ANALYSIS, SIMULATION AND OPTIMIZATION OF THE MILKING PROCESS IN A COWSHED FOR THE PRODUCTION OF PARMIGIANO REGGIANO

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ABSTRACT
The aim of this study is to optimize the current milking process of a cowshed, which provides milk for the production of Parmigiano Reggiano cheese. The ultimate goal of the analysis is to reduce the time required for milking operations, thus optimizing the whole management of the farm processes. The analysis described is based on a real case study, referring to a farm located near Parma (Italy). To optimize the milking process, a discrete-event simulation model was designed under Simul8^{TM} professional platform. The model reproduces the main processes of the cowshed, and in particular, the movements of the animals inside the cowshed, during milking. Real data were collected to allow the reproduction of the milking process. Exploiting again the simulation model, two new configurations of the cowshed layout were designed and tested, and their performance, in terms of the total time required for milking, was compared to the current one, showing interesting savings.

Keywords: simulation; animal behavior; milking process; Parmigiano Reggiano production.

1. INTRODUCTION

In Europe, the dairy sector is one of the most important sectors within the food industry. The production of milk intended for the dairy industry is estimated around 159 million tons per year in 2013 (European Commission, 2015). The main cheese producers of Europe are Germany, France, the United Kingdom, Poland, the Netherlands and Italy, which together account for almost 70% of the EU production (European Commission, 2015). Parmigiano Reggiano is a typical Italian hard cheese, known among the most typical products of the Italian food industry (Bellesia et al., 2003) and as one of the oldest cheeses in Europe, dating back to the 13th-14th century (Zannoni, 2010).

The production of Parmigiano Reggiano is located mainly in the North of Italy, in a limited geographic area, to comply with the protected designation of origin of the product (Zannoni, 2010). A specific consortium (i.e., *Consorzio del Parmigiano Reggiano*) collects the small and medium sized cheese factories and cooperatives that operates in the production of Parmigiano Reggiano. In 2013, the main figures of the Parmigiano Reggiano production sector were as follows: over 15.6 million tons of milk processed per year, which led to the production of more than 2.9 million wheels of cheese in 2013. The production of Parmigiano Reggiano cheese employs approx. 88% of the total production of cow's milk of Italy. The breeders operating in the Parmigiano Reggiano production chain are more than 3,100, with approx. 340 active dairy companies (Regione Emilia-Romagna, 2014). Approx. 33% of the production is exported outside Italy.

Parmigiano Reggiano is produced using raw, semi-skimmed milk, which can not in any way be subjected to chemical treatment nor been addicted with any substance. A specific set of rules, indeed, regulates the production of Parmigiano Reggiano cheese, to comply with the quality standards and protected designation of origin of the product (Consorzio del Parmigiano-Reggiano, 2011). Among others, this set of rules defines the feed for cows, the milk, the milking process and the manufacturing process of the cheese.

In this paper, we focus on the milking process for a cowshed that produces milk for the manufacturing of Parmigiano-Reggiano cheese. The farm analyzed is located in the area of Parma (Italy). The objective of the analysis was, overall, to improve the current milking process carried out at the farm, in terms of the total time, thus enhancing the productivity of the whole process. The analysis was supported by an *ad hoc* discrete-event simulation model, developed under Simul8^{TM} professional platform. The remainder of the paper is organized as follows: section 2 provides an overview of the farm analyzed and describes the current (AS IS) milking process. Section 3 describes the data collection related to the AS IS scenario. Section 4 details the simulation model used to reproduce the milking process of the farm. Section 5 describes two alternative (TO BE) configurations that were designed to improve the AS IS milking process, as well as their analysis by means of the simulation tool. Section 6 summarizes the main findings of the study, the related implications and limitations, and indicates possible future research activities.

2. THE CONTEXT AND THE "AS IS" MILKING PROCESS

The farm analyzed owns 171 cows, and carries out two milking operations per day, one in the early morning and one in the afternoon. Milking processes are carried out in an appropriate room (milking room), where up to 16 cows can be handled simultaneously. Milking operations usually take approx. 3 hours, which is lower than the maximum allowed time of 4 hours, according to the requirements of Consorzio del Parmigiano-Reggiano, (2011). Currently, the milking process employs two people per work shift, resulting, overall, in 4 people involved in the milking activities. A scheme of the cowshed is proposed in Figure 1.

