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OPTIMIZATION OF SUGARCANE HARVEST OPERATIONS THROUGH PARALLEL MACHINE SCHEDULING APPROACH

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Abstract: The manual harvesting of sugarcane is highly labor consuming process. Assigning labors to harvesting operations is tedious task in the peak time. In the peak time of harvest, lot of shortage for labors as well as the transportation equipments. In this paper parallel machine scheduling with longest process time and load balance techniques are used to assign the labors (Gang) to the fields. Seven gangs are used to assign the 107 Acre of land to harvest in one month. The parallel machine scheduling approach gives the maximum make span of 23 days, and transportation cost also reduced from 112350 rupees to 90000 rupees.
Index Terms: Harvesting, Parallel Machine, Load Balance, Make span.

1. INTRODUCTION

Sugarcane is one of the important cash crops plays a vital role in Indian economy. The sugar industry is the second largest agro-based industry, next only to textiles [1]. The sugarcane cultivation area has been continuously increasing for the last eight decades. India ranks second in area and sugarcane production, with about 50.6 lakh ha area and 3361.5 lakh tones sugarcane production, next to Brazil. About 45 million farm families and a large number of dependant labors directly and indirectly engaged in sugarcane cultivation and in sugar industry [2].

Sugarcane harvesting involves base cutting of sugarcane, stripping and retracing of sugarcane, detopping, bundle making and finally transport of sugarcane to the sugar mills. Among sugarcane farm operations, harvesting and transportation are very important and have high workload. The harvest operators identify farms harvest time according to the amount of sucrose [3]. The harvest time is very important in order to achieve maximum sugar content. If the sugarcane is harvested early or late, productivity declines due to lower sugar levels. Eventually, the delay in sugarcane harvesting could reduce sugar production by 20 to 30% [4]. The manual harvesting of sugarcane by using tools is highly labor consuming process. About 850-1000 man working hours per hectare is required for harvesting of sugarcane manually [5].
Harvesting is performed manually by casual labor with the help of hand knives, cutting blade or hand axes, except few incidences of mechanized harvesting used. The tasks involved in harvesting are mainly crop cutting (harvesting), bundling of the produce (usually bunches in different weight groups) and loading the produce on vehicles. Male laborers are employed more in activities that need more physical labor such as cutting, loading, etc. The share of female laborers (in total labor) varies across states but it is usually less than that of male laborers.

1.1Problems faced by Sugarcane Farmers:

Sugarcane growers face the problems encountered during cultivation, harvesting as well as marketing of sugarcane. Major problems like, insufficient availability of finance, water supply, good quality seeds and fertilizers and technical guidance for proper planting and harvesting of sugarcane.
1. Many of farmers do not come forward to take loan from the various legally approved financial institutions. Instead they approach local money lenders with higher interest rates because of easy and quick availability of loans.
2. Improper harvest scheduling orders from the factory which will in turn affect the low yield in sugar content.
3. Delay in harvesting due to unavailability of local labors in the peak demand.
4. Many labors reject for harvesting of second and third season crop due to stress in cutting the harder sugarcane. Sometimes even they demand for higher wages for cutting
5. Non availability of transportation system to carry the cut sugarcane to factory.
6. Weather conditions which will affect cutting as well as the transportation system

1.2 Harvesting machine problems: Mechanized harvesting requires specific conditions that entail planning during the planting of the crop. The seeds must be planted on flat ground, with a specific distance between the rows, closer to the surface than for manual harvesting [6]. Also, the plant must grow straight upright, with no bends. In terms of harvesting and post-harvesting, producers perceive some key disadvantages, such as that the harvester cannot cut as close to the ground as a manual harvester, which reduces the average length of sugarcane collected. Other disadvantages from the producer perspective are that re-growth of the stumps is less uniform, making subsequent harvests less effective, and compaction under the weight of the tractor negatively affects the quality of the soil.

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1.3 Transportation of sugarcane problems:

The manual carts, tractor trolleys and trucks are the main carriers used to transport sugarcane from farm to various destinations. The tractor trolley is the most common mode of transportation. As nearly more than two-thirds of the sugarcane produce is transported through tractor trolley only. The distance is a major component of transportation cost., proper route planning is main consideration for optimization of the transportation cost. The major problems involved in transportation of sugarcane from farm to main road and main road to factory.

