Applying a Mathematical Model to Compare, Choose, and Optimize the Management and Economics of Milking Parlors in Dairy Farms

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Abstract: Dairy farms are growing in several areas of the world, with consequent need for a modernization of milking equipment. The objective of this research is to evaluate milking parlors in current and future situations in modern farms. Several Italian farms were studied: three farms with side-by-side milking parlors (50 cows, 82 cows, and 100 cows), two with herringbone milking parlors (70 cows and 90 cows) and two with rotary milking parlors (360 cows and 900 cows). The choosing and evaluation of milking parlor parameters is based on results of previous research, using the mathematical model developed in the Czech University. The time for milking and the final specific direct costs are the main parameters which enable evaluation and choosing of suitable milking parlor from the dairy; neglect or promotion of only one of the mentioned criteria may lead to uneconomic investment or impaired operation of a farm. The evaluation of existing milking parlors can help to enhance the milking process and operations from the point of view of either technical improvement or improved activity of milkers. The results of measurement and calculation in current farms are compared with possible future enlarged farms. The study demonstrated that increasing the capacity of dairy farms enables a reduction of the final specific direct costs for milking.

Keywords: cost; dairy cow; equipment; farm; milking process

1. Introduction

Livestock production in countries with intensive agriculture is undergoing major and rapid changes [1–4]. Capacity of farms is expanding and increasing the average annual milk production per cow. European housing systems are steadily changing from stanchion barns towards loose cowsheds and larger herd sizes [5–7]. These factors have led to a modernization of dedicated equipment.

The function of the milking parlor is one of the factors which affects the efficiency of milk production. Several aspects influence the choosing and proper use of these systems and should be carefully considered in advance during the design of the dairy farm.

The question for medium and large farms is how to choose an appropriate type of milking parlor. Therefore, it is important to compare different solutions and find the strengths and weaknesses of each.

Leading equipment producers offer a variety of milking parlors for different capacities of farms, recommending the possible level of automation and number of milkers involved in the process [1,8,9]. However, local conditions differ according to the production, economic, market, and labor situation of each area. Consequently, the same equipment has different operating conditions in different countries. Although the use of automatic milking systems (AMS) is developing, the high cost of this solution discourages many farmers.

There are two divergent interests in choosing the appropriate milking parlor, of manufacturer/ dealer who strives for the highest price contract, and of the farmer who would like to receive the best product, for the price as favorable as possible.

Several authors have presented recommendations focused on the problems of milking parlors and AMS, debating on performance and developing economic analysis [10–12], but not including sub-economic characterizing data. Some publications [13,14] present selection models, but not in a universal approach which could be adapted everywhere. Basic equations used for the calculation of several parameters are presented by Gaworski and Priekulis (2014) [5]. Similar calculations, completed with economic results valid for rotary milking parlors, are presented by Ozolins et al. (2012) [15].

Currently there is a variety of mathematical models, including stochastic [16] which can help to optimize the solution of various functional dependencies.

Different aspects can be considered in the decision-making process to determine the correct milking parlor for each farm: animal welfare, capacity, price, number of milkers, complexity of the operation, reliability, dimensions [17] and installation in the building, maintenance and service, and other aspects such as producer satisfaction [18]. Incorrect evaluation may result in problems during the operation and negatively affect the performance of the farm, in some cases with unnecessary waste of finance, without any real benefit.

Results based on the mathematical model focused on the conditions of dairy farms and milking production in the Czech Republic are presented by Kic [19,20].

This present paper aims to apply the same model, adapted to parameters valid for Italian farms. Dairy farms in Italy are undergoing a rapid growth from traditional small farms, and milking technology should be modernized. For these farms, it is useful to evaluate different equipment and operating conditions by selected and uniform criteria. This method enables comparison of the parameters identified on Italian dairy farms with results of previous research from other European countries, e.g., Czech Republic [19,20], Latvia [21], Estonia [22], and Poland [23].

2. Material and Methods

2.1. Description of the Model

The first parameter taken into consideration is represented by the milking time. The advantage of reducing the duration of milking operation enables cows to have the opportunity to take feed and rest, to go grazing, and so on. The duration of a single effective milking of the entire herd can be derived from Equation (1).

$$T_{vd} = \frac{N}{Q_{LS}} + T_{pr} \tag{1}$$

where: T_{vd}—the duration of one milking, min; N—the number of lactating cows on the farm, cow; Q_{LS}—the real capacity of a milking parlor, cow min^{-1}; T_{pr}—duration time of working breaks, min.

