DESIGN OF EXPERIMENTS IN TRUCK COMPANY

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ABSTRACT

Purpose: Design of experiment (DOE) represent very powerful tool for process improvement vastly supported by six sigma methodology. This approach is mostly used by large and manufacturing orientated companies. Presented research is focused on use of DOE in truck company, which is medium size and service orientated. Such study has several purposes. Firstly, detailed description of improvement effort based on DOE can be used as a methodological framework for companies similar to researched one. Secondly, it provides example of successfully implemented low cost design of experiment practise. Moreover, performed experiment identifies key factors, which influence the lifetime of truck tyres.

Design/methodology: The research in this paper is based on experiment conducted in Slovakian Truck Company. It provides detailed case study of whole improvement effort, together with problem formulation, design creation and analysis, as well as the results interpretation. The company wants to improve lifetime of the truck tyres. Next to fuel consumption, consumption of tyres and their replacement represent according to them, one of most costly processes in company. Improvement effort was made through the use of PDCA cycle. It start with analysis of current state of tyres consumption. The variability of tyres consumption based on years and types was investigated. Then the causes of tyres replacement were identified and screening DOE was conducted. After a screening design, the full factorial design of experiment was used to identify main drivers of tyres deterioration and breakdowns. Based on result of DOE, the corrective action were propose and implement

Findings: Based on performed experiment our research describes process of tyres use and replacement. It defines main reasons for tyre breakdown and identify main drivers which influence truck tyres lifetime. Moreover it formulates corrective action to prolong tyres lifetime.

Originality: The study represents full description of problem solving procedure-from problem definition to evaluation of corrective action. It can be also understood as methodological guidelines for similar companies. Moreover it is example of good practise. It shows how to conduct low cost DOE based improvement effort in non-manufacturing company.

Keywords: design of experiments; process improvement; full factorial design; tire tread; screening design; SME

1   INTRODUCTION

Organizations try to secure their long-term economic success by continuous improvement of their products, processes and services in order to maximize their wellbeing (Szabo et al., 2013). Success of such improvements is determined by understanding how these elements behave and interact inside and outside of their own system.

Design of Experiments (DOE) is known as statistical method used by scientist and practitioners to better understand complex phenomena. It can be defined as a "systematic, rigorous approach to engineering problem-solving that applies principles and techniques at the data collection stage so as to ensure the generation of valid, defensible, and supportable engineering conclusions" (Firka, 2011). Approach was founded by Sir Roland A. Fisher who used it for agricultural research (Barad, 2014). Its purpose is "to study effects of simultaneous, multiple variable in the most economical way" (Chompu-inwai et al., 2014). Barad (2014) adds, that its economy lies in its ability to obtain reliable results based on relatively small sample (trials). Moreover Johnson and Steele (2012) supply other four advantage to prove effectiveness of this method. They are: 1.efficient capturing of data; 2.complex scope on solving problem; 3.better understanding of interaction between process inputs; 4. evidence based support of decision. DOE also represent a direct replacement of OFAT (one factor at a time) framework as well as Shaninin's sequential testing method (Antony et al., 2011).

Even though number of studies prove usefulness of DOE in manufacturing (see Ilzarbe, 2008), non-manufacturing (see Antony et al., 2011) or even simulation (Kleijnen, 2005) environment, its application in real organizations remain somewhat limited (Tanco et al., 2008; Firka, 2011). However, because of rapid growth of continuous improvement methodology based on Six sigma, organizations are more encourage to use DOE more (Ilzarbe, 2008). On the other hand as recent studies showed DOE is usually use as improvement tool for large organization to their support manufacturing (Ilzarbe, 2008 ; Chompu-inwai et al., 2014) and also non-manufacturing processes (Antony et al., 2011). There is only a limited number of case-studies describing implementation of DOE in SME (Chompu-inwai et al., 2014) or in non-manufacturing areas (Antony et al., 2011).

That is the reason, why we decided to present case study describing implementation of DOE in SME and also in non-manufacturing area of SME.

