Application of the "boundary line analysis method" for the optimisation of the number of tractors used in an agricultural company

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Abstract: The "boundary line analysis method" calculates the minimal total annual operational costs used for the optimisation of number of tractors owned by agricultural companies. This calculation reflects the actual need of tractors used in the selected time periods during a year. The above method is based on data gained during five day periods (so-called pentads) in the plant production Farm Estate Lány which belongs to the Czech University of Life Sciences Prague. Based on the annual use of tractors in the company, operational costs involve tractors owned and hired. The calculated curve changes in relation to the total annual costs for the owned tractors. The economically optimal number of the owned tractors would be reached at the minimum point where the total annual costs curve is low whilst all working operations in the company have been done. Due to the use of tractors during the pentads, it is recommended to own exactly the number of tractor-machine sets given by the calculated minimum. For all the other works, it is advisable to use hired tractors, operationally leased tractors or outsourced services.

Key words: costs optimisation, tractors deployment, tractor number optimisation

The current economic situation requires that agricultural companies optimise their costs to be able to achieve the production profitability. The optimisation can be done in many ways. Regarding tractors, it can be solved by determining their optimal number in the company, decreasing of operational cost, changing the production structure and technological methods or using more efficient and larger tractors categories.

Pulley and Chaplin (2008) developed a computer application called the Common Agricultural Tractor Selection System (CATSS). It uses mathematical models for many aspects of technological operations in order to select the cost-effective and proper type of tractor and to determine the technological operation of soil tillage and sowing in spring. The climate conditions (the temperature of soil surface, the dew point etc.) with the soil type, the previous method of soil tillage, etc. are considered. Søgaard and Sørensen (2004) created a model for the optimisation of tractor-machine sets that minimises costs. It takes into account all items of the variable and fixed costs, the farm size and the crop rotation. The output of this model gives a proposal on the optimal machine size and the related power and number of tractors. The program also calculates the costs and time needed for the working operations.

Audsley (1984) created another program to elaborate the tractor-machine sets optimisation and the costs calculation for the autumn tillage followed by the soil preparations and sowing. It uses the weather forecasting, the effect of soil compaction and the compliance with the timeliness of sowing. Jannot and Cairol (1994) developed a model that allows designing the optimal layout of crops in the farm. Based on this, it is possible to calculate gross profit, the demand for manpower, equipment requirements and the size of the machine managed land. Camarena et al. (2004) created a model for multiple farms that allows the selection of machines from a database for each farm separately. This model allows calculating minimal costs for each of the modelled farms based on its size, the time working progress, the possible

Supported by the Ministry of Education, Youth and Sports of the Czech Republic (Projects No. MSM 6046070905).

combinations of machines, variable and fixed costs predictions including future changes.

Akarte and Askhedkar (1994) concentrated on the calculations of economic effectiveness of tractors deployment with regard to the break-even point calculation of each operation as tillage, soil preparation, sowing etc.

Wan Ismail (1998) monitored the tractors deployment and came to the conclusion that the farms, which grow more types of crops, reach a higher level of tractor utilisation than the farms with monocultures. This is caused by the necessity to perform more different working operations with respect to the higher number of crops. Thereby, it is efficient to focus on limiting the number of the main types of crops and to reduce the operation costs of tractors.

Abrham et al. (2007) described the system AGROTEKIS used in the Czech Republic. It works with tables showing and comparing machine costs, the technical support of operations, the technology and economics of crop production.

None of the above mentioned programs allows for the optimisation of the number of tractors owned by the farm with regard to the tractors deployment according to works during the year and the possibility to provide a part of works through hired services in order to reduce the costs related to the tractors deployment.

MATERIAL AND METHODS

The optimisation of the number of tractors based on the boundary line analysis is demonstrated on the following example. The Farm Estate Lány (further SZP Lány) cultivates 2955.29 ha of land, of which 2667.56 ha is arable land. The farm owns 23 tractors, whereas 12 tractors are equipped with an engine up to 100 kW, 6 tractors up to 170 kW, 5 tractors above 170 kW and their average age is 18 years. The number of tractors deployed was monitored throughout the year in different pentads and also the number of working hours of the tractors was recorded. Monitoring was performed in line with the following operation groups: soil tillage, fertilisation, grain and fodder crops harvesting, and overheads. There were monitored the costs of tractors owned and hired.

