Design of robotic dairy barns

The most important recent development in the dairy industry is robotic milking. Dairy barns with milking robots are becoming more and more interesting from an economical point of view. Today already over 200 robots have been installed on commercial Dutch farms. As robotic milking barns (RMB) are expensive, it is important to develop models which make it possible to discuss the optimal layout of an RMB and the optimal capacities of the various facilities in the barn depending on the herd size before actually constructing it.

In an experimental farm in Duiven in the Netherlands the agricultural research center IMAG-DLO is investigating the behaviour of the cows in an RMB. Based on extensive measurements and observations, it was concluded that it is necessary to incorporate the stochastic behaviour of the cows in the design of an RMB. Another aspect, which makes this design complex, is the interaction between the facilities in the barn: increasing the capacity of bottleneck facilities will shift queues and alter the location of bottlenecks, possibly forcing the designer to increase the capacity elsewhere.

Below we describe the RMB and discuss some of the performance aspects. The basic layout of the RMB we are dealing with is shown in figure 1.

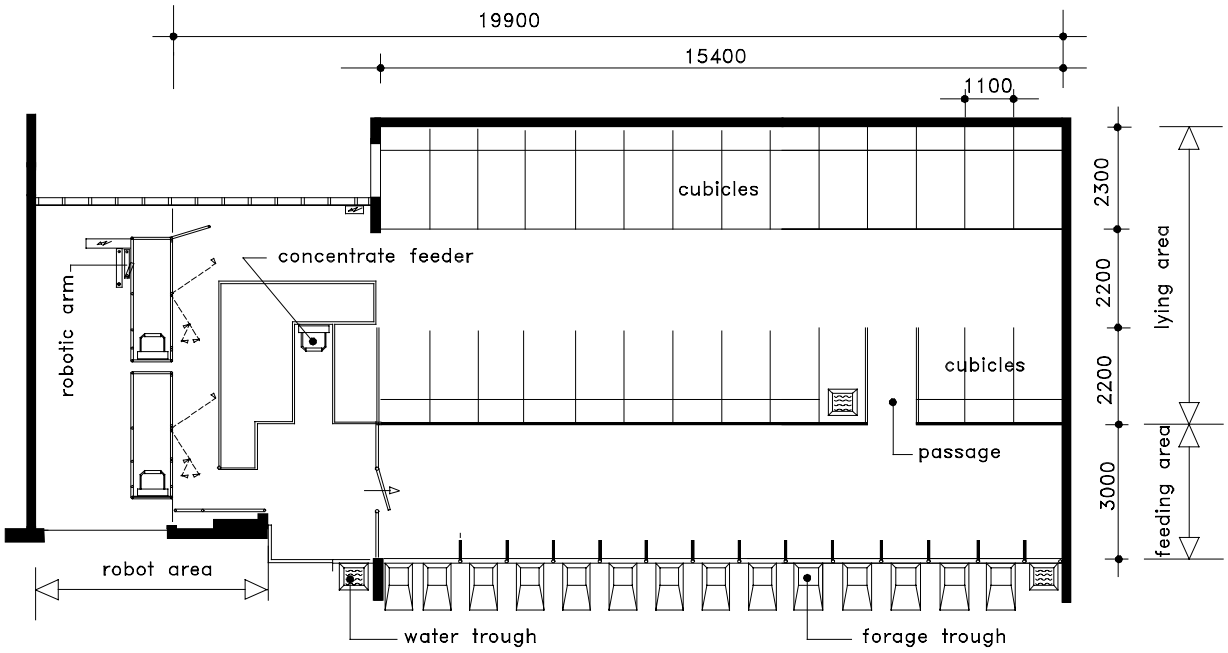

Figure 1: Layout of the experimental barn in Duiven. Dimensions in mm. (source: IMAG-DLO)

In the barn we distinguish five facilities.

- **The Milking robot.** The milking robot is shown in figure 2. Milking robots are different from the ordinary milking machines in one crucial aspect: the robot uses

sensors to find the teats of the cow and then connects the cups to the teats with a robot arm.

