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Component Selection for Livestock Farms Using Linear Programming

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Robert M. Finley, Elbert F. Turner, Jr.
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For livestock feeders, matching components for feed storage, processing and handling is an important problem involving many possible combinations of capital and labor. The optimal system is highly dependent upon capacities and costs of various components as well as costs of capital and labor on given size farms. Hence, what is least cost on, say, a medium size farm with abundant capital and labor probably will not be least cost on, say, a large farm with limited capital and labor.

Our objective is to examine some economic factors affecting choice of feed storage, feed processing and feeding systems on farms of various sizes. Our locus is primarily set in Northern Missouri and hence data (and results) reflect corn belt farming and should be generally applicable for a large geographical area.

To implement the study it was necessary to (1) develop suitable coefficients for labor, capacity and cost of common feed storage, processing and feeding alternatives; (2) adapt these coefficients to a linear programming matrix to be solved for a minimum cost system; and (3) examine the effects of varying size, labor and investment capital.

Storage, handling, processing and feeding of feedstuffs must be viewed as an enterprise having the sole purpose of storing, handling, processing, and feeding livestock at the lowest cost possible, consistent with the appropriate livestock management program. Obvious limitations to a study of this nature are apparent. Storage and materials handling systems offer economies to size of operations making necessary the establishment of compensating ranges of linearity within various alternatives. Many factors can not be effectively considered in a solution of the program. Effects of length of harvest period, timeliness of operations, multiple-use of facilities and personal preferences are not within the scope of this study. The development of the coefficients used in establishing the matrix was made difficult by a lack of labor and cost data for many items of equipment.

THE SETTING AND THE DATA

The matrix was arranged in a flow pattern similar to that found in feed storage and processing systems. This permitted establishment of minimum requirements for storing quantities of grain and hay and transfer of stored grain through an alternative for grain handling and to a processing system.

Total grain and supplement needs are delivered to feeding alternatives by use of another transfer activity and equals grain delivered to processing plus a protein tonnage added at processing. Processed feed flows to feed distribution components for cattle and hogs, picking up hay from the storage unit.

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To achieve desired comparisons, requirements were established for three sizes of operation. Each size of operation considered is outlined in Tables 1 and 2. Each of the three sizes was programmed with nine combinations of relative labor and capital availability.

TABLE 1. LIVESTOCK ON FARMS OF VARIOUS SIZES

	Small Farm	Medium Farm	Large Farm
Steers[1]	38	100	283
Cattle Ration (tons)			
Grain	45	120	365
Protein	3.9	15	29.1
Hay	42	105	336
Hog Litters Per Year	20	40	60
Swine Ration (tons)			
Grain	65	134	195
Protein	11.7	23.4	35.1

[1]Wintered, grazed and full fed to market; 132 days wintering, 120 days full fed.

TABLE 2. REQUIREMENTS AND LIMITATIONS FOR FARMS OF VARIOUS SIZES

		Required Level		
Requirement or Limitation	Units	Small Farm	Medium Farm	Large Farm
Store Grain[1]	Tons/year output	110.0	254.0	560.0
Handle Grain[1]	Tons/year output	110.0	254.0	560.0
Store Hay[1]	Tons/year output	42.0	105.0	336.0
Supply Protein Concentrate	Tons/year output	15.6	38.4	64.2
Process Grain and Protein	Tons/year output	125.6	292.4	624.2
Feed Cattle	Tons/year fed	90.9	240.0	730.1
Feed Hogs	Tons/year fed	76.7	157.4	230.1

[1]Farm produces and stores all feed except protein concentrate.

Farm size represents the combined effects of producing corn on a fixed acreage of land with the cattle feeding enterprise adjusted to use all remaining production after allowing for feed needs for a given size hog enterprise for each farm size. Acreage devoted to hay production was assumed variable and equal to the needed hay for the cattle ration. Acreage of corn was: small size farm, 52 acres; medium size farm, 120 acres; and the large farm, 267 acres.