Problems involved in transportation are - long waiting time in queues at mill gates due to reasons such as slow processing at mill gate, traffic jams, factory break down etc., These delays cost them heavily in terms of time and money. Extra cost earning by farmers for any minor and major incidence during transportation - such as trolley overturned, trolleys getting stuck in the sludge are also not uncommon. Farmers are required to pay a customary tip (beta) to the transportation driver from each field basis or trip basis,

1. Delay in transportation of cane from farm to main road because of road conditions.
2. Reduction in sugar content due to late crushing.
3. Improper route problems
4. Mode of logistics (Bullock cart or tractors).
5. In time consideration for crushing or too much weighting time in the queues.

2. Objectives

1. Main objective is to optimize the harvesting time (manual method)
2. To identify various factors and input costs in the overall harvesting and transportation.

2.0 LITERATURE SURVEY

A review of literature has been undertaken to understand the current status of scheduling of biomass handling operations and to identify the research problem. A preliminary review of research papers from leading journals has been made.

A well known optimization problem of flow shop with sequence dependent setup times was studied by Logendran et [7] and Zandieh et al [8]. The study deals about a set of *m* machines and a set of *n* jobs in series where each job has a set of *m* tasks that must be processed on each of the *m* machines. All the jobs have to be processed in a sequence from machine -1 to machine - *m*. In sequence dependent setup times scheduling, each job is assigned with the setup times which will depend upon the preceding job. In order to schedule biomass handling operations as a SDST flow shop problem, a *job* in the flow shop is described as 'field' and the 'set-up time' in the flow shop is described as the 'inter-field travelling time'. The following assumptions are made for the formulation of the optimization problem.

1. All fields are in a state and operated on at time zero.

2 There exists a single machinery depot from where machines departs from, when being assigned tasks, and returns to, after the completion of the assigned tasks.

3. All parameters, tasks times and travel times, are deterministic.

The job queue operates following the first in first out (FIFO) principle, meaning that after completion of the task in a field, the field joins the queue for the next sequential task.

The first scientific approach for supporting this decision process of scheduling operations to labor and machine in agriculture appeared in early 1980s [9], mainly based on linear programming methodologies. Wijingaard [10] implemented and compared three different models for farm operations management namely, a dynamic programming model, a linear programming model, and a simulation model. Recent approaches for a long term cropping schedule involve other methodologies such as stochastic programming by Darby-Dowman et al 2000 [11], hybrid Petri nets by Guan et al [12] and met heuristics (e.g. simulated annealing, and genetic algorithms) (Guan et al) [13].

This study is the continuation of the work presented in Bochtis et al. [14] where the problem of scheduling of multiple-fields sequential biomass handling operations was addressed with the well- known industrial flow shop with set up times. The purpose of the study was to identify the feasibility of applying industrial planning methods to biomass supply chain. Specifically, the results showed a significant case-based reduction of 9.8% in the total operations time for the optimal schedule as compared with a schedule based on the knowledge of the manager.

The only approache given by Basnet et al [15] where a scheduling method for harvesting of renewable resources was introduced based on a Travelling Salesman Problem (TSP) combined with greedy and tabu search heuristics, and the approach of Bochtis and Sorensen [16] where the scheduling problem for agricultural field operations was used as a vehicle routing problems with time windows (VRPTW). Both approaches do not consider the capacity of the machinery as an integral part of the planning problem and they do not connect the derived schedule with the operational cost as a parameter to improve the manager's assessment between time and cost.

3. DATA COLLECTION:

A data is collected from the XYZ leading Sugar factory in Vijayapura district in Karnataka. The industry has a capacity 6000 MT of sugar production capacity. The industry divided the harvesting area in five divisions. The divisions are made through the distance the farms are located from the mill (table 1). Number of farmers and area cane grown will change based on the farmers decision to grow the sugarcane.

The Peak demand for harvest comes under December and January month (Table 1). In the December month highest area to be harvested is in division 2 (table 2) among the five divisions. There are about 14 villages in Factory division 2(table 3) at a distance of 8 to 30 kms from the mill. Among the 14 villages only one village is selected for study where 128 acres of land has harvested.

