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Optimization Model for Machinery Selection of Multi-Crop Farms in Elsuki Agricultural Scheme

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ABSTRACT

The optimization machinery model was developed to aid decision-makers and farm machinery managers in determining the optimal number of tractors, scheduling the agricultural operation and minimizing machinery total costs. For purpose of model verification, validation and application input data was collected from primary & secondary sources from Elsuki agricultural scheme for two seasons namely 2011-2012 and 2013-2014. Model verification was made by comparing the numbers of tractors of Elsuki agricultural scheme for season 2011-2012 with those estimated by the model. The model succeeded in reducing the number of tractors and operation total cost by 23%. The effect of optimization model on elements of direct cost saving indicated that the highest cost saving is reached with depreciation, repair and maintenance (23%) and the minimum cost saving is attained with fuel cost (22%). Sensitivity analysis in terms of change in model input for each of cultivated area and total costs of operations showing that: Increasing the operation total cost by 10% decreased the total number of tractors after optimization by 23% and total cost of operations was also decreased by 23%. Increasing the cultivated area by 10%, decreased the total number of tractors after optimization by(12%) and total cost of operations was also decreased by 12% (16669206 SDG(1111280 $) to 14636376 SDG(975758 $)). For the case of multiple input effect of the area and operation total cost resulted in decrease maximum number of tractors by 12%, and the total cost of operations also decreased by 12%. It is recommended to apply the optimization model as pre-requisite for improving machinery management during implementation of machinery scheduling.

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Introduction

Farm machinery plays an important role in agricultural production. It contributes a major capital cost in most agricultural business since it is a major component of any agricultural planning and development strategy in many countries. It concerned with efficient selection, repair, operation, maintenance and replacement of farm machinery (Hunt, 2001).

Machinery selection of power units and their machinery complement for farming operations, which is important part of machinery management decision that may lead to profit or loss for all or part of the farm enterprise (Wenging et al., 1999). The use of an oversized fleet of tractors and machines results in higher costs and loss of fuel use efficiency. Inadequate machines set can extend the time scheduled for the different agricultural operations that can affect crop yields. Therefore, the wrong decision may lead to either over or under utilization of power units and machineries, and may ultimately lead to a huge pile of unused scrap in tractor yards and problem of financial debt (Mohamed, 2007). The goal of a good machinery manager should be to have a system that is flexible enough to adapt to arrange of weather and crop conditions while minimizing long-run costs production risks (Edwards, 2001).

The optimum selection of farm machinery is in fact a complex problem in machinery management. The complexity arises due to the wide range of machinery types, different sizes available, capital investment, competent technicians, labor requirements, timeliness, types of crops, unbalanced crop rotation, and other related factors.

Most developing countries are facing acute problems with regard to mechanization of cultural operations. In Sudan, government programs for improving agricultural sector was made on most multi-farm agricultural projects through rehabilitation policies of fixed assets. Unfortunately, this approach has resulted in a large number of written machinery in the yards of workshops, untimely field operations, low and unsustainable crop yields (Mohamed et al., 2013). In most of irrigated and rainfed schemes in Sudan there is a lack of reliable management information system to aid decision-making concerning costs determination. There is no definite approach to evaluate the economic performance of agricultural machinery in these schemes. Elsuki scheme as one of these irrigated schemes, during the short life span of the scheme, a machinery rehabilitation program was adopted and the end results were disappointing.

One possible solution is to develop a machinery management decision-aid model (software) to aid in decision-making with respect to machinery selection, planning, scheduling and evaluation.

With the computer becoming available and more appropriate, the complexity of the farm machinery problem had led to numerous efforts to develop models to assist in efficient and effective management of machinery (Grzechowiak, 1999; Ekman, 2002). Currently optimal models were developed for machinery selection and optimization based on linear programming techniques. They aid in solving problems of machinery choice and minimization of machinery total costs. Mohamed (2007) developed a computer model to aid decision–makers to prepare their machinery strategic planning, linear programming technique was used and the application of the optimization model resulted in reducing the number of tractors and cost of operations. Ismail (1998) developed Crop Production Machinery System (CPMS) model to predict the machinery requirements and to determine the cost of production. For cost analysis he concluded that multiple crops in a rotation will increase machinery and tractor utilization, and reduce costs and increase profits.