The operation costs of tractors owned by the company can be determined as the sum of the annual fixed costs and variable costs depending on the number of hours of the actual use during the year at the selected intervals. The annual fixed costs consist of depreciation costs, costs reflecting interest of own capital, bank interest or margin finance leases, the mandatory insurance and vehicle insurance costs, the costs of storing and garaging. The variable costs consist of the fuel and lubricants costs, maintenance and repair costs, labour costs for the operators as well as the costs of supplies. The costs of operations hired can be calculated the as the contract price of the service multiplied by the number of hours of operation. The total annual costs are calculated afterwards as the sum of the costs of tractors owned by the company and the costs paid for the services. This relationship is expressed by the following Equation 1.

$$TAC = \sum_{i=1}^{n} \left(\frac{AFC}{I_i} \times T_v + \int_{t=0}^{x} T_{vp} \times UVC \times dt \right) + \sum_{i=1}^{n} \int_{t=0}^{x} T_N \times C_p \times dt \quad \text{(CZK/year)} \qquad (1)$$

where:
TAC = total annual costs of tractors operation in the company (CZK/year)
AFC = annual fixed costs of the owned tractor operation (CZK/year)
T_{vp} = number of the necessary owned tractors in the company in the interval
T_v = number of tractors owned by the company within a year
UVC = unit variable costs of the owned tractor operation (CZK/hour)
i = intervals of tractors operation within a year (p = 0 to n)
C_p = price for service per hour (CZK/hour)
T_N = number of the hired tractors in the company in the interval
t = hours of tractors operation within the interval (t = 0 to x) (h)
I_i = number of intervals of tractors operation ($I_i = \Sigma i$)

The intervals of monitoring the number of hours of tractors deployed can be chosen differently, e.g. a day, pentad, week, decade etc. Due to the dependence of agriculture on the natural and climatic conditions and agro-technical deadlines, monitoring of the tractors deployment was based on pentad intervals. To register the deployment of tractors, every pentad during the year can be used (p = 0 to 73), whereas the actual number of hours of the tractors deployment in a pentad is recorded (t = 0 to x). Also the pentad constant (k_p) can be used for registering, which means the deployment of 40 standard hours of tractor use (standard number of hours of one tractor in a pentad, i.e. in five days – 8 × 5 = 40 hours of work per one tractor per pentad; t = 40). Subsequently, the Equation 1 can be modified into the shape of the Equation 2, where a year is divided into pentads and the number of the actual tractors deployment hours in a pentad is used for cost calculation. Alternatively, Equation 1 can be adjusted into the incremental form as presented in Equation 3, if the pentad constant for the calculation of cost is applied.

$$TAC = \sum_{p=1}^{73}\left(\frac{AFC}{P_p} \times T_v + \int_{t=0}^{40} T_{vp} \times UVC \times dt\right) + \sum_{p=1}^{73}\int_{t=0}^{40} T_n \times C_p \times dt \qquad \text{(CZK/year)} \qquad (2)$$

where:
t = hours of tractors operation within a pentad (t = 40) (hour)
P_p = number of pentads of tractors operation (P_p = 73)
T_{vp} = number of owned tractors used in the pentad
p = pentad of tractors operation within a year (p = 0 to n)

$$TAC = \sum AFC + \sum_{p=0}^{n}(T_{vp} \times UVC \times k_p) + \sum_{p=0}^{n}(T_N \times C_p \times k_p) \qquad \text{(CZK/year)} \qquad (3)$$

where:
k_p = pentad parameter (k_p = 40) (h/tractor and pentad)

The total costs of tractors can be determined by multiplying the number of hours of using tractors and the costs of their operation in accordance with the above mentioned equation. Therefore, these costs represent the area shown in the chart. Using the method of the boundary line analysis, the proportion of costs attributable to tractors belonging to the company (the area under the line showing the number of own tractors) and the costs of the operation outsourced (the area shown in the chart above the line) can be illustrated. The proportion of costs attributable to the owned and hired tractors is variable for different combinations of the number of tractors. The optimal number of tractors is the minimum inflexion point (break-even point) of the total cost curve. This minimum can be found through the local minimum, i.e. if the first derivative of the Equation 3 is raised to zero. Also, the result can be derived analytically by calculating the total costs for different combinations of the number of tractors owned by the company and the number of tractors hired, resulting in the determination of cost minimum.