Table 1 Total Sugarcane Area Harvested in year 2020 – 2021

Sl. No.	Month	Total Sugarcane Harvest Area in Hectors	Number for Formers
1	June - 19	374	177
2	July -19	892	389
3	August - 19	1111	521
4	September - 19	2898	1284
5	October - 19	370	155
6	November - 19	1612	813
7	**December - 19**	**5386**	**889**
8	January - 20	5106	2311
9	February - 20	4338	1643
10	March - 20	2335	657
11	April - 20	273	67
12	May - 20	854	408

*Source data from XYZ sugar company

Table 2. Area wise cane harvesting in the month of December 19

Factory Division 1 (0 to 7 kms)			Factory Division 2 (8 to 30 kms)			Factory Division 3 2 (7 to 50 kms)			Factory Division 4 (7 to 50 kms)			Factory Division 5 (7 to 50 kms)		
villages	**Area**	**Farmers**	**villages**	**Area**	**Farmers**	**villages**	**Area**	**Farmers**	**villages**	**Area**	**Farmers**	**villages**	**Area**	**Farmers**
7	1050	150	14	1445	271	62	1240	210	20	700	98	13	951	160

*Source data from XYZ sugar company

Table 3. Factory Division 2 (8 to 30 Kms)

Sl. No.	Name of the village	Distance from the Factory (kms)	No. of Farmers	Area Harvested
1	Village 1	8.4	15	100
2	Village 2	9.2	16	100
3	Village 3	11	20	112
4	Village 4	13	18	102
5	Village 5	14.9	22	105
6	Village 6	15	21	106
7	Village 7	16	20	123
8	Village 8	16.5	22	103
9	Village 9	18	20	103
10	Village 10	18	14	102
11	Village 11	18.5	16	102
12	Village 12	19	24	107
13	Village 13	22	21	103
14	Village 14	27	22	102
TOTAL			**271**	**1445**

*Source data from XYZ sugar company

The factory has 325 gangs as a workforce to harvest the cane (each gang consists of 10 male and 10 female labours). Each gang works for 6 to 7 hours to harvest 0.7 acres of land in a day. Presently the factory assigns the gangs to farms as first come first serve bases and always it is not sufficient with the assigned gangs to complete the harvest operation on time. The factory has assigned 7 gangs to harvest 107 acres (table 4) of land in 31 days.

Table 4. Harvest area

Field No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Total
Area Harvest in Acres	5	4	5	3	5	4	7	5	4	6	5	6	6	6	2	4	4	5	4	3	2	4	4	4	107

*Source data from XYZ sugar company

4. METHODOLOGY:

4.1 Parallel Machine Scheduling: When similar type of machines is available in multiple numbers and jobs can be scheduled over these machines simultaneously. The existence of parallel machines environment is common in real world flow shop and job shops systems. Knowledge of parallel machines modeling is useful to design the large-scale flexible flow shop and job shop systems. The main objective function of using parallel machine scheduling is to minimize the make span. Some of these heuristics include longest processing time first (LPT) rule and load- balancing heuristic.

4.2 ASSUMPTIONS

A variety of assumptions is made in sequencing and scheduling problems The nature of these assumptions depends on the sequencing environment. The following list contains typical assumptions generally applied to scheduling problem with variations depending on the situation.

1) the set of the jobs(fields) and the set of the machines (gangs) are known and fixed;
2) all fields and all gangs are available at the same time and are independent;
3) all fields and all gangs remain available during an 8hours period per day;
4) the processing time (in days) for each field on all gangs is fixed, has a known probability distribution function, and sequence independent;
5) setup times are included in processing times ;
6) all fields and all gangs are equally weighted;
7) no preemption is allowed;
8) a definite due date is assigned to each field;
9) each fields is processed by all the gangs assigned to it;
10) each gang processes all the field assigned to it,
11) the process plan for each job is known and fixed.

4.3 MINIMIZATION OF MAKESPAN PROBLEM (Pm || Cmax):
This problem deals with scheduling m parallel machines when the objective function is to minimize the makespan. A variety of heuristics are employed to determine a near-optimal schedule. Some of these heuristics include longest processing time first (LPT) rule and load- balancing heuristic.

Longest Processing Time first (LPT) Rule

A common heuristic used in parallel machines scheduling is the LPT rule. According to this heuristic, jobs are arranged in decreasing order of process times. The jobs having large values of process times are given high priority for scheduling on the parallel machines. The following relationship can be used to find how far the solution obtained by the LPT rule is far from an optimal solution.

$$\frac{C_{max}(LPT))}{C_{max}(OPT))} \leq \frac{4}{3} - \frac{1}{3m}$$

If the above condition is not satisfied, than the Cmax(OPT) is calculated by using above relation. Cmax optimal value is calculated by using Load Balancing heuristic method;

Based on the Harvest days priority is assigned (table 5) to the fields. Machines are coded as gangs (G1 to G7) which perform the similar jobs, jobs are fields for harvesting.

