Evaluation and Improvement of machinery management system of the Rahad Project using Adecision - aid Model

Maysara Ahmed Mohamed, Hassan Ibrahim Mohammed and Omer Mohamed El Tom

1Department of Agricultural Engineering, College of Agricultural Studies, Sudan University of Science and Technology
2Department of Agricultural Engineering Faculty of Agriculture, University of Khartoum.

ABSTRACT

A decision–aid model for selecting and evaluating optimum machinery sizes in multi-farm fields was developed to aid in decision – making. The developed algorithm consists of submodels that combine in overall unified one model. A submodel was developed to estimate machinery sets and their related costs. Evaluating the program financial and technical factors were determined. Then, linear programming was employed to improve the utilization of resources. Input data was collected from Rahad irrigation Scheme for the last five years. The model was verified by comparing its outputs with Rahad existing machinery scheduling program for two, three and four course rotation. The model succeeded in reducing the peak number of required tractors in July by 30, 29 and 16% for two, three and four course rotation respectively. Application of the optimization model resulted in reducing the total number of tractors and costs of operations to execute the program. Analysis of the financial indicators showed a positive status for the running Rahad scheduling program. Technical indicators reflected the increase in labor demand by the increase in crop intensity while power utilization per area and maximum number of tractors were inversely related to crop intensity. The power distribution efficiency was improved slightly by optimization technique for the various crop rotations.

Key words: decision-aid, multi-farm, optimum machinery, management.

Introduction

Farm machinery contributes a major capital input cost in most agricultural business since it is a major component of any agricultural planning and development strategy in many countries. Agricultural machinery management is the section of farm management that deals with the optimization of the equipment phases of agricultural production. It is concerned with the efficient selection, operation, repair and maintenance, and replacement of machinery. Machinery selection of power units and agricultural machines for farming operations, can lead to profit or loss of 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 sets 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 of tractors and problem of financial debt.

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 mechanisation of cultural operations. In Sudan, government programmes 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. 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. Rahad scheme as one of these irrigated schemes, has a high level of mechanization during the short life span of the scheme, two machinery rehabilitation programs were adopted and the end results were disappointing.

One possible avenue to solve the dilemma is to develop a machinery management decision-aid model (software). The management model needs to aid 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. These developed computer models are user interactive models. 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. In Sudan, one of the pioneer models is that developed by Boll (1996). Bakri (1993) developed programs for estimating cost of mechanized operations based on cost theories. Modeling of machinery management in multi-farms was made by Massoud (2005) for estimating the size of the required machinery fleet on basis of predicting available working days. In 2007 Nimat adapted Primavara program to schedule and select agricultural machinery in multi-farm fields. However, in these two models the estimated size of needed machinery is not the optimally required size. The general objective of this study is to develop an analytical, user-friendly computer model for farm machinery management as an aid for decision-makers. The specific objectives are: to select optimum machinery sets, operations costs for multiple farms, construct machinery selection computerized decision-aid program on basis of financial indicators and technical parameters and apply the model for the case of Rahad scheme.

Materials and Methods

Model Development:

Program technique, structure and Style:

The agricultural machinery management model is a button menu driven composed of sub-modules and interactive in nature. The general flow diagram of the model is shown in Fig. (1.0). The program is composed of an introductory interface and a main menu (Fig. 1.0). It derives through sub-modules distributed over the spreadsheets. Integer linear programming was used in the program as a tool of optimization technique. The objective function of the model is to minimize the total costs. Output data is then shown in appropriate visible format. The model was formulated with 60 columns (decision variable) and 14 rows as constraints. The results from integer linear programming (ILP) solving package are then displayed using special report. The optimization model requires the installation of the optimization unit quantitative systems for business (QSB) which works within the Excel medium.

The program main features and the functions of the developed modules are as follows:

Module 1: The machinery programming and scheduling module. It computes the required power units and machinery fleet sizes from the user input parameters and the build-in data to complete the field operations during specific period of time.