As regards of a human working process and working operations, the total time of single milking, preparation, and subsequent work included, is determined by Equation (2).

$$T_{cd} = T_{vd} + T_p + T_c \tag{2}$$

where: T_{cd}—total duration time of a single milking including preparatory operations and finishing work after milking, min; T_p—the time of preparatory work before milking, min; T_c—the time of finishing and cleaning work after milking, min.

When period T_{cd} is short enough, then there is enough time for workers (milkers) to carry out the other activities (feed preparation, cleaning, control of animals etc.). Therefore, the time should be a criterion for optimization and the selection of a suitable milking parlor for the farm.

The second decisive criterion should be the economic criteria. It is necessary to compare the specific data, which are in this case the final specific direct costs of a milking parlor per cow and year $^uC_{MP}$, calculated according to Equation (3) as a sum of specific labor costs of milking per cow and year

^uC_W, specific costs of the milking equipment per cow and year ^uC_P including construction, and specific costs ^uC_S of supplies including the water, electricity, disinfectants etc. per one cow and year.

$$^uC_{MP} = {}^uC_W + {}^uC_P + {}^uC_S \tag{3}$$

where: $^uC_{MP}$—the final specific direct costs of milking parlor, EUR cow^{-1} year^{-1}; ^uC_W—the specific labor costs per cow and year, EUR cow^{-1} year^{-1}; ^uC_P—the specific costs of the milking equipment, EUR cow^{-1} year^{-1}; ^uC_S—the specific costs of consumed supplies, EUR cow^{-1} year^{-1}.

Specific labor costs ^uC_W are determined on the basis of labor requirements per cow per year T_r (h cow^{-1} year^{-1}) obtained by using Equation (4) and average hourly wage of the milker. The labor requirement T_d can be used by Equation (5).

$$T_r = \frac{365 \cdot T_d}{60} \tag{4}$$

where: T_r—the labor requirement for milking per cow per year, h cow^{-1} year^{-1}; T_d—the milking labor requirement per cow per day, min cow^{-1} day^{-1}.

$$T_d = i \cdot \left[\frac{N \cdot (t_{rc} + t_p + t_c) + T_{pr} \cdot n_{ds}}{N} \right] \tag{5}$$

where: i—the number of milkings per day, day^{-1}; t_{rc}—the average net labor requirement for milking per cow, min cow^{-1}; t_p—the time of preparatory work before milking per one cow, min cow^{-1}; t_c—the time of finishing and cleaning work after milking calculated per one cow, min cow^{-1}; T_{pr}—duration time of working breaks, min.; n_{ds}—the real number of milkers, pers.; N—the number of lactating cows on the farm, cow.

Specific costs of the equipment ^uC_P are evaluated as specific data of total operating costs of the machine per single 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 supplies ^uC_S are determined 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 during their operation, water, disinfection etc. All is re-computed per cow and year (EUR cow^{-1} year^{-1}).

The real number of milkers for the whole farm n_{ds} is the rounded integer n_d. The theoretical required number of operators n_d is based on the calculation of Equation (6).

$$n_d = \frac{Q_{PL}}{W_d} \tag{6}$$

where: n_d—the theoretical required number of milkers per one parlor, pers.; Q_{PL}—the required capacity of the milking parlor, cow min^{-1}; W_d—the working capacity of one milker, cow min^{-1}.

The maximum reasonable number of operators per a parlor n_{dm} is a criterion to avoid the idle time or work complications. It is obtained by the number of milking stalls m_Z divided by the number of clusters n_s that can operate one milker.

$$n_{dm} = \frac{m_Z}{n_s} \tag{7}$$

where: n_{dm}—the maximum number of milkers per one parlor, pers.; m_Z—the number of milking stalls in milking parlor, pcs; n_s—the maximal number of clusters per milker, pcs.

An important technical parameter is the theoretical number of stalls in a parlor m_T, obtained by using Equation (8).

$$m_T = Q_{PL} \cdot (t_d + t_v) \tag{8}$$

where: m_T—the theoretical number of milking stalls per parlor, pcs; t_d—the average duration of milking by machine per one cow, min; t_v—the average idle time of a cluster, min.

$$t_v = t_n + t_s + t_m \tag{9}$$

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

2.2. Description of the Farms and Milking Parlors

Described model was employed to evaluate the process in three groups of farms typical for current situation in the Italian primary sector. All data (e.g., construction and equipment costs, costs of supplies, labor costs etc.) used for the calculation were collected from modern dairy farms in Italy.

