HARVEST SIMULATION

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Weather influences many aspects of agricultural production. It directly affects many physical operations in farming and significantly increases the realm of uncertainty, making farm decision-making most complex. The rate and efficiency of harvesting cereal grains are very dependent of weather conditions. Due to the wide fluctuations in weather, sizing machines and selecting best methods of harvesting are difficult tasks.

The primary objective of a recent investigation (1) was to develop accurate models of accepted harvesting systems by incorporating the effects of weather, previous growing conditions and machine operation into the models. The complexity of climatic, biological and machine interactions during harvest was analyzed by using digital computer simulation models (4,8,10). By using simulation techniques, the stochastic nature of many of the parameters involved in harvesting operations may be included in the models.

In constructing a harvest simulation model, it is necessary to identify and quantify as many variables as possible and then make the decision as to which will contribute significantly to the performance of the model.

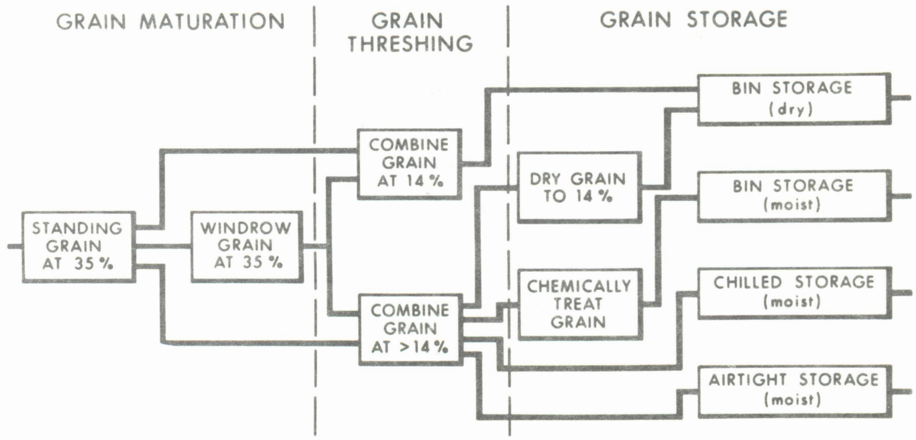

Figure 1 Network combinations of alternative harvesting systems.

PROCEDURE

The process of harvesting cereal grain consists of three basic events: grain maturation, grain threshing and grain storage. The network in Figure 1 shows the possible alternative combinations of harvest events available to a farm operator. The function of each step is regulated by certain operating conditions, processing rates and limiting conditions (Figure 2). The four harvest systems used for simulation in this study were:

1. combining swathed or windrowed grain moist (CSM),
2. combining swathed or windrowed grain dry (CSD),
3. straight combining moist (SCM), and
4. straight combining dry (SCD).

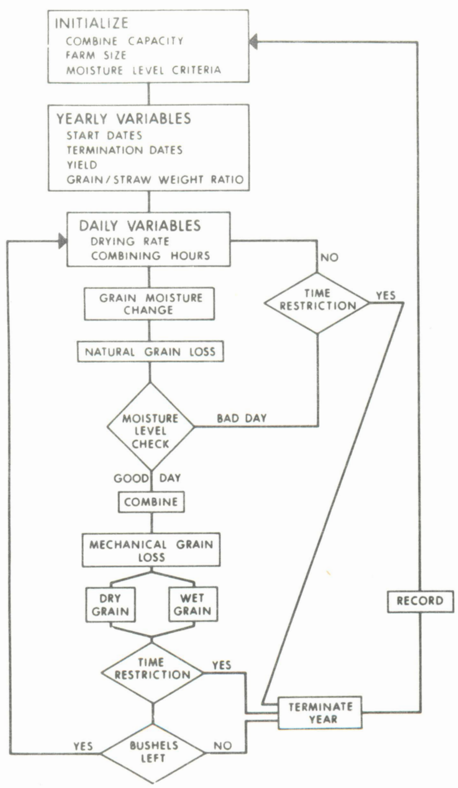

Figure 2 Simplified flow diagram of the harvesting models.

To obtain simulation results for a wide range of farming situations, simulation runs were made using six combine capacities[a] on three farm sizes in each of the Beaverlodge, Lacombe and Lethbridge areas of Alberta.

