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Combine Harvest Scheduling Program for Rough Rice using Max-coverage Algorithm

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Abstract

Purpose: This study was conducted to develop an optimal combine scheduling program using Max-Coverage algorithm which derives the maximum efficiency for a specific location in harvest seasons. **Methods:** The combine scheduling program was operated with information about combine specification and farmland. Four operating types (Max-Coverage algorithm type, Boustrophedon path type, max quality value type, and max area type) were selected to compare quality and working capacity. **Result:** The working time of Max-Coverage algorithm type was shorter than others, and the total quality value of Max-Coverage algorithm and max quality value type were higher than others. **Conclusion:** The developed combine scheduling program using Max-Coverage algorithm will provide optimal operation and maximum quality in a limited area and time.

Keywords: Max-Coverage algorithm, Combine, Optimization, Schedule

Introduction

Consumption patterns of rice have changed recently: the total consumption of rice has been reduced, but the consumption of high-quality rice has increased. There are many factors that influence the yields of high-quality rice such as varieties, place of production, weather, growth, harvesting dates, drying, storage, processing, distribution, and cooking. However, post harvesting process cannot improve the quality of rice, so the quality should be maintained during the whole process. Therefore, good harvesting practices maximize the high-quality rice yields. The time of harvest controls the quality of rice. Harvesting too early will result in a larger percentage of unfilled or immature grains, which will lower yield and in cause higher grain breakage during milling. Harvesting too late will lead to excessive losses and increased breakage in rice. It also causes the low quality in post harvest process, drying, storage, and milling (Keum, 2008). There are different ways to determine the correct harvest time. Among them rice moisture content is a key factor for determining suitable harvest time. Correct harvest time considering prediction model of moisture content gives maximum harvest recovery, milled rice recovery, and head rice recovery. This reduces the cost of drying process and maximizes the farmhouse income (Kocher et al., 1990; Lu et al., 1994; Lu et al., 1995; Thompson et al., 2006).

Farmers use combine harvester to save time and labor cost as well as to harvest their crops at a suitable time. The rate of mechanization using combine harvester has increased up to 99%, but the operation of combine harvester has run by regional features or conventional practice not by quality or total amount of yield (Kim et al., 1999; Park et al., 2008). However, in Europe and USA research has been reported on the optimization of combine operation using GPS signal to detect the harvesting place, to calculate total amount of harvest and moisture content, and to measure moving speed with sensor

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(Choi et al., 1995). However, small cultivated areas per household and limited equipment hinder the prediction of yield and proper use of machine. As a result, the combine harvester cannot be applied at a suitable time (Chung et al., 2009). So far research has been focused on the route for optimal harvest in one farm; there is little research on the combine application for the entire farmland work or traveling path. Therefore, research on the combine harvest scheduling program is needed.

Average possible harvesting period is less than 10 days in Korea, and operating hours of combine are about 63 hours per year. Due to the short harvest season it is necessary to set up the combine harvest scheduling program. Max-Coverage algorithm is used to set up the combine harvest scheduling program. The pattern of Max-Coverage algorithm is Boustrophedon whose path follows zigzag pattern in a designated area (Kim, 2010). Boustrophedon path algorithm can complete the work at the designated area if there is no limit in working time and condition. For this reason many research have been conducted to improve the Boustrophedon path method. However, most improved algorithm was on the reduction of working time at the designated area, not on the algorithm for the quality of work (Garcia and Gonzalez, 2004). The work should be focused on the improvement of the quality of work with limited time. Max-Coverage algorithm can predict the optimal paths for limited time and area, and it can be used for artificial intelligent robot such as cleaning robot, mine detection robot, security robot, and agricultural robot for harvesting (Kim et al., 1999; Jeon et al., 2009).

The work area and quality of farmland should be considered in applying for the Max-Coverage algorithm of combine harvest. The total quality value is constructed by the total sum of quality considering the dimension and degree of maturity of farmland.

Thus, the purpose of this study is to develop the combine harvest scheduling program for rough rice using Max-Coverage algorithm. The developed combine scheduling program using Max-Coverage algorithm will provide optimal operation and maximum quality in a limited area and time.

Material and Methods

Max-Coverage algorithm of combine harvest

Figure 1 shows the basic concept of Max-Coverage algorithm. The allowed time for operation is called deadline, and the optimal path can be modified by the deadline. For example, the square in figure 1 indicates the operation time, and line indicates moving time. The total operating time is 28 hours from the start to finish the work. If the deadline is reduced to 10 hours, starting to left path cannot finish the work at the limited time because the moving time is long. However, starting to right path can work more task than the former because it has short moving time (Jeon et al., 2009).