Three farms (A, B, C) feature side-by-side milking parlor (with 50 cows, 82 cows and 100 cows), two farms (D, E) are equipped by herringbone milking parlor (with 70 and 90 cows) and two farms (F, G) have rotary milking parlors (with 360 cows and 900 cows).

The farms were chosen so that all were focused on the breeding of Italian Frisian dairy cattle.

3. Results and Discussion

Parameters of the Milking Parlors

Basic capacity data of farms and real parameters are presented in Tables 1–3. All milking parlors are equipped by automatic cluster remover.

Table 1. Analyzed dairy farms with side-by-side milking parlors.

Parameter	Nomenclature	Farm A	Farm B	Farm C
Number of cows	N	50	82	100
Type of milking parlor	-	2×6	2×9	2×10
Number of milking stalls	m_{TR}	12	18	20
Year of installation	-	2007	2011	2011
Costs of milking parlor equipment per one milking stall (EUR)	-	6667	5000	6000
Number of milkers	n_{dR}	2	1	2
Time of a single milking (min)	T_{cdR}	80	115	110

Table 2. Analyzed dairy farms with herringbone milking parlors.

| Parameter	Nomenclature	Farm D	Farm E
Number of cows	N	70	90
Type of milking parlor	-	2×7	2×8
Number of milking stalls	m_{TR}	14	16
Year of installation	-	2011	2011
Costs of milking parlor equipment per one milking stall (EUR)	-	6429	5625
Number of milkers	n_{dR}	1.5	2
Time of a single milking (min)	T_{cdR}	80	130

Table 3. Analyzed dairy farms with rotary milking parlors.

Parameter	Nomenclature	Farm F	Farms G
Number of cows	N	360	900
Type of milking parlor	-	Rotary	Rotary
Number of milking stalls	m_{TR}	32	80
Year of installation	-	2011	2006
Costs of milking parlor equipment per one milking stall (EUR)	-	9375	18,750
Number of milkers	n_{dR}	2.5	5
Time of a single milking (min)	T_{cdR}	180	225

The evaluation of current milking conditions enabled us to compare of all farms and milking parlors. The summarized results of measurements and calculations at the Farms A–G are depicted in Figures 1 and 2.
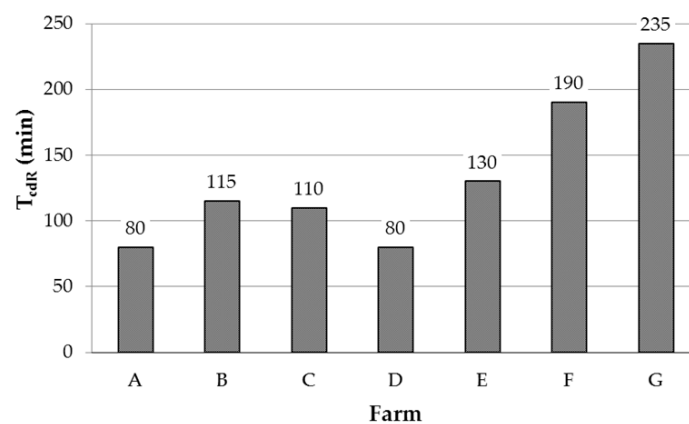
Figure 1. Current real e Time of a single milking TcdR (min) at all analyzed dairy farms.
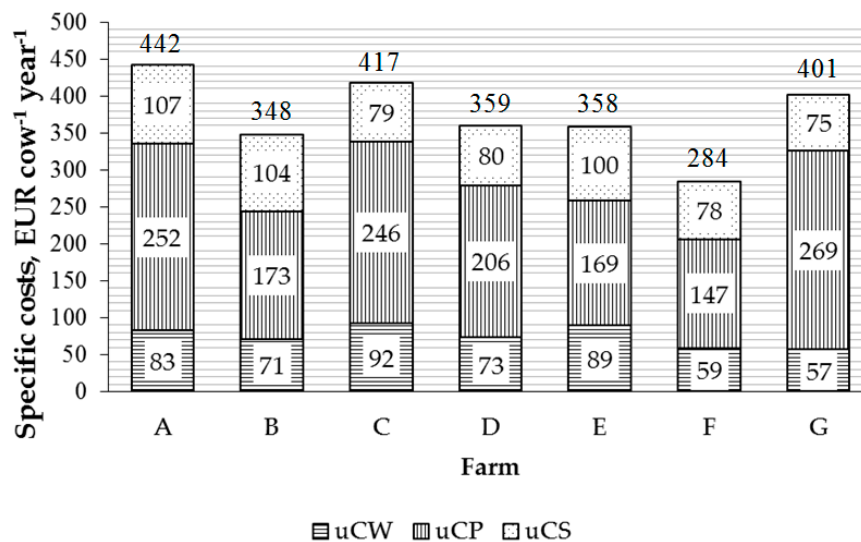
Figure 2. Final specific direct costs of milking uCMP (EUR cow^{-1} year^{-1}) in the milking parlors in current situation at all dairy farms (uCW—specific labor costs (EUR cow^{-1} year^{-1}); uCP—specific costs of the milking equipment (EUR cow^{-1} year^{-1}); uCS—specific costs of consumed supplies (EUR cow^{-1} year^{-1}).

