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Management of Agricultural Machinery

Fauzi Ibrahim[1*], Agus Apriyanto[1], Adam Wisnu Murti[1], dan Novia Utami Putri[1]

[1]Department of Agricultural Mechanization, Lampung State Polytechnic, Jl. Soekarno Hatta No.10, Bandar Lampung 35141, Indonesia
Korespondensi Penulis: Fauzi Ibrahim. *Email: fauziibrahim@polinela.ac.id

ABSTRACT

The integration of intelligent machinery and autonomous vehicles into agricultural operations offers opportunities for enhanced efficiency and reduced environmental impact. Innovations in sensing, actuation, and information and communication technologies (ICT) present significant potential for advancing agricultural practices. However, fully leveraging these advancements requires revisiting traditional agricultural machinery management processes. Conventional planning methodologies, such as job-shop scheduling, must be augmented with modern approaches like route optimization and sequential task scheduling. This review highlights current advancements and future needs in agricultural machinery management, focusing on five key management tasks across strategic, tactical, operational, and evaluative levels. The study identifies the importance of integrating these tasks with advanced tools and models to enable efficient and sustainable agricultural operations. Future directions emphasize adaptive planning, real-time decision-making, and enhanced system integration to address location-specific and environmental challenges.

***Keywords**: agricultural, machinery, management*

1. INTRODUCTION

For decades, improving the physical performance of agricultural machinery has been the primary driver of advancements in agricultural productivity and efficiency. This progress was largely influenced by the benefits of economies of scale, leading to enhanced mechanical functionality. However, environmental and biological constraints, such as soil compaction, now limit further significant improvements in machinery size and weight (Rasmussen, 1982; Takeshima et al., 2013; Zhizhang & Hanlin, 2014).

Modern engineering developments in sensing and actuating technologies, combined with advancements in information and communication technologies (ICT), have the potential to revolutionize agricultural operations. These technologies can enhance machine efficiency and reduce environmental impacts. However, fully exploiting these innovations requires a re-evaluation of traditional agricultural machinery management processes. Current operations planning methodologies, such as job-shop planning, need to incorporate new features like route optimization and sequential task scheduling (Bello et al., 2021; Jaleta et al., 2019; Rijk, 2005; Takeshima et al., 2013).

The introduction highlights the unique challenges of agricultural machinery management compared to industrial systems. The agricultural

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domain faces greater variability and unpredictability due to environmental factors, such as weather and crop growth, which make risk-based decision-making a norm. This necessitates integrating advanced tools and adaptive methodologies for effective management(Li et al., 2018; Lu et al., 2024; McNulty & Grace, 2009).

The review aims to identify and outline the current state and future needs for agricultural machinery management, preparing the field for intelligent, sustainable, and autonomous agricultural operations. Five core management tasks capacity planning, task time planning, scheduling, route planning, and performance evaluation are explored, offering a comprehensive perspective on their roles across various management levels (Amare & Endalew, 2016; Lak & Almassi, 2011; Luo, Liao, Zang, et al., 2016; Pingali, 2007).

2. METHODS

2.1 Management Phases and Levels

The management of agricultural machinery can be divided into distinct phases, as outlined by ASABE standards:

a. Planning: Selection of system components and prediction of expected performance.
   1) Maintenance plan
      Create a thorough maintenance plan and track tasks to ensure that equipment is regularly serviced.
   2) Clean equipment
      Clean equipment regularly, especially at the end of a season or before storing it, to prevent rust and staining.
   3) Track resources
      Track resources per crop, field, and season to help make quick decisions and mitigate risks.
   4) Forward and backward planning
      Consider how forward and backward planning can help anticipate challenges and seize opportunities.
   5) Agricultural maintenance
      Prevent breakdowns and accidents, and keep planting, fertilizing, and harvesting on schedule.
   6) Tillage equipment
      Use tillage implements to prepare a seedbed while conserving moisture, destroying weeds, and minimizing erosion.
   7) Planters and seeders
      Use planters and seeders to consistently place seeds and apply pesticides and fertilizers (Asoegwu & Asoegwu, 2007; Awaluddin & Hendra, 2018; Luo, Liao, Zou, et al., 2016; Sims & Kienzle, 2017).

b. Scheduling: Determination of the timing for various operations, considering factors like time availability, labor supply, job priorities, and crop requirements.
c. Operating: Execution of operations using labor and machines.
d. Controlling: Monitoring and adjusting systems using productivity measures and standards.
   1) Inspect for damage
      Check your machinery for any signs of damage after each use, before storing, and at regular intervals. Look for loose pieces, strange noises, cracks, dents, or leaks.
   2) Keep machinery clean
      Regularly clean your machinery to remove dirt, debris, and crop residue. This prevents corrosion and keeps your machinery running optimally.
   3) Perform regular oil changes
      Regularly change the oil and check belts and hoses to keep your machinery running efficiently.
   4) Be aware of manufacturer recalls
      Keep up with manufacturer recalls to ensure your machinery is safe and reliable.
   5) Take agricultural maintenance training
      Training can help you learn best practices to prevent injuries.
   6) Keep detailed records
      Keep accurate and organized records of your farm activities. This can help you identify areas for improvement and make informed decisions.
   7) Use agriculture software
      Agriculture software programs can be adapted to meet the needs of individual farms (Awaluddin & Hendra, 2018; Luo, Liao, Zou, et al., 2016; Melly et al., 2020).