2   METHODOLOGY

The research in this paper is based on experiment conducted in Slovakian truck company. The experiment was part of process improvement effort executed from 2009 to 2012 on process of tires maintenance. Although mentioned process is only an auxiliary process, it directly influence the company's primary process called the transportation. Moreover, according to management of company, tires expenditure and their replacement represent next to the fuel consumption second most costly process in company. The improvement effort was based on Deming's PDCA cycle. This framework was chosen because company has good experience with it. The initial phase of PDCA known as "Plan" has several steps:

1) Identification of tires deterioration process

2) Definition of strategic framework

3) Analysis of current state of tires consumption (quantification of problem)

4) Identification of causes, which influence the tires deterioration process

5) Execution of screening experiment

6) Design of full factorial experiment.

The "Do" phase of PDCA cycle dealt with realisation of experiment. Concretely, it was 2^4 full factorial experiment conducted from September 2011 to January 2012. The four factors were chosen from previously selected seven factors based on results of previous screening experiment. The route from Košice in Slovakia to Onesti in Ukraine was chosen as experimental one. It took 4 days to pass and was selected because it was long enough (2000 km) to measure deterioration of tires. The deterioration was measured by tread depth gauge called Vigor 0-25mm. Its measurement accuracy was 0.01 mm. Measurement were executed at the same place in every tire. It was above tire TWI mark in the first drain of tire tread pattern. Moreover every tire was marked in order to assure that during experiment will be put at the same position and same side of the truck. These precautions enable to measure deterioration of tire as difference between previously measured tread depth and current one. Tires inflation as well as technical condition of the truck were check before every trial. The values of tire inflation used in experiment were carefully chosen, in order to not effect manoeuvrability of truck, and fulfil legislative requests, as well as safety of truck and material. Based on company request, range of tire inflation used in this paper is not exactly the range used in experiment. It was adjusted by multiplication of constant. During the experiment, organization executes 16 rides with same material and approximately same weight in order to gain 32

measurement (left and right tire) of tires' tread depth. The frequency of rides were determine by the frequency of orders of this specific delivery.

In the "Check" phase of PDCA the analysis of the experiment were conducted. The whole phase was divided into three parts. First part covering identification factors, which significantly (level of significance $\alpha \geq 1$ %) affect deterioration of tires tread. Second part analyse identified factors and level of their influence on researched process. The last part dealt with optimisation and definition of optimal setting for lowest tires tread deterioration. Most of conducted calculations and graphs were created by use of Destra V.10 from Q-Das ltd. Preliminary study was evaluated by Minitab 17.

The last phase known as "Act" dealt with implementation of result from "Check" phase into the practise and formulation of corrective action.

3   RESEARCH

As was mentioned before, presented case study describe improvement of tires' maintenance process. Such improvement effort was based on Deming's PDCA cycle. Description of particular phases are presented below.

3.1 Plan

The structure of plan phase consists from 6 steps, which were presented in methodology. Regarding the scope of the paper, the first 4 steps will be described only briefly.

The whole improvement start with identification of tires deterioration process, which is briefly described in Figure 1. In the next phase, the strategic framework of whole improvement effort was determined by management of company.
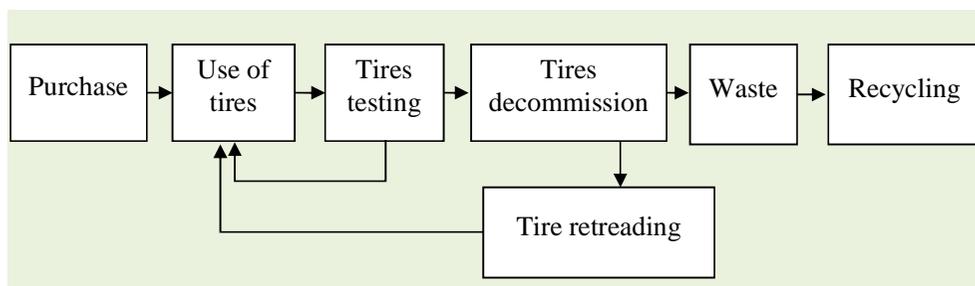
Figure 1 – Tires deterioration process

The strategic framework was used to describe limitations and boundaries of improvement effort. It was pre-determined and represent settings, that could not be changed by improvement action. It include such conditions:

- Conducted improvement actions cannot have negative impact on requirements of stakeholders.

