research octane number.
- Restriction (4) associated to density.
- Restriction developed by the mixing benzene content. This restriction is an additive expression.
- Restriction what relates the sulfur content of the commercial gasoline. This restriction is an additive expression, too.
- Restriction associated to total quantity of the commercial gasoline.
- The restriction group (5) refers to the available quantity of each gasoline component.
- The restriction group (7) associated to non-negativity condition of each variable.

Using the MATLAB function `lp`, they is obtained the optimal solution

$$\boldsymbol{X}^{opt} = \begin{bmatrix} 0 \\ 431.3 \\ 357.2 \\ 0 \\ 2105.4 \\ 160.5 \\ 761.3 \\ 184.3 \end{bmatrix}.$$

This solution satisfies the restrictions system (12). In same mode, all the restriction of the commercial gasoline are satisfied, table 2. This fact reflects the robust character of the optimization algorithm and the validity of the mathematical model.

4.3 Comparison between the BOSS Results and the Author's Model Results

The authors have tested the BOSS optimization system for the same example presented in section 4.1. The quantities of the eight gasoline components are presented in table 3.

$$min\ F = 528.9\ x_1 + 431.3\ x_2 + 575.4\ x_3 + 561.9\ x_4 + 2105.4\ x_5 + 160.5\ x_6 + 1465.4\ x_7 + 446.8\ x_8\,; \tag{11}$$

$$\begin{cases} 94.1\ x_1 + 74\ x_2 + 102.6\ x_3 + 105.5\ x_4 + 91.7\ x_5 + 115\ x_6 + 110\ x_7 + 96\ x_8 \geq 379200 \\ 1{,}531 x_1 + 1.408 x_2 + 1{,}307 x_3 + 1{,}161 x_4 + 1{,}266 x_5 + 1{,}340 x_6 + 1{,}259 x_7 + 1{,}639 x_8 \geq 521 \\ 0.062\ x_1 + 1\ x_2 + 0.376\ x_3 + 0.720\ x_4 + 1.240\ x_5 + 0\ x_6 + 0\ x_7 + 0.02\ x_8 \geq 3180 \\ 5.4\ x_1 + 1\ x_2 + 30\ x_3 + 1\ x_4 + 10\ x_5 + 15\ x_6 + 1\ x_7 + 15\ x_8 \geq 2960 \\ 87.7\ x_1 + 135.3\ x_2 + 104\ x_3 + 210\ x_4 + 211\ x_5 + 79.4\ x_6 + 79.4\ x_7 + 36\ x_8 \leq 80800 \\ x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 = 4000 \\ \mathrm{x}_1 \leq 528.9 \\ \mathrm{x}_2 \leq 431.3 \\ \mathrm{x}_3 \leq 575.4 \\ \mathrm{x}_4 \leq 561.9 \\ \mathrm{x}_5 \leq 2105.4 \\ \mathrm{x}_6 \leq 160.5 \\ \mathrm{x}_7 \leq 1465.4 \\ \mathrm{x}_8 \leq 446.8 \\ \mathrm{x}_\mathrm{i} \geq 0,\ \mathrm{i} = 1,\ldots,8 \end{cases} \tag{12}$$

Table 1: The properties of the mixing components of the gasoline commercial product.

Component of gasoline	Research octane number	Density [g/cm^3]	Benzene concentration [% vol]	Sulfur concentration [ppm]	Final boiling point [°C]	Quantity [t]	Cost [RON/t]
	o_i	d_i	z_i	s_i	r_i	b_i	c_i
1	94.1	0.653	0.062	5.4	87.7	528.9	677.8
2	74.0	0.710	1.0	1	135.3	431.3	617.1
3	102.6	0.764	0.376	30	104	575.4	735
4	105.5	0.861	0.720	1	210	561.9	647.8
5	91.7	0.790	1.240	10	211	2105.4	677.8
6	115.0	0.746	0	15	79.4	160.5	1032.8
7	110.0	0.793	0	1	79.4	1465.4	923
8	96.0	0.610	0.02	15	36	446.8	677.8

Table 2: The values of the restriction functions.

Restriction	Value
Quantity	0 + 431.3 + 357.2 + 0 + 2105.4 + 160.5 + 761.3 + 184.3 = 4000
Research octane number	95.38 ≥ 94.8
Density	0.7673 ≥ 0.7673
Benzene concentration	0.795 ≥ 0.795
Sulfur concentration	9.53 ≥ 7.4
Final boiling point	154.89 ≤ 202

The optimal BOSS solution is different in accord to MATLAB optimal solution, especially to the component 1 and 4. For the component 7 and 8, the calculated quantity with MATLAB program is 50% in rapport to the quantity calculated by BOSS software. However, the quantity of the component 2, 3, 5 and 6 are identical values.

The source of the differences between the optimal solution calculated by BOSS software and MATLAB software is the mathematical model.

Table 3: Comparison between the BOSS solution and the MATLAB solution.

Gasoline component	Quantity [tons]	
	BOSS	MATLAB
x_1	528.9	0
x_2	431.3	431.3
x_3	575.4	357.2
x_4	561.9	0
x_5	2105.4	2105.4
x_6	160.5	160.5
x_7	1465.4	761.3
x_8	446.8	184.3

The obtained results indicate that the BOSS mathematical model is more complicate than the author's mathematical model. The analysis of the mathematical model developed by the authors has evidenced other deficiencies according to BOSS software. In table 4 there is presented a comparison between the gasoline properties estimated by BOSS software and the author's model. The author's model is in total according with the BOSS software for density and benzene concentration.

Unfortunately, the author's model is in des-according with the final boiling point of the gasoline.

Table 4: Comparison between the gasoline properties estimated by BOSS software and the author's model.

Gasoline properties	Unit	BOSS	Author's model
Research octane number	-	94.8	95.38
Density	g/cm^3	0.7673	0.7673
Benzene concentration	% vol	0.795	0.795
Sulfur concentration	ppm	7.4	9.53
Final boiling point	^{0}C	202	154.89

5 CONCLUSIONS

The paper presents the author's research into industrial in line gasoline blending. The study has reported differences between the optimal solution calculated by Blend Optimization and Supervisory System and the optimal solution obtained by using the author's model. The authors have identified the gut components of the proposed mathematical model

(Research octane number, density and benzene concentration) but in same time, they have incriminated the major deficiencies of model (sulfur concentration and final boiling point).

The research of the authors will continue with the next steps:

- experimental determination of the physical properties of the compounds used to the gasoline reformulating;
- the blend of the gasoline with know composition and experimental determination of the physical properties of the blend;
- the verification of the calculus relations used in the gasoline blend mathematical model.

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