Mathematical model for optimal arrangement of milking parlor

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Abstract: Milking is a key operation on dairy farms. The capacity and function of milking parlor influences production conditions (time of operations, needs of labor, total costs), so actually it affects the efficiency of the whole dairy farm. This paper presents a structure and principal parts of mathematical model which was created with the aim to enable to farmers and designers to choose suitable type of milking parlor for specific farm conditions. Three principal questions important for optimization of milking parlor are: technical parameters, indicators of labor productivity and economic criteria. The model structure was created with the aim to find the answer to all of them. The model includes in calculation main parameters of typical arrangements of milking parlors used in modern dairy farms. The inputs are primarily parameters of a dairy farm like a capacity, number of milking per day, available time for milking process in the farm and others. There is a proposed number of milking stalls with the level of automation, number of operators, costs of labor, etc. The optimization is based on the evaluation of all partial results, which are compared in terms of needs of time, labor and specific costs, calculated successively for different proposed milking parlors. This model was verified mainly with some results from measurements in the Czech large scale farms with different technical levels of milking parlors. It can be easily adapted to changed conditions, due to new generations of milking parlors with more modern equipment and facilities or for different production and economic situation.

Keywords: Farm, cows, equipment, labor productivity, specific costs, Czech Republic

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1 Introduction

Livestock production in countries with intensive agriculture is currently undergoing big and rapid changes. These changes are also taking place in many dairy farms. If farmers want to be competitive, they must achieve bigger milk yields and higher quality of milk, which is mainly associated with purity and composition of milk, partly thanks to better milking system on the farm. Capacity of farms are therefore expanding and increasing the average annual milk production per cow. These factors lead to modernization of milking equipment. European housing systems are steadily changing from stanchion barns towards loose cowsheds and larger herd sizes (Maton et al., 1985; Hansen, 1999; Gaworski and Leola, 2014; Gaworski and Priekulis, 2014). Due to these changes, many dairy farmers will have to design and build new milking parlor systems. A similar process of enlargement and modernization of dairy farms can also be expected in many non European countries, where this model, new knowledge and findings from this research could be applied.

There are available solutions offered by manufacturers of either milking parlors (MP), or automated milking systems (AMS), equipped with milking robots. Many books, reports and scientific publications present results of research and recommendations focused on the problems of AMS, usually also including comparison of AMS and milking parlors, in some publications information related to problems of performance and economic analysis (Bottema, 1992; Kic and Nehasilova, 1997; Kic, 1998; Maltz et al., 2003; Priekulis and Laurs, 2012). Leading companies producing milking equipment usually offer a variety of constructions of

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milking parlors recommended for different capacity of farms. They also recommend the possible level of automation and number of milkers which should work in the milking process. But there are rather big differences in local conditions of the farms according to the production, economic, market and labor situation of the country or province. Although the use of AMS for large farms with a big capacity is developing, the high cost of this solution discourages many farmers. The question for medium and large farms is to currently choose an appropriate type of milking parlor.

There are various practical recommendations in the literature, based on many years of experience, sometimes with results of measurements from farms (Maton et al., 1985; Brunsch et al., 1996; Dolezal et al., 2000; Chiumenti, 2004). In his research work Hensen (1999) solved problems of optimal number clusters per milker. However, there are usually not sub-economic data included which results in a specific numerical data, characterizing the overall result of milking parlor solutions. Some publications (Provolo, 1992; Provolo and Marcon, 1993) present models focused on the choosing of milking parlors, but not in a complete universal approach which could be adapted everywhere. Results of research and basic equations used for calculation of several parameters of milking parlors presented Brunsch et al. (1996). Similar calculations, completed with several important economic results which are valid for rotary milking parlors are presented by Ozolins et al. (2012).

The aim of this paper is to show the structure, function and possibilities of computational procedures compiled into a mathematical model, which as a result provides a clear and objective numerical data (money and time) for the milking parlor on the farm. The model of calculation was tested in agricultural production conditions of the Czech Republic. This model can be quite easily modernized and completed by new data from newly developed milking equipment or adapted to different local conditions.