Labor was considered as in high, medium or low quantity, depending on the value of

TABLE 3. ALTERNATIVE GRAIN STORAGE COMPONENTS

Numerical Designation	Description of Storage Unit	Loss Assumptions	Investment Capital/Ton	Annual Cost Per Ton			Hours Labor Per Ton Per Year
				Fixed	Variable	Total	
1	Round steel bin, 21 x 16., with concrete floor, drying floor, heat unit and 3 hp. fan. 75 to 124 tons capacity.	7% field loss 2% storage loss	$30.38	$2.88	$2.39	$5.27	.06
2	Round steel bin, 27 x 16 ft., with concrete floor, drying floor, heat unit and 5 hp. fan. 125 to 160 tons capacity.	7% field loss 2% storage loss	27.82	2.64	2.27	4.91	.04
3	1 to 6 round steel bins, 24 x 16 ft., with concrete floor, drying floor, heat units and 7½ hp. fan. 0 to 260 tons capacity.	7% field loss 2% storage loss	21.08	2.03	1.76	3.79	.035
4	Rectangular steel storage bin, 24 x 64 ft., concrete floor, metal air ducts, heat unit and 5 to 7 ½ hp. fan. 261 to 350 tons capacity.	7% field loss 2% storage loss	26.43	2.57	2.34	4.91	.05
5	Rectangular steel bin, 24 x 64 ft., concrete floor, metal air ducts, heat unit and 5 to 7½ hp. fan. 261 to 350 tons capacity.	7% field loss 2% storage loss	25.07	2.44	2.31	4.75	.04
6	Rectangular steel bin, 24 x 64 ft., concrete floor, metal air ducts, heat units and two 5 hp. fans. 351 to 520 tons capacity.	7% field loss 2% storage loss	24.65	2.40	2.30	4.70	.04
7	Rectangular steel bin, 36 x 80 feet, concrete floor, metal air ducts, heat units and two 7½ hp. fans. 521 to 650 tons capacity.	7% field loss 2% storage loss	23.56	2.29	2.28	4.57	.04

TABLE 3 CONTINUED

TABLE 3. ALTERNATIVE GRAIN STORAGE COMPONENTS

Numerical Designation	Description of Storage Unit	Loss Assumptions	Investment Capital/Ton	Annual Cost Per Ton			Hours Labor Per Ton Per Year
				Fixed	Variable	Total	
8	Wood frame bin, 12 x 10 x 1 ft. per 2.67 tons, concrete floor, metal air ducts, heat unit and up to 7½ hp. fan. 28 to 320 tons capacity.	7% field loss 2% storage loss	$16.34	$2.05	$1.96	$4.34	.04
9	Wood frame ear corn bin, 12 x 12 x 1 ft. per 1.613 tons, concrete floor, metal air ducts and 1½ to 5 hp. fans. 16 to 192 tons capacity.	7% field loss 2% storage loss	16.45	2.44	1.35	3.79	.05
10	Commercial grain storage, average 6 months, commercial drying, average 4% moisture reduction.	7% field loss 2% storage loss	0	0	5.63	5.63	.06
11	Round steel bin, 21 x 16 ft. and concrete floor. 75 to 124 tons capacity.	14% field loss 2% storage loss	14.71	1.47	.91	2.41	.05
12	Round steel bin, 27 x 16 ft. and concrete floor. 125 to 160 tons capacity.	14% field loss 2% storage loss	13.57	1.36	.91	2.27	.03
13	Round steel bins, 1 to 6, 24 x 16 ft. and concrete floor. 161 to 960 tons capacity.	14% field loss 2% storage loss	12.86	1.29	.89	2.18	.03
14	Rectangular steel bin, 24 x 48 ft. and concrete floor. 0 to 260 tons capacity.	14% field loss 2% storage loss	18.93	1.89	1.02	2.91	.04
15	Rectangular steel bin, 24 x 64 ft. and concrete floor, 261 to 350 tons capacity.	14% field loss 2% storage loss	17.57	1.76	.99	2.75	.03
16	Rectangular steel bin, 36 x 64 ft. and concrete floor. 351 to 520 tons capacity.	14% field loss 2% storage loss	17.15	1.72	.98	2.70	.03
17	Rectangular steel bin, 36 x 80 ft. and concrete floor. 521 to 650 tons capacity.	14% field loss 2% storage loss	16 06	1.61	.96	2.57	.03
18	Wood frame bin, 12 x 10 x 1 ft. per 2.67 tons, with concrete floor. 28 to 320 tons capacity.	14% field loss 2% storage loss	8.84	1.70	.64	2.34	.03