One approach used to refine weather data into a form usable for simulation is to generate probability distribution of 'good' and 'bad' days (8, 11) according to specified criteria such as precipitation or relative humidity. Since harvesting operations are dependent on grain and straw moisture conditions, an attempt was made to use this criteria to determine working and non-working days. If a relationship between moisture changes in the grain plant, weather and other field variables could be established, the estimation approach of 'good' and 'bad' days would not be required. However, while some progress was made in this direction, the amount and completeness of available data on moisture changes with respect to weather and other physical variables limited results to values for the coefficients of determination in the order of 0.60. Rather than completely abandon this approach, estimates of daily moisture changes were formulated from the available data (Table I).

[a] Calculated using MacHardy's Formula (8)

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TABLE I. ESTIMATED DAILY DRYING RATES OF STANDING WHEAT

Month	Mean Drying Rate	Range of Drying
August	4.24%	-8.50 to 16.75
September	3.75%	-11.25 to 18.75
October	2.66%	-15.25 to 20.50
November	1.90%	-18.00 to 22.00

TABLE II. ESTIMATED MONTHLY VARIATIONS IN COMBINING HOURS PER DAY.

Month	Mean Hours Available		Range
	Dry	Moist	
August	10	13	± 4
September	8	11	± 4
October	6	9	± 4
November	4	7	± 4

The date of spring seeding and the fluctuating weather condition of the growing season influence the date at which the grain will reach maturity. Termination of harvesting operations may occur because of continuous unsatisfactory weather. Probability distributions (Figure 3) provided the yearly variations of these parameters for the simulation models.

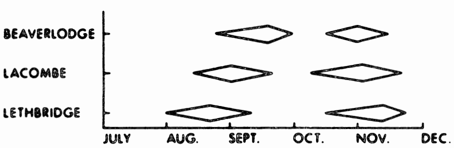

Figure 3 Harvest starting and termination dates.

Yield distributions for the three areas were taken from survey results. (6, 7). Yearly changes in grain-to-straw weight ratios were also included in the simulation because of the limiting effect of straw on combine output (9).

The number of hours available for combining each day depends on weather conditions, mechanical breakdowns and available labor. This variation was estimated on a monthly basis (Table 11) with daily values picked at random.

Grain losses reported by Dodds (2, 3), and Johnson (5) were used in calculating grain losses for each of the four harvest systems.

Once the variables relating to the systems were known or assumed, they were combined in each model in such a manner as to represent reality. The daily and yearly stochastic variables were chosen by Monte Carlo procedures. Each simulated harvest was computed (12) on a daily basis until the season was terminated, either by unsatisfactory weather conditions or harvest completion.

RESULTS AND DISCUSSION

The simulation models produced yearly distributions of:

1. the number of days required for harvesting,
2. the number of maturation days required from physiological maturity (35% moisture content) of the grain to commencement of harvest,
3. the number of days when combining was stopped due to unfavorable combining conditions,
4. the number of years out of 100 years when total acreage to be harvested was completed,
5. the number of bushels left in the field because harvest was not completed,
6. the number of moist and dry bushels harvested, and
7. grain losses attributed to natural and mechanical factors.

Sample output from one simulated run is shown (Table III). The accuracy of results of the simulation depends on the reliability of the estimates for the parameters concerned with each event in the harvesting sequence. The logical assumptions were substantiated that (Figures 4 and 5).

1. grain acreage to be harvested and combine capacity affect percentage completion,
2. moist grain harvesting systems will be completed before dry grain harvesting systems, and
3. the practice of swathing grain increases the chances of completion.

Completion percentages are a function to combine capacity, acres to be harvested and time available for harvesting. The time required to harvest a given grain acreage decreases as combine capacity increases (Figure 6). For a given combine capacity, the time required to harvest increases as acreage increases. An increase in the harvesting time required decreases the chances of completion. Total harvest days are a summation of maturation days, bad days and actual combining days. Once combining had commenced, a day was recorded as "bad" if the grain moisture level rose above 14% for the dry systems and above 25% for the moist systems. Most of the difference in total days between systems is due to the difference in maturation days (Table IV). However, the effect of bad days is noticeable, especially at the smaller combine capacities (Table V).

Output from the simulation models also included the accumulated quantity of grain not combined over the 100 harvest seasons and the amount of grain lost due to natural and mechanical losses. These figures could provide a penalty factor for an economic evaluation of the alternative harvesting systems.

