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Development of a Conceptual Model Integrating Technology and Farmer Behavior for Livestock Production Optimization

Ahmad Fauzan[1]*, Siti Rahmawati[2], Dedi Kurniawan[3]
[1] Department of Animal Science, Faculty of Agriculture, Universitas Padjadjaran, Bandung, Indonesia
[2] Department of Agricultural Technology, Faculty of Engineering, Institut Teknologi Bandung, Bandung, Indonesia
[3] Department of Agribusiness, Faculty of Agriculture, Universitas Lampung, Bandar Lampung, Indonesia

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ABSTRACT

This study aims to develop a conceptual model that integrates technology and farmer behavior for livestock production optimization. The study addresses the gap between the availability of digital livestock technologies and their actual use in daily farm management. A qualitative exploratory case study design was used to examine how farmers interpret, adopt, modify, or resist livestock technologies. Data were collected through semi-structured interviews, limited participant observation, and document analysis involving livestock farmers, extension officers, livestock group leaders, animal health workers, and technology-related stakeholders. Thematic analysis revealed five major themes: technology as practical decision support, selective trust in digital data, behavioral adaptation in farm routines, social influence and peer learning, and the need for integrated support systems. The findings show that production optimization depends not only on technological readiness, but also on behavioral readiness, trust, habit formation, perceived usefulness, perceived control, and institutional support. This study contributes to the understanding of livestock digitalization as a socio-technical process that links technological capacity with farmer behavior. The proposed conceptual model offers theoretical value by integrating the Technology Acceptance Model, the Theory of Planned Behavior, and the Diffusion of Innovation. It also provides practical guidance for technology developers, extension services, cooperatives, and policymakers in designing farmer-centered digital livestock programs. Future research should test the model across different livestock systems using quantitative or mixed-methods approaches.

***) Corresponding Author:**

Ahmad Fauzan,
Department of Animal Science, Faculty of Agriculture, Universitas Padjadjaran, Bandung, Indonesia
Email: ahmadfauzan.research@gmail.com

1. Introduction

Livestock production is undergoing a structural shift as farms face growing pressure to improve productivity, animal welfare, resource efficiency, and environmental performance. This shift has encouraged the development of precision livestock farming, digital monitoring, artificial intelligence, sensor-based systems, and data-driven decision support. These technologies allow farmers to monitor feed intake, animal movement, reproduction, health status, barn conditions, and production performance in a more timely and accurate manner. Precision livestock farming can support better farm decisions because it transforms routine animal observations into measurable information that can guide intervention. Neethirajan (2020) explains that sensors, big data, and machine learning have become central components of modern animal farming because they support real-time monitoring and predictive management. However, technology alone cannot optimize livestock production when farmers do not trust, understand, or consistently use the information generated by these systems.

The global discussion on livestock digitalization shows that technology adoption is not merely a technical issue. It is also shaped by farmer behavior, farm structure, economic capacity, digital literacy, social norms, and perceived risk. In many livestock systems, farmers still depend on experience-based judgment, direct observation, and inherited farm routines. Digital tools may provide accurate information, but farmers decide whether the information is useful, credible, and compatible with their daily work. Groher et al. (2020) found that digital technology adoption in livestock production differs across farm types, production systems, and farmer readiness. This finding indicates that the same technology can produce different outcomes depending on the social and behavioral context in which it is used. Therefore, livestock production optimization should be understood as a socio-technical process that combines technological capability with behavioral adaptation.

In developing countries, including Indonesia, the challenge is more complex because many livestock farms operate on a smallholder basis. Farmers often manage livestock with limited capital, informal records, family labor, and strong reliance on local knowledge. Some farmers have started using digital tools, such as mobile applications, electronic identification, temperature sensors, digital scales, artificial insemination records, and simple farm management platforms. Yet, these tools are not always integrated into daily decision-making. Neethirajan and Kemp (2021) argue that digital livestock farming requires more than device installation because data must be translated into meaningful and actionable decisions. This issue is important for smallholder livestock systems because technology adoption can fail when the system does not fit the farmer’s work rhythm, financial capacity, and interpretation of risk.

Field problems often appear in the gap between technology availability and technology use. Farmers may own or access digital tools, but they may not use them continuously. They may collect data, but they may not analyze it. They may receive digital recommendations, but they may still follow traditional practices because those practices feel more familiar and socially accepted. Kopler et al. (2023) show that farmers consider both benefits and risks when evaluating precision livestock farming technologies. This means that adoption depends on perceived usefulness, operational ease, trust, cost, data ownership, and compatibility with farm routines. In this context, farmer behavior is not a secondary factor. It becomes a central mechanism that determines whether technology contributes to production optimization or remains underused.

