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Research Paper

A simulation model for a rice-harvesting chain

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Management of rice harvesting presents a number of unique challenges that require development of dedicated tools. Challenges include in-field trafficability constraints affecting the transport units, the increased number of combine unloading events due to low grain hopper capacity, and the transport cycle times for different fields. Furthermore, when a combine reaches the headland area, sequential decisions must be made whether to stop harvesting and proceed to the unloading location or to continue harvesting with a full or reduced operating width. The objectives were to: 1) develop a simulation model that incorporates operational features unique to rice harvesting, 2) use the model to provide performance evaluation measures, and 3) to demonstrate the capabilities of this model as a tool for operations management. Experimental field operations were carried out to identify the necessary set of input parameters and to validate the simulation model. From measurements taken for validation, it was found that the error in operational parameter prediction was considerably low, ranging from 2.59 % to 3.12 %. In addition, using the simulation model, the practice of selectively harvesting at a reduced operating width was compared with the practice of harvesting a full operating width. It was found that harvesting at a reduced operating width significantly increased capacity (up to 7%), particularly when the available transport unit capacity was a system performance limiting factor.

1. Introduction

Among field operations, harvesting is the most complex operation because it involves multiple units that must be coordinated to achieve optimisation of the overall system's performance. Units include harvesters, transport units, and handling units. For this purpose, a number of system engineering approaches have been developed and applied to the operational management of individual tasks involved in the harvesting process. Previous work includes, area coverage planning (Ali, Verlinden, & van Oudheusden, 2009), route planning methods for transport units (Bochtis, Sørensen, & Vougioukas, 2010; Jensen, Bochtis, Sørensen, Blas, & Lykkegaard, 2012), the sequential scheduling of harvesting and handling operations (Bochtis et al., 2013; Orfanou et al., 2013), simulation models for harvesting cost prediction (de Toro, Gunnarsson, Lundin, & Jonsson, 2012), and performance evaluation and documentation systems (Amiama, Bueno, Alvarez, & Pereira, 2008). However, the majority of the developed models cannot be applied to all cropping systems. In particular, the management of the harvesting of rice presents a number of specific challenges that require the development of dedicated tools.

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During the cropping period rice fields are covered by water, and although it is removed before harvesting, the soil remains muddy, making the field area not trafficable for the transport units used for unloading the combine since they usually carry crop loads many times greater than the capacity of the combine grain hopper. The process of unloading the harvested crop from the grain hopper to a transport unit therefore usually occurs with the combine in the headland area and the transport unit stationary on a road next to the field. Furthermore, because one of the two headlands in a rice field is adjacent to an irrigation channel, one headland is available for the unloading process, a condition that adds further operational restrictions. Also, because of trafficability, the grain hopper of the combine has restricted capacity, resulting in an increase in the number of unloading occurrences and, depending on the operating width and the distance to the storage facilities, a higher number of transport units than typically required of other grain-harvesting operations. It should also be noted that rice production systems usually include a number of relatively small fields. They are typically in the range of 2–6 ha so as to manage field submersion and are geographically dispersed at various distances from the storage facilities, resulting in considerable variations in the transport cycle times between the fields thereby complicating decisions on the number and capacities of the transport units required.

Furthermore, combines operating in rice harvesting generally use tracks in the front axis and thus cannot move rapidly within the field area when harvesting and when travelling towards the headland for unloading. Typical travelling speeds are approximately the same as the harvesting speed (4–5 km h^{-1}). This results in high non-productive times due to in-field travel, and this frequently results is a decision to harvest at a reduced operating width while travelling towards to the unloading location if there is still space in the grain hopper. Consequently, sequential decisions must be made each time that a combine reaches a headland area. Thus, the general norms of field efficiency and productivity for grain harvesting cannot be applied in this complex system of sequential decisions.

The objective of this study is to develop a targeted simulation model for rice harvesting that incorporates all of the particular operational features mentioned above. To quantify input parameters and validate the simulation model, a number of experimental operations were carried out and monitored. The capabilities of the simulation model as an operations management tool were demonstrated, providing performance evaluation measures (e.g., harvester utilisation and area capacity) as a function of the number of the transport units and the distance between the field and the storage facilities. Finally, the practice of implementing a reduced width was compared to the practice of harvesting solely in the full width to assess the best practice for farmers.

2. Simulation model development

2.1. *The decision-making process*

As mentioned in earlier, a number of sequential decisions must be made during rice harvesting. To develop the simulation process of rice harvesting, the logic behind the combine operator's decision making was analysed and modelled. The process of analysing and modelling was based on the on-site inspection of farmer practices and by interviewing a group of experts (combine operators and contractors) in an area of northern Italy. Because in-field travel speed is only slightly higher than the harvesting speed of the combine in paddy fields, the operator always tries to avoid in-field travel because this task is non-productive. Therefore, based on the remaining grain hopper capacity, the operator could decide to unload or harvest at full or reduced speed. This decision-making process occurs each time the operator reaches a headland. The logic of the decision is different if a turn occurs on headland next to, or far from, the unloading location, and if transport unit is available at the unloading location. In-field travel only occurs when there is insufficient space in the grain hopper to perform a harvesting pass while utilising at least 30% of the full cutting bar width. Otherwise, during the final harvesting pass before unloading, the combine, while moving towards the unloading location, will harvest at a reduced widths ranging from 30 to 100% of the cutting bar width.

The logic of the operator's decision-making process is presented in Fig. 1. Each time the combine reaches a headland area, the operator considers the availability of a transport unit (TU) at the unloading location, whether the headland that is reached is next to the unloading location, and the current grain quantity in the grain hopper to determine whether to continue harvesting along the next pass, at a full operating or a reduced operating width or to proceed to the unloading location (involving in-field travel when the transport unit is located at the opposite headland and/or waiting for a transport unit to arrive).

Regarding the transport units, a standard cycle of activities is presented in Fig. 2. The model synchronises the work process of the combine and of the transport units through the unloading task of the combine to a transport unit.

2.2. *Modelling of the work process*

For modelling the work process of the various tasks that are involved in rice harvesting, the IDEF3 modelling scheme was used (see http://www.idef.com/ – Knowledge Based Systems, Inc., East College Station, TX, USA). IDEF is a structured process modelling technique that is used to describe workflows as an ordered sequence of events and to describe the objects that are involved in these processes (Kusiak & Zakarian, 1996). IDEF has been recently implemented to describe various processes in the agricultural domain, e.g., in traceability systems in the grain supply chain (Thakur & Hurburgh, 2009), in the vegetable supply chain (Hu, Zhang, Moga, & Neculita, 2012), in harvesting in static rose cultivation systems (van 't Ooster, Bontsema, van Henten, & Hemming, 2013), and for information management systems in viticulture (Peres et al., 2011).

An IDEF3 process flow diagram is composed of units of behaviour (UOBs), links, and junctions. The UOBs (e.g., the texted and numbered boxes in Fig. 3) refer to a process, action, decision, or any other procedure that is performed within a system. The UOBs are numbered progressively. In general, three types of links are used between UOBs, namely