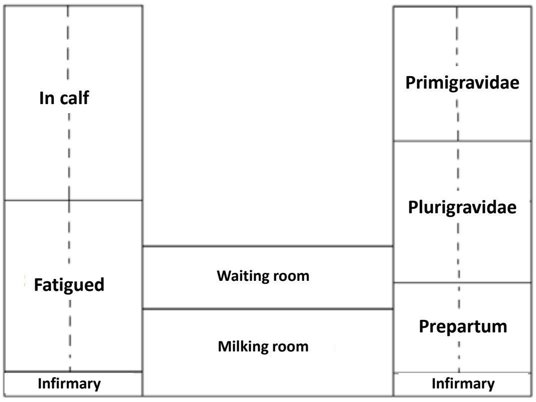

Figure 1: scheme of the cowshed and animals' groups

The milking process requires the cows to move from their positions in the cowshed (where they are located for most of the day) to the waiting room and then to the milking room. The waiting room is directly linked to the cowshed, so that the cows can easily reach it. One group of animals is moved at a time. Indeed, the cows can be classified in different groups, called 1-fatigued, 2-in calf, 3-primigravidae; 4-plurigravidae. The first group to be milked is that of fatigued cows, which consists of 48 animals. This group includes the oldest cows, which do not have a high production of milk and that require, under some circumstances, more time to complete the milking process. The second group to be milked is that of the in calf cows, which consists of 48 animals. Their milk production may not be so high, although the time required for milking is, in general, shorter. The third group is the smallest one (24 animals) and includes cows that, up to that moment, had only one pregnancy. The last group includes 51 animals, which, up to that moment, had more than one pregnancy. The last two groups of cows provide, in general, the highest quantity of milk, although the production may vary significantly during the year. Indeed, the daily production of the plant can slightly vary, reflecting the variation in the production of milk by cows across the year, due, in turn, to breed, season, or other management factors (e.g., nutrition or frequency of milking) (Jialina et al., 1998). In addition, the status of an animal can also change in time: for instance, a cow belonging to group 3 (primigravidae) could become a member of group 4 (plurigravidae) after some time. Sometimes, cows can be moved to the farm infirmary, because of health problems. The milk produced by these animals should not be used for the production of Parmigiano Reggiano for a given time period, because of the possible presence of antibiotics.

The whole amount of milk produced by the milking process is moved to a tank, where it is stored at 18°C, and subsequently moved to the cheese manufacturing company.

3. DATA COLLECTION

On the basis of the analysis of the current milking process, the aim of the work done in this paper was to look for alternatives configurations of that process, at the same time keeping the layout of the cowshed unchanged. As mentioned, the analysis was supported by a discrete-event simulation model, whose construction required some preliminary data, primarily related to the time required to move the animals in the cowshed. Those data were collected through direct measurements. It was found that the time required to move the animals ranges from three minutes for the groups closer to the milking room (i.e., plurigravidae and fatigued) to four minutes for the groups more distant (primigravidae and in calf). This time was considered as adequate, in the light of the number of animals to move. The time required for milking operations was also recorded. The milking process has a defined structure, including:

- Preparation phase, including washing of the breast and of the immediate surrounding areas, and subsequent accurate drying, made with paper, which is then trashed;
- Attachment phase, where the employee checks the health status of the breast and sticks the teats of the milking to the cows' nipples. From this moment on, the data for the milk production, time and cow identity are recorded in the database of the farm;
- Detachment phase, which is the opposite of the attachment phase. This is an automatic step;
- Post-dipping phase, which is carried out with an appropriate detergent used on the cows' nipples.

The data related to the milking process were collected exploiting both the farm's information system and direct measurements. Specifically, the data related to 9 days (18 milking processes) were extracted from the farm's database. This set of records included the following pieces of information: (1) animal number, (2) group number; (3) milk production; (4) milking start time; (5) milking end time; (6) milking duration. During the period of measurement, the farm's database recorded 48 fatigued cows, 48 in calf, 24 primigravidae and 51 plurigravidae.

The analysis of the data recorded showed that, on average, a cow produced 10.24 l of milk per day in the analyzed period. At the same time, however, the production is quite variable (see Figure 2).