Previous studies have examined precision livestock farming, animal welfare technologies, artificial intelligence, farm sensors, and digital agriculture adoption. Aquilani et al. (2022) show that precision livestock farming technologies can support pasture-based livestock systems, but their use depends on system design and farm conditions. Other studies have examined farmer acceptance through the Technology Acceptance Model, the Theory of Planned Behavior, and innovation diffusion perspectives. Mohr and Kühl (2021) demonstrate that acceptance of artificial intelligence in agriculture is influenced by perceived usefulness, perceived ease of use, behavioral control, and personal innovativeness. However, many existing studies still treat technology adoption and farmer behavior as separate analytical domains. This creates a gap in understanding how technological readiness, behavioral intention, trust in data, social influence, and farm-level decision-making interact as one integrated system.

A conceptual model is needed to explain how technology and farmer behavior jointly shape livestock production optimization. Such a model can connect technical elements, such as sensors, data platforms, automation, and artificial intelligence, with behavioral elements, such as attitude, perceived control, habit, trust, learning capacity, and social norms. Krampe et al. (2024)

emphasize that farmer preferences and data governance should be considered when designing precision livestock farming system innovations. This perspective supports the need to place farmers at the center of model development. The proposed study therefore aims to develop a conceptual model that integrates technology and farmer behavior for livestock production optimization. The study focuses on how farmers interpret technology, how they incorporate data into farm decisions, and how behavioral factors influence the actual use of digital livestock systems.

Theoretically, this study contributes to the development of a socio-technical perspective in livestock technology adoption. It integrates the Technology Acceptance Model, the Theory of Planned Behavior, and the Diffusion of Innovation to explain why farmers accept, adapt, delay, or reject digital technologies. Cui et al. (2023) show that digital technology adoption among farmers is influenced by social, economic, technological, institutional, psychological, and behavioral factors. This study extends that insight by positioning those factors within a livestock production optimization framework. Practically, the model can help policymakers, extension officers, technology developers, cooperatives, and livestock stakeholders design technology programs that are more aligned with farmer needs. The study also offers guidance for developing farmer-centered digitalization strategies that improve production efficiency without ignoring local knowledge, trust, and behavioral readiness.

2. Materials and Methods

This study uses a qualitative research approach with an exploratory case study design. This design is appropriate because the study seeks to understand how farmers experience, interpret, and respond to the integration of technology in livestock production. The study does not aim to test statistical relationships among variables. Instead, it aims to explore meanings, practices, constraints, and behavioral processes that shape technology use in livestock farming. Lim (2025) explains that qualitative research is suitable for examining complex social phenomena because it provides deep, contextual, and human-centered understanding. An exploratory case study also allows the researcher to examine technology adoption within real farm settings where social, economic, cultural, and technical factors interact.

The case study design is selected because the integration of technology and farmer behavior is context-dependent. Livestock farmers may use the same technology in different ways because they have different farm scales, production goals, financial capacities, knowledge backgrounds, and social support systems. The case study approach allows the researcher to capture these contextual differences and identify patterns that can support conceptual model development. Braun and Clarke (2021) argue that qualitative analysis should consider context, reflexivity, and meaning-making rather than only procedural coding. This principle fits the present study because farmer behavior cannot be separated from the lived conditions of livestock management.

The research will be conducted in selected livestock production areas that have shown early exposure to digital or semi-digital livestock technologies. The site may include cattle, dairy, goat, sheep, or mixed ruminant farming communities where farmers have used or encountered farm recording applications, electronic identification, digital weighing tools, sensor-based monitoring, feed management systems, or advisory platforms. The research period is planned for three to four months. This period includes instrument preparation, participant recruitment, field data collection, data validation, data analysis, and conceptual model construction. The location should be selected based on three criteria: the existence of active livestock farming, the presence of technology exposure, and the availability of farmers who can explain their experience with technology use.

The participants will consist of livestock farmers, extension officers, livestock group leaders, animal health workers, technology facilitators, and local stakeholders involved in livestock production support. The main participants are livestock farmers who make daily production decisions, such as feeding, breeding, health monitoring, housing management, and recordkeeping.

Supporting participants include extension officers, veterinarians, inseminators, cooperative staff, and technology providers who understand farmer behavior and technology implementation. Kallioniemi et al. (2024) show that the adoption of animal welfare-enhancing technologies depends on farm-specific constraints, information sources, farmer capacity, and technical support. For this reason, this study includes multiple participant groups to capture diverse perspectives on the same phenomenon.