2 Materials and methods

2.1 Structure of model

The structure of this model is based on the requirement to find criterion that would include all costs that are involved in the operation of milking parlors and efficiency of the milking process. The criterion was determined a direct unit costs. The basic structure of the model is presented in Figure 1. The calculation includes many simple equations; not all sub-steps for calculating are included in this paper. Therefore, only fundamental computational steps and some key operations important for understanding the structure of calculation are presented in this article. The model has been programmed in MathCAD 2001 Professional.

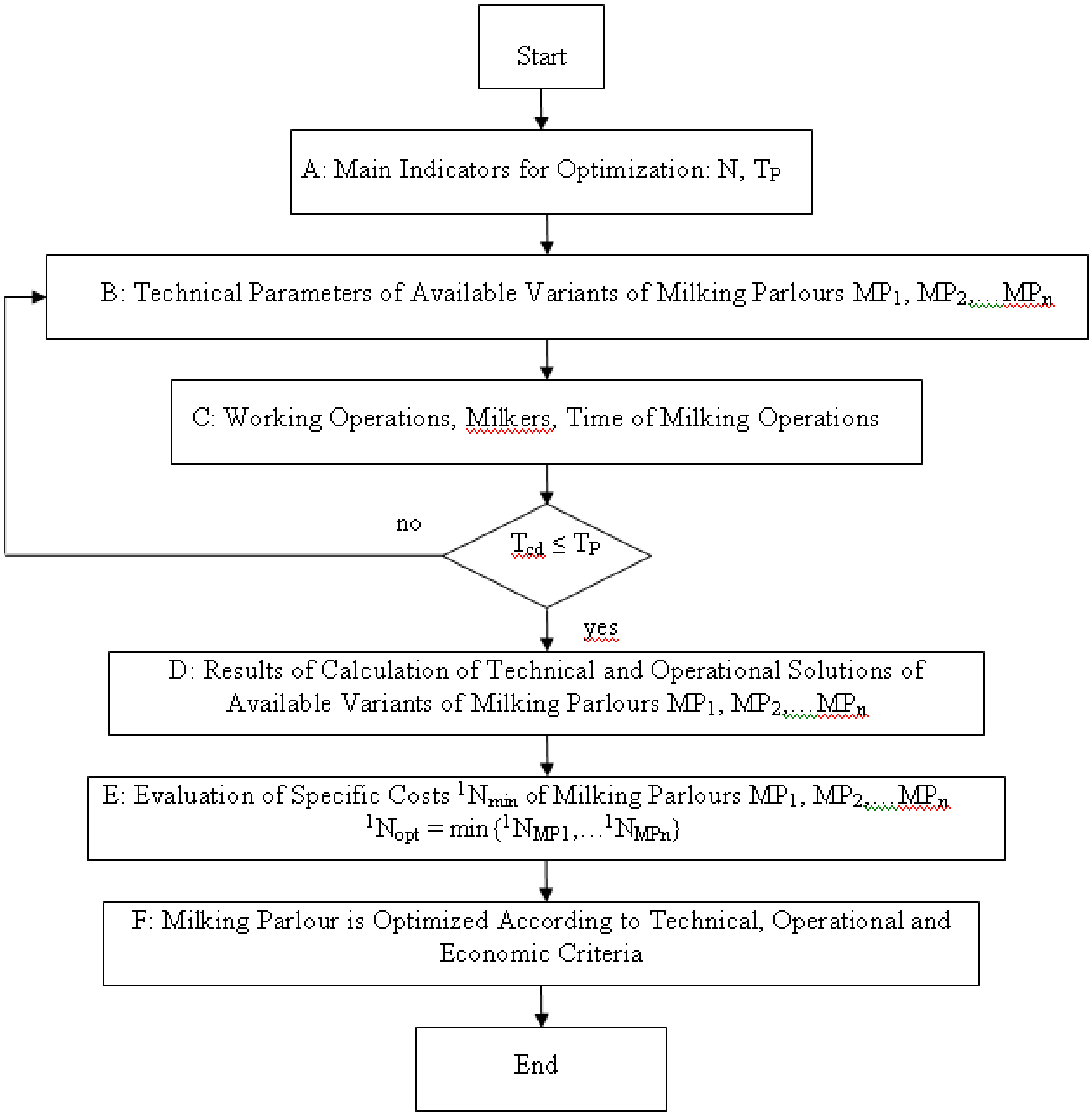

Figure 1 Structure of model

2.2 Main parameters of milking operation

The first step is a determination of the required capacity of milking parlors Q_{PL} calculated by an Equation (1) from number of lactating cows N on the farm.

$$Q_{PL} = \frac{N}{T_P - T_Z} \qquad (1)$$

where, Q_{PL} is the required capacity of the milking parlor, cow/min; N is the number of lactating cows on the farm; T_P is the time limit per one milking, min; T_Z is the eventual idle time of the milking parlor during the milking time (time reserve), min. Time limit per one milking is important because under-dimensioning of parlor leads to its better use for longer periods during the day, but in practical terms this often means long-term continuous movement of animals around the farm, mutual disturbance of groups of animals arriving and leaving the milking parlor and therefore short time for feeding, rest and organization of all work activities on the farm.

The working capacity of milker W_d is calculated by using Equation (2) as the reciprocal of the labor requirement for milking per cow t_{rc}.

$$W_d = \frac{1}{t_{rc}} \qquad (2)$$

where, W_d is the working capacity of one milker, cow/min; t_{rc} is the average net labor requirement for milking per cow, min/cow.

The average labor requirement per one cow t_{rc} is calculated on the basis of the observed mean work routine time per cow. These values were studied and published for all types of available milking parlors e.g. in (Dolezal et al., 2000). The theoretical required number of milkers, n_d is based on the calculation of Equation (3).