RESULTS AND DISCUSSION

Calculation of the total annual operation cost of all tractors in the company has been done as presented in the Equation 1. Combinations of the number of owned tractors in the interval 0 to 30 tractors are used. The number of 30 tractors was used due to modelling the costs above the maximum number of tractors necessary to perform all operations during the season as well as the number of tractors owned by the company. The aim was to simulate the development of costs of the company, if it owns more tractors than it actually has. A range of 0 to 22 units was used for the hired tractors, where the upper limit corresponds to the maximum number of tractors that are necessary to provide all working operations during the season. In terms of all working operations, an economically optimal combination of the owned and leased tractors is achieved in the minimum of the total annual costs for tractors operations. The cost modelling was done using the VBA in the MS Excel.

Figure 1 shows the tractors deployment during the year according to the realisation of working operations of basic soil tillage (ZZP), fertilisation and operations related to the cultivated crops and overhead costs (works that cannot be assigned to any of the working processes).

When modelling the costs of operating tractors, the number of the owned tractors was in the interval 0 to 30 units and the number of the hired tractors was within the interval 22 to 0 tractors. Model calculations were done for different combinations starting with the combination when all works were done only by the hired tractors and no owned tractors up to the combination of 30 owned and no hired tractors.

As it is evident from the Figure 2, which shows the progress of the total annual costs of all tractors for different combinations of the owned and hired tractors, there is a gradual degressive reduction of costs from the amount of CZK 7.9 million. The reason for this reduction is the growth of number of owned tractors that were fully used. The curve minimum is achieved at deployment of 9 owned tractors, when the total costs are CZK 5 million, whereas the costs of owned tractors achieve the amount of CZK 4.1 million and of hired tractors CZK 0.9 million. This is the optimal number of owned tractors in the terms of costs.

From this number of owned tractors, almost a linear increase of costs is evident. This is caused by the increase of the number of owned tractors, where the owned tractors are not fully utilised which leads to

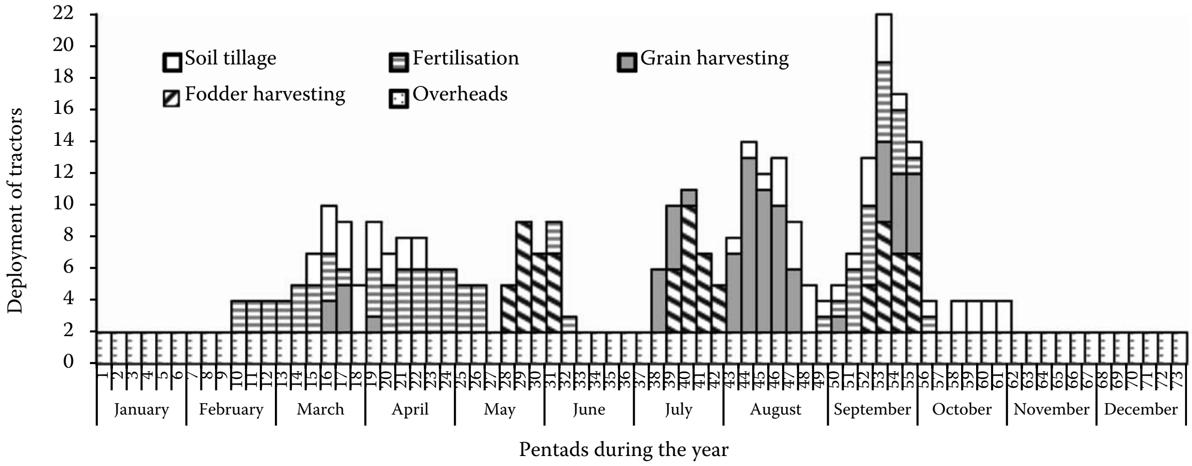

Figure 1. Chart of the tractors used during a year according to working processes