Module 2: machinery cost module is used to calculate ownership and operating cost for each field operation.

Module 3: This module is intended to give an initial evaluation of machinery management status. Thus it is directed to generate evaluation outputs in terms of technical (machine effective field capacity based on ASAE (2003), Hunt (1995) and financial (internal rate of return (IRR), the Net Present Value (NPV), and the discounted benefit/cost ratio) indicators.

Module 4: Generates the optimum machinery sets to complete field operations at total minimum costs. Integer linear programming technique was used on basis of output of machinery performance and economic parameters of tractor-machine costs.

Module 5: This an overall final technical and financial evaluation module.

Machinery programming and Scheduling module:

The machinery programming and scheduling module is used to compute the fleet size of power units and machinery required to complete the field operations during specific period of time. The user enters the required input data for selected field operations for the crop under consideration. Consequently, the program computes the effective field capacity (EFC) (ha/hr), the effective working days. Hence, Required number of machines =: OPA / (EFC (ha/hr)* hrs/day * AWD*days “)

Where: OPA = operation area(ha), AWD = available working days. The programme estimates fleet size for each operation and presents calculation results for all operations in a tabular form.

Estimation of costs:

Tractor and machinery cost calculation module: This module includes calculation of costs of each operation. Calculation is made by determining costs of power unit and machine used as shown bellow:

Fixed costs (FC):

- It include the depreciation (D) cost, interest rate (I), taxes (T), insurance (I), and shelter (S).
- Purchase price (PP): It is a market value of the tractor and it is subjected to current market prices.
Depreciation (D): In this study the method used is the straight – line method which is a simplest and an easy calculation method. The depreciation is determined as follows:

\[ D = \frac{PP - SV}{L} \]

Where: \( D \) = Annual depreciation value ($), \( PP \) = Purchase price ($), \( SV \) = Salvage value (%), \( L \) = Tractor life (years).

Interest on investment (I): It is a direct cost on capital calculated as:

\[ I = \left( \frac{PP + SV}{2} \right) \times I \]

Where: \( I \) = Interest cost ($), \( PP \) = Purchase price ($), \( SV \) = Salvage value at the end of the machine life, \( i \) = Interest rate (%).

Taxes, insurance and shelter (TIS): These items are used to be calculated as a percentage of purchase price as follows:

\[ \text{TIS cost} = \text{TIS} \% \times \frac{\text{PurchaseP}}{100} \]

Variable costs:

Variable costs are calculated on per hour basis, and include:

1. Repair and maintenance cost: it is computed as a percentage of purchase price as follows:

\[ \text{R&M Cost/hr} = \text{R&M} \% \times \frac{\text{PP}}{100} \times \text{annual hrs of use} \]

Where: \( \text{R&M} \) = Repair and maintenance, \( \text{PP} \) = Purchase price ($)

2. Fuel and oil costs: The fuel costs can be calculated as follows:

\[ \text{Fuel Cost} = \text{Fuel consumption lit/hr} \times \text{fuel price ($/lit)} \]

\[ \text{Oil Cost} = \text{Fuel Cost} \times 0.15 \]

3. Labor cost (LC): Labor cost computed as per time and the charge is taken according to the running rates in the specific area.

Total annual cost (TAC): Total annual cost (AC) is the summation of total fixed cost (MC) and total variable costs (TC):

\[ AC = MC + TC \]

The agricultural operation total cost is generally designed on either a per – unit area or hour unit basis hence, agricultural operation cost ($/ha) = Operation cost ($/hr)/machine output (ha/hr). The total is expressed as follows:

\[ \text{TCO} = \text{MTC} + \text{TTC} \]

Where: \( \text{TCO} \) = Total cost of agricultural operation ($), \( \text{MTC} \) = Machine total fixed and variable costs ($), \( \text{TTC} \) = Tractor total fixed and variable costs.