- Conducted improvement actions cannot have negative effect on fuel consumption.

- Conducted improvement actions cannot have negative effect on truck safety, truck manoeuvrability or it can have negative influence to any other performance parameters of truck.

- The structure of company's truck fleet cannot be changed.

The next step consists of analysis of current state. It represents important stage of plan phase. Aim of the analysis was to estimate potential cost of specified problem and therefore define the suitable budget for its elimination. It starts with review of tires consumption in company. Based on the available accounting documents, the number of tires used during the years 2004 till 2009 was estimated. As further analysis showed consumption of tires became more costly from one year to another. For example in 2006 expenditure regarding tires management constitute in average 4.6% of yearly truck revenue, on the other hand in 2009 similar expenditures represent in average 9.15% of yearly truck revenue, which represent almost 100% increase during the two years. Other part of preliminary analyses consisted of comparing lifetime of tires according to their vendors. The lifetime was measured as a number of kilometres, that truck with this tire went. Although company compared tires from three different producers, according to boxplot analysis presented in Figure 2, the lifetime of tires didn't significantly increase based on change of manufacturer. Because tires with better performance produced by Manufacturer B are about 15% more expensive than competition, the difference between efficiency of reviewed tires became even narrower.
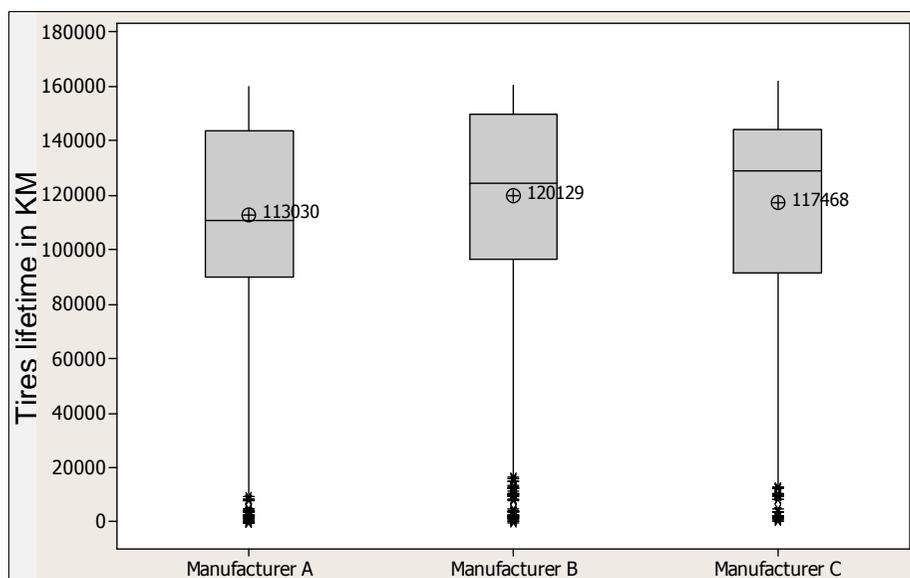