the growth of the fixed costs per 1 hour of operation. Hired tractors are used only in seasonal peaks when it is not possible to perform the works by own tractors. Reaching the number of 22 owned tractors, no hired tractors are used and all operations are provided only by the owned tractors. At this point, the costs of the operation of owned tractors amount to CZK 7 million. As the number of owned tractors rises beyond this limit, the linear growth of costs is continuing, which is caused by the accumulation of fixed costs that cannot be traced to working operations because of the tractor under-utilisation.

The companies that are holding a high number of tractors regardless their utilisation should keep this fact in mind. Such overcapacity increases their costs that are not spent effectively. In the terms of the total costs, it is apparent from the chart that during the season, it is efficient to lease tractors for certain operations which leads to costs saving.

The Figure 3 shows the progress of the hired tractors costs, of the owned tractors costs and the total costs. The curve of the total costs is in early stage characteristic by a fast decrease with the increasing number of owned tractors, later it gradually slows down. This is caused by the fact that the costs of services are higher than the costs of the operation of owned tractors. Therefore it comes to a quick cost reduction at the beginning as the number of owned tractors increases. The minimum of the total cost curve is in the point of optimal number of tractors operating in the company. From this point, the curve of the total costs is gradually growing. Crossing over the number of 22 owned tractors means, that there is no need to use any hired tractor and therefore no costs of the hired tractors occur. The curve of the cost of owned tractors is declining with their growths; it is obvious that this is caused by decreasing the proportion of the fixed costs per 1 hour of the

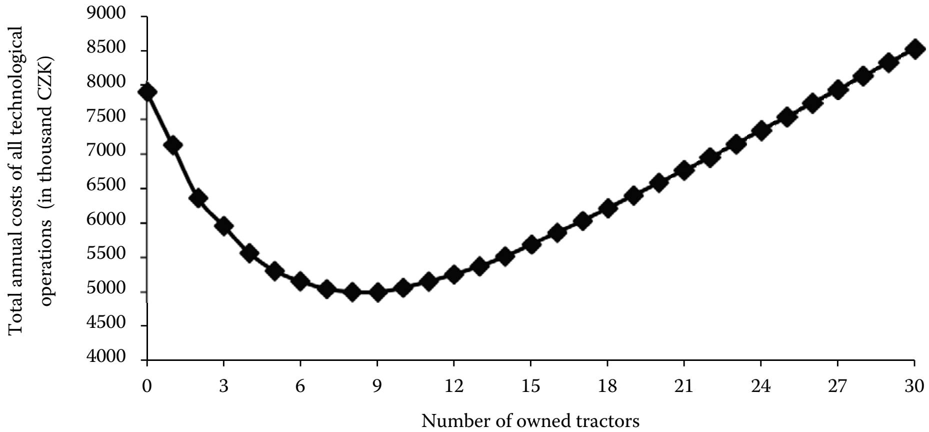

Figure 2. Progress in the total annual costs for the increasing number of owned tractors when other needed operations are done by hired tractors

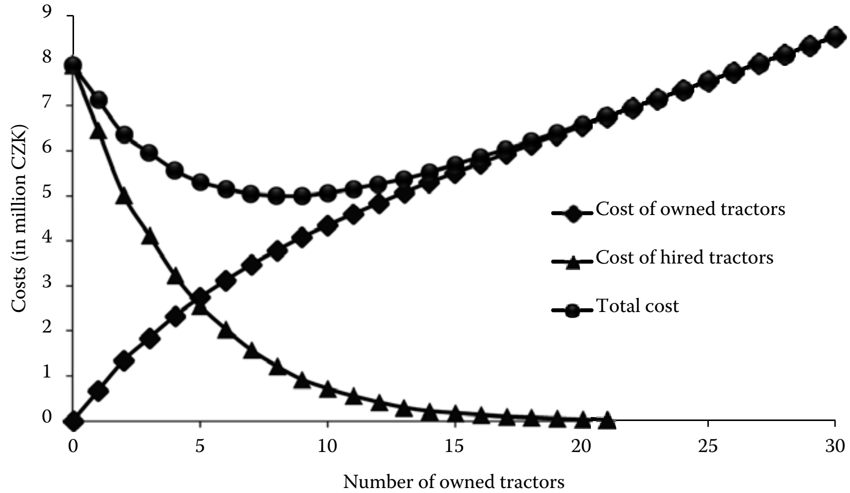

Figure 3. Development of the costs of owned tractors, hired tractors and total costs