TABLE 3 CONTINUED

TABLE 3. ALTERNATIVE GRAIN STORAGE COMPONENTS

Numerical Designation	Description of Storage Unit	Loss Assumptions	Investment Capital/Ton	Annual Cost Per Ton Fixed	Annual Cost Per Ton Variable	Annual Cost Per Ton Total	Hours Labor Per Ton Per Year
19	Wood frame ear corn storage, 12 x 12 x 1 ft. per 1.613 tons with concrete floor. 16 to 192 tons capacity.	14% field loss 2% storage loss	$10.85	$1.94	$ .64	$2.58	.03
20	Commercial grain storage	14% field loss 2% storage loss	0	0	3.85	3.85	0
21	Glass lined high moisture storage with bottom unloading system. 100 to 140 tons capacity.	6% field loss 0% storage loss	55.00	5.22	.28	5.50	.04
22	Glass lined high moisture storage with bottom unloading system. 141 to 280 tons capacity.	6% field loss 0% storage loss	41.07	3.90	.28	4.18	.02
23	Glass lined high moisture storage with bottom unloading system. 281 to 560 tons capacity.	6% field loss 0% storage loss	28.51	2.71	.28	2.99	.02
24	All steel high moisture storage bin, conical concrete floor, auger unloader. 141 to 280 tons capacity.	6% field loss 0% storage loss	30.23	2.87	.28	3.15	.02
25	All steel high moisture storage bin, conical concrete floor, auger unloader. 281 to 560 tons capacity.	6% field loss 0% storage loss	21.43	2.04	.28	2.32	.02

opportunity cost used. Capital availability was handled in a similar fashion.[1] The result was a total of 27 comparisons of least cost feed storage and processing systems.

Components used are classified into various sub-systems:
Grain Storage (Table 3; Numerical Designation 1-25)
Grain Handling (Table 4; Numerical Designation 26-33)
Feed Processing (Table 5; Numerical Designation 34-46)
Cattle Feeding (Table 6; Numerical Designation 47-55)
Hog Feeding (Table 7; Numerical Designation 56-58)

The opportunities for forming a given system are many and allow for a wide range of labor and capital usage.

The cost data were derived from many sources including dealers' prices, published standards, etc. (adjusted as needed to place all assumed factors on a common basis). A certain degree of arbitrariness exists whenever such data are assembled but perhaps a framework is set forth that will enable other researchers to derive their own appropriate input relationships.

The cost coefficients are in terms of annual total costs, including all fixed and variable costs except labor. Generally fixed costs are computed as a given percentage based on the original total investment, with variable costs added to arrive at annual total cost. All cost coefficients are expressed as annual costs per ton use for a component. Labor costs are excluded from the coefficients but are reflected in by use of a labor requirement and an opportunity cost on labor.

All capacities and costs are expressed in tons to provide a common denominator for all materials processed and stored. Capacities were of importance in establishing cost and linearity ranges and in fulfilling the use requirements for a system components.

To consider the effects of field and storage loss differences between alternative grain storage and hay storage units, input and/or output quantities were varied by a given factor. For example, one ton of grain storage supplies only .84 tons of grain to the overall system when, say, field losses are 14 percent and storage losses are 2 percent. Thus, the excess storage cost serves as a penalty for excessive losses. Field loss is included to reflect part of the net advantage or disadvantage implied in selecting a harvest stage for use with a particular storage unit.

Labor use data were developed for each alternative in each set of components. These, too, were expressed in hours per ton per year, based on the best input studies and estimates available.

Rationing of capital, and the importance of total capital investment, necessitated use of capital investment figures. These inputs were stated in terms of total dollar investment per ton of capacity. Capacity of handling and processing systems is sometimes cited as a factor determining the optimum design of these components for a given situation. It was found in developing coefficients for capacities that investment requirements, labor consumption, and annual cost were influential long before any reasonably likely hourly, daily or yearly limit on time or tonnage handling per unit of time. Trial program matrices considered time limits but were not found to be of significance in any solution.