Use of computer models for machinery management in Sudan is in fact are pioneer models that developed by Bol (1996) for matching of a single tractor power and optimum implement size, followed by a series of master thesis at Universities of Khartoum and Gezira (Bakri, 1993) for developing programs for estimating cost of mechanized operations based on cost theories.

Modeling of machinery management in multi-farms was made by Masoud (2005) for estimating the size of the required machinery fleet on basis of predicting available working days. A linear programming model for farm machinery selection was designed by Osman (2011) to aid in optimization of farm machinery. The model led to the optimal solution in terms of minimization of cost of operations by 12% and reduction of tractor number by 11%, Abdoon (2010) designed an optimization model to minimize machinery total costs for Binna Agricultural Scheme (Sudan), the model succeeded in reducing number of tractors and operations total costs by 29.4 %.

The general objective of this study is to develop an analytical, user-friendly computer model for farm machinery management as an aid for selecting optimum power units sets, operations costs for multiple farms, and apply the model for the case of Elsuki Agricultural Scheme.

Materials and Methods

Characterization of Study Area

The study was conducted within the area of irrigated clay plains of Sudan in Elsuki agricultural scheme, which is one of important irrigated schemes in Sudan, with total area of about 11,500 feddans(4832hectare). The scheme is located in Sennar State about 291 km from Khartoum. It is subtended by latitude 14º-13º N and longitude 33º-34º E. The names of the agricultural machinery used in the research area and the working widths and capacities of the agricultural machinery should given in Table 1. In addition, Table 2 illustrate, the production pattern of the crops produced in research area (season 2013-2014)

Table 1 The agricultural machinery used in the research area and their capacities for each operation and crops (season 2013-2014)

Crop	Agricultural operation	Area (ha)	Field capacity (ha/hr)
Cotton	Chiseling	2100	1.05
	Harrowing	2100	1.26
	Ridging	2100	1.68
	Planting	2100	1.26
	Herbicides	2100	4.53
	Fertilizer	2100	5.16
	Ridging	2100	1.68
Dura	Chiseling	2731	1.05
	Harrowing	2731	1.26
	Ridging	2731	1.68
	Planting	2731	1.26
Sun flower	Chiseling	2521	1.05
	Harrowing	2521	1.26
	Ridging	2521	1.68
	Planting	2521	1.26

Table 2 The production pattern of the crops produced in research area (season 2013-2014)

Crop	Area (hectare)	Productivity (Ton)
Cotton	2100	2000
Dura	2731	7312
Sun flower	2521	6000

The climate is tropical climate, where the average rainfall is 400-500 mm per year, starting from mid-July until late September. Temperature ranging between 37-40°C. Rainfall is reflected in the high humidity of up to approximately 80-85% of the fall months, and in February, March and April, reaching almost 35 %. In winter temperatures drop to up to 12°C on average. The main crops grown are: Cotton, Sorghum, Sunflower and Ground nuts with four course rotation.

Model Development (Main Functions and Features)

The Decision–aid model for agricultural machinery management is a computer interactive model developed based on the decision-aid concept which allows the user to interact directly with the program.

The computer model consists of machinery programming section and machinery cost section (Figure 1). The main functions of the model are: To compute scheduling of field operations at total minimum costs, the program computes the power units and from the user input parameters or from the build-in data, calculation of total cost for each field operation, a monthly programming technique was used on basis of output of machinery performance and operations, generates the optimum power units sets to complete field operations, integer linear programming technique was used on basis of machinery performance and economic parameters of tractor-machine costs, and the program output was evaluated on basis of technical indicators.