tractor operation. After reaching the number of 22 owned tractors, which can provide all the work, the costs in the company are created by the proportion of fixed costs because the work of these tractors is not necessary with regard to the scope of the cultivated area. The shape of the total cost curve shown in the Figure 3 has already been described above. It is evident that from the number of 22 tractors the curve is similar to the curve of costs of owned tractors, when no tractors are additionally used due to the limited scope of works which is reflected in the strong performance of fixed costs.

Figure 4 is a curve showing the differences between the costs of the operation of owned and hired tractors. At 5 tractors, the operation costs of the owned and hired tractors are approximately at the same level. It is apparent from the figure that the costs are falling rapidly in the early stage, as the number of owned tractors is going up. The costs compared to the previous value fell by 26.7% and at the increased number of owned tractors reach the rate one to two also by 26.7%. Subsequently, if the number of owned tractors is increased to three, the costs will be by 17.7%, at four tractors by 17.3% and at five the costs are reduced by 9.1%, when their minimum is achieved. By this point, there is evident a fast reduction of the difference between the costs of the hired and owned tractors, where the difference is gradually decreasing with the increased number of owned tractors. From five own tractors, the costs tend to grow with respect to the number of own tractors by 11.3%; 10.3% etc., and the difference between costs is getting smaller with the increasing number of own tractors. Using 22 own tractors, the increment is constant and makes 2.5%.

The costs of outsourced services are higher than the costs of own tractors, which can explain the fast cost reduction achieved. At 5 own tractors, there is secured the need of most working operations during the year and increasing the number of tractors results in the cost growth mainly due to the increased

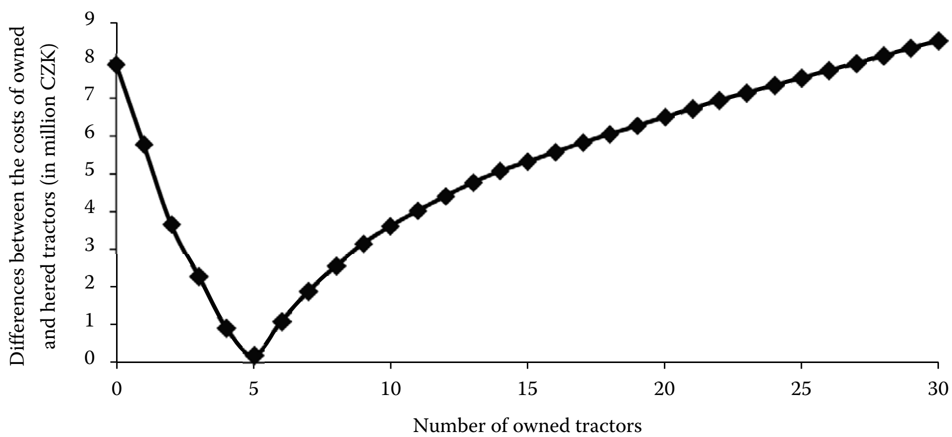

Figure 4. Chart of absolute differences between the costs of owned and hired tractors