[1]Labor costs were assumed to be $1; $5; $10 per ton and capital was charged at 2%; 8%, 14%. These values represent wide opportunity costs for labor and capital and should approximate opportunity costs encountered for farms in the area and serve as a basis for comparisons. Hence labor availability was high when the cost was $1; medium when cost was $5; and low when the cost/ton was $10. Similarly when the opportunity cost of capital was only 2%, capital availability (quantity) was high; medium at 8% and low at 14%.

TABLE 4. ALTERNATIVE GRAIN HANDLING COMPONENTS

Numerical Designation	Description of Handling Equipment	Investment Capital/Ton	Annual Cost Per Ton Fixed	Annual Cost Per Ton Variable	Annual Cost Per Ton Total	Hours Labor Per Ton Per Year
26	Portable 6" x 30' auger with gasoline engine, bin sweep and unloading augers with motors. For use with storage units 1 and 11.	$ 8.40	$1.27	$ .01	$1.28	.06
27	Portable 6" x 30' auger with gasoline engine, bin sweep and unloading augers with motors. For use with storage units 2 and 12.	5.92	.89	.01	.90	.06
28	High labor equipment for use with storage units 3 and 13. Same as 28 and 29 above.	2.00	.30	.01	.31	.06
29	High investment-low labor equipment with 35' vertical bucket elevator, 6" distributing auger, 4" return auger and bin sweep. For use with storage units 3, 6, 7, 8, 13, 16, 17 and 18.	3.83	.41	.01	.42	.02
30	High labor component for storage units 4, 5, 6, 7, 8, 14, 15, 16 17 and 18. Same as 28 above with added labor required to clean bin corners.	2.58	.39	.01	.40	.07
31	Portable 15" x 40' chain elevator, gasoline engine, and 12" x 24' drag, for ear corn storage units 9 and 19.	10.70	1.39	.06	1.45	.08
32	Trucking to commercial storage. Average 10 miles, 6 tons per trip.	0	0	.25	.25	.09
33	Power-take-off driven blower for high moisture grain.	3.94	.51	1.55	2.06	.06

TABLE 5. ALTERNATIVE FEED PROCESSING EQUIPMENT

Numerical Designation	Description of Feeding Processing Equipment	Investment Capital/Ton	Annual Cost Per Ton			Hours Labor Per Ton Per Year
			Fixed	Variable	Total	
34	Portable power-take-off driven mixer-grinder. 0 to 140 tons per year.	$25.00	$3.55	$ .67	$4.22	.52
35	Portable power-take-off driven mixer-grinder. 141 to 280 tons per year.	8.57	2.38	.67	3.05	.52
36	Portable power-take-off driven mixer-grinder. 281 or more tons per year.	3.21	.73	.67	1.40	.52
37	Portable power-take-off driven grinder, 50% use of wagon-mixer. 0 to 140 tons per year.	19.64	3.14	.66	3.80	.50
38	Portable power-take-off driven grinder, 50% use of wagon-mixer. 141 to 280 tons per year.	6.55	.94	.66	1.60	.50
39	Portable power-take-off driven grinder, 50% use of auger wagon-mixer. 281 tons or more per year.	2.46	.45	.66	1.11	.50
40	Automatic electric grinder-blender, overhead supply bins, 4" auger and 1 holding bin. 0 to 140 tons per year.	20.71	2.87	.14	3.01	.24
41	Automatic electric grinder-blender, overhead supply bins, 4" auger and 4 holding bins. 141 to 280 tons per year.	11.90	1.30	.14	1.44	.24
42	Automatic electric grinder-blender, overhead supply bins, 4" auger and 4 holding bins. 281 or more tons per year.	7.14	1.00	.14	1.14	.24
43	Custom mobile grinder-mixer. 0 to 140 tons per year.	0	0	3.50	3.50	.20
44	Custom mobile grinder-mixer. 141 to 280 tons per year.	0	0	3.30	3.30	20
45	Custom mobile grinder-mixer. 281 or more tons per year.	0	0	2.20	2.20	.20
46	Custom grinding at elevator. Average 10 miles trucking.	0	0	4.75	4.75	.70