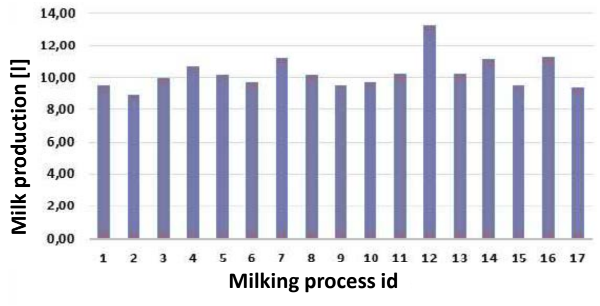

Figure 2: milk production [l]

With respect to the time required for milking, the data elaborated from the farm's information system led to the results reported in Figure 3.

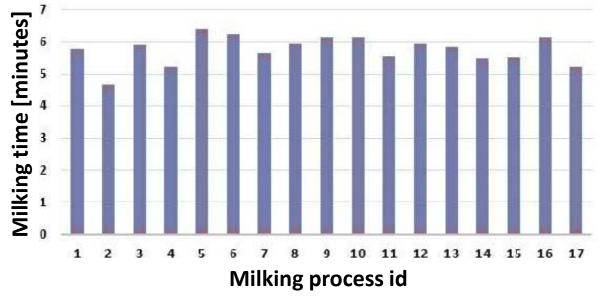

Figure 3: time required for milking.

Moreover, for 10 days (20 milking processes), direct measurements were made at the farm. During these measurements, the time required to complete the following activities on the animals was recorded:

- Cows' movement from their position to the waiting room;
- Exit of the cows from the milking room and return in their positions.

Also, some measurements were carried out to assess the time required to the employees to complete some specific activities, such as:

- Preparation Phase
- Attachment phase
- Detachment phase.

The time required for milking was not measured because it could be directly derived from the data recorded in the farm's database.
Finally, the detailed movements of the cows in the cowshed during milking were analyzed. As mentioned, the milking room is equipped with two sets of milking machines, each one able to handle 8 cows, resulting in 16 animals handles simultaneously. As an example, let us consider the first group of cows to be handled (i.e., group 1-fatigued); their initial movement inside the cowshed is described in Figure 4.

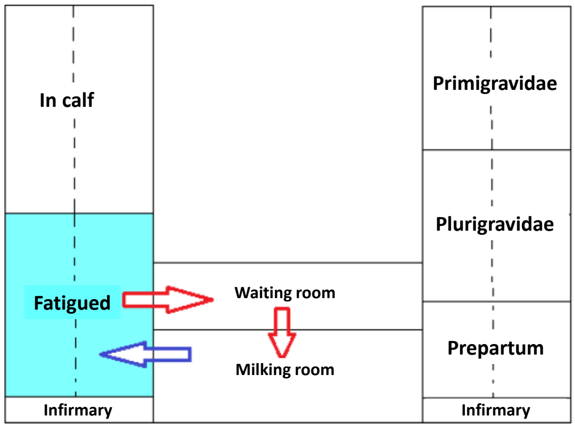

Figure 4: example of cows' movements in the cowshed.

Once the milking process of group 1 starts, the cows should be moved back to their positions, while group 2 of cows should be moved to the milking room, as shown in Figure 5.

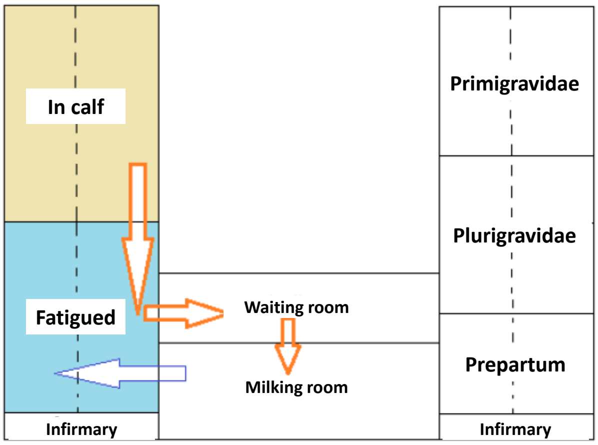

Figure 5: example of cows' movements in the cowshed.

Similarly, the movements of group 3 and 4 of cows were analyzed.

4. THE MODEL

The "AS IS" status of the milking process was reproduced in a simulation model, developed *ad hoc* exploiting the commercial software Simul8^{TM} (Visual Thinking International Ltd). Simul8^{TM} uses dynamic discrete simulation and is commonly exploited to simulate systems that involve processing of discrete entities at discrete times. Examples of those systems are production, manufacturing, logistic or service provision systems. As output, it generates statistics of performance parameters and metrics of the production system examined (Concannon et al., 2007).
The scheme of the model is proposed in Figure 6.