Moist grain harvesting systems have the advantage of a shorter grain maturation period and are less vulnerable to unfavourable weather. The trends suggest that bad days may become a major factor in completion of very large acreages (Table VI). The number of actual combining days required varies with the capacity of

TABLE III. SAMPLE OUTPUT OF ONE HARVEST SIMULATION COMBINATION

District: Beaverlodge	Combine Capacity (lbs/min): 195						Acres: 1000	
	Combine Swath Moist		Combine Swath Dry		Straight Combine Dry		Straight Combine Moist	
	Mean	S.D.*	Mean	S.D.	Mean	S.D.	Mean	S.D.
Total Days	18.43	8.07	27.64	11.39	30.88	11.65	19.71	9.46
Maturation Days	5.26	4.04	8.62	4.60	11.30	6.63	6.67	5.53
Bad Days	0.52	1.49	5.03	5.95	7.21	7.60	1.20	2.99
% Completion	98		82		74		95	
Bushels Left	26535 in 2 years		183219 in 18 years		295667 in 26 years		49215 in 5 years	
Grain Loss	158	8	172	9	221	23	119	14
Bu. Harvested Dry	10622	5152	18678	4864	16384	5152	7855	5440
Bu. Harvested Moist	9648	5184	-	-	-	-	11495	5824
Cost of Drying ($)	1024	677	-	-	-	-	1320	748
Cost of Chemical ($)	543	359	-	-	-	-	700	397

* Standard Deviation

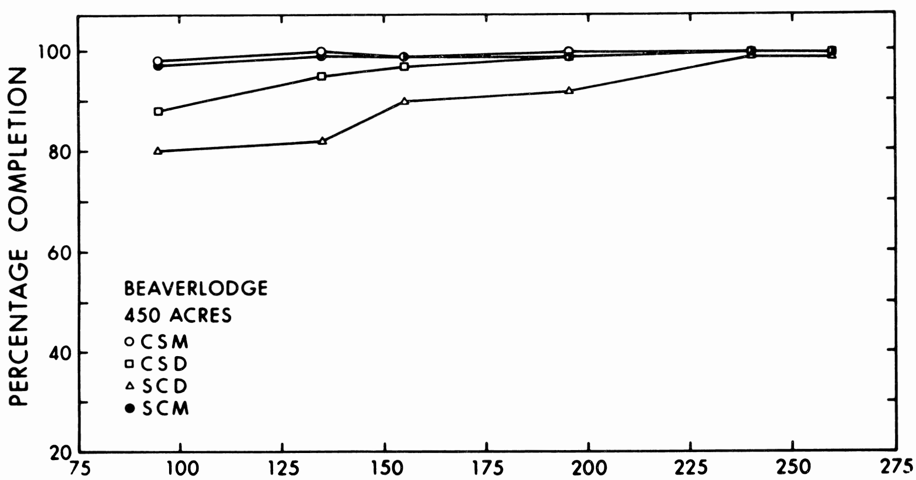

Figure 4 Computed harvest completion of 450 acres in the Beaverlodge area.

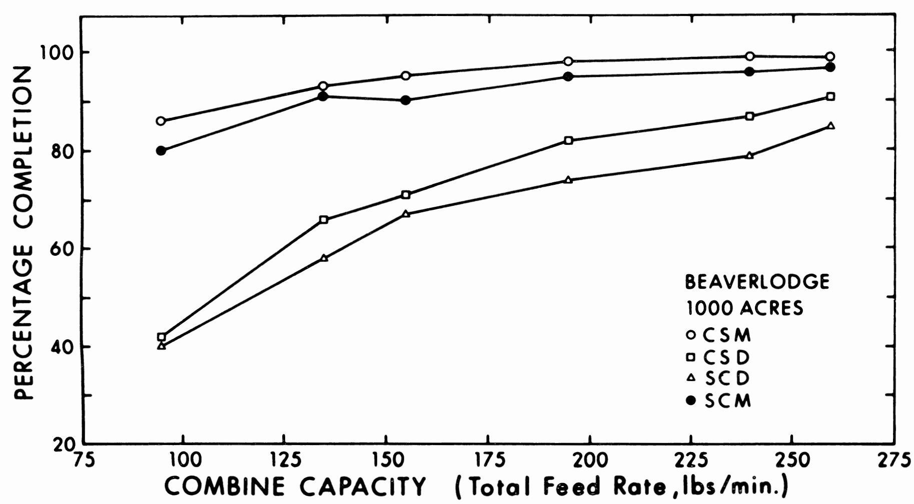

Figure 5 Computed harvest completion of 1000 acres in the Beaverlodge area.

the machine and the number of hours available for combining.