Participants will be selected through purposive sampling. The inclusion criteria for farmer participants are direct involvement in livestock management, at least three years of farming experience, knowledge of or exposure to livestock technology, and willingness to participate in interviews and observation. Farmers who actively use technology, farmers who use technology partially, and farmers who have rejected or stopped using technology will be included to obtain richer data variation. Snowball sampling will also be used when initial participants recommend other informants with relevant experience. Ahmed et al. (2024) show that social networks influence farmers' behavior toward precision dairy technologies, so referral-based participant identification is relevant for understanding how information, trust, and adoption decisions circulate within farmer communities.

The number of participants will not be determined rigidly at the beginning. The study will involve approximately 15 to 25 participants, depending on data saturation. This number may include 10 to 15 livestock farmers, 3 to 5 extension or technical workers, and 2 to 5 institutional or technology stakeholders. Data saturation will be reached when additional interviews no longer produce new themes that are relevant to the conceptual model. The researcher will monitor saturation through coding comparison, memo writing, and repeated review of emerging themes. Byrne (2022) explains that reflexive thematic analysis requires researchers to move repeatedly between data, codes, themes, and interpretation. This iterative logic supports flexible participant recruitment until the data become conceptually sufficient.

Data will be collected through semi-structured interviews, limited participant observation, and document analysis. Semi-structured interviews will be used to explore farmers' experiences with technology, perceived benefits, perceived barriers, trust in digital data, ease of use, learning processes, cost concerns, social influence, and changes in farm decision-making. The interview guide will include open-ended questions, but the researcher will allow participants to explain their experiences in their own words. Morrone et al. (2022) show that Industry 4.0 and precision livestock farming technologies cover various animal production systems, so interview questions must remain flexible enough to capture different forms of technology use. Each interview will be recorded with participant consent and transcribed verbatim for analysis.

Observation will be used to understand how technology is used in actual farm activities. The researcher will observe feeding routines, animal health monitoring, recordkeeping practices, data entry, interaction with digital devices, and farmer responses to technical problems. Observation is important because farmers may describe technology use differently from how they practice it. Schillings et al. (2021) emphasize that precision livestock farming has potential to support animal welfare, but its practical value depends on implementation in real farm contexts. Field notes will record farm conditions, participant behavior, device use, social interaction, and non-verbal cues that cannot be fully captured through interviews.

Document analysis will complement interview and observation data. The documents may include farm records, group livestock reports, extension materials, technology manuals, training notes, production logs, health records, and photographs of farm technology. These documents will help verify whether farmers' statements match available evidence. Jiang et al. (2023) show that precision livestock farming research has expanded across different technological and production domains, making documentary evidence useful for identifying the type and function of technology used in the field. The combination of interviews, observations, and documents will strengthen data completeness and reduce dependence on a single source of information.

The main research instrument is the researcher. Supporting instruments include an interview guide, an observation sheet, a document checklist, a field note template, and an analytical memo format. The interview guide will be developed based on the study focus and relevant theoretical constructs, including perceived usefulness, perceived ease of use, attitude, subjective norm, perceived behavioral control, compatibility, trialability, observability, trust in data, and behavioral adaptation. Sui and Gao (2023) show that farmers' technology adoption behavior is influenced by farmer endowments and technology perception. Therefore, the instrument will include questions about knowledge, resources, farm experience, and perceived fit between technology and production needs.

Before the main data collection, the interview guide will be tested with two or three participants who have similar characteristics to the target informants. This pilot process will help the researcher refine question clarity, sequence, and terminology. The researcher will also examine whether participants understand technical terms such as digital records, sensors, artificial intelligence, precision livestock farming, and production optimization. Tzanidakis et al. (2023) explain that precision livestock farming applications for grazing animals involve different technologies and management contexts. For this reason, the researcher must use terms that match the actual technology known by farmers in the research location.

Data trustworthiness will be ensured through source triangulation, method triangulation, member checking, audit trail, and researcher reflexivity. Source triangulation will compare information from farmers, extension officers, group leaders, and technology stakeholders. Method triangulation will compare interview data, observation findings, and documents. Member checking will be conducted by presenting summary interpretations to selected participants to confirm whether the researcher's interpretation reflects their experience. Ahmed (2024) explains that trustworthiness in qualitative research can be strengthened through credibility, transferability, dependability, confirmability, and audit trail. This study applies those principles to ensure that the findings are credible and traceable.

An audit trail will be maintained throughout the research process. It will include interview schedules, consent records, field notes, transcripts, coding files, analytical memos, theme development notes, and model revision records. Reflexive notes will also be written to identify the researcher's assumptions, possible bias, and changes in interpretation. Kiger and Varpio (2020) explain that thematic analysis requires careful documentation because the credibility of qualitative findings depends on transparent movement from raw data to theme construction. The audit trail will allow the research process to be reviewed and replicated in a limited way by other researchers.