TABLE 6. ALTERNATIVE CATTLE FEEDING COMPONENTS

Numerical Designation	Description of Hog Feeding Component	Investment Capital/Ton	Annual Cost Per Ton Fixed	Annual Cost Per Ton Variable	Annual Cost Per Ton Total	Hours Labor Per Ton Per Year
47	Fence line bunks, concrete pad and standard wagon with hoist. Hand unloaded. High labor input for 0 to 560 tons per year.	$ 2.91	$ .26	$ .59	$ .85	.35
48	Fence line bunks, concrete pad and standard wagon with hoist. Hand unloaded. High labor input for 561 tons or more per year.	1.35	.12	.38	.50	23
49	Self unloading wagon and fence line bunks with concrete pad. 0 to 1000 tons per year.	3.55	.32	.38	.70	.10
50	Self unloading wagon and fence line bunks with concrete pad. 1000 or more tons per year.	2.30	.21	.11	.32	.04
51	Mechanical feeder including auger, bunk, concrete pad, roof over feeders, motors, and controls. 0 to 300 tons per year.	10.14	1.91	.01	1.92	.136
52	Mechanical feeder including auger, bunk, concrete pad, roof over feeders, motors, and controls. 301 to 600 tons per year.	7.76	1.65	.01	1.66	.034
53	Fence line bunk and 50% use of portable power-take-off grinder-mixer to distribute ration. Concrete pad provided.	4.61	.46	.15	.61	.10
54	Self feeder, 50% use of portable power-take-off grinder-mixer to distribute and concrete pad.	8.68	1.01	.15	1.16	.10
55	Self feeder, auger wagon and concrete pad.	7.43	.93	.15	1.08	.10

TABLE 7. ALTERNATIVE HOG FEEDING COMPONENTS

Numerical Designation	Description of Hog Feeding Component	Investment Capital/Ton	Annual Cost Per Ton Fixed	Annual Cost Per Ton Variable	Annual Cost Per Ton Total	Hours Labor Per Ton Per Year
56	Self feeders on concrete pad with 50% use of portable power-take-off grinder-mixer to distribute.	$6.01	$1.06	$ .15	$1.21	.10
57	Self feeders on concrete pad with 50% use of auger wagon to distribute feed	4.76	1.04	.15	1.19	.10
58	Self feeders on concrete pad with 4" auger system to fill feeders directly from storage.	4.76	.95	.01	.96	.05

EFFECTS OF LABOR AVAILABILITY AND COMPONENT SELECTION

Available labor did not have profound effects upon selection of components for an optimum system. Within given farm size, availability of labor had no influence on the grain storage or grain handling components; or hog feeding activities. (See Tables 8, 9, 10.) However, changes attributable to quantity of available labor were apparent in the feed processing and cattle feeding components. In the case of the large farm (Table 10) abundant labor favored use of a fence line bunk and hand-unloading wagon; but a self unloading wagon or portable mixer-grinder unit was substituted when average or low labor situations provided. This was the only response shown to labor quantity relative to cattle feeding sub-systems.

Feed processing with high labor availability called for PTO grinder and auger wagon-mixer or an automatic electric mill for large and medium farm sizes. With average or low labor availability the power take off grinder and auger wagon-mixer combination was dropped and a custom mobile grinder-mixer was substituted.

As shown in Table 11, the total and per ton labor requirement in the small farm situation was higher for both the low and high labor quantity assumptions than for the average level. In the medium and large farm situations essentially no change was noted in labor from the average to the scarce labor cases. There was, however, a marked increase in labor input on both the medium and large size farms when labor is relatively plentiful.

Capital use decreased with an abundance of labor on the medium and large size farms, but increased a bit on the small farm, indicating a complementary relationship between consumption of labor and capital at smaller levels of operation. This resulted mainly from the inclusion of on-farm processing in the two high labor-high capital quantity cases instead of custom processing. (See Table 8.)

As labor became more abundant on the medium and large farms, the tendency to substitute labor for capital was evident. With a few exceptions, increased labor use resulted in decreased capital use and lower annual total cost was the pattern shown when comparing situations with high labor to those of average and low labor availability.

Total and per ton annual cost varied within a narrow range with different labor levels for a given farm size. This finding suggests that substitution of capital for labor occurs when labor has a relatively low opportunity cost.

Next we evaluate data based on the effects of varied quantity of investment capital. It seems relevant at this point to note that the labor-capital effects are inter-related and that in the discussion of one the concurrent effects of the other must be recognized.