$$n_d = \frac{Q_{PL}}{W_d} \quad (3)$$

The maximum reasonable number of milkers per a parlor, n_{dm} is a very important criterion to avoid the idle time. It is calculated by the number of milking stalls m_S divided by the number of clusters n_s that can operate one milker.

$$n_{dm} = \frac{m_z}{n_s} \quad (4)$$

where, n_{dm} is maximum number of milkers per one parlor, m_z is number of milking stalls in milking parlor, n_s is maximal number of clusters per milker. The real number of milkers for the whole farm n_{ds} is the rounded integer n_d. It is a very important criterion to ensure a successful function of milking parlor in real farm conditions.

For the exact calculation of parameters of a milking parlor it is important to use the real capacity of the milking parlor, Q_{LS}, determined by using Equation (5).

$$Q_{LS} = n_{ds}.W_d \quad (5)$$

where, Q_{LS} is the real capacity of a milking parlor, cow/min; n_{ds} is the real number of milkers.

An important technical parameter is the theoretical number of milking stalls in parlor m_T, calculated by using Equation (6).

$$m_T = Q_{PL}.(t_d + t_v) \quad (6)$$

where, m_T is the theoretical number of milking stalls in milking parlor; t_d is the average duration of milking by milking machine per one cow, min; t_v is average idle time of a cluster, calculated by using Equation (7), min.

$$t_v = t_n + t_s + t_m \quad (7)$$

where, t_n is average time for cluster attachment, min; t_s is average time to remove the cluster, min; t_m is time for manipulation with cluster, min.

The labor requirement per milking is calculated by using Equation (8).

$$T_d = \frac{i.N.(t_{rc} + t_p + t_c) + T_{pr}.n_{ds}}{N} \quad (8)$$

where, T_d is the labor requirement during milking per cow per day, min; i is the number of milking per day; t_p is the time of preparatory work before milking, calculated per one cow, min/cow; t_c is the time of finishing and cleaning work after of milking, calculated per one cow, min/cow; T_{pr} is time of working breaks, min.

