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Research Paper

Profit maximisation algorithm including the loss of yield due to uncertain weather events during harvest

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A general LP model and a profit maximisation algorithm for harvesting during an agro-technical period have been created. The profit was based on the crop yields on a primary farm and the rental of combines to surrounding farms for their harvests. In contrast to the standard approach, the use of integer variables was avoided in the proposed model. The objective function included the risk of yield reduction due to bad weather conditions and the deliberate extension of the harvest on the primary farm, with the aim of higher profits from combine rentals. The model involved two conflicting criteria: the minimisation of risk during harvest on the primary farm and the maximisation of combine rentals; both of these aims were successfully incorporated into the objective function. The operational reliability of combines and tractors was taken into account in model creation. A general model was applied to a large farm (1380 ha) during a period of harvest and transport of oilseed rape, wheat and winter barley into storage (June–July). The farm that was considered is equipped with enough machinery to harvest other farms and on its own parcels simultaneously.

1. Introduction

1.1. Agriculture in Serbia

The Republic of Serbia includes approximately 4.22 Mha of arable land and 80% of the total land area is comprised of small farms. On average, these small farms occupy approximately 2.43 ha of land each, which is not conducive to the utilisation of highly productive machinery and the realisation of high yields (Nikolić, 2010). The primary field crops are maize (46.3%), wheat (15.7%), winter barley (2.78%) and oilseed rape (1.1%). Wheat and maize harvest on small farms requires combine rentals from large farms (occupying approximately 1000 ha) and mid-sized farms (occupying from 100 to 1000 ha of land). The goal of this study was to determine the optimal selection of combine harvesters to offer for rent to maximise the profit on a large farm.

1.2. Literature review

Determining the structure of the machinery pool based on production conditions and the economical use of available machinery and other resources is a key problem for equipping farms with the proper agricultural machinery (Savin, 2004).

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Nomenclature

Notation

- t_{vzpk} harvest time per combine harvester type v using tractor z with pair of trailers type p at parcel k for crop transport, (h)
- t_{tv} total harvest time of combine harvester type v on farm, (h)
- tb_{vk} time of tank loading for combine harvester type v at parcel k, (h)
- t_{zpk} spent time for transport per tractor type z with pair of trailers type p from parcel k to silo, (h)
- tu_p unload time of pair of trailers type p, (h)
- p_{vk} operational productivity, per combine harvester type v at parcel k, (ha h^{-1})
- p_{zpk} operational productivity, per tractor type z with pair of trailers type p at parcel k, (t h^{-1})
- c_v tank capacity of combine harvester type v, (t)
- ct_p capacity of pair of trailers type p, (t)
- sc_{vk} speed of combine harvester type v on parcel k, (km h−1)
- s_{zp} speed of tractor type z with loaded pair of trailers type p, (km h^{-1})
- s_z speed of tractor type z with empty trailers, (km h^{-1})
- e_v expense of combine harvester v, (€ h^{-1})
- e_{v*} expense of tractor type z, (€ h^{-1})
- e_{zp} transport expense of pair of trailers type p attached to the tractor type z, (€ h^{-1})
- r_v rental price of combine harvester type v, (€ h^{-1})
- i_k harvest income from parcel k, (€ t^{-1})
- y_k crop yields of parcel k, (t ha−1)

Subscripts

- v type of combine harvester
- p type of trailer
- n_v number of combine harvesters type v
- n_z number of tractors type z
- m_p number of pairs of trailers type p
- nt_{vzpk} number of tractors type z required on parcel k with the use of pair of trailers type p that should be employed by combine type v
- w_v working width of combine harvester type v, (m)
- a_k surface area of parcel k, (ha)
- d_k distance from parcel k to silo, (km)
- wh working hours per day, (h)
- R_v operational reliability of combine harvester type v
- R_z operational reliability of tractor type z
- D_v effective number of harvest days during the observed period for combine harvester type v
- D_z effective number of working days in the observed period for tractor type z
- M meteorological reliability
- mtc meteo-technical coefficient of reliability
- I number of independent events caused by bad weather conditions
- A number of days in an agro-technical period
- $\overline{A}$ average number of harvest days on the farm
- V number of types of combine harvesters
- Z number of types of tractors
- P number of types of trailers
- K number of parcels
- W number of combine harvester and tractor operators employed on the farm company
- $\underline{y}_k(\overline{A})$ crop yields of parcel k reduced for the factor of risk, (t ha^{-1})
- z type of tractor
- k ordinal number of parcel

Linear programming is one of the methods that uses planning criteria that incorporate the capacities and structure of the machinery pool, as well as the use of existing machinery. Over the last four decades, the practical application of linear (integer or mixed) programming in agriculture has been widely used. Audsley, Dumont, and Boyce (1978) created a linear programming model to find the optimal cultivation techniques that would maximise the farm's gross margins from different arable crop rotations of all cereals or from cereals and root crops. The machinery, labour, crops and optimum times for harvest, cultivating and planting were determined according to this program. Edwards and Boehlje (1980) constructed a model that simulated the completion of field operations and the calculation of net after-tax machinery costs. They compared ten machinery sets over a range of parameters to determine the least-cost set under various conditions. Labour availability and the crop acre had the greatest effect on the size of the least-cost machinery set, whereas the crop mix, latitude and the expected gross revenue had less effect. Fokkens and Puylaert (1981) developed a mathematical model as a tool for organisation of the harvest on a large-scale grain farm. They created three types of variables to determine the combine and transport capacity, the transfers of combine harvesters and the number of unloading pits for each crop. The following constraints were considered: constraints related to the number of combine harvesters, transport trailers and receiving capacity (the numbers of employers and tractors were not limited); a constraint specifying that all crops had to be harvested; constraints computing the number of combine harvester transfers; and constraints that ensured that there were no excess combine harvesters on a particular farm. The objective function was created to minimise the total harvest costs. Butterworth (1985) explained a procedure aimed at assisting advisers coping with the ever-changing price situation and the difficulties of determining how various types of farms should be developed, providing that the aim was to achieve the maximum profit. Jannot and Cairol (1994) used linear programming to suggest investments in farm equipment for an existing farm. Based on the gross margin of each crop, the optimal crop layout, the farm profit and the workforce requirements, they calculated the machinery and land resource needs. Caixeta-Filho, Swaay-Neto, and Wagemaker (2002) used linear programming to maximise the farm's total contribution margin, subject to constraints such as market-