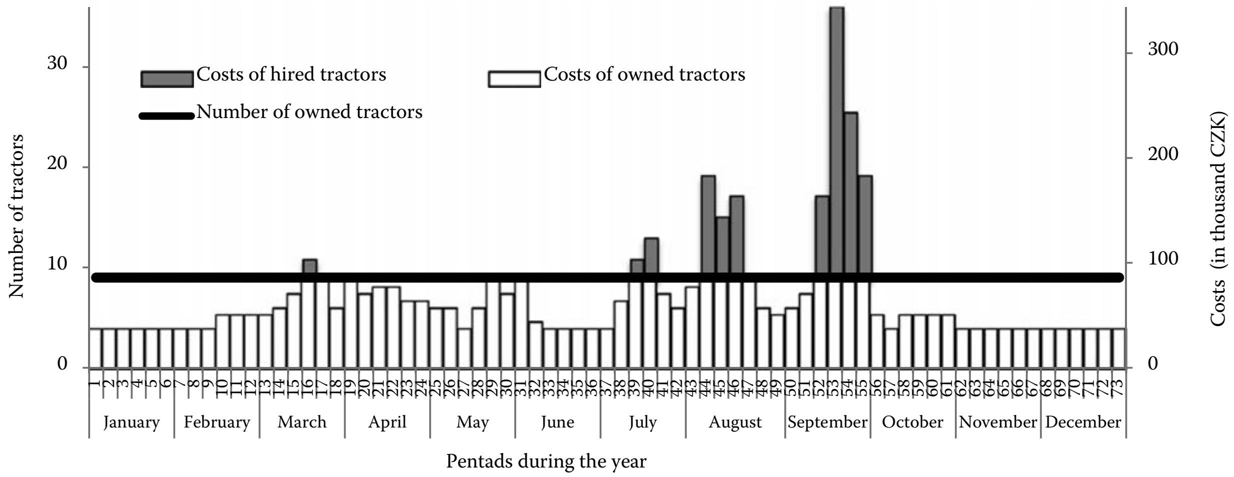

Figure 5. The structure and timing costs of owned and hired tractors

proportion of fixed costs and the fast reduction of the costs of hired tractors that are used only if needed. The optimum of the total costs is achieved only when 9 own tractors are used, because at this number of tractors the lowest sum of costs of the owned and hired tractors is achieved, i.e. the minimum of the total costs.

The total costs of tractors can be calculated by the Equation (2). These costs in line with the pentads are shown in the chart on Figure 5 in the columns. As it is apparent from the Figure 5, using the method of the boundary line analysis divides the chart into two parts. The area under the line shows the costs of the work provided by owned tractors. The area above the line shows the costs of the work of hired tractors, i.e. the situation when the number of owned tractors in the pentad is not able to provide all operations. There is also evident a higher number of tractors, which are needed in ten pentads only, especially during the harvest time when different working operations cumulate. From this perspective, it is possible to solve the optimisation by organisational measures (e.g. by increasing the tractors shifts, by the change of the structure of crops etc.).

Using the method of the boundary line analysis that integrates the area of the chart and summarises the total annual costs in each pentad of the year, the development of the total annual costs can be modelled using different combinations of the number of owned and hired tractors. From Figures 6, 7 and 8, there is noticeable the change of costs (the areas of the chart) at using owned tractor in the amount of 0; 22 and 30 vehicles. It shows also the increase of the costs in the pentads. Comparing Figures 6 and 7 shows that in the case of works provided by owned tractors, the costs are higher in the pentads when the tractors are not fully used due to the fixed costs per 1 hour of work. On the contrary, the costs of hired tractors are higher in the pentads when the peaks are compared to the works done by owned tractors