Labor requirement T_d is used by Equation (9) for the calculation of labor requirements per year T_r, which is used for the calculation of labor costs. Another important result is duration of one milking T_{cd}, which is compared with the demanded time limit of milking T_P.

$$T_r = \frac{365 T_d}{60} \quad (9)$$

where, T_r is the labor requirement for milking per cow per year, h/cow/year.

The duration of one real milking T_{vd} is calculated according to Equation (10) and total time of duration of one milking T_{cd} including preparatory operations and finishing work after milking. It is calculated by using Equation (11).

$$T_{vd} = \frac{N}{Q_{LS}} + T_{pr} \quad (10)$$

where, T_{vd} is duration of one real milking, min.

$$T_{cd} = T_{vd} + \frac{(t_p + t_c).N}{n_{ds}} \quad (11)$$

where, T_{cd} is total time of duration of one milking including preparatory operations and finishing work after milking, min.

2.3 Determination of specific direct costs of milking parlor

Final specific direct costs of a milking parlor per cow and year, $^1N_{MP}$, are calculated as a sum of specific labor costs per cow and year ^1N_W, specific costs of the milking equipment per cow and year ^1N_P including the parlor construction, and specific costs ^1N_S of consumed supplies including the water, electricity, disinfections etc. per one cow and year.

$$^1N_{MP} = {}^1N_W + {}^1N_P + {}^1N_S \quad (12)$$

where, $^1N_{MP}$ is the final specific direct costs of milking parlor per cow and year, EUR/cow/year; ^1N_W is specific labor costs per cow and year, EUR/cow/year; ^1N_P is specific costs of the milking equipment per cow and year, EUR/cow/year; ^1N_S is specific costs of consumed supplies per cow and year, EUR/cow/year.

The components of costs include the following three main parts, which were originally expressed in CZK (Czech Crowns). But for the purpose of this paper all costs were converted into EUR by average normal rate 1 EUR is 27.5 CZK. Specific labor costs ^1N_W are calculated on the basis of labor requirements per cow per year T_r (h/cow/year) and average hourly wage of the milker.

Specific costs of the milking equipment ^1N_P are calculated as specific data of total operating costs of the milking machine converted per one cow. Therefore it includes the amortization of machinery, which is the purchase price of the machine expressed by percentage of machine amortization, further amortization of construction that includes construction costs and percentage of building amortization and the cost of servicing, maintenance and repairs, which are usually expressed as a percentage of planned acquisition costs. Specific costs of consumed supplies ^1N_S are calculated as a sum of costs of all necessary operating materials and energy. The consumption of electricity is proportional to the power inputs of motors and all electrical appliances of milking parlor during their operation, water, disinfection etc. All is re-calculated per cow and year (EUR/cow/year).

3 Results and discussion

The use of this model and results of calculations are shown on the conditions of dairy farms in the Czech Republic. Two typical applications of the model are presented in the following results.

3.1 Milking parlor in large capacity farm

The first farm is the large capacity dairy farm with 750 cows, with an average annual milk yield about 9000 kg of milk per cow per year. There are three milkings per day in this farm. The farm was first equipped with central milking parlor designed as two AutoTandem milking parlors 2 × 5 (two rows, each with five milking stalls) (variant A). After several years, farmers changed the milking parlor and installed two herringbone milking parlors 2 × 10 (two rows, each with ten milking stalls) (variant B). The possible future installation of the new milking parlor could be a rotary milking parlor either with 24 milking stalls (variant C) or 36 milking stalls (variant D). The results are presented in Figures 2 and 3.