Figure 2 – Analysis of lifetime of tires based on manufacturer

Plan phase continued with detailed analysis of tires deterioration process. The analysis was conducted to determine causes of tires breakdown. As boxplots showed, lifetime of tires has high variability. The length of tires life time is determined by reasons, which cause their retirement. Based on review of check sheets of 1000 tires, there are 6 main reasons causing end of tire's lifetime. The importance of particular causes were investigate by Pareto analysis.
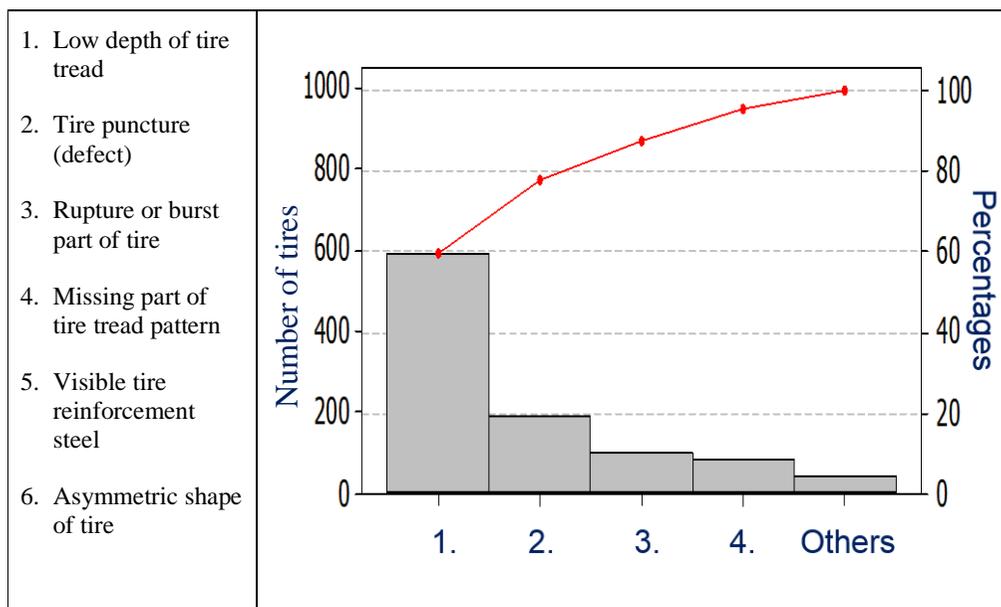

Figure 3 – Pareto analysis of tire rejection

According to results of Pareto analysis presented in Figure 3 the main reason causing 60% of tire rejection is low depth of tire tread. That is why the improvement team organize an brainstorming session, that focus on identification of causes of low depth of tire tread. For better understanding of issues, that can be tackled by improvement effort, found causes were categorized into four categories, which are presented in Table 1.

Table 1 – Categorization of causes of low depth of tire tread

Causes, which organisation can measure and cannot influence	Causes, which are hard to measure for organization, but they can be influenced	Causes, which organization don't want to influence	Causes, which organization can measure and can influence
Weather	Drivers attention	Car brand	Tire tread type
Traffic	Process of tire maintenance	Number and type of axle trees	Truck geometry

Causes, which organisation can measure and cannot influence	Causes, which are hard to measure for organization, but they can be influenced	Causes, which organization don't want to influence	Causes, which organization can measure and can influence
Tire temperature	Experience of employee of tire repair shop	Type of truck breaks	Tires brand
Tire shape	Cleanliness of truck company area	Maximum carrying capacity	Tire inflation
Truck lock-on		Type of cargo	Quality of tire
Type of road		Quality and type of wheel disk	Tire location in the truck
Road surface		Speed of truck	Wheel load
Number of road holes		Length of road	Tire installation process
Road quality		Safety of driver and cargo	Structure of route
Road cleanliness		Road surface of loading and unloading site	Tires material
Breaking frequency			Wheel disk material
Breaking intense			Driving technique of drivers
Truck breakaway			Storage of tires
Road material			Tires dimension

3.2 Screening experiment

Screening experiment was next step of plan phase. Its aim was to roughly determine, which of identified suspicious factors should have impact on examined variable and therefore had to be fully investigated by full factorial DOE. Secondary objective of screening experiment was to test whether the route as well as measurement procedure are appropriate for full factorial experiment. The screening experiment examined 7 factors by
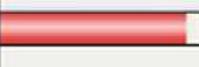
conducting 8 trips from Kosice in Slovakia to Onesti in Romania. Seven selected factors and their levels are presented in Table 2.