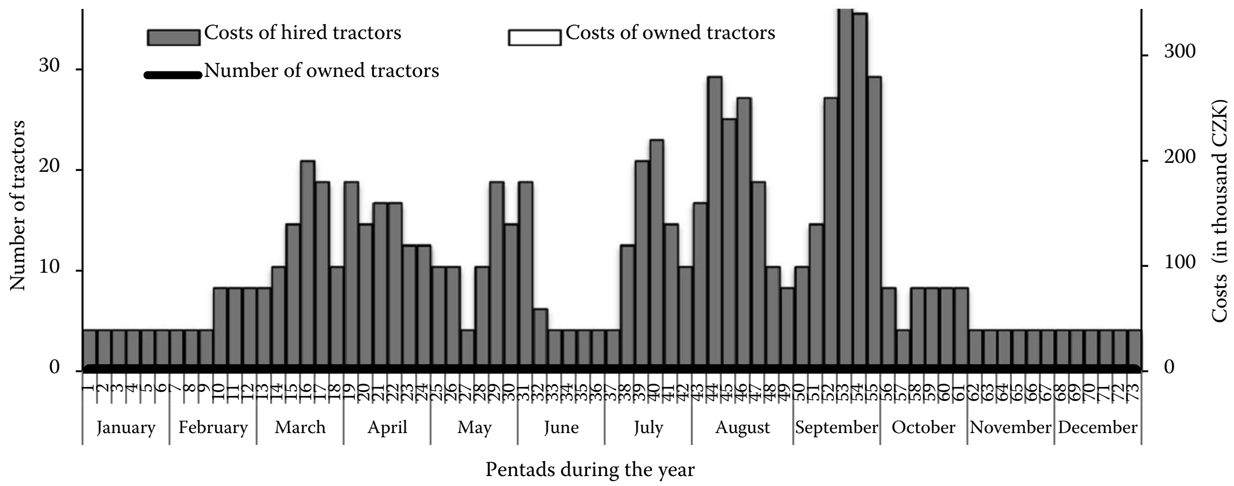

Figure 6. The costs in each pentad during the realisation of work by hired tractors only

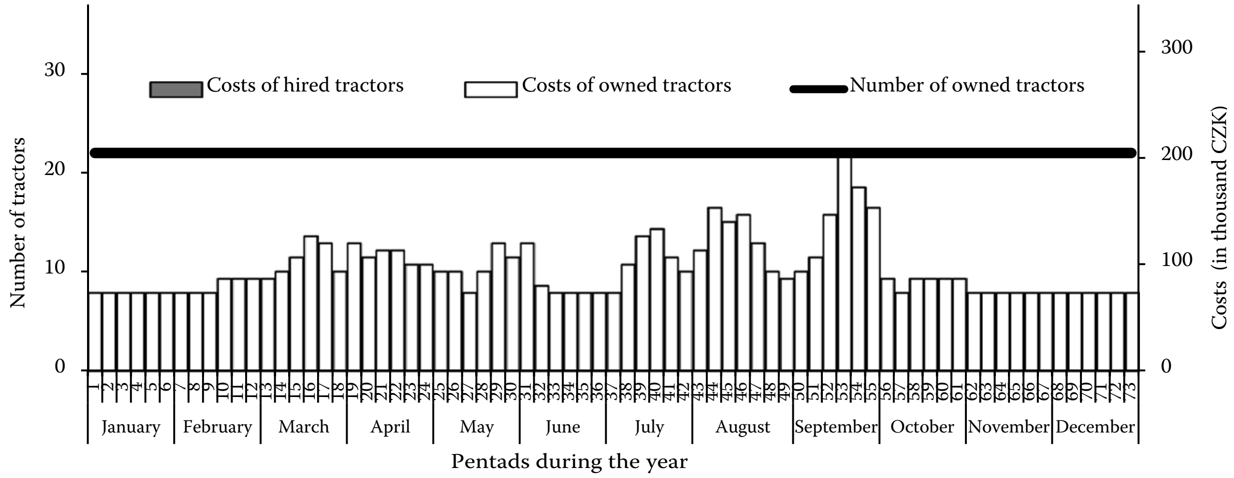

Figure 7. The costs in each pentad during the realisation of work by 22 owned tractors

solved by providing the services. As it is shown in Figures 7 and 8, the increasing number of owned tractors that are not fully used leads to the increase of the costs due to the fixed costs growth.

CONCLUSIONS

Many agriculture companies keep using tractors of a high average operation age which often reflects the bad technical conditions or high fuel consumption. Also the number of tractors owned by the companies is higher than necessary for the working operations. If the company wants to reduce its cost, it is essential to evaluate the structure of tractors and to get rid of the useless tractors. The optimisations cannot be solved only from the economic perspective, as it is important to consider the agro-technical requirements too.

The "boundary line analysis method" can help the company to decide what number of tractors is economically optimal with respect to their deployment during the year in the pentads. Furthermore, the results of the analysis can be used to determine which volume of works can be provided by services, and based on the working operations in the pentads, to select the appropriate operations to be provided by services.

