Decision Support Systems Development for an Artificial Insemination Project in Community Based Precision Livestock Farming

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Abstract. The success of an artificial insemination of cattle depends on the accuracy of timing of semen injection within a certain duration of time during the estrus phase of the female cattle. Contemporary practice in traditional cattle reproductive system relies on the visual observation of estrus indicators. This paper proposes for the design of a Decision Support System assisting the determination of semen injection to post-partum female cattle. The system would suggest the time frame for injection treatments, the distance of the location from the centre point, and the best route of the treatments for multiple locations based on the shortest route path algorithm. The paper concludes with the potential contributions of such system for the development of Precision Livestock Farming and rural farmers’ prosperity.

1. Introduction
Over the last decades the efficiency of cattle reproduction has become a challenging matter in livestock farming. Even in the most developed countries where livestock farming is considered in advance and sophisticated state [1]. While the reproduction rate represents the productivity in the business, estrus detection is the key factor in the profitability of the dairy cattle [2]. The success of an artificial insemination of cattle depends on the accuracy of timing of semen injection within a certain duration of time during the estrus phase of the female cattle. The anticipation toward the upcoming estrus of cattle allows farmers to ensure the insemination done effectively.

Contemporary practice in traditional cattle reproductive system relies on the visual observation of estrus indicators. The challenges in estrus detection are associated with difficulties to match the insemination within the short duration of estrus [3] and cattle’s discrete behavioral change [4]. In this regard, estrus detection methods [5-7] require significant effort of the breeder’s working time and detecting skills.

Technology of electronic and/or automatic estrus detector has developed in response to the need of the roaming numerous herd of cattle [1, 2, 8-10]. Indeed, the investment is considered economic for the numerous quantity of the flock. The cost associated with the deployment of such technologies, in consequence, will be skyrocketed for managing only a small number of cattle in smallholder livestock farming. Therefore, the development of a participatory technological adoption is highly appreciated [11]. The conceptual framework encourages the development and the adoption of technologies to be shared for an extendable number of owners. In addition to reducing the cost spent per owner, the shared use of the technology would induce the utilization of the technology’s maximum capacity.

This research aims to answer two problems posed to the traditional livestock farming environment. The first objective is adopting reproduction technology, to the traditional livestock farming in rural areas.
of Indonesia. Given traditional farmers’ circumstances, they offer limited capacity in technology investment, both financially and skill and/or knowledge proficiency. To be successfully deployed, technology developed and later implemented into such environment should take those circumstances into consideration. The consideration leads to the second objective of the research. The second objective is related to the identification of the appropriate method to implement estrus detection technology in the practice of traditional livestock farming. Addressing the objectives of the research, this paper proposes the design of a Decision Support Systems on the management of Artificial Insemination on cattle. The design was developed according to physical and behavioral indicators of cattle in estrus.

The rest of this paper is organized as follows. The next section would review the development of DSS and followed by the relevant literature on estrus in cattle in the third section. The fourth section suggests the profile of follicular cycle. The proposed design of the DSS is presented in the fifth section. This paper concludes with the potential contribution of the DSS for the development of Precision Livestock Farming in a rural area of Indonesia.

2. Adopting decision support technology into community

The decision support system is a concept as well as a discipline developed to aid the decision making purposes of top management. The information system was developed to address the need of tactical decision making which is lacking in the ordinary information systems [12]. The main principle of a decision support system is the use of communication technologies, data, documents, knowledge and/or models to assist decision makers in the activity to identify and solve problems, complete decision tasks, and make decisions [13]. Traditionally, a decision support system is a long questionnaire that comprises procedures to overcome a particular problem. With recent development of information systems, such protocol can be achieved more efficiently by deploying interactive computer programs. The analysis could be done systematically by using all the knowledge, data, and the responsibilities the problem depends on [14]. Hence, a decision support system could be integrated into larger information systems possessing information sources and resources that are relevant to problem solutions.

Despite insemination and the success of insemination is an essential part in cattle reproduction stages, very limited number of literature delved into the adoption of information system technology to support the process. Precision livestock literature has been overwhelmed by the investigation on the automation of estrus detection [1-3, 5, 7-10, 15, 16]. A limited number of scholarly articles, to the author’s knowledge, discussed the use of data obtained from the estrus detection to be the source of further investigation in estrus and/or insemination in cattle [17].

Apart from those above mentioned, a few literature on the adoption of DSS in livestock farming focuses specifically on the analysis of manure management [13, 18]. The researches address particularly the mitigation of environmental, health, and social impact caused by manure excreted by cattle farming. Although the researches might not be relevant to the topic, it benefits this research by underlining the potency of decision support systems to advantage livestock farming theory and practice.