Current real time of a single milking TcdR is the shortest (80 min) at Farm A with 50 cows and side-by-side milking parlor and also Farm D (70 cows) with herringbone milking parlor. This situation

can be assessed in terms of farm organization and cows breeding as a very positive. Farmers have sufficient time for other activities and cows have long time of quiet period in the farm for the rest.

On the other side, the use of milking parlor is short, resulting in high final specific costs of milking uCMP (Figure 2), with the specific costs of the milking parlor uCP representing the main part of it. The specific costs uCP are 252 and 246 EUR cow^{-1} $year^{-1}$ at the farms A, C. respectively The highest specific costs uCP are 269 EUR cow^{-1} $year^{-1}$ are calculated for Farm G, with the greatest herd (900 cows), and equipped by the most expensive rotary parlor with 80 stalls.

The comparison of specific labor costs shows that the most expensive rotary milking parlor on the Farm G on the other side reduces the specific labor costs uCW to 57 EUR cow^{-1} $year^{-1}$, which are the lowest specific labor costs from all farms.

It is interesting to compare the real parameters of milking parlors, the operating conditions, and the resulting parameters of the surveyed Italian dairy farms with the results found in other EU countries. The situation in the Czech Republic [19,20], Latvia [21], Estonia [22], and Poland [23] is slightly different. With respect to these countries, in fact, in Italy, the milking parlors are technically sized with a higher number of milking stalls and higher capacity, which allows short milking time, but this is reflected in higher parlor costs.

There are also some differences between the farms in each country, which is due to different types of milking parlors with different purchase prices and different operating costs. For smaller farms specific cost is an obvious difference. In Italy, the final specific costs uCMP are from 358 to 442 EUR cow^{-1} $year^{-1}$, but for example in Poland, only 162 to 252 EUR cow^{-1} $year^{-1}$ and from 200 to 238 EUR cow^{-1} $year^{-1}$ in the Czech Republic. However, the duration of one milking Tcd is currently comparative; it is 70 min to 130 min in Italy, 75 min to 120 min in Poland, and 75 min to 150 min in the Czech Republic.

This is particularly evident in smaller farms with fewer dairy cows (approximately 50 dairy cows to 200 dairy cows). Prospectively, however, in the case of enlargement of farms, it will be an advantage which will enable the achievement of better results and lower specific costs.

For larger farms, the difference between the time required for milking Tcd is not so significant (211 min in Italy, 192 min to 366 min in the Czech Republic, 198 min to 378 min in Estonia and 132 min to 191 min in Latvia), only costs on Italian farms are slightly higher than in the Czech Republic or Latvia or Estonia. This is caused by higher labor costs and by slightly higher purchase and other specific costs for milking parlors, e.g., in the case of large farms with over 750 cows in Italy, the final specific costs uCMP are approximately 400 EUR cow^{-1} $year^{-1}$, while in the Czech Republic from 136 to 210 EUR cow^{-1} $year^{-1}$, about 200 EUR cow^{-1} $year^{-1}$ in Estonia, and from 164 to 225 EUR cow^{-1} $year^{-1}$ in Latvia.

The time analysis of the current state in milking parlors shows that in most cases there are considerable time reserves and that the technical possibilities of milking are not always well used. This is particularly pronounced on Farms A, C with a small number of dairy cows and equipped with side-by-side milking parlors. Also, time use on Farm D with herringbone parlor is insufficient. A certain minor shortening of milking time could also be achieved in rotational milking parlors (Farm F and G).

The evaluation of current milking conditions is a background for calculations of more exact theoretical parameters of milking parlors. Current parameters and theoretical values of possible improvements of three different types of milking parlors will be analyzed separately.

The theoretical number of stalls in a parlor m_T in accordance to Equation (8), the theoretical required number of milkers n_d based on Equation (6) and the maximum reasonable number of milkers per a parlor n_{dm} resulting from the Equation (7) are presented in Tables 4–6.