EFFECTS OF CAPITAL AVAILABILITY ON COMPONENT SELECTION

While labor availability did not have great effect on choice of optimal components, the same was not true for capital availability. In general, component selection follows a logical pattern of "buying" labor saving components as capital becomes abundant. On the other hand, situations with low capital levels[2] tended to select low investment (although high annual cost) items such as custom processing and commercial storage. The close relationship between labor and capital is apparent in the selection of system components (Tables 8, 9, 10). Some occasional complementary as well as the expected competitive relationships are shown; the complementary relationships are usually slight and never extend the entire range of observations.

[2]Exceptions were the medium and large farms with high labor.

TABLE 8. COMPOSITION OF LEAST COST SYSTEMS WITH SMALL FARM SIZE

System Component	LOW LABOR Quantity of Capital			AVERAGE LABOR Quantity of Capital			HIGH LABOR Quantity of Capital		
	High	Average	Low	High	Average	Low	High	Average	Low
Grain Storage	Wood Frame	Wood Frame	Commercial	Wood Frame	Wood Frame	Commercial	Wood Frame	Wood Frame	Commercial
Grain Handling	Low Labor Elevator and Augers	Low Labor Elevator and Augers	Trucking	Low Labor Elevator and Augers	Low Labor Elevator and Augers	Trucking	Low Labor Elevator and Augers	High Labor Portable Auger	Trucking
Feed Processing	Custom Mobile Mill	Custom Mobile Mill	Custom Mobile Mill	Custom Mobile Mill	Custom Mobile Mill	Custom ic Mobile Mill	Auto-Electric Mill and Bins	Custom Mobile Mill	Custom Mobile Mill
Cattle Feeding	Fence Line Bunk, PTO Mix-Grinder	Fence Line Bunk, PTO Mix-Grinder	Self Unloading Wagon, Fence Line Bunk	Fence Line Bunk, PTO Mix-Grinder	Fence Line Bunk, PTO Mix-Grinder	Self Unloading Wagon, Fence Line Bunk	Fence Line Bunk, PTO Mix-Grinder	Fence Line Bunk, PTO Mix-Grinder	Self-Unloading Wagon, Fence Line Bunk
Hog Feeding	Self Feeder and Augers	Self Feeder and Augers	Self Feeder and Augers	Self Feeder and Augers	Self Feeder and Augers	Self Feeder and Augers	Self Feeder and Augers	Self Feeder and Augers	Self Feeder and Augers

TABLE 9. COMPOSITION OF LEAST COST SYSTEMS WITH MEDIUM FARM SIZE

	LOW LABOR Quantity of Capital			AVERAGE LABOR Quantity of Capital			HIGH LABOR Quantity of Capital		
System Component	High	Average	Low	High	Average	Low	High	Average	Low
Grain Storage	Round Steel	Wood Frame	Commercial	Round Steel	Wood Frame	Commercial	Round Steel	Wood Frame	Commercial
Grain Handling	Low Labor Elevator and Augers	Low Labor Elevator and Augers	Trucking	Low Labor Elevator and Augers	Low Labor Elevator and Augers	Trucking	High Labor Portable Auger	High Labor Portable Auger	Trucking
Feed Processing	Auto-Electric Mill and Bins	Auto-Electric Mill and Bins	Custom Mobile Mill	Auto-Electric Mill and Bins	Auto-Electric Mill and Bins	Custom Mobile Mill	Auto-Electric Mill and Bins	Portable PTO Grinder and Auger Wagon	Portable PTO Grinder and Auger Wagon
Cattle Feeding	Fence Line Bunk, PTO Mix-Grinder	Fence Line Bunk, PTO Mix-Grinder	Self Unloading Wagon, Fence Line Bunk	Fence Line Bunk, PTO Mix-Grinder	Fence Line Bunk, PTO Mix-Grinder	Self Unloading Wagon, Fence Line Bunk	Fence Line Bunk, PTO Mix-Grinder	Fence Line Bunk, PTO Mix-Grinder	Self-Unloading Wagon, Fence Line Bunk
Hog Feeding	Self Feeder and Augers	Self Feeder and Augers	Self Feeder and Augers	Self Feeder and Augers	Self Feeder and Augers	Self Feeder and Augers	Self Feeder and Augers	Self Feeder and Augers	Self Feeder and Augers