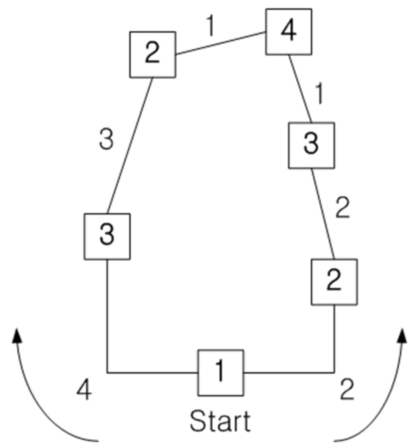

Figure 1. Example of Max-Coverage algorithm showing the change of path by deadline.

The optimal path can be modified by the change of deadline. However, the application of Max-Coverage algorithm to combine harvest should consider the dimension and quality of farmland. Information about combine operation and farmland is needed for applying Max-Coverage algorithm into the combine harvest scheduling algorithm. The basic concept of algorithm is that the largest total quality value considering dimension and quality value of farmland should be conducted first. After the first operation, the algorithm is computed the schedule comparing the second largest total quality value and work amount of combine considered its moving time. Thus, the schedule is set up to maximum quality value within allowed time.

Combine harvest scheduling program

Combine input information of combine harvest scheduling program uses combine capacity (CC) and combine average speed (CAS), and farmland input information uses harvest area size (HAS), distance between farmlands (D), and quality value (QV). Considering farmland size and quality, total quality value (TQV) is calculated as in equation (1). Combine moving time (CMT) is produced as in equation (2) with consideration of combine average speed and distance between farmlands. Loss total quality value (LTQV) is calculated as in equation (3) because the total quality value is lost with the proportion of combine moving time.

$$TQV = HAS \times QV \tag{1}$$

$$CMT = \frac{D}{CAS} \tag{2}$$

$$LTQV = (CMT \times CC) \times QV \tag{3}$$

where, TQV : Total Quality Value
HAS : Harvest Area Size [m^2]
QV : Quality Value
CMT : Combine Moving time[m/h]
D : Distance[m]
LTQV : Loss Total Quality Value
CC : Combine Capacity[m^2/h]

Figure 2 shows the flow chart of combine scheduling basic algorithm. Operation date, farmland information, and combine information is inputted. Using quality value of the day and target area, total quality value is calculated and sorted from the largest for conducting the sequence. Using combine capacity, the operating time is calculated. After the first harvesting process is completed, the program is scheduled to conduct the second largest total quality value. If the time of second task is set up as the total quality value and combine moving time, the task which produces maximum total quality value should go first. If the task area is beyond the size of maximum operating area per day, the work will be stopped. Since the quality value is changing constantly after the first work, the information should be inputted daily. The scheduling will be provided except the harvested farmland.

Figure 3 shows input data screen of combine scheduling program. The basic information of the program is shown on the main screen: farmland information such as farmland name, size, address, and quality value along with combine capacity and combine average speed. After the harvest time is set up with the input information, the program will be run. The right window provides the combine operation order in an hourly manner, and all data will be provided in text files.

Figure 4 shows the output data screen of combine scheduling program. Operation time, moving time, and rest time will be shown on the output screen. This program uses a software program Visual C++ 6.0 developed by Microsoft.

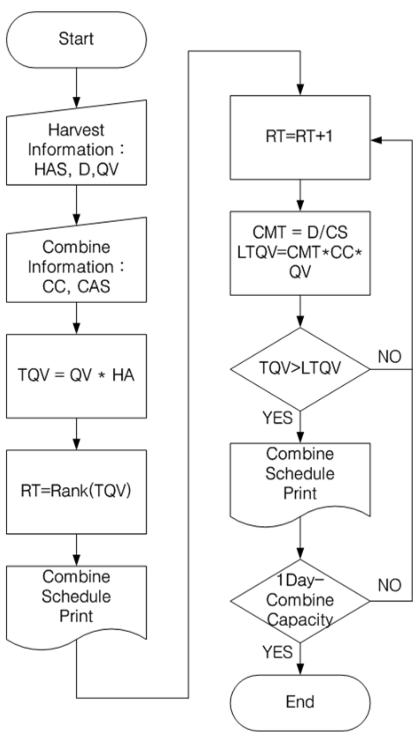

Figure 2. Flow chart of the combine scheduling basic algorithm.

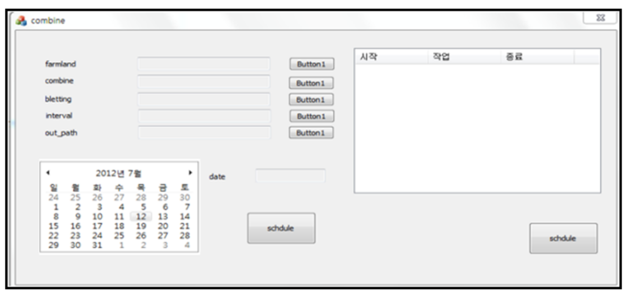

Figure 3. Input data screen of combine scheduling program.