The theoretical values are determined with respect to the current duration of a single real milking operation time T_{vd} and the total duration of one milking including preparatory and subsequent operations T_{cd}. These T_{cd} time values are supposed not to be too much changed from real current values, therefore the T_{cd} is similar to T_{cdR}.

Table 4. Theoretical values of main parameters of side-by-side milking parlors in Farms A, B, and C.

Parameter	Nomenclature	Farm A	Farm B	Farm C
Number of milking stalls	m_T	6	6	10
Number of milkers	n_d	1	1	2
Maximum number of milkers	n_{dm}	1	1	2
Time of one milking (min)	T_{cd}	86	119	94

**Table 5.** Theoretical values of main parameters of herringbone milking parlors in Farms D and E.

Parameter	Nomenclature	Farm D	Farm E
Number of milking stalls	m_T	8	6
Number of milkers	n_d	1.5	1
Maximum number of milkers	n_{dm}	1.5	1
Time of one milking (min)	T_{cd}	70	164

Table 6. Theoretical values of main parameters of rotary milking parlors in Farms F and G.

Parameter	Nomenclature	Farm F	Farm G
Number of milking stalls	m_T	16	32
Number of milkers	n_d	2.5	5
Maximum number of milkers	n_{dm}	2.5	5
Time of one milking (min)	T_{cd}	174	211

The theoretical values presented in Tables 4–6 resulted in the changes of final specific direct costs of milking uCMP (EUR cow^{-1} year^{-1}). We calculated the theoretical values with the aim to reduce the investment costs but with respect to the time for milking.

As the sufficient number of milking stalls could be smaller than real number of existing milking parlors, it influenced mainly the specific costs of the milking equipment uCP (EUR cow^{-1} year^{-1}), which are therefore lower. The results of theoretical final specific direct costs of milking uCMP (EUR cow^{-1} year^{-1}) are summarized in Figure 3.
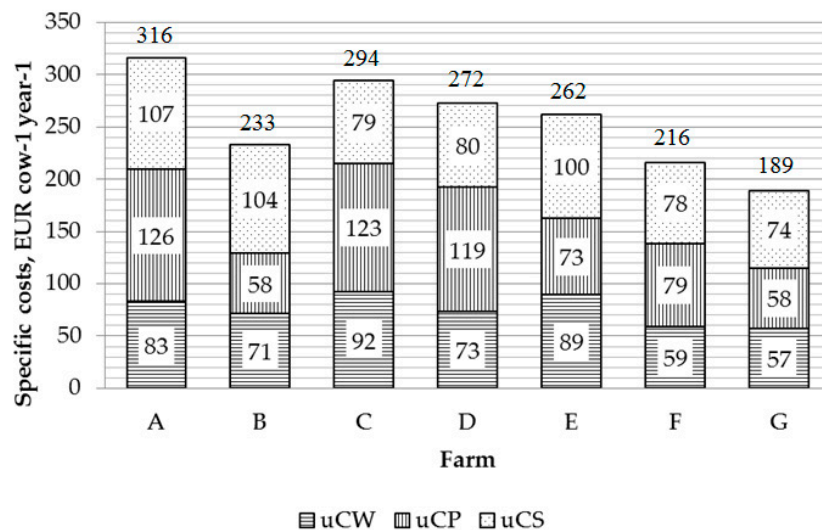
Figure 3. Theoretical final specific direct costs of milking uCMP (EUR cow^{-1} year^{-1}) in the modified milking parlors according to the calculation at all dairy farms (uCW—specific labor costs (EUR cow^{-1} year^{-1}); uCP—specific costs of the milking equipment (EUR cow^{-1} year^{-1}); uCS—specific costs of consumed supplies (EUR cow^{-1} year^{-1})).

4. Conclusions

The following conclusions can be drawn from the research performed in the farms and from the results of the model calculation:

- The milking time and the final specific direct costs are key parameters for the evaluation and choosing of suitable milking parlor;
- Both parameters in the proposed methodology include the main technical parameters, indicators of labor productivity, and economic criteria;
- Neglect or promotion of only one of the mentioned criteria may lead to uneconomic investment or impaired operation of a farm;
- The evaluation of existing milking parlors can help to improve the milking process and operations from the point of view of either technical improvement or improved activity of milkers;
- The preliminary calculations performed as initial basis of the project allow analysis of positive and negative aspects of various milking parlors solutions;
- Increased capacity of dairy farm enables reduction of the final specific direct costs for milking.

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