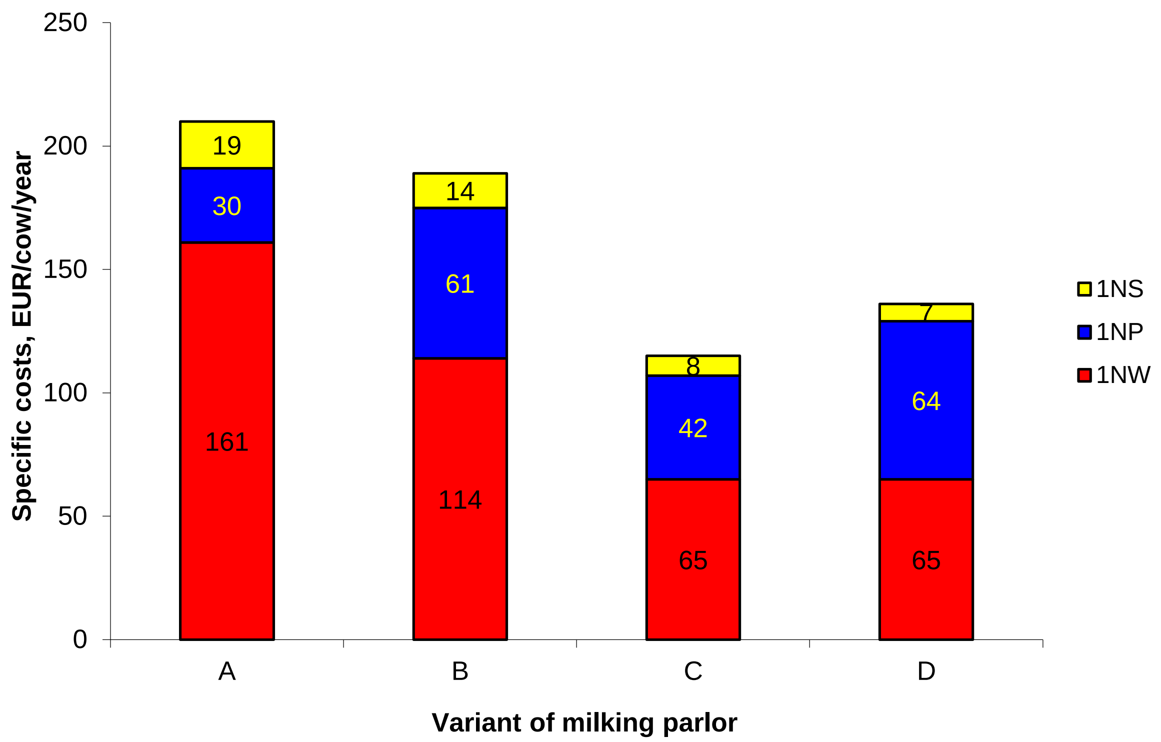

Figure 2 Farm 750 cows. The final specific direct costs $^{1}N_{MP}$ of the milking parlor.

The variant A (AutoTandem) was an extremely unsuitable solution of the milking parlor. It was very expensive mainly due to high costs of labor and because the time of one milking process lasted over 6 hours, which complicated the operations on the farms. The whole milking process lasted over 18 hours per day. The solution B (herringbone) enables shortening of milking time and therefore also reduced the costs of labor. The variant C (rotary parlor 24 stalls) is the best solution from the point of view of cost reduction and also because the time per one milking is reduced. The shortest time for milking is in the case D (rotary parlor 36 stalls) but the costs are higher, mainly due to higher investment costs.