Table 5:

Field No	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Area Harvest Acres	5	4	5	3	5	4	7	5	4	6	5	6	6	6	2	4	4	5	4	3	2	4	4	4
Harvest time in days	**7**	**6**	**7**	**5**	**7**	**6**	**10**	**7**	**6**	**9**	**7**	**9**	**9**	**9**	**3**	**6**	**6**	**7**	**6**	**5**	**3**	**6**	**6**	**5**
LPT priority	**6**	**12**	**7**	**21**	**8**	**13**	**1**	**9**	**14**	**2**	**10**	**3**	**4**	**5**	**23**	**15**	**16**	**11**	**17**	**22**	**24**	**18**	**19**	**20**

Step 1: Priority is given to field 7, 10, 12, 13, 14, 1 and 3 and seven gangs are assigned. Completion time is calculated.

Resource	LPT priority	Field No.	Start Time	Process Time	Completion Time
G1	1	7	0	10	10
G2	2	10	0	9	9
G3	3	12	0	9	9
G4	4	13	0	9	9
G5	5	14	0	9	9
G6	6	1	0	7	7
G7	7	3	0	7	7

Step 2: Priority is given to field 5, 8, 11, 18, 2, 6 and 9 and seven gangs are assigned. Completion time is calculated.

Resource	LPT priority	Field No.	Start Time	Process Time	Completion Time
G6	8	5	8	7	15
G7	9	8	8	7	15
G2	10	11	10	7	17
G3	11	18	10	7	17
G4	12	2	10	6	16
G5	13	6	10	6	16
G1	14	9	11	6	17

Step 3: Priority is given to field 16, 17, 19, 22, 23, 24 and 4 and seven gangs are assigned. Completion time is calculated.

Resource	LPT priority	Field No.	Start Time	Process Time	Completion Time
G6	15	16	16	6	22
G7	16	17	16	6	22
G4	17	19	17	6	23
G5	18	22	17	6	23
G2	19	23	18	6	24
G3	20	24	18	5	23
G1	21	4	18	5	23

Step 4: Remaining fields are assigned and completion time is calculated.

Resource	LPT priority	Field	Start Time	Process Time	Completion Time
G6	22	20	23	5	28
G7	23	15	23	3	26
G4	24	21	24	3	27

Gantt chart is plotted for the above 4 steps and the maximum Makes pan is 28 days.

<table>
<tr><th>DAY</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>13</th><th>14</th><th>15</th><th>16</th><th>17</th><th>18</th><th>19</th><th>20</th><th>21</th><th>22</th><th>23</th><th>24</th><th>25</th><th>26</th><th>27</th><th>28</th></tr>
<tr><th>G1</th><td colspan="10">Field 7</td><td colspan="7">Field 9</td><td colspan="6">Field 4</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>G2</th><td colspan="9">Field 10</td><td colspan="8">Field 11</td><td colspan="7">Field 23</td><td></td><td></td><td></td><td></td></tr>
<tr><th>G3</th><td colspan="9">Field 12</td><td colspan="8">Field 18</td><td colspan="6">Field 24</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>G4</th><td colspan="9">Field 13</td><td colspan="7">Field 2</td><td colspan="7">Field 19</td><td colspan="4">Field 21</td><td></td></tr>
<tr><th>G5</th><td colspan="9">Field 14</td><td colspan="7">Field 6</td><td colspan="7">Field 22</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th>G6</th><td colspan="7">Field 1</td><td colspan="8">Field 5</td><td colspan="7">Field 16</td><td colspan="6">Field 20</td></tr>
<tr><th>G7</th><td colspan="7">Field 3</td><td colspan="8">Field 8</td><td colspan="7">Field 17</td><td colspan="4">Field 15</td><td></td><td></td></tr>
</table>

Gantt chart 1

For finding optimality of schedules, the following ratio between C_{max}(OPT) and C_{max}(LPT) is observed

$$\frac{C_{max}(LPT)}{C_{max}(OPT)} \leq \frac{4}{3} - \frac{1}{3m}$$

Since, there are 7 machines (gangs), so m = 7. The ratio is less then 1.29
The ration 1.29 indicates that LPT rule will give 29% more value of C_{max} in worst case as compared to C_{max} using optimal methodology. Hence, the optimal value of C_{max} should be 23 days, as calculated as follows

Since, $C_{max}(LPT) = 1.28 \times C_{max}(OPT)$,

This implies that; $C_{max}(OPT) = C_{max}(LPT)/1.29 = 28/1.29 = 22.22$ Approx. 23 days