Administrative costs: These costs refer to management, supervision and operational staff. In Rahad and Gezira schemes, overhead and administrative costs are assumed as 10% of the final operating costs (Salih, 1996). In this study, the administrative costs are determined as 10% of the operating costs and added to the total cost of field operations.

The limited resources involved in this model include available machinery, field cultivated areas, and time scheduled for field operations. The objective function used in the model is:

\[ M \text{in C} = \sum_{i=1}^{40} \sum_{j=1}^{60} C_{ij} X_{ij} \]

Where:

- \( C \equiv \text{Total field operations cost ($/ha),} \)
- \( C_{ij} \equiv \text{Cost of operation j with crop I ($/ha),} \)
- \( X_{ij} \equiv \text{Number of power units and machinery for operation j.} \)

The model is subject to some constraints the following constraints that need to be satisfied:

Constraint (1): \[ \sum_{i} a_{ij} t_{ij} x_{ij} = b_{i} \]

Where: \( a_{ij} \equiv \text{coefficient of the output of variable } x_{ij} \text{ (ha/hr)}, t_{ij} \equiv \text{Time coefficient,} \)

Constraint (2): \[ \sum_{j} x_{ij} n \leq s_{i} \text{ Where: } n=1,2,-----12, s_{i}=\text{total of machines for j ths operations for n month.} \]

Constraint (3): \[ \sum_{j} x_{ij} \leq M \text{ Where: } M=\text{total available machines for the agricultural season.} \]

Constraint (4): \[ x_{ij}=1 \text{ when machine } x_{j} \text{ is used, } x_{ij}=0 \text{ when } x_{j} \text{ is not used} \]

The structure of the model is shown in Fig. (2). Input data are entered in two phases: crop data and machinery data. The crop and machinery input data is converted into standard matrix form which can be passed to an integer linear programming (ILP) solver. The QSBS optimizer is used here for the purpose of the study. QSBS can be loaded as part of the program installation process. Finally the solution solver creates reports which summarize decision variables values, their cost contribution and total minimum cost ($).

Modules for initial and final evaluation of performance:

The technical and financial feasibility of using agricultural machines for execution of field activities is made initially following determination of maximum power and implement units and latter at a final stage to ascertain the optimum number of power and implement units rather than the maximum ones. The procedure adopted by the algorithm is as follows:

-Technical evaluation parameters includes:

1. Labor Parameter = Number of labor / Programmed area (ha)
2. Power area utilization = Total kws of tractors used / programmed area (ha)
3. Power time utilization = Total kws of tractors used / working days
4. Power distribution efficiency = Total deviation / (average of tractors × number of months)
5. Maximum number of power units needed = Maximum number of tractors used.
6. Minimum number of power units needed = Minimum number of tractors used.
The financial evaluation parameters includes determination of Net Present Value (NPV), Discounted Benefit/Cost ratio, Benefit/Cost ratio (B/C) and the internal rate of return (IRR) indicators as follows:

Benefit/Cost ratio (B/C): The present value of the benefit stream divided by the present value of the cost stream. Hence, B/C. Net Present Value (NPV, NPW) is computed by subtracting the total discounted present value of cost from that of the benefit stream. \( NPV = \sum \frac{B - C}{(1 + i)} \). - Internal Rate of Return (IRR): The procedure has been applied for IRR calculation as follows: \( IRR = \left[ \frac{FV}{M - M} / FV + FV \right] + M \). Where: \( FV = \) Present value of cash flow at the minimum discount rate, \( FV = \) Present value of cash flow at the maximum discount rate, \( M = \) Minimum discount rate, \( M = \) Maximum discount rate.

The optimization module:

This an integer linear programming module which deals with the efficient allocation of limited resources for agricultural production. The cost of field operation \( C_{ij} / \text{ha} \) was assumed to be a coefficient of the decision variable \( X_{ij} \).