Data Collection and Analysis

The required input data for the machinery programming was collected for two seasons namely 2011-2012 and 2013-2014 from primary and secondary sources. Primary data was collected using formal and personal contacts from Elsuki Agricultural Scheme (Sennar State). The primary data include: typical field working speeds (km/h), recommended field operations efficiency (%) machine width and local purchase prices. It also includes type and size of machines and tractors available, crops grown, area programmed for each crop, type of field operations, operations calendar dates, machinery capacity, i.e., (output), working hours per day, cost of field operation/fed(hectare), fuel consumption, number of power units required for field operation, labor wage charge, tractor and machines service life in hours, and contract (hiring) charge per ha or by operation and monthly budget. The secondary data was collected from the most relevant published data and periodical reports (ASAE, 1993 and 2003 and Hunt, 1995). The secondary data collected included machinery cost data that include: purchase price ($) for tractors and machinery, interest rate of investment on machinery (%), taxes, insurance, shelter (TIS %) and repair & maintenance rate (%). All collected data were given for this study in form of tables and displayed on the computer screen when necessary during the entry of input data. Statistical techniques used to analyze the model result data includes Student t-test.

Results and Discussion

Model Verification

Program verification of any computer is concerned with establishing whether the program is true or sound representation of reality (Cheng et al., 1992). It is intended to check that the model or program meets a set of design specifications. The model output was compared to the applied system of Elsuki agricultural scheme for season 2011/2012. At that time 123 tractors were available to mechanize all agricultural operations. The model succeeded in reducing the maximum number of tractors, by 8% of Elsuki agricultural scheme. This result agreed with Mohamed (2007) who reported that number of tractors was reduced by 17%,30% for four and two course rotation respectively. Has been rewriten due to the rviewer (C) comments.

Model Validation

Validation of computer model is intended to ensure a system or a model result that meets the operational needs of the user. It concerns with model effectiveness or its suitability for satisfying the purpose of model building (Summers et al., 1999). This can be achieved by comparing model output with real system machinery in Elsuki agricultural scheme. The analysis will be the total number of tractors (power units), fuel, labor, repair and maintenance costs.

Purpose of Model Building

It was stated earlier that purpose of building machinery management programs includes :

- Minimization of total number of tractors (power unit).
- Minimization of total costs of operations.
- Saving of operating costs.

Minimization of Total Number of Tractors:

Table 3 shows the effect of optimization model in reducing the total number of tractors. It was reduced from 123 to 95 tractors and the improvement achieved as a reduction of 23%. Similar results were obtained by Mohamed (2007), that for scheduling of the operations number and distribution of tractors and machinery for Rahad scheme where number of tractors was reduced by 17%,30% for four and two course rotation respectively. The result is also in agreement with Osman (2011) who stated that the model resulted in reduction of number of tractors by 11%.

The statistical analysis using t-test table 4 indicates that optimization of machinery reduced the total number of tractors for all operations significantly ($P<0.05$) with Elsuki agricultural scheme.

Minimization of Total Costs of Operations

Table 5 shows the effect of optimization model on reducing the total costs of operations. The optimization model resulted generally in reducing costs of operation from 6790SDG (453$)to 4840 SDG (323$) (23 %). The result obtained due to the reduction of the total number of tractors resulted from the optimization model.