Swathed grain systems also have the advantage of shorter grain maturation periods and are consequently less vulnerable to unfavorable weather. Using percentage completion as an indication of the success of each system, combining swathed grain moist is the best harvest alternative and straight combining dry is the worst alternative (Figures 4 and 5). These results have been substantiated (1) with two more locations and several more farm sizes.

As expected, the longer and more favorable harvesting seasons of the southern locations in the Province were reflected in the total number of harvest days and harvest completion percentages (Figure 7). However, this trend was offset by the greater grain yields experienced in the Lacombe area. This suggests that anticipated yields as well as available harvesting days should be considered when deciding upon combine capacity.

An important product of simulation is the distribution of observations about the mean values. Mean values with larger variance can be considered less reliable (Figure 8). The large and even distribution of total harvest days for the smaller combine capacities indicates less reliability of completion than for the larger capacities. The blunt upper

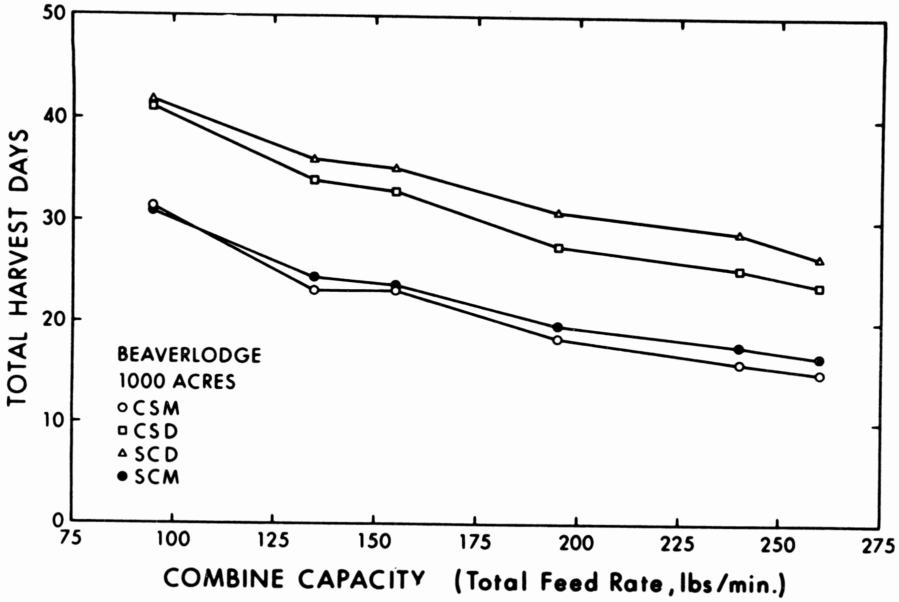

Figure 6 Computed total harvest days of 1000 acres in the Beaverlodge area.

TABLE IV. COMPUTED NUMBER OF MATURATION DAYS FOR THE THREE FARM LOCATIONS.

	CSM*		CSD		SCD		SCM	
Location	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Beaverlodge	4.8	3.0	8.1	3.6	11.2	6.9	6.3	4.7
Lacombe	4.3	2.3	7.4	3.1	9.6	4.5	5.5	3.5
Lethbridge	4.1	2.2	7.2	2.8	9.2	4.2	5.3	3.6

*** CSM - combine swath moist.** **SCD - straight combine dry.**

CSD - combine swath dry. **SCM - straight combine moist.**

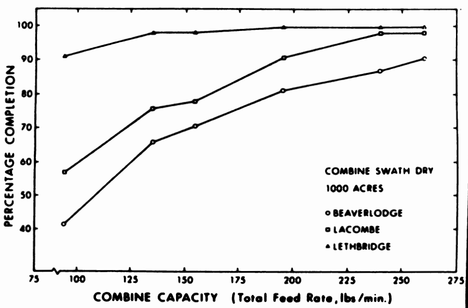

Figure 7 Computed harvest completion of the 'combine swath dry' sequence.

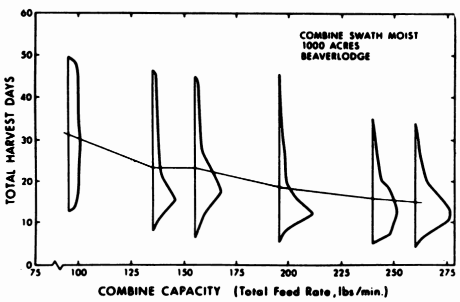

Figure 8 Computed distributions of total harvest days of the 'combine swath moist' sequences for Beaverlodge area.

end of these distributions are caused by maximum time restrictions imposed by the date distributions (Figure 2). Time restrictions decrease the success of harvest completion (Figure 5).