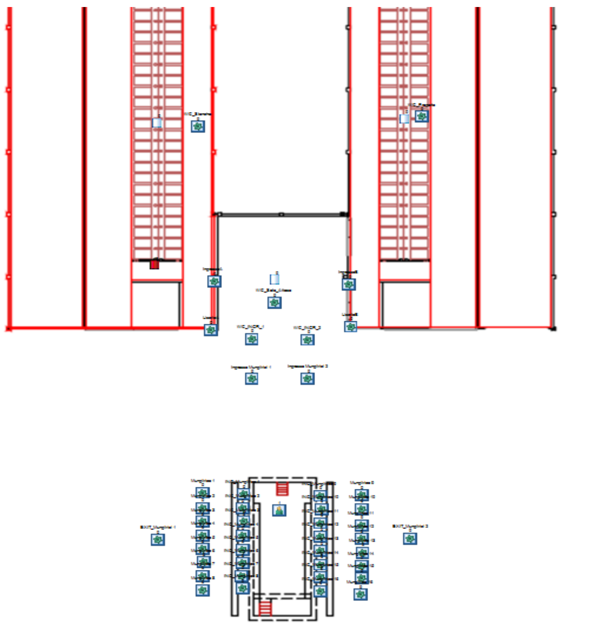

Figure 6: scheme of the Simul8™ model – AS IS scenario.

The model makes use of the input data described in section 3. Appropriate logics were embodied in the model to reproduce the behavior of the cows in the cowshed (cf. Figures 4 and 5), as well as the random order by which the cows move to the waiting room and milking room. Overall, the model includes 61 variables and 13 labels and takes the input data from 16 excel files.
To validate the model, we compared the results returned, in terms of the total time required for the milking process, with those measured during the data collection phase. In the real process, the total time required for milking varies from 2 hours 40 minutes to 3 hours. The results obtained through simulation reproduce the real scenario quite well, as can be seen from the frequency distribution in Figure 7.

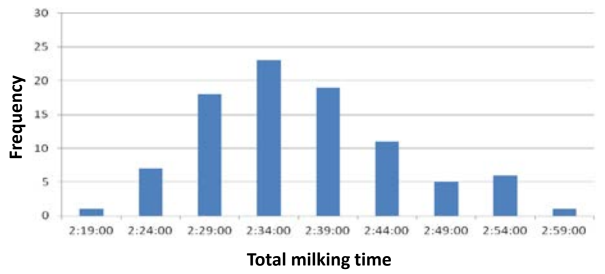

Figure 7: simulated results for the milking time - AS IS scenario.

The model was used to derive some further outcomes, such as the total amount of milk produced and the total production of milk per animal (cf. Figures 8 and 9). In can be seen from these figures that the model estimate the milk production per cow to range from approx. 11 to approx. 12 liters/cow, which is in line with the data collected from the real process. Therefore, the model could be considered as validated.

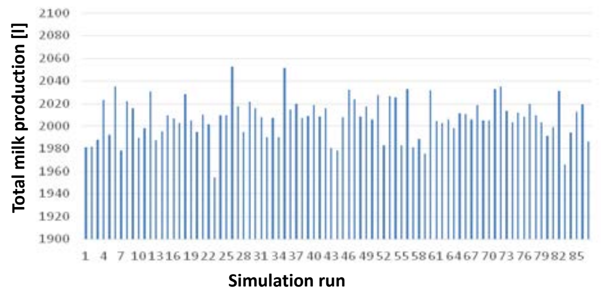

Figure 8: simulated results for the total milk production – AS IS scenario.

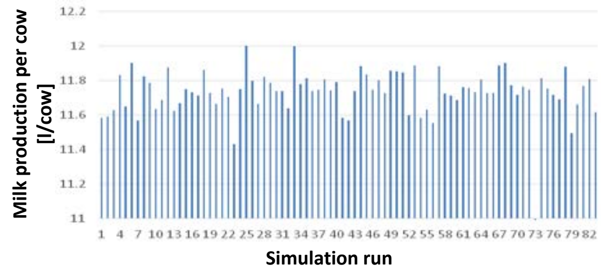

Figure 9: simulated results for the total milk production per cow – AS IS scenario.