The optimal value of C_{max} can be calculated by using Load Balancing heuristic as follows;

Let T_w = Total work content of all fields in the problem. Then, tentative load per gang may be estimated by taking the ratio of T_w and m as follows:

Load per gang = sum of Tw / 7

Load per gang =158/7 =22.57 aprrox. 23 days

Hence, tentative load per gang is 23 days. **Table 6** presents combination of jobs for which average load per gang is 23. Optimal schedule is presented in Gantt chart 2

Table 6. Optimal Schedule using Load Balancing Heuristic

Gang	Field Nos.	Process Times (days)	Total days
G1	1, 2,3, 21	7+6+7+3	23
G2	4,5,6,20	5+7+6+5	23
G3	7,8,9	10+7+6	23
G4	10,11,18	9+7+7	23
G5	16,17,19,15	6+6+6+3	21
G6	12,13,24	9+9+5	23
G7	14,22,23	9+6+6	21

Gantt chart 2: for $P_7 || C_{max}$ schedule is presented in below Figure

<table>
<tr><td>DAY</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td></tr>
<tr><td>G1</td><td colspan="7">Field 1</td><td colspan="6">Field 2</td><td colspan="7">Field 3</td><td colspan="3">Field 21</td><td></td></tr>
<tr><td>G2</td><td colspan="5">Field 4</td><td colspan="7">Field 5</td><td colspan="6">Field 6</td><td colspan="5">Field 20</td><td></td></tr>
<tr><td>G3</td><td colspan="10">Field 7</td><td colspan="7">Field 8</td><td colspan="6">Field 9</td><td></td></tr>
<tr><td>G4</td><td colspan="9">Field 10</td><td colspan="7">Field 11</td><td colspan="7">Field 18</td><td></td></tr>
<tr><td>G5</td><td colspan="6">Field 16</td><td colspan="6">Field 17</td><td colspan="6">Field 19</td><td colspan="3">Field 15</td><td></td><td></td><td></td></tr>
<tr><td>G6</td><td colspan="9">Field 12</td><td colspan="9">Field 13</td><td colspan="5">Field 24</td><td></td></tr>
<tr><td>G7</td><td colspan="9">Field 14</td><td colspan="6">Field 22</td><td colspan="6">Field 23</td><td></td><td></td><td></td></tr>
</table>

Cmax = 23 days

The optimized harvesting schedule is presented in Gantt chart 2. It is notices that all the 24 fields are harvested in their totality, not accounting for surpluses in actual sugarcane harvest. The maximum make span obtained from the parallel machine scheduling is 23 days, still there is a possibility of assigning the gangs to the fields as the idle time calculated for each gangs are 2 to 3 days.

5. TRANSPORTATION COST FARM TO FACTORY:

Sugarcane transportation cost occupies a large portion of sugarcane production cost. The harvested cane is supplied to the factory through tractors or the bullock carts depending upon the distance the farms are away from the mill. Transportation cost from farm to mill, the factory charges about 35 rupees per ton, and the transportation cost for the 3210 ton come around 112350 rupees. Proposed mode of parallel machine scheduling, transportation cost comes around 90000 rupees (shown in table 7)

Table 7: Transportation cost

Gang	Noof days harvested	Total Acre harvested	Weight of cane harvested in tons (30 tons in 1 acre)	No. of loads per tractor (16 Ton per tractor)	Transportation cost (Rs 450 per load * no of loads)
G1	23	16	480	30	13500
G2	23	15	450	28	12600
G3	23	16	480	30	13500
G4	23	16	480	30	13500
G5	21	14	420	26	11700
G6	23	16	480	30	13500
G7	21	14	420	26	11700
Total		**107**	**3210**	**200**	**90000**

6. RESULTS:

By using parallel machine scheduling approach, The maximum make span obtained from the parallel machine scheduling is 23 days, still there is a possibility of assigning the gangs to the fields as the idle time calculated for each gangs are 2 to 3 days. Transportation cost also reduces from 112350 rupees to 90000 rupees.

7. CONCLUSION:

Assigning labors to harvest operations is major problem in peak period of sugarcane harvesting. Parallel machine scheduling approach with LPT and load balancing used to optimize the harvesting time and cost. This numerical case study based on historical data shows that the system has the potential of improving the operational time of harvesting as well as the cost of transportation. Parallel machine schedule still can be applied to the other divisions of the factory in order to get the optimum make span.

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