Harvest models have certain limitations. Only the main variables relating to the real situation have been used. More reliable estimates are needed, particularly in these areas concerning the effects of weather on drying rates of grain and grain moisture changes on combine capacity. While not all the possible alternatives were included in the study, the value (and limitations) of simulation techniques applied to a complex operation such as harvesting were apparent from the results obtained.

Determination of optimal or least cost combinations of subsystems was not considered in this study because of the large number of combinations involved and the lack of economic data relating to many harvesting operations. However, a study of the results obtained suggests the following:

1. A possible advantage of moist grain in harvesting systems, especially in northern locations and/or on large acreage farms for at least a portion of the crop.
2. The economic feasibility of moist grain systems will largely depend on the cost of handling the moist grain, i.e., the cost of increased combine capacity considered against the cost of alternate grain treatments (drying, chilling, sealed storage or chemical preservation).
3. The importance of system reliability and level of risk should be considered in the assessment of alternative systems since many operators may trade greater long term rewards for a steady yearly return.

The value of simulation as a tool for decision making in agriculture may not yet be fully established. On the basis of this study, it would appear that a sound basis is provided for assessment of alternative combinations which other evaluation techniques do not offer.

SUMMARY

The complexity of climatic, biological and machine interactions during cereal grain harvest was analyzed by computer simulation models. The harvesting period was divided into three basic events (grain maturation, grain threshing and grain storage) to simplify model construction. The stochastic variables in the models were discussed and quantified. Four alternative harvest systems experiencing 100 harvesting seasons were analyzed for performance. Simulation runs were made using six various combine capacities on three farm sizes in each of the Beaverlodge, Lacombe and Lethbridge areas of Alberta. Special attention was given to the success of each system, (percentage completion) and to the length

TABLE V. COMPUTED NUMBER OF BAD DAYS FOR THE THREE FARM LOCATIONS.

Farm Size Cultivated acres/yr.	Capacity (lb/min)	CSM Mean	CSM SD	CSD Mean	CSD SD	SCD Mean	SCD SD	SCM Mean	SCM SD
BEAVERLODGE AREA									
1000	95	.98	1.9	9.7	6.6	11.5	7.5	2.1	4.7
1000	135	.67	1.3	7.5	6 5	9.6	8.2	1.9	4.5
1000	155	.58	1.8	7.4	6.7	8.8	7.8	1.7	4.5
1000	195	.52	1.5	5.0	6.0	7.2	7.6	1.2	3.0
1000	240	.39	1.3	4.7	5.5	6.5	7.4	1.2	3.4
1000	260	.33	.83	4.1	5.9	5.5	7.7	.96	3.4
LACOMBE AREA									
1000	95	1.1	2.7	11.2	9.2	15.1	11.3	2.1	4.6
1000	135	.65	1.9	8.2	8.2	11.9	11.3	1.4	4.2
1000	155	.35	1.3	7.5	8.6	10.6	10.4	1.3	3.4
1000	195	.16	.44	5.7	7.3	8.6	10.6	.43	1.1
1000	240	.15	.59	3.8	5.6	6.4	8.5	.38	1.2
1000	260	.27	.88	3.1	4.8	5.2	7.6	.59	1.5
LETHBRIDGE AREA									
1000	95	.16	.69	6.8	8.2	9.4	11.6	.37	1.4
1000	135	.10	.48	3.7	5.3	5.6	8.1	.22	.78
1000	155	.11	.45	3.5	5.7	5.0	7.6	.24	.83
1000	195	.08	.46	1.7	3.0	3.0	5.6	.30	.85
1000	240	.08	.39	1.5	2.4	2.3	3.4	.26	1.1
1000	260	.06	.28	1.2	2.3	2.3	6.0	.35	1.3

TABLE VI. COMPUTED NUMBER OF BAD DAYS FOR THE BEAVERLODGE AREA.

Capacity (lb/min)	Farm Size (Cultivated acres/yr.)	CSM Mean	CSM SD	CSD Mean	CSD SD	SCD Mean	SCD SD	SCM Mean	SCM SD
155	280	.16	.71	1.7	3.3	2.8	5.2	.23	.76
155	450	.20	.80	3.0	4.6	5.1	7.1	.56	1.6
155	1000	.58	1.8	7.4	6.7	8.8	7.8	1.7	4.5

of the harvesting operations. Determination of optimal or least cost combinations were not considered. Several implications arising from the results were discussed and the need for more reliable data with regard to variables noted.

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