The results of the analysis show that outsourcing may be efficient especially during the season peaks with regard to the costs that are related to the possession of own tractors and their use during the year. The season peaks occur only in a few short periods of time when a high number of tractors is needed in the company. Providing works in these periods can be done by significantly reduced total costs related to tractor operations.

Reducing the number of tractors in the company can also increase the use of tractors, thus introducing

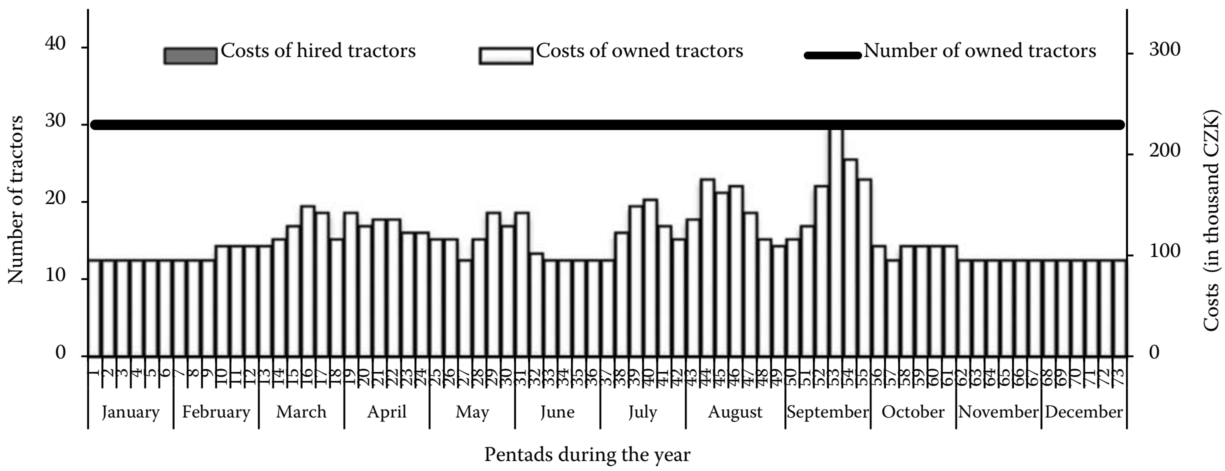

Figure 8. The costs in each pentad during the realisation of work by 30 owned tractors

more shifts during the peak times. For this to occur, agriculture companies have to focus on the renewal of tractors. By purchasing new tractors with a higher reliability, it is possible to ensure a timely implementation of the work required in the enterprise. More shifts can be used especially for the operation with the basic soil tillage and sowing.

One of the crucial factors needed for the optimisation of the number of machines in the company is the consideration of the negative impact of delayed work operations. It is important to perform all the work operations in a timely manner in order to avoid unnecessary losses or additional costs.

Kolek et al. (1997) focused on the tolerance of winter rape, winter wheat and spring barley with regard to their delayed harvest. The aim of this observation was to determine the biological process of the losses and quality changes of the above when harvested after their optimal maturity period. Higher losses were recorded on rape, relatively small losses on winter wheat and spring barley. Qualitative traits such as the weight of one thousand seeds, oil and protein content, the proportion of front grain and other remained unchanged. However, a higher risk of losing food quality or malting quality was noticed. The amount of the losses depends on the harvested crop as well as the weather conditions during the given year.

Kavka et al. (1997) concluded from their observations that the possibility of using combine harvesters from the external service providers makes the own crop more profitable during poor weather conditions (especially when the bad weather lasts long which affects negatively the crop peaks). Determined by the bad weather, only short periods of time are propitious for the harvest. This means that the necessary tools and machines are needed at the same time and cannot be used gradually (as it would be applicable during the normal weather conditions). Therefore, even a company which is able to perform all the operations with its own machines needs to cooperate with other agriculture companies or to outsource the services if the challenge of a "foul weather" occurs. This is important so that the unnecessary costs can be minimised.

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Received: 11th January 2013
Accepted: 9th May 2013

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