Data collection and analysis:

The required input data was categorized as primary and secondary source data. Primary data was collected using formal and personal contacts with individual agricultural engineers from Rahad scheme. The secondary data was collected from bulletins, operation manuals and specifications sheets of machinery and tractors, agricultural operations scheduling program and internal periodical routine reports. The data given was for the season 1999-2000 to 2004-2005. Other secondary data was collected from the most relevant published national and international data and periodicals. The main source data were the ASAE yearbook (1997,2003), Hunt (1995). Descriptive statistical techniques were used to analyze the model results using "SPSS" software. These techniques include: t-test, chi-sq., and analysis of variance.
Results and Discussion

Model Verification:

The model output was compared to the initial and actually applied mechanization system of Rahad at its time of initiation in 1977. At that time 456 medium tractors were purchased as maximum number of tractors to mechanize almost all cultural operations for two course crop rotation of cotton and groundnut. The mathematical model succeeded in reducing the maximum number of required tractors by 30% for the two course rotation of the Rahad scheme. However, when the program is applied for three-course rotation likewise it reduces the number by 29% and 16% for four course rotation. Hence, it is clear from figures (4,5, and 6) that increasing number of crops in the rotation results in decrease in the number of required tractors. This result is in agreement with Ismail (1994, 1998) who reported that increasing the number of crops in a rotation, will increase machinery utilization. The results agreed with Mas'oud (2005) who reported that, increasing crops in a rotation resulted in reducing the number of implements.

Model validation:

This is achieved by comparing model output with real system of machinery in Rahad scheme. As detailed below the analysis will take the total cost, number of fleet size, financial indicators and technical parameters as a tool for statistical analysis.
Fig. 4: Machine distribution before and after optimization process for 4-course rotation of Rahad Project.

Fig. 5: Machine distribution before and after optimization process for 3-course rotation of Rahad Project.

Fig. 6: Machine distribution before and after optimization process for 2-course rotation of Rahad Project.
Minimization of total number of tractors:

Table (1) shows the effect of optimization model in reducing the total number of tractors with respect to the various rotations. It is clear from the table that the best improvement in total number of tractors can be attained with three course rotation (reduction by 27%), for four course rotation percentage reduction of a number of tractors is 15% while in two course rotation it is (7% reduction). The results is in agreement with Ademosun (1986). The t-test results indicate that there is a significant difference (P = 0.05) in executing optimization for four crop rotation only.

Table 1: Number of tractors before and after optimization.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Before optimization</th>
<th>After optimization</th>
<th>Improvement (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation</td>
<td>2</td>
<td>865</td>
<td>808</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>737</td>
<td>541</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>701</td>
<td>599</td>
</tr>
</tbody>
</table>

Minimization of total costs of operations (Fixed and variable costs):

Effect of optimization module on reducing the total cost of operations for different crop rotations is given in table (2). Optimization algorithm resulted generally in reducing the costs of operations for all crop rotations. Maximum reduction is achieved with three course rotation (33%). While the least improvement is obtained with two course rotation (9%). Examination of the data using t-test indicates that optimization of machinery scheduling reduced the total cost of all operation significantly (P = 0.05) with four course rotation as compared to the other two rotations. The result is comparable with those given by Ismail (1994, 1998) who stated that increasing the number of crops in a crop rotation reduces the machinery cost. The results also agreed with Alam and Awal (2001).

Table 2: Total cost of operations before and after optimization.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Before optimization</th>
<th>After optimization</th>
<th>Improvement (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation</td>
<td>2</td>
<td>8645</td>
<td>7898</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>8226.8</td>
<td>5511.9</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>7460.2</td>
<td>5520.5</td>
</tr>
</tbody>
</table>

5.2.2 Evaluation of implementation of machinery scheduling program:

A set of evaluation indicators for financial (Net Present Value, Benefit/Cost ratio, and Internal Rate of Return) and technical parameters (labor parameter, power-area utilization, power distribution efficiency and maximum number of power units at critical time) were used to quantify the performance of programming of mechanized field operations in the Rahad scheme for different crop rotations. The aim is to flag out the weak areas and to use the evaluation scheme offered by the model as a tool to control and upgrade the weak areas. Each one of these indicators is viewed as follows :-

A) Financial indicators:

Using World Bank (1977) and Gittinger (1986) reference values to evaluate financial indicators, from table (3), the results indicate feasible status because NPV and B/C are positive and IRR is more than current finance interest rate (18%) for the cases pre and post optimization.