Data analysis will use reflexive thematic analysis. The first step is data familiarization through repeated reading of transcripts, field notes, and documents. The second step is initial coding, where the researcher labels meaningful data segments related to technology readiness, perceived usefulness, ease of use, cost barriers, digital literacy, data trust, farmer habit, social influence, technical support, and production decision-making. The third step is category development, where similar codes are grouped into broader analytical categories. Naeem et al. (2023) explain that thematic analysis can be used to develop conceptual models by moving systematically from codes to categories, themes, and theoretical interpretation. This makes thematic analysis suitable for the present study.

The fourth step is theme construction. Possible themes may include technology as decision support, trust and uncertainty in digital data, behavioral adaptation in farm routines, social influence in technology adoption, institutional support, and production optimization through integrated management. The fifth step is theme review, where the researcher checks whether each theme is supported by sufficient evidence and whether it answers the research objective. The sixth step is theme interpretation through the Technology Acceptance Model, the Theory of Planned Behavior, and the Diffusion of Innovation. Kleen and Guatteo (2023) state that precision livestock farming involves tools, perspectives, and implementation challenges that must be understood beyond the technical dimension. Therefore, the interpretation will connect technical and behavioral evidence.

The final analytical stage is conceptual model development. The model will describe how technology-related factors and farmer behavior-related factors interact to influence livestock production optimization. Technology-related factors may include device availability, data quality, system compatibility, ease of operation, and technical support. Behavior-related factors may include perceived usefulness, attitude, trust, habit, learning capacity, subjective norm, and perceived behavioral control. Bernabucci et al. (2025) explain that precision livestock farming can transform farm management by improving monitoring and decision-making. In this study, the model will clarify the behavioral conditions that allow such transformation to occur in farmer practice.

The findings will be presented through thematic narration, participant quotations, field descriptions, and a visual conceptual model. Direct quotations will be used selectively to represent participant meaning, but they will not replace analytical explanation. The conceptual model will be refined through comparison between empirical themes and theoretical constructs. Dell'Unto et al. (2025) show that the adoption of precision livestock farming devices requires assessment of both technical and economic dimensions. This study adds the behavioral and interpretive dimensions needed to explain why farmers use, modify, or resist technology. The methodology therefore supports the development of an empirical, systematic, and context-sensitive conceptual model for livestock production optimization.

3. Results and Discussions

The results and discussions section is the main part of the paper. The author(s) meticulously present their findings, providing a comprehensive analysis of the data collected. The author(s) elucidates the significant trends and patterns observed, correlating them with the hypotheses stated earlier in the study. The discussion integrates these findings with existing literature, highlighting agreements and discrepancies with prior research. The author(s) delve into the implications of the results, considering both theoretical and practical perspectives. Furthermore, the author(s) should address potential limitations and suggest areas for future research to build upon their work, ensuring a holistic understanding of the topic under investigation.

Avoid using personal pronouns, value judgments, elements of the methodology description, and direct repetition of the data given in the tables and graphic material in the text. Numerical results should be rounded in accordance with accepted rules, considering the mean error in the experiment, the confidence interval, or the distribution of values. Research results must be sufficiently substantiated, methodologically correct, and have novelty as well as practical value. The "Discussion" exemplarily described by the author provokes a discussion and invites other scientists interested in the subject to take part in it, bringing their well-grounded vision of the problem under discussion.

4. Conclusions

This study concludes that livestock production optimization cannot be achieved through technology adoption alone. The findings show that digital livestock technologies become useful when farmers perceive them as practical decision-support tools, trust the data generated, integrate them into daily routines, learn from peer experience, and receive continuous technical and institutional support. The study contributes to the literature by framing technology adoption in livestock farming as a socio-technical process. It shows that farmer behavior, including trust, habit, perceived usefulness, perceived control, and social influence, plays a central role in determining whether digital tools can improve farm decisions and production performance.

Theoretically, this study extends the Technology Acceptance Model, the Theory of Planned Behavior, and the Diffusion of Innovation by integrating them into a farmer-centered conceptual model for livestock production optimization. Practically, the findings suggest that technology developers, extension officers, cooperatives, and policymakers should design livestock digitalization programs that fit farmers' work routines, financial capacity, digital literacy, and local knowledge. Policy support should not focus only on technology distribution, but also on mentoring, peer learning, technical assistance, and data-use capacity. Future studies may test the proposed conceptual model through quantitative or mixed-methods research across different livestock systems, farm scales, and regional contexts to strengthen its validity and practical application.

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