5. TO BE CONFIGURATIONS

5.1. Definition of the TO BE scenarios

Once validated, the simulation model was used to examine two alternative configurations for the milking process, resulting in as many TO BE scenarios.

1. The first configuration examined considers a milking room with the same structure as that of the AS IS scenario. The equipment installed in the milking room, however, has a higher capacity, allowing to handle 24 cows (instead of 16) simultaneously. To simulate this TO BE configuration, some adjustments were made to the original simulation model, as well as to some of the input data. From a practical perspective, such a configuration would also require a slight reorganization of the space available in the milking room, to be implemented. Nonetheless, it is reasonable to expect that increasing the production capacity of the milking room will result in a decrease in the time required to complete the milking activities, resulting in a more efficient process.
2. The second TO BE configuration considered requires the complete reorganization of the cowshed layout, with the milking room and waiting room located in a different position compared to the AS IS scenario. A scheme of this TO BE configuration is proposed in Figure 10. The new positions of the milking room and waiting room would be useful, in particular, to

facilitate the movement of in calf and primigravidae cows, compared to the original structure of the cowshed. The second TO BE scenario would obviously modify the movements of the cows in the cowshed. Therefore, the model logics were slightly changed to reproduce the new cow movements. It is also hypothesized that 24 cows can be handled simultaneously in this configuration.

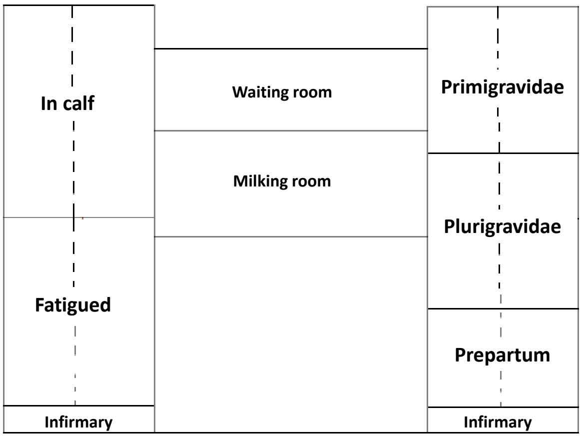

Figure 10: scheme of the second TO BE configuration.

5.2. Results for the first TO BE scenario

Simulating this TO BE configuration required some changes in the input data of the model (MS Excel™ files). For instance, the time required for preparation, washing, attachment and detachment were recalculated, considering the presence of 24 cows instead of 16 in the milking room. Conversely, data related to the behavior of the cows (e.g., the time for their movement or the waiting rime) or those related to the milking process (e.g., the milking time and milk production) were not changed. With respect to the simulation model, simulating this TO BE scenario required adding 4 work centers in the milking process, to take into account the increased number of cows that can be handled simultaneously. The new model is proposed in Figure 11. Specific logics were defined for these new work centers. The relevant results obtained for the first TO BE configuration (with 300 simulation runs) are reported in Figure 12.

It can be seen from Figure 12 that, with this new configuration, the milking time decreases (overall) by approx. 20 minutes, equally shared among the different groups of cows (i.e., 5 minutes per group, on average). By saving 20 minutes in the milking process, employees can be allocated to different activities for a total of approx. 20x2x2=80 minutes per day.

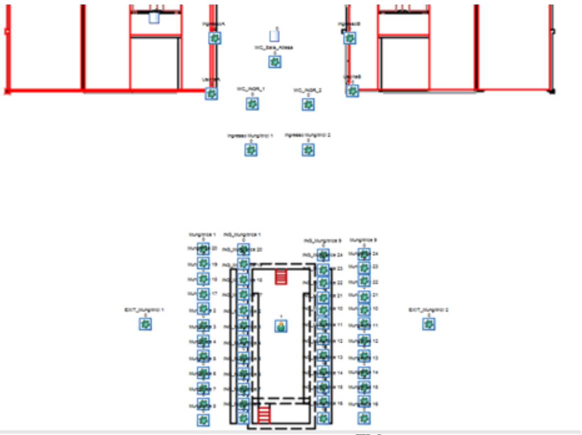

Figure 11: scheme of the Simul8™ model – TO BE scenario #1.