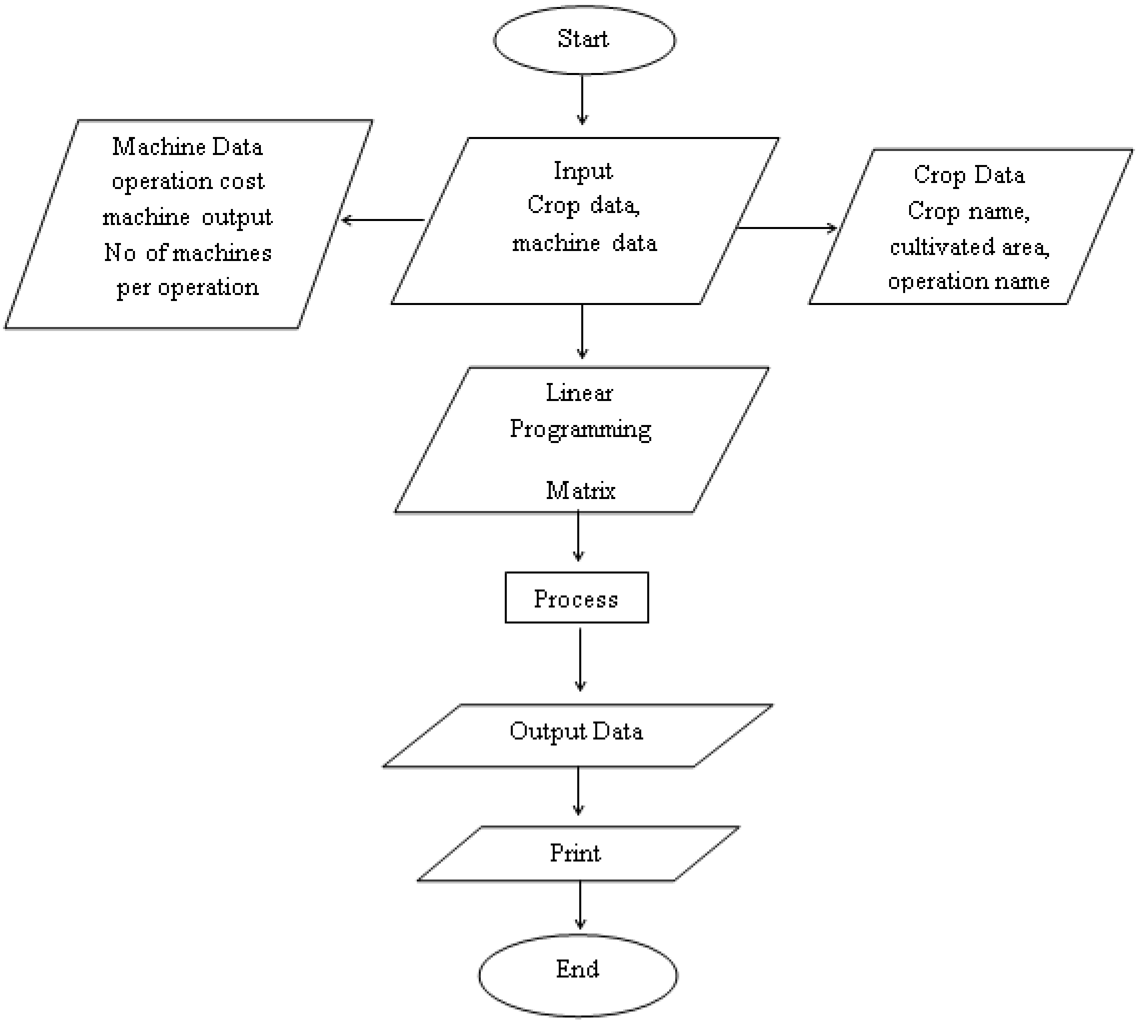

Figure 1 Model flow chart

Table 3 Number of tractors before and after optimization

Item	Before Optimization	After Optimization	Difference	Improvement %
Number of tractors	123	95	28	23%

Table 4 t-test analysis for total number of tractors before and after optimization.

Source	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair1 before-after	106.00000	18.38478	13.00000	-59.18066	271.18066	8.154	1	0.078

Table 5 Total costs of operation before and after optimization.

Item	Before Optimization	After Optimization	Difference	Improvement %
Operations total cost (SDG)	6790	4840	1950	29%

Table 6 t-test analysis for total costs of all operations before and after optimization.

Source	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair1 before-after	5E+008	743318550.3	5E+008	-6E+008	-7E+009	1	1	0.500

The statistical analysis using t-test indicates that optimization of machinery reduced the total costs of all operations significantly (P<0.05) (Table 6). The results are in agreement with Osman (2011) and also agreed with Alam and Awal (2001). Whom concluded that mono crop system power and power cost requirements were greater than that in multi-crop system.