These phases operate across multiple management levels:

a. Strategic Level: Focuses on designing the production system for multiple years, including labor and machinery for selected crops.
b. Tactical Level: Involves creating a detailed production plan for 1–2 years, narrowing down labor and machinery inputs for specific crop plans.
c. Operational Level: Deals with short-term activities, scheduling specific jobs, and tasks within the cropping cycle.
d. Execution Level: Concerned with implementing and controlling task performance in real time.

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e. Evaluation Level: Compares planned operations with actual execution to identify areas for improvement.

The review excludes the execution level due to limited studies in this area, focusing instead on the other levels, which provide structured frameworks for effective machinery management in agriculture. These levels address the unique challenges of agricultural production, such as biological variability and environmental unpredictability, and emphasize the integration of data-driven and adaptive decision-making approaches (Bello et al., 2021; Lu et al., 2024; Pingali, 2007).

2.2 Agricultural Machinery Management Tasks

The review identifies five key tasks essential for effective agricultural machinery management, spanning various phases and levels of operation:

a. Capacity Planning
This task involves selecting machinery and supporting equipment to meet operational demands. It focuses on optimizing machinery size, cost, and efficiency while addressing uncertainties in agricultural settings, such as weather and crop growth variability.

b. Task Time Planning
Task time planning assigns time durations to specific activities, such as field operations and transportation. It serves as a prerequisite for scheduling, allowing for accurate predictions of labor and machinery requirements.

c. Scheduling
Scheduling allocates resources like labor and machines to tasks over specific time periods, optimizing objectives such as minimizing delays or maximizing efficiency. In agriculture, this includes addressing seasonal field operations and the sequencing of shared resource usage.

d. Route Planning
This task focuses on optimizing the movement of agricultural vehicles in the field. It includes spatial configuration planning, determining fieldwork tracks, and sequencing movements to minimize travel distance, time, and operational costs.

e. Performance Evaluation
Performance evaluation compares planned operations with actual outcomes. It involves data processing, compliance checks, and summarizing operational performance to provide feedback for future planning. These tasks address challenges unique to agriculture, such as biological variability, environmental constraints, and the need for precision. By integrating advanced tools and adaptive methodologies, these management tasks aim to enhance the efficiency, sustainability, and adaptability of agricultural machinery operations(Asoegwu & Asoegwu, 2007; Lak & Almassi, 2011; Luo, Liao, Zang, et al., 2016; Luo, Liao, Zou, et al., 2016).

In agricultural machinery management, five core tasks play a crucial role in ensuring the success of system implementation. Each task has a specific function in supporting operational efficiency and sustainability, but they also face unique challenges. These challenges, especially in the agricultural sector, often stem from environmental variability, resource limitations, and the demand for high precision.

With advancements in modern technology, such as real-time data systems, artificial intelligence (AI)-based analysis tools, and optimization algorithms, innovative solutions can now be applied to overcome these challenges. These technologies enable better data integration, adaptive decision-making, and more structured operational execution.

The following table summarizes the five core tasks in agricultural machinery management, their key challenges, and technology-based solutions that can be implemented to enhance effectiveness and efficiency:

Tabel 1. Core Tasks, Challenges, and Technological Solutions in Agricultural Machinery Management

Core Task	Challenges	Technology Solution
Capacity Planning	Weather and crop variability.	Real-time data from weather and crop sensors.
Task Time Planning	Uncertainty in task durations.	Predictions using historical data and AI.
Scheduling	Seasonal resource synchronization.	Automated scheduling with software tools.
Route Planning	Field topography and soil moisture.	Route optimization using GPS and AI algorithms.
Performance Evaluation	Limited availability of real data.	Automated data collection with sensors.

With the approaches outlined above, each management phase can be optimized to create

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smarter, more efficient, and sustainable agricultural systems.

3. RESULTS AND DISCUSSION

The future of agricultural machinery management lies in adaptive planning and the seamless integration of data and technologies across management levels. Key requirements for each management task are highlighted as follows:

a. Capacity Planning
Future models should incorporate real-time data and feedback from other management levels, allowing for adaptive and precise machinery selection and planning tailored to specific farm conditions.

b. Task Time Planning
Task time planning needs to evolve to include stochastic measures, such as reliability and availability, and enable precise predictions using automated data collection from past operations.

c. Scheduling
Sequential scheduling approaches must address the complexities of large-scale operations, integrating diverse machinery types, biological constraints, and field conditions for optimized resource allocation.

d. Route Planning for Agricultural Vehicles
Route planning must evolve into mission planning for autonomous machines, considering dynamic conditions like yield variability and trafficability. Integration of planning for primary and supporting units will enhance collaborative efficiency.

e. Performance Evaluation
Future systems should automate performance evaluation using activity recognition and advanced fault detection for both individual machines and cooperative systems. This will enable real-time adjustments and improved planning cycles. Overall, the future of agricultural machinery management emphasizes real-time decision-making, adaptive tools, and integration across strategic, tactical, and operational levels. These advancements will support sustainable and efficient agricultural practices, addressing environmental challenges and site-specific needs.

4. CONCLUSION

The review highlights advancements in agricultural machinery management, emphasizing the integration of industrial engineering approaches such as vehicle routing, job-shop scheduling, and advanced optimization techniques. It underscores the growing focus on planning for cooperative multi-machine systems, paving the way for autonomous operations. Real-time decision support systems are identified as critical for adaptive and precise machine control. However, a lack of integration across strategic, tactical, and operational levels limits the full exploitation of location-specific data. Future research must prioritize adaptive planning, automated data collection, and cross-level integration to enhance efficiency, sustainability, and resilience in addressing agricultural and environmental challenges.

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