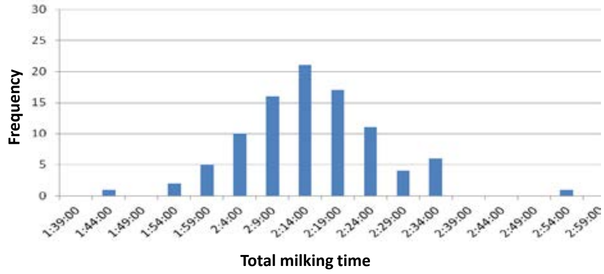

Figure 12: simulated results for the total milking time – TO BE scenario #1.

5.3. Results for the second TO BE scenario

Simulating the second TO BE configuration required some modifications to the input data, in terms of the time required to the cows to enter the milking room and the waiting room, as well as to go back to their locations in the cowshed. These data were recalculated based on the modified distances to be covered in the new configuration. Conversely, the simulation model was not changed in its structure.

The relevant results obtained for the second TO BE configuration (with 300 simulation runs) are reported in Figure 13.

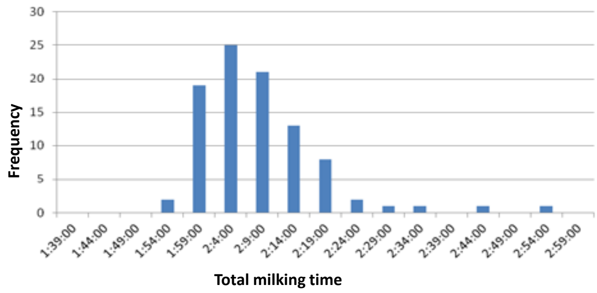

Figure 13: simulated results for the total milking time – TO BE scenario #2.

As can be seen from Figure 13, with this new configuration the time required for milking reduces to approx. 2 hours (between 2 hours 5 minutes to 2 hours 10 minutes), resulting in a significant saving compared to the original scenario. Only some simulation runs returned a milking time close to 3 hours. Approx. 20,000 liters of milk are produced at every milking process, with an average production of 11.7 liters of milk per cow. As per the previous scenario, by saving approx. 30 minutes per milking process, employees could be allocated to different activities for a total of 30x2x2=120 minutes per day.

6. CONCLUSIONS

The aim of this study was to optimize the current milking process of a cowshed, which provides milk for the production of Parmigiano Reggiano cheese. The ultimate goal of the analysis was to reduce the time required for milking operations, thus optimizing the whole management of the farm processes.

To reach this aim, an *ad hoc* simulation model was developed to reproduce the milking process at the cowshed. The discrete-event simulation model was designed under Simul8™ professional platform. The main processes of the cowshed, and in particular, the behavior of the animals (e.g., their movements, waiting time and so on), were reproduced in the model, grounding on real data collected at the cowshed.

In line with the fact that the animals' behavior can significantly vary in time, the data collected were found to be characterized by high variance. Nonetheless, the simulation model allowed to estimate the time required for milking with a good approximation. Then, exploiting again the simulation model, two alternative configurations of the cowshed layout were tested and the related performance, in terms of the total time required for milking, was compared to the current one.

Both the new configurations of the milking process show interesting savings, in terms of the total time required for milking, compared to the current scenario. The first solution, in particular, allows saving approx. twenty minutes, compared to the AS IS scenario, allowing milking operations to be completed in approx. two hour and a quarter. As for the second configuration, the time saving is even greater, due to the greater proximity of all four groups of cows to the waiting room. On average, the groups most isolated, today, employ four minutes to reach the milking room. The final time saving is approx. half an hour compared to the initial situation.

From the practical perspective, both solutions could be considered for implementation by the company analyzed, although the first one is easier to be implemented, because it does not require modifications to the cowshed layout.

From the scientific point of view, this paper shows that simulation can be used also to reproduce very stochastic situations, such as the behavior of animals, with a good approximation, thus providing useful findings to the cowshed owners.

Among the limitations of the present study, it should be mentioned that the two TO BE scenarios examined does not cover all possible alternative configurations for the milking process examined. Other TO BE scenarios could be designed considering, for instance, modifications to the equipment used for milking. Therefore, future research could be directed toward the development of additional TO BE scenarios. Another point is that, as recalled earlier in the paper, the production of milk can significantly vary during the year (Jialina et al., 1998). In this work, the data collection phase was carried out at the beginning of the summer, reflecting the period where the milk production is lower. Repeating the analysis in a different period of the year could be useful to confirm the validity of the model, as well as to assess the sensitivity of the results as a function of the milk production.

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