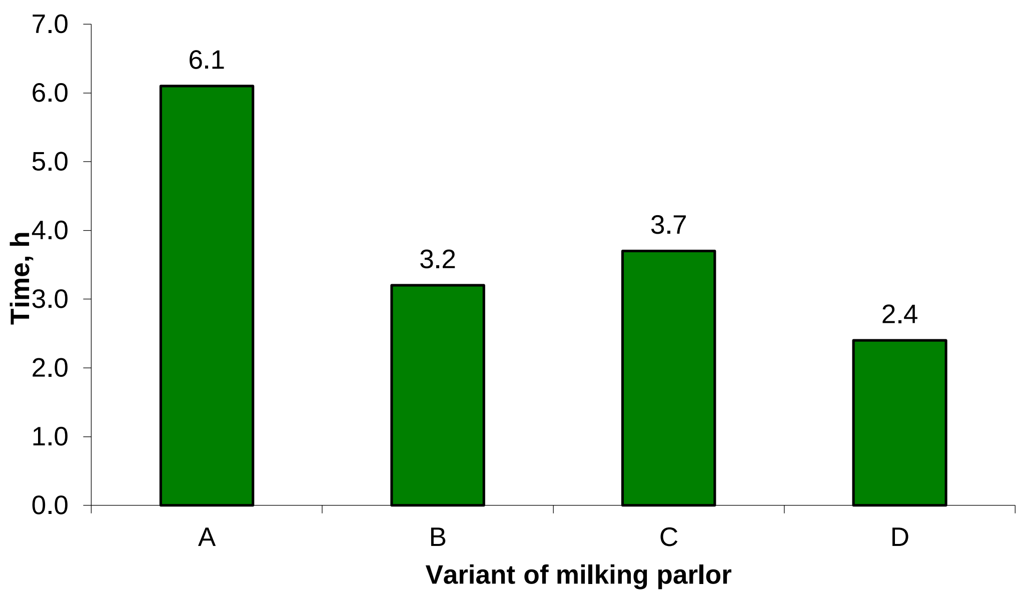

Figure 3 Farm 750 cows. Time T_{cd} per one milking.

3.2 Milking parlor in a small or medium capacity farm

The second farm is a small capacity dairy farm with 80 cows, with an average annual milk yield of about 7500 kg of milk per cow per year. There are two milkings per day in this farm. The farm was first equipped with AutoTandem milking parlor 2 × 3 (two rows, each with three milking stalls) (variant A), operated by 1 milker. Since the milking parlor is rather old and needs modernization, farmers decided to install a new herringbone milking parlor 2 × 6 (two rows, each with six milking stalls) (variant B). The results of the calculations are presented in the Figures 4 and 5. Variants A1 and B1 are the results of calculations for the current farm with capacity of 80 cows. Farmers, however, expect to increase the capacity of the farm to 160 cows (variants A2 and B2), or even to 200 cows (variants A3 and B3).