Figure 4. Output data screen of combine scheduling program.

Table 1. Four types of combine work

	Items	Contents
①	Max-Coverage algorithm	Scheduling with TQV order
②	Boustrophedon path	Scheduling with sequential order from the nearest farmland with a zigzag path
③	Max quality value	Scheduling with quality value priorities order without considering distance between farmlands
④	Max area	Scheduling with cultivating area order without considering distance between farmlands

Table 2. Farmland information for simulation program

Farm land No.	harvest area size (m^2)	Distance between farmlands(m)						
		Distance from Farm land No.1	Distance from Farm land No.2	Distance from Farm land No.3	Distance from Farm land No.4	Distance from Farm land No.5	Distance from Farm land No.6	•••
1	22,316							
2	15,674	210						
3	19,486	380	170					
4	14,295	600	330	170				
5	18,370	750	510	340	180			
6	8,271	870	640	460	300	120		
7	11,065	910	710	510	360	220	110	
8	14,466	780	600	40	230	100	240	
9	5,448	670	490	280	110	220	350	
10	10,843	580	410	200	110	300	430	
11	7,899	490	310	110	200	390	520	
12	8,258	410	230	120	290	480	600	
13	18,100	280	110	240	400	600	710	
14	13,966	120	260	380	550	750	860	
15	7,383	250	350	500	640	810	930	
16	15,729	340	450	390	530	710	810	
17	18,580	550	640	210	370	540	650	
18	15,796	680	790	370	210	380	480	
19	12,668	840	840	510	350	210	350	
20	12,882	970	110	630	480	350	210	
21	8,492	100	930	770	460	430	320	
22	17,055	900	820	660	580	310	440	
23	8,300	760	690	510	320	480	570	
24	12,580	660	590	420	420	580	680	
25	11,954	530	470	310	550	710	800	
26	15,254	380	320	480	690	840	940	

Performance analysis

Table 1 compares four types of combine work to test the performance of the developed combine scheduling program. The first type calculates the schedule using the program with Max-Coverage algorithm. The second type plans the schedule which commands the work in sequential order from the nearest using Boustrophedon path which is like zigzag shape. The third type commands the work from the best quality to worst quality farmland without considering the distance between farmlands. The fourth type schedules the work from the largest farmland size.

The information of farmland which is target area for the simulation is in the table 2. Rice farmlands are selected for the target area. The simulation program is tested at the paddy fields in Yesan area, Chungnam. 26 farmlands are selected, and the total area is 345,125 m^2. The average cultivated area per household is 13,274 m^2. The largest one is 22,315 m^2; smallest one is 5,447 m^2. The distance between farmlands is calculated by adding distance from corner of finished farmland to road and distance from the road to corner of next farmland. The total distance of road was 14,010 m, the average distance between farmlands is 422 m and the longest distance is 990 m. The shape of most farmland is rectangle, and some farmlands adjacent the road are round shape.

The ranges of quality value are 0.1 ~ 1.0 and 10 steps are set up with interval of 0.1. Moisture content 24%, w.b. is considered as the best harvest point, so its quality value is set as 1.0 (Keum, 2008). When the rice is harvested with over 24%,w.b. of the moisture content, it become cracked. The moisture content is decreased by 0.5% from the 8.25 days of possible working period in Chungnam. Quality value changes at an interval of 0.1 in accordance with 0.5% moisture content, because the quality become bad either over or under moisture content 24%, w.b. (Choi et al., 1995).

Combine capacity is based on a combine manufactured by D company. Its capacity is 6,000 m^2/h, and the average speed is 5.0 m/h (MIFAFF, 2011). For this study the combine capacity is set up 4,200 m^2/h, and average speed is set up 5.0 m/h which reaches 70% of the standard (Park et al., 2008).

Result and Discussion

Figure 5 shows the working areas of each combine scheduling type. The task lasts for 10 days to the area of 345,125 m^2. Boustrophedon type took the longest working hours with the same working area. Max-Coverage algorithm type and max area type showed similar performance, but it became lowered after 6.5 days of working. The max area type combine worked in small farmlands only after finishing large ones, so it took more time in traveling to the next farmland than working in the farmland. In the meantime, Max-Coverage algorithm type showed similar working area from the start to the end of task. Max quality value type showed similar working area on the first day, but it took longer working days than Max-Coverage algorithm type. It took similar working days with max area type.