Table 2 – Factors selected for screening experiment

Factors	Levels		Variable
A. Driving technique	Non experienced driver	Experienced driver	Discrete
B. Tire price	Expensive	Cheap tire	Discrete
C. Tire inflation	8 kPa	8,3 kPa	Continuous
D. Type of tire tread	Universal tread	Winter tread	Discrete
E. Truck condition	New truck	Old truck	Discrete
F. Truck type	Semi-automatic-trailer	Trailer	Discrete
G. Length of tire storage	From storage	Direct from manufacturer	Discrete

Results from screening experiment verified, that selected route is sufficient for measuring decreasing depth of tire tread. Moreover the experiment helps to estimate four factors which could significantly influence depth of tire tread. Evaluation of experiment is presented in Table 3. Very rough estimate of factors' impact is presented in last column. Four mostly influential factors are driving technique, tire inflation, tire price, truck type. These factors were selected for full factorial design of experiment.

Table 3 – Results of screening experiment

x_i	level	b_i	s_{b_i}	E_i	$|E_i|$
Intercept		0.255	0,000	---	
A	1	0,0250	0,000	-0,0500	
B	1	0,0150	0,000	-0,0300	
C	8,000	0,0400	0,000	-0,0800	
D	1	-0,00000000000	0,000	0,00000000000	
E	1	-0,00000000000	0,000	0,00000000000	
F	1	0,00500	0,000	-0,0100	
G	1	0,00000000000	0,000	-0,0000000000	

3.3 Full factorial DOE

Last step of planning phase consist of creation of full factorial design, which can be implement during the "DO" phase. Screening experiment revealed four significant factors so improvement team decide for full factorial 2^4 plan, which require 16 runs. Because chosen combination of route and transported material were frequent in the organization, use of full factorial design instead of fractional factorial design was preferred. In order to gain more precise results, the runs were randomized. English translation of final plan is presented in Table 4.

3.4 Do

The Do phase consist of execution of runs according to plan presented in Table 4. As was mentioned earlier, the tire tread worn out was measured as decrease in depth of tire's tread. The samples were collected from left and right leading tire of truck after the run. The gaps between runs were not similar. They depend on frequency of the orders.

3.5 Check

Check phase consists of evaluation of experiment and determination of factors which significantly influence the depth of tire tread and therefore tire deterioration process. It starts with evaluation of regression model presented in table 5.

Table 4 –Plan of full factorial design

run no.	A - Driving technique	B - Tire inflation	C - The price	D - Truck type
1	experienced	8,3	expensive	trailer
2	non-experienced	8,3	expensive	trailer
3	non-experienced	8,3	cheap	semi-automatic trailer
4	experienced	8	cheap	semi-automatic trailer
5	non-experienced	8	cheap	semi-automatic trailer
6	non-experienced	8	expensive	semi-automatic trailer
7	experienced	8,3	expensive	semi-automatic trailer
8	experienced	8	expensive	trailer
9	non-experienced	8,3	cheap	trailer
10	experienced	8	expensive	semi-automatic trailer
11	experienced	8	cheap	trailer
12	non-experienced	8,3	expensive	semi-automatic trailer
13	experienced	8,3	cheap	semi-automatic trailer
14	experienced	8,3	cheap	trailer
15	non-experienced	8	cheap	trailer
16	non-experienced	8	expensive	trailer

Table 5 –Evaluation of full factorial design

x_j	level	b_j	s_{b_j}	t_j	$|t_j|$	P
Intercept		0.188	0.00256	73.424***		< 0.0001
A		0.0159	0.00256	6.231***		< 0.0001
B		-0.0228	0.00256	-8.918***		< 0.0001
C		-0.0109	0.00256	-4.276***		0.000579
D		0.000937	0.00256	0.367		0.719
AB		0.00281	0.00256	1.100		0.288
AC		0.00219	0.00256	0.855		0.405
AD		0.00156	0.00256	0.611		0.550
BC		-0.00281	0.00256	-1.100		0.288
BD		0.000313	0.00256	0.122		0.904
CD		0.00469	0.00256	1.833		0.0855
ABC		-0.00469	0.00256	-1.833		0.0855
ABD		0.000937	0.00256	0.367		0.719
ACD		-0.00219	0.00256	-0.855		0.405
BCD		-0.00219	0.00256	-0.855		0.405
ABCD		-0.00156	0.00256	-0.611		0.550