3. Estrus Cycle and Indicators

Cattle’s estrus cycle is a cyclical pattern of ovarian activity that facilitates the shift from a reproductive non-receptive to receptivity [19]. The receptivity of female cattle implies the stages of the animal’s fertility. The variation in physiological condition is induced by the changes of reproductive hormones in female cattle that enable mating, lead to ovulation, and an environment in the uterus that allows the establishment of conception [20]. The hormonal state variability influences physical as well as behavioral changes that denoted the condition of female cattle in estrus [21, 22].

The physical indicators of estrus cycle are expressed by the changing of the physical condition of cattle that could be observed or sensed by humans. The physical indicators may occur on the onset, or along the duration of estrus. Two main physical estrus indicators are vaginal mucus and the increase of body temperature. Cattle’s body temperature may increase during the estrus cycle. The rise of body temperature is observed around the surge of LH during estrus [23, 24]. The direct correlation between estrus and temperature increase, however, has not been concluded yet [1, 20].
Another physical indicator of estrus is the excretion of a liquid substance from female cattle’s vagina. Vaginal fluid is the first physiological medium that sperm cells encounter in the female genital tract. The vaginal mucus becomes more plentiful, watery, translucent, less vicious and easier to traverse by spermatozoa during the follicular phase of the ovarian cycle [25]. The electrical conductivity (or resistance) of vaginal and cervical mucus changes significantly during estrus [20]. Measurement of changes in electrical resistance of vaginal and cervical mucus has been used to predict the timing of insemination in farms with varying degree of success. The electrical resistance in cattle has been shown to vary within animals at different stages of estrus [10]. Yet, the report doesn’t account for other variabilities caused by individual cattle condition, diet, or disease that may lead to inaccuracy in resistance reading.

Numerous behavioral changes indicating estrus condition were suggested in the literature [4]. Most of them, however, may not be applied to small holder livestock farming context. Sniffing at the other cow’s vagina or resting chin at the other cow, for example, only relevant in a big herd. Three behavior indicators suitable for small holding livestock farming are namely standing heat and walking activity. The most pronounced estrus behavioral indicator in cattle is standing heat [20]. Female cattle indicate in estrus when they stand still with limited body movement. Sometimes they move their tail sideways, and receptive to be mounted by other cow [9]. Despite the focus on standing heat observation predominate literature of estrus detection [1, 10, 26], the efficiency of standing heat detection ranges from 50% to 90% [20].

The second behavioral indicator of estrus is walking activity. Literature suggest that the increase of walking activity indicates estrus condition in cattle [7]. Pedometer measurements ascertain that cattle in estrus tend to restless which increases the number of steps of the animal [15, 16, 20]. However, similar walking activity also observed during early stage of pregnancy for the increase of lactation [7]. This indicator, therefore, needs other estrus indicator such as mounting or being mounted to confirm such indication pertinent to cattle in estrus.

4. The Follicular Wave
The follicular wave is the wavelike dynamic that demonstrate the growth of follicles in the ovary [2, 19, 22] as indicated in Figure 1. Each follicle wave is initiated after the demise of the previous wave. A flock of follicles materialized on the fourth day subsequent to the exuviation of the mature eggs. Each follicle wave is initiated by the release of follicle stimulating hormone (FSH) from the anterior pituitary [27]. According to the literature, the duration of estrus cycle varies. Forde and Beltman [19], for example, argued that the normal duration of estrus cycle is between 18 to 24 days. While Boer and his associates [27] suggested the cycle between 20 to 22 days. Despite a single consensus on the normal duration of the estrus cycle in post-partum female cattle has not been concluded, scholars agreed on the mechanism and phases of estrus cycle.

The cattle estrus cycle is signified by the growth of follicle in the ovary. New follicles of less than 3-4 mm in diameter emerge every 10 days. The growth of the follicles is indicated by the increase in size and the reduction in population of follicles (8-41). At the onset the growth rate of these follicles is similar to a dominant follicle is selected to continue growth while the rest are becoming atretic and regress [28]. The maturity of the follicle is indicated by the surge in LH (Luteinizing Hormone) on the final hours of the third estrus waves [22] that paves the way to the ovulation or the release of dominant follicle to be fertilized by sperm. The rise of LH succeeded by the increase of progesterone triggers the ovary preparation for pregnancy.
5. Design of the Decision Support Systems

The interface of the Decision Support Systems proposed in this paper comprises three main sections as illustrated in Figure 2.

The first section is the Input interfaces consist of the entry for information about the cattle owners and the cattle they owned. These may be keyed in once per cattle owner and/or cattle owned. The other interface is the entry of cattle estrus data. Those entries record the estrus characteristics of cattle based on the observation. Since simulating estrus period recreates the estrus pattern of individual cattle, the entry of estrus data is vital for the Decision Support Systems.