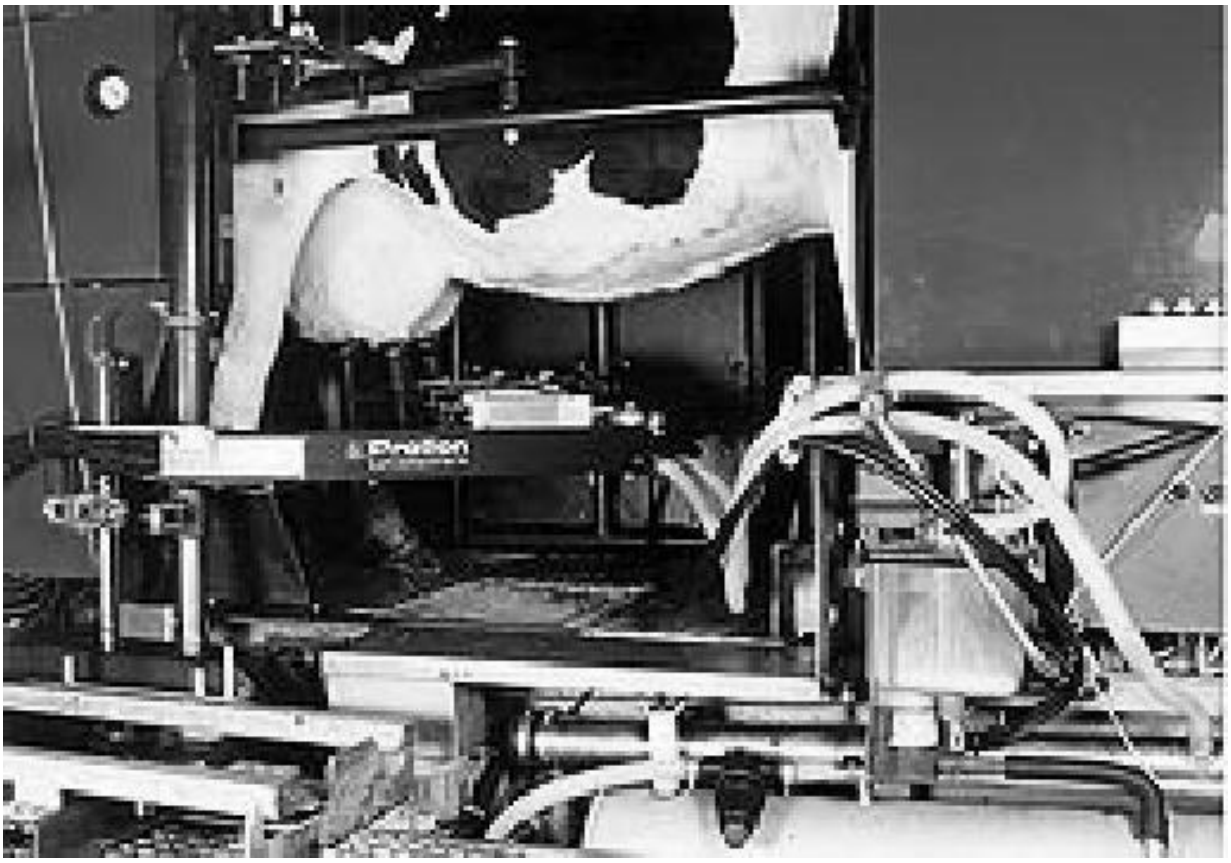

Figure 2: A milking robot (source: IMAG-DLO)

There are at least two good reasons for using robots. First, it saves a serious amount of labour and second, it makes it possible to go from milking twice a day to three or even more times a day. When cows are milked three times a day their production is increased by about 15 percent.

- **The Concentrate feeder.** Each cow is allowed to receive only a limited amount of 'concentrate.' So the Concentrate feeder must have the equipment to be able to identify the cows and to decide how much concentrate to give to the cow. Cows are very fond of the concentrate. Therefore the Concentrate feeder can be and is used to get the cows to pass through the Milking robot. In the present design in Duiven the cows can only reach the Concentrate feeder via the robot.

The three more conventional facilities are:

- **The Forage lane.** Forage lanes are cheap. There are no limitations on foraging. The only condition is that there must be enough eating positions at the forage feeder to prevent the cows from becoming aggressive.

- **The Water troughs.** A 'high-yielding' cow may drink upto 180 liters a day. Water troughs are cheap, but of significant physiological importance.

- **The Cubicles.** In the cubicles the cows can lay down, rest, and avoid confrontations. They spend roughly 50 percent of their time in the cubicles. Cubicles only require space, some fencing and bedding material (wood shavings, sand, rubber mattresses).

Further we introduce one more, artificial, facility that we will call:

- **Walking.** The space in between the facilities is used for walking, idling or grouping. This takes nearly 25 percent of their time, so 5 to 6 hours a day. In that time they cover at most a few kilometers, so a better word for the facility might be 'Standing.' Anyway, the walking area should be large enough to accommodate somewhat more than 25 percent of the herd.

From extensive measurements in the experimental barn in Duiven information has been obtained on the behavior of the cows. There is data available on the times spent in the robot, concentrate feeder, forage lane, water troughs and the cubicles, and on the 'transition' behavior of the cows between these facilities. From the measurements in Duiven we also know that Walking takes (approximately) 23.8 percent of the time. This implies that the mean time to 'walk' from one facility to the next is 5.36 minutes.

Waiting is something cows do not like. In this respect they do not differ from humans. When a cow is waiting for a facility and another cow arrives, aggressive behaviour might occur. Particularly at the scarce facilities Milking robot and Concentrate waiting has to be limited. Some waiting for Cubicles is not really a problem because Walking seems to be an alternative for the Cubicles. So in the discussion about the design we focus on mean waiting times and the queue lengths. Given the transition behavior, service times, capacities and herd size we should be able to evaluate waiting times, queue lengths and utilizations for the various facilities. From these we can discuss and judge the design under consideration.

Now you are asked to:

- Develop a model to evaluate the performance of the RMB (clearly discuss assumptions and limitations);

- Develop an (approximate) MVA approach to evaluate the performance of the RMB;

- Use this model to design an RMB for a herd of 50 cows; the design criterion that may be used is an upper limit of (say) 2 minutes for the mean waiting time in each facility. Describe your procedure used to determine the 'optimal' design.

- Cows are milked 3 or 4 times a day. The model will probably predict that the number of visits to the robots is (much) greater (check!). The reason is that cows do not always want to be milked, but they just want to get some concentrate food. In that case they unnecessarily occupy the robots. This loss of capacity can be reduced by using a 'selective gate' in front of the robots: cows are only allowed to pass if they have to be milked. Use your model to evaluate the effect of using a selective gate.

- Typically cows in a herd are socially ranked. The low-ranking cows tend to wait longer in front of facilities than the dominant ones (they may be pushed away). Incorporate social rank into the model and demonstrate its effect on the performance of the RMB.

- Write a clear report on your findings.