A: Driving technique, **B:** Tire inflation , **C:** Tire price, **D:** Truck type

According to the results, three of four factors, such as A: Driving technique, B: tire inflation and C: tire price have statistically significant (α=0,01) impact on depth of tires tread. On the other hand experiment didn't revealed any statistically significant interaction between factors. The influence of factors on tire tread worn-out (mm) is presented by slope of the line in Figure 4. The steeper line means higher impact.
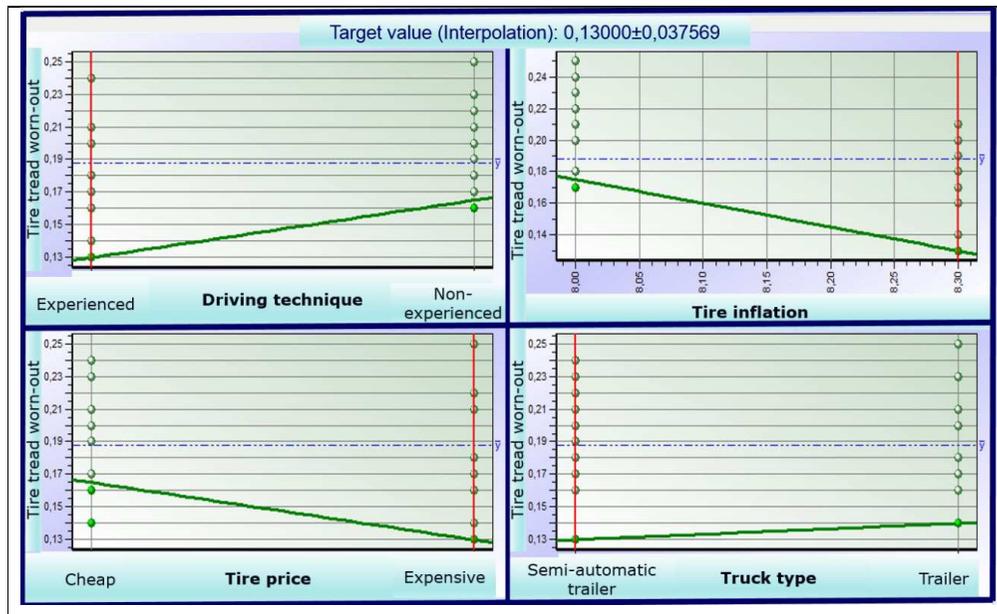
Figure 4 – Overview of factors' influence

Based on previous two figures, it can be claim, that the tire inflation has from all examined factors most significant impact on depth of tires tread. Although the exact range of inflation cannot be publish, the rule: "the higher tire inflation, the lower tread worn-out" is valid. Second most significant factor is driving technique. According to the results if other researched parameters have their optimal values, it was estimated that experienced driver causes approximately 21% less tire tread worn-out, than non-experienced one. The last of identified factors is tire price. Based on our findings the tire price (as a very vague measure of tire quality), has also significant impact on depth of tire tread. Similar to previous factor, also in term of tire price it was estimated, that if other researched parameters have their optimal values, the changing from cheap tire to expensive one can save almost 20% of tire tread worn-out.