The second section is the Simulation Generator. Based on the individual cattle estrus data, the predicted estrus cycle is simulated. The simulation could be run for individual cattle or several cattle at once. Given post-partum cattle and heifers indicate different pattern of the estrus cycle, their estrus prediction should be distinguished separately in the simulation. Each of simulation results provides the prediction on the estimated upcoming estrus in detail. The user or inseminator could make use of the report prior to preparing for the insemination. The level of detail generated in the simulation should be in hours or days.

The third section is the Report generator. In addition to generating the Insemination Timetable, data collected through the cattle estrus observation would sufficiently being utilized for the other purposes.
The DSS would facilitate the monitoring of cattle’s pregnancy, calving schedule, and post-partum monitoring.

The fields of data designated for each interface is elucidated in Table 1.

| Input     | Description                                                                 | Frequency                  |
|-----------|-----------------------------------------------------------------------------|-----------------------------|
| Owner ID  | The information about the cattle owner                                       | Once entry per Owner ID     |
| Cattle ID | Identification of the female cattle / heifer                                 | Once entry per cattle       |
| Cattle Age| The estimated age of the cattle in month                                     | Once entry per cattle       |
| Pregnancy status | Information about the pregnancy of each cattle, including the months into pregnancy or failed insemination. | Multiple entry              |
| Cattle Location | Cattle geo location by pen’s coordinates                                      | Once entry per Cattle      |
| Follicle size | Record the size of follicle                                                  | Multiple entry              |
| Post-partum day | Indicate the estimated days into the follicular wave                        | Multiple entry              |
| LH Level  | Record the level of LH in cattle’s blood                                     | Multiple entry              |
| Progesterone Level | Record the level of progesterone in cattle’s blood                           | Multiple entry              |
| Body Temperature | Record on the temperature of the cattle                                    | Multiple entry              |
| Vaginal Mucus | Record on the visual appearance of corpus luteum                            | Multiple entry              |
| Standing Heat | Record on the visual observation of cattle’s standing heat behaviour        | Multiple entry              |
| Mounting  | Record on the readiness of cattle to be mounted by the other cow            | Multiple entry              |

**Simulation Generator**

| Simulation Generator | Description                                                                                     | Frequency                  |
|-----------------------|-----------------------------------------------------------------------------------------------|-----------------------------|
| Estrus cycle simulation | Simulation of estrus cycle based on cattle data.                                               | Anytime needed              |
| Insemination route simulation | Simulation on the route to conduct insemination from central point including the calculation for the shortest path for multiple insemination locations. | Anytime needed              |
| Calving schedule simulation | Simulation on the estimated calving timetable based on the cattle’s pregnancy.                 | Anytime needed              |

**Output**

| Output                  | Description                                                                                     | Frequency                  |
|-------------------------|-------------------------------------------------------------------------------------------------|-----------------------------|
| Insemination Timetable  | Reports generated from Estrus Cycle Simulation.                                               | Anytime needed              |
| Pregnancy monitoring    | Reports on the time to pregnancy age.                                                          | Anytime needed              |
| Calving timetable       | Reports on the estimated timetable of the calving of several cattle                           | Anytime needed              |
| Post-partum monitoring  | Reports on the monitoring of cattle after delivering calf.                                      | Anytime needed              |

6. **Concluding remark, limitation and recommendation for future research**

While detecting estrous phase of female cattle or heifers was become a challenging matter, the decision support system proposed in this paper is potentially increasing the success rate of Artificial Insemination in traditional livestock farming. Predicting the ovulation window on the third follicular wave would likely increase the accuracy of artificial insemination. The ovulation schedule suggested by the system assists inseminator to have the adequate preparation prior to conducting artificial insemination. Despite individual farmers may contribute to the accuracy by informing the technician for the visual indicators of the cattle, the schedule would help anticipate the insemination treatment beforehand.
In a wider context, the decision support systems could be being integrated with a farm management system that overseeing the whole livestock farming aspects in entirety [29]. While the Precision Livestock Farming (PLF) is considered expensive for farmers in the third world countries for the high-tech devices required, the community based precision agriculture [30, 31] mitigates the cost for the comparable impacts. The use of automatic sensor devices could be reduced by employing either man-operated measurement tools or trained observers. Observing the visual estrus indicators of cattle, for instance, could be carried out by involving the community in the activities. Thus, the Artificial Insemination Management Decision Support Systems potential advantages the community by managing the cycle of calving of domestic cattle.

Due to the requirement to mimic the natural estrus cycle, the system needs to collect data as much estrus cycles as possible. The more data on estrus cycle are collected; the accuracy of the simulation is likely. The duration of data collection, in consequence, would be prolonged linear with the expected increase of the simulation accuracy. This would be the first limitation of this decision support system. The next limitation is the inability of the systems to predict the irregularity of estrus cycle caused by factors external the cattle such as the changes in cattle’s diet, stress, etc. The DSS, therefore, assumes physical aspects of the cattle under study are remaining constant.

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