B) Technical indicators:

Table (4) shows the effect of each rotation on the technical parameters. The technical parameters include: labor parameter and power utilization, power utilization includes power-area utilization, power distribution efficiency and maximum number of power units needed at critical time period. The parameters were chosen to reflect the most important elements of machinery scheduling and operation that need to be controlled. Labor demand parameter increases with increase in cropping intensity. This may be attributed to the increase of number of the required machines by decreasing cropping intensity. The selection of power distribution efficiency and the maximum number of power units needed at critical time period is selected to aid decision maker to exercise control over the number of power units to use either by purchasing or hiring. The benchmark for power-area utilization (in terms of tractor power per unit area) is cited by Atia (1996) as 0.04 kw/ha for Africa and 0.07 kw/ha, for Asia. As given in table (4) power utilization per ha decreased by 50%, 25% and 13% for two, three and four course rotation respectively. Power utilization per unit area was found to be 0.04, 0.06
and 0.07 kw/ha for two, three and four course rotation respectively. These results are in agreement with the values cited by Atia for Asia and Latin America.

Table 3: Financial evaluation before and after optimization.

<table>
<thead>
<tr>
<th>Rotation</th>
<th>Four - course</th>
<th>Three - course</th>
<th>Two - course</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimization Indicators</td>
<td>Before</td>
<td>After</td>
<td>Before</td>
</tr>
<tr>
<td>Benefit / Cost ratio</td>
<td>2.34</td>
<td>1.85</td>
<td>2.6</td>
</tr>
<tr>
<td>Net Present Value</td>
<td>2476.9</td>
<td>1746.5</td>
<td>3400.6</td>
</tr>
<tr>
<td>Internal Rate %</td>
<td>31</td>
<td>31</td>
<td>37</td>
</tr>
</tbody>
</table>

Table 4: Technical evaluation before and after optimization.

<table>
<thead>
<tr>
<th>Rotation</th>
<th>Four - course</th>
<th>Three - course</th>
<th>Two - course</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical parameter</td>
<td>Before</td>
<td>After</td>
<td>%</td>
</tr>
<tr>
<td>Labor parameter</td>
<td>0.02</td>
<td>0.02</td>
<td>-</td>
</tr>
<tr>
<td>Power - area utilization (kw/ha)</td>
<td>0.08</td>
<td>0.07</td>
<td>13</td>
</tr>
<tr>
<td>Tractor distribution efficiency %</td>
<td>0.97</td>
<td>0.94</td>
<td>3</td>
</tr>
<tr>
<td>Max. No. of tractors</td>
<td>185</td>
<td>185</td>
<td>-</td>
</tr>
</tbody>
</table>

Conclusions and Recommendations:

The developed model is simple user – friendly, self guidance, interactive, menu driven and composed of sub modules with the capabilities for the case of intensive cropping farm. The optimization model is capable to estimate the planned objectives of building machinery management program. Moreover, the model offers the opportunity to compare alternative course of rotation (different rotations) in terms of the verified objectives.

Tests of the model verification and analysis on statistical basis for the case of Rahad scheme reveals the opportunity to improve the control over machinery system, power utilization time and tractor distribution efficiency in Rahad scheme. Validity and sensitivity tests of the model in comparison with the original design program of machinery in the Rahad scheme gave a confidence, robustness and reliability to use the program for any multi – crop farm.

Results of the comparison of the overall performance index of the simulated and observed performance of four-course rotation of the Rahad scheme calls for the revision of the Rahad current machinery management system. To overcome the peak demand for tractors during July in Rahad Scheme, it is recommended to apply the optimization module of the machinery management algorithm in order to improve both the financial and technical performance evaluation indicators.

References