Final part of experiment evaluation consists of determination of optimal settings. The aim of optimizing task was to minimize tires tread worn-out, which will minimize the decrease of tires' tread depth, which should improve tires' deterioration process as well as their lifetime. Founded optimal settings are presented in the Figure 5.
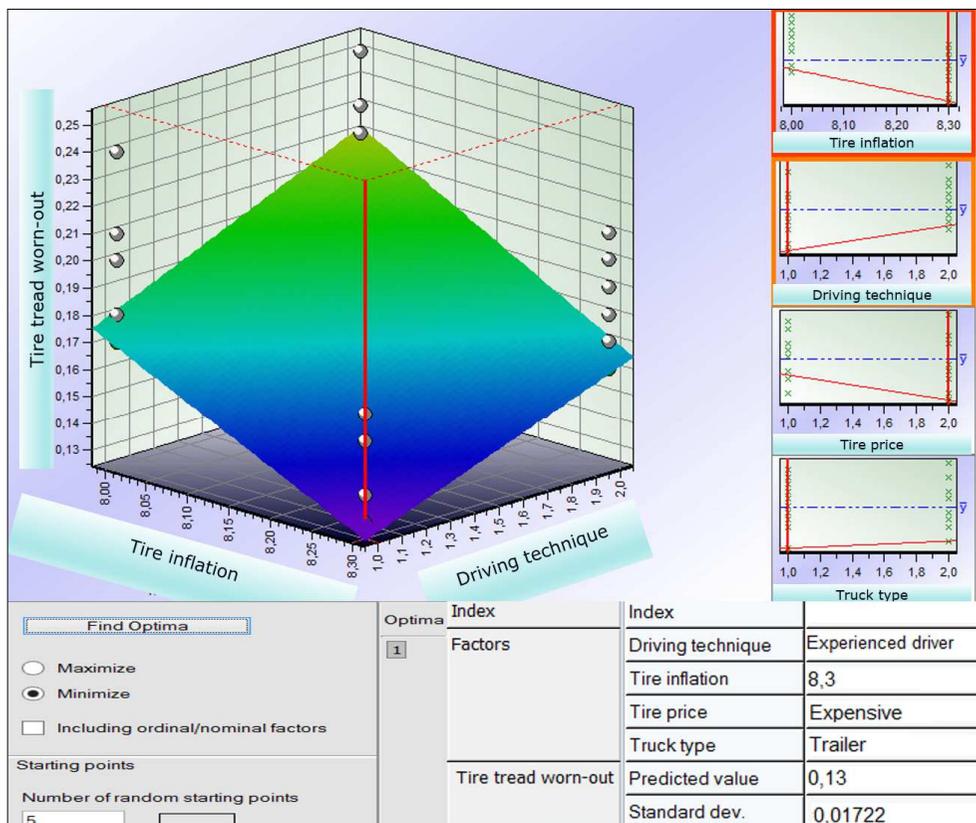
Figure 5 – Overview of optimal setting

3.6 Action

Action phase of improvement effort focus on formulation of corrective action based on results of experiment. First task was to implement actions, which can secure appropriate pressure in trucks' tires. Therefore organization establish system of tires' presure controls. These controls were executed by members of company's security service and conducted during refueling process. Every trucks with schleduled route longer than 1000 km had to be check before journey. For other trucks with schleduled shorter routes, organization create system of radom controls. Because every driver is responsible for its truck, insufficient tire pressure had effect on performance evaluation of the driver. According to another experiment conducted in truck company, driving technique is also main driver of fuel consumption. Therefore company decide that drivers with constantly excesive consumption of fuel as well as drivers with high consumption of tires must conduct draving lessons from driver with lowest average fuel consumption. In termo of tires organization decide to purchase expensive tires, unless the purchase price exceed 20% of tire from manufacturer of the cheap tires.

The final stage of action phase consists of collecting data, monitoring improvement, and prepare background for further efforts.

4 CONCLUSION

Presented improvement effort is an typical example of low-cost experiment. Appart from sets of new tires, organization didn't have to buy any equipment or hire extra man power. The whole experiment were conducted from internal sources and organization doesn't recognized any extraordinary increase of costs during its length. Moreover, based on managed logistics none of internal processes had to be stopped or postpone during the experiment. Frequent delivery of goods chosen for experiment to destination chosen for experiment, enable use of full factorial design. Experiment identified three significant factors and led to implementation of four corrective actions, which doesn't require additional costs.

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