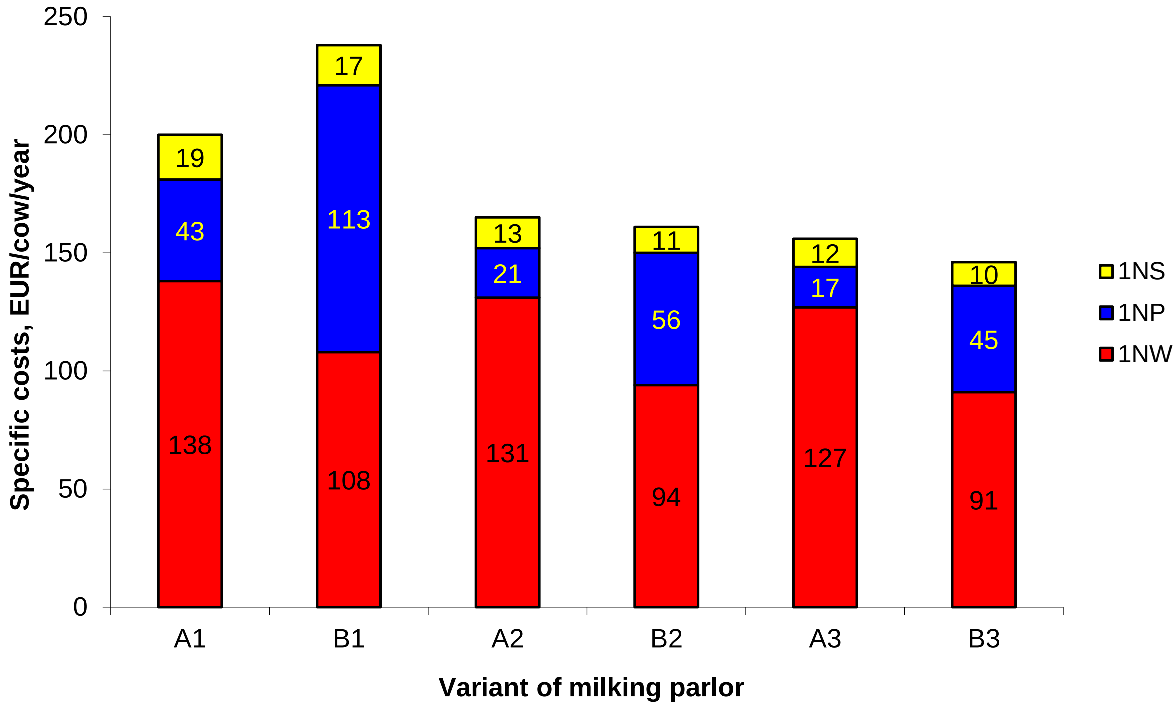

Figure 4 The final specific direct costs ${}^{1}N_{MP}$ of milking parlor.

The variant A1 (AutoTandem) has been used for many years. The main part of the direct costs is due to labor costs.- The share of specific costs of milking equipment is rather small. The new herringbone milking parlor (variant B1) used for the current capacity of 80 cows increased the specific costs of milking equipment and slightly reduced labor costs. The final specific direct costs including all costs are higher. After enlarging the farm capacity to 160 cows (variants A2 and B2) the total specific direct costs are lower in the new herringbone milking parlor (B2). The benefit of this new solution (B2) is a shorter time per one milking than A2. These aspects are more progressive and more obvious in the case of expansion of the farm to 200 cows (variants A3 and B3). In this case the duration of milking process (A3) in AutoTandem 2 × 3 would be nearly 6 hours, which would create technical and organizational problems for the farms. This would disturb the cows for many hours during the day.

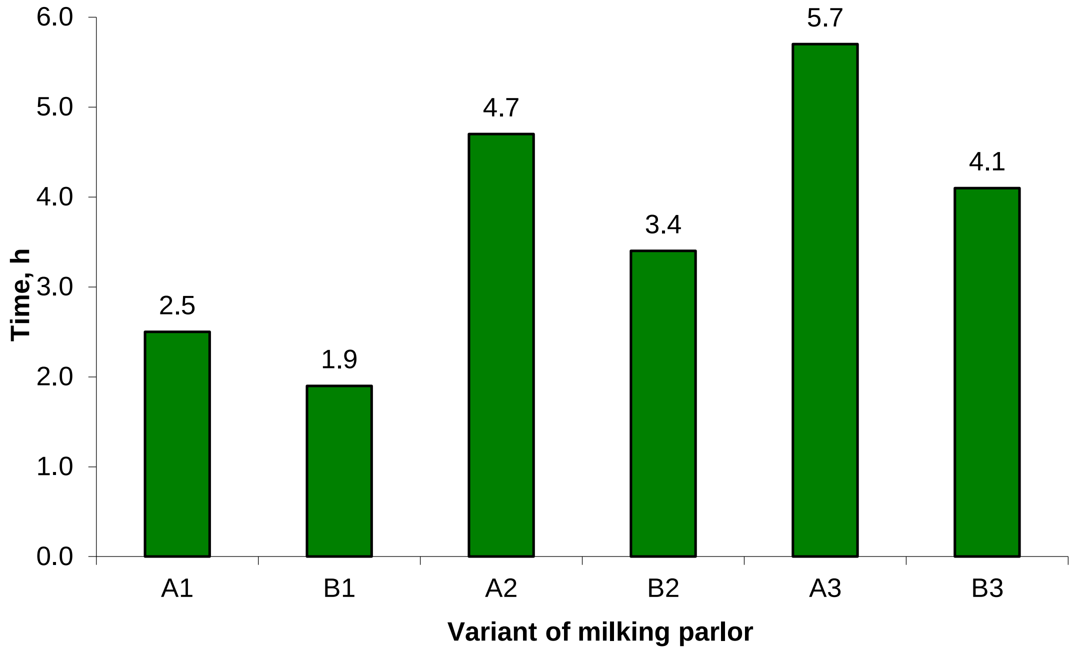

Figure 5 Time T_{cd} per one milking.