Table 3 shows the working area per day of each combine scheduling type. Average working area, maximum, and minimum area are represented in the table. The working period of Max-Coverage algorithm type turned out 7.8 days which was the shortest in four types. In addition, the difference between the maximum area and minimum area showed consistent width comparing with other types. With max area type the difference between the maximum area and minimum area was the largest in four types because it showed the highest maximum area and lowest minimum area. Max quality value type showed the smallest difference between the maximum area and minimum area, however, it took longer time than the Max-Coverage type. Boustrophedon type showed small

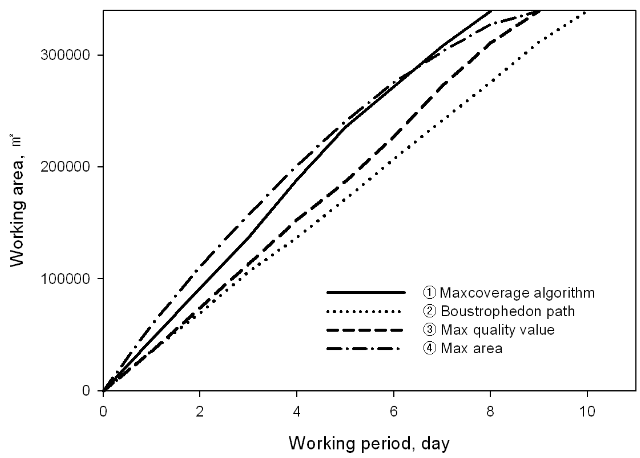

Figure 5. Comparison of working areas of each combine scheduling type.

Table 3. Working area per day of each combine scheduling type

	Working period (day)	Average working area (m^2/day)	Maximum working area (m^2/day)	minimum working area (m^2/day)
① Max-Coverage algorithm	7.8	43,531	51,745	36,111
② Boustrophedon path	9.7	35,004	36,705	30,756
③ Max quality value	8.5	39,946	45,440	34,153
④ Max area	8.5	39,946	59,381	27,605

Table 4. TQV and combine average moving distance and per day of each combine scheduling type

	TQV (average/day)	TQV (maximum/day)	TQV (minimum/day)	Combine Average Moving Distance (m/day)
① Max-Coverage algorithm	32,927	41,275	23,915	1,536
② Boustrophedon path	22,422	31,331	8,501	426
③ Max quality value	29,488	36,035	21,209	1,680
④ Max area	24,813	32,352	17,857	1,592

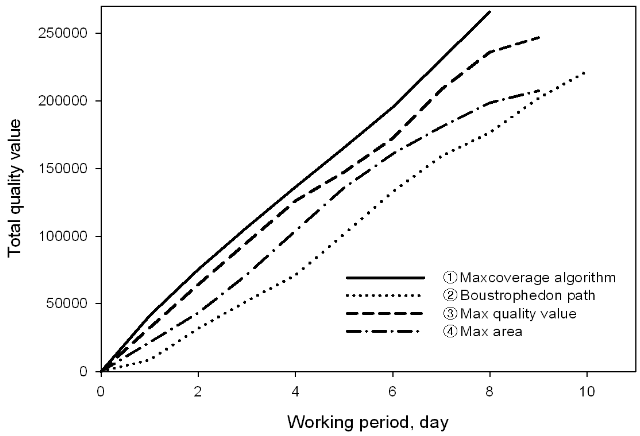

Figure 6. Comparison of TQI according to combine scheduling type.

average working area and the longest working period.

Figure 6 shows the accumulated total quality value (TQV) of each combine scheduling type. The highest TQV showed in Max-Coverage algorithm type and max quality value type. The difference of TQV between Max-Coverage algorithm type and max quality value type will be larger if the distance between farmlands is longer. However, Max-Coverage algorithm type was the best type for high quality harvest in short period. Besides, compared with other types TQV of one day harvest was consistent. Max quality value type showed the change of inclination due to the long traveling time. This is because it should keep on at the end of working time regardless of quality. Max area type and Boustrophedon type showed long working period and low TQV.

Table 4 shows working period and TQV per day of each combine scheduling type. In case of Max quality value type, average of TQV per day is higher and average moving distance of combine is shorter than other types when considered working period. Otherwise, in case of max quality value type, average of TQV per day is higher than the other two types but average moving distance of combine is longest. Boustrophedon type showed short moving distance of combine but average of TOV per day is lowest, and max area type showed that average of TQV per day was lower and high difference of maximum between minimum.

Conclusions

The purpose of this study was to develop a combine schedule program using Max-Coverage algorithm which showed maximum efficiency in a limited area and time. Combine information, farmland information was inputted to apply Max-Coverage algorithm into combine harvest scheduling algorithm. The task was done in a sequential order after total quality value of target area was calculated. Next task was decided after comparing total quality value which considered traveling time. Four types of combine work were tested to compare the performance of the developed combine scheduling program. Max-Coverage algorithm type, Boustrophedon path type, max quality value type, and max area type are compared in terms of quality and performance. Max-Coverage algorithm type had the fastest working speed and highest total quality value. From the result of this study, the developed combine scheduling program using Max-Coverage algorithm will provide optimal operation and maximum quality in a limited area and time.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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