Saving of Direct Costs

Direct costs include costs of depreciation, fuels, labor, repairs and maintenance costs. The effect of optimization model on elements of direct costs is shown in table 7. From the table it is clear that the highest cost saving is reached with depreciation, repair and maintenance cost (23%) and minimum cost saving is attained with fuel (22%). This may be attributed to the reduction in total number of tractors. These results are in line with Mohamed (2007) and Osman (2011).

Statistical analysis of the data using t-test indicated that optimization of machinery reduced the direct cost of Elsuki agricultural scheme significantly (P<0.05) (Table 8).

Optimization Model Sensitivity Analysis

Effect of changing agricultural operations cost by 10%: Table 9 shows the effect of changing costs of agricultural operations on maximum number of tractors. The significant effect on maximum number of tractors was shown as a decrease by 23 % when the cost of operations was increased by 10 %.

*Effect of changing cultivated area by 10 %:*The cultivated area was increased by 10 %. The increase of cultivated area indicates that there is a decrease in the maximum number of tractors from 123 to 108 tractors and improvement is about 12 %, likewise the total cost of operation decreased from 16 669 206 SDG (1111280$)to 14 636 376 SDG (975758$)with improvement of 12 % (Table 10).

Changing both cost of operations and cultivated area by the same percentage (10 %) upward resulted in a decrease of maximum number of tractors by 12 %. And the total cost of operations also decreased by 12 % (Table 10).

Table 7 Direct costs before and after optimization.

Item	Before Optimization	After Optimization	Difference	Improvement(%)
Depreciation	1 500 228.5	1 158 713.1	341 515.4	23
Repair&Maintenance	15 002.3	11 587.1	3 415.2	23
Fuel	1 162 444.4	900 952.4	261 492	22
Total	2 677 675.2	2 071 252.6	606 422.6	23

Table 8 t-test analysis for direct costs of all operations before and after optimization.

Source	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair1 before-after	1100260	1802021.821	901010.9	-1767159	3967678	1.221	3	0.309

Table 9 Effect of changing agricultural operations cost by 10%.

Parameters	Before Optimization	After Optimization	Difference	Percentage (%)
Number of tractors	123	95	28	23
Total cost of operations	16 669 206	12 874 590	3 794 616	23
Depreciation	1 500 228.5	1 158 713.1	341 515.4	23
Fuel cost	1 162 444.3	900 952.3	261 492	22
Repair & Maintenance cost	150 02.2	11 587.1	3 415.1	23

Table 10 Effect of changing cultivated area by 10%.

Parameters	Before Optimization	After Optimization	Difference	Percentage (%)
Number of tractors	123	108	15	12
Total cost of operations	16 669 206	14 636 376	20 32830	12
Depreciation	1 500 228.54	1 317 273.84	182 954.7	12
Fuel cost	1 162 444.377	1 016 144.377	146 300	13
Repair & Maintenance cost	15 002.2854	13 172.7384	1 829.547	12

Conclusions and Recommendations

Conclusions

- The model reduced the total number of tractors for Elsuki agricultural scheme by 23% for season 2013-2014.
- The optimization model reduced the total cost by 23%. Due to reduction of operations of total number of tractors.
- Sensitivity analysis was run with respect to change of single input and compound inputs (cost of operation and cultivated area) on model output (max. number of tractors and total operations costs).
- The impact of optimization algorithm on elements of direct costs (operating and costs) showed that the highest cost saving is with depreciation and repair and maintenance (23%) and the minimum cost saving is attained with fuel cost (22%).

Recommendations

- It is recommended to apply the optimization model as pre-requisite for improving machinery scheduling system.
- The model can be used for new agricultural projects to initiate new machinery system by determining machinery sets.
- The model can be improved in the future by considering machinery scheduling using Program Evaluation Review Technique (PERT).
- Model verification, application and sensitivity analysis need to be replicated by considering other complex and a wide range of agricultural operations to be handled by the model.

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