4 Conclusions

The following conclusions can be drawn from the experience of the described model and results of the calculations:

- The model can help to find a more economic solution for the future farms.
- The model is useful for preliminary calculations in the preparatory phase before developing a project to evaluate (positives and negatives) various solutions of milking parlors.
- The model can be used for evaluation of existing milking parlors in the farms with the aim to improve the milking process and operations from the point of view of either technical improvement or improved activity of milkers.
- The share of labor costs for milking in the milking parlors decreases with increasing capacity of the farm and with higher level of milking parlor.

References

Bottema, J. 1992. Automatic milking: reality. In: *Proceedings of the International Symposium on prospects for Automatic Milking, 23-25 November*. Wageningen, Netherlands.

Brunsch, R., O. Kaufmann, T. Lupfert. 1996. *Rinderhaltung in Laufstallen (Loose housing of cattle)*. Eugen Ulmer. Stuttgart. (in German).

Chiumenti, R. 2004. *Rural buildings*. Edagricole scolastico, Milano (in Italian).

Dolezal, O., J. Hlasny,F. Jilek, O. Hanus, J. Vegricht, J. Pytloun, E. Matous, and J. Kvapilik. 2000. *Mleko, dojeni, dojirny (Milk, milking, milking parlours*). Agrospoj, Prague (in Czech).

Gaworski, M., and A. Leola. 2014. Effect of technical and biological potential on dairy production development. *Agronomy research*, 12 (1): 215-222.

Gaworski, M., and J. Priekulis. 2014. Analysis of milking system development on example of two Baltic countries. In: *Proc. 13th International scientific conference Engineering for rural development, 29-30 May:* 79-84. Latvia University of Agriculture, Jelgava.

Hansen, M.N. 1999. Optimal number of clusters per milker. *Journal of Agricultural Engineering Research*, 72 (4): 341-346.

Kic, P., and D. Nehasilova. 1997. *Dojicí roboty a jejich vliv na zdravotní stav mléčné žlázy (Milking robots and their effect on mammary gland´s health).* UZPI, Prague (In Czech).

Kic, P. 1998. *Nove trendy v zemedelske technice (Trends in farm mechanization).* UZPI, Prague (In Czech).

Maltz, E., N. Livshin, A. Antler, Y. Edan, S. Matza, and A. Antman. 2003. Variable milking frequency in large dairies: performance and economic analysis – models and experiments. In: *ECPLF Proceedings Precision livestock farming*. Wageningen Academic Publishers. ATB Agrartechnik Bornim.

Maton, A., J. Daelemans, and J. Lambrecht. 1985. *Housing of animals.* Elesevier, Amsterdam, Oxford, New York, Tokyo.

Ozolins, A., J. Priekulis, and A. Laurs. 2012. Research in rotary parlour operation. In: *Proc. 11th International scientific conference Engineering for rural development, 24-25 May,* 43-46. Latvia University of Agriculture, Jelgava.

Priekulis, J., and A. Laurs. 2012. Research in automatic milking system capacity. In: *Proc. 11th International scientific conference Engineering for rural development, 24-25 May,* 47-51. Latvia University of Agriculture, Jelgava.

Provolo, G. 1992. Technical and economic assessment of the operations of milking machines by using a simulation model. *Informatica e Agricoltura, Supplemento agli Atti dei Georgofili*. Firenze, VII serie, 39, 411-420. (in Italian).

Provolo, G., and L. Marcon. 1993. Simulation model for the technical-economic choice of milking equipment. In: *Atti del V. Convegno Nazionale AIGR,* Maratea, 3, 153-160. (in Italian).