TABLE 10. COMPOSITION OF LEAST COST SYSTEMS WITH LARGE FARM SIZE

	LOW LABOR			AVERAGE LABOR			HIGH LABOR		
	Quantity of Capital			Quantity of Capital			Quantity of Capital		
	High	Average	Low	High	Average	Low	High	Average	Low
Grain Storage	Round Steel Bins	Round Steel Bins	Commercial	Round Steel	Round Steel	Commercial	Round Steel	Round Steel	Commercial
Grain Handling	Low Labor Elevator and Augers	Low Labor Elevator and Augers	Trucking	Low Labor Elevator and Augers	High Labor Portable Auger	Trucking	High Labor Portable Auger	High Labor Portable Auger	Trucking
Feed Processing	Auto-Electric Mill and Bins	Auto-Electric Mill and Bins	Custom Mobile Mill	Auto-Electric Mill and Bins	Auto-Electric Mill and Bins	Custom Mobile Mill	Auto-Electric Mill and Bins	Portable PTO Grinder and Auger Wagon	Portable PTO Grinder and Auger Wagon
Cattle Feeding	Fence Line Bunk, PTO Mix-Grinder	Fence Line Bunk, PTO Mix-Grinder	Self Unloading Wagon, Fence Line Bunk	Fence Line Bunk, PTO Mix-Grinder	Fence Line Bunk, PTO Mix-Grinder	Self Unloading Wagon, Fence Line Bunk	Fence Line Bunk, Wagon and Scoop	Fence Line Bunk, Wagon and Scoop	Fence Line Bunk Wagon and Scoop
Hog Feeding	Self Feeder and Augers	Self Feeder and Augers	Self Feeder and Augers	Self Feeder and Augers	Self Feeder and Augers	Self Feeder and Augers	Self Feeder and Augers	Self Feeder and Augers	Self Feeder and Augers

TABLE 11. LABOR AND CAPITAL REQUIREMENTS FOR VARIOUS FARM SIZES AND DIFFERENT LABOR LEVELS

Farm Size	Labor Availability	Hours Labor Used		Capital Used		Annual Cost	
		Total	Per Ton	Total	Per Ton	Total	Per Ton
Small	Low	74.20	.44	$ 2246.75	$13.40	$1027	$6.13
	Average	67.54	.40	2246.75	13.40	1027.88	6.13
	High	71.38	.49	3067.92	18.30	1006.29	6.00
Medium	Low	170.60	.43	$ 6770.32	$17.03	$1786.81	$4.49
	Average	170.60	.43	6770.32	17.03	1787.14	4.49
	High	232.70	.59	6626.52	16.67	1667.83	4.19
Large	Low	440.46	.46	$17,856.46	$18.60	$4001.90	$4.17
	Average	442.66	.46	17,514.89	18.24	3944.43	4.11
	High	666.78	.69	14,662.55	15.23	3958.25	3.77

On the small size farm, as available capital was varied from low to average, labor use decreased slightly but capital use more than doubled. As a result, total annual costs decreased (Table 12). Table 14 shows that in changing from low to average capital levels, the small farm used about 2 hours less labor, $1529 more capital and annual cost was decreased slightly by approximately $188 per year. As the opportunity cost of capital was further reduced (indicating a high capital level) a change from average to high capital level was observed. However, the optimal situation indicated about the same amount of total labor used (< .2 hours more). Capital increased by about $913 and annual costs were $20.12 lower. On a per ton basis, annual cost decreased sharply when capital increased to average but decreased only slightly when capital increased from average to high.

Resource use on the small farm exhibited two basic differences from the larger sizes compared. With the change from low to average capital the medium and large farms increased labor use whereas slightly less labor was used on the small farm. In changing from average to high capital, the medium and large farms reduced labor use, while the small farm slightly increased labor used. This indicates that capital can be substituted for labor up to a point; then the relationship becomes complementary. As still more capital becomes available, the substitution relationship reappears.

Further study of Table 14 shows that relaxation of capital restraints for the medium farm case from the low to the average supply gives only 2.4 hours increase in labor consumption; however, capital use increased by about $5086 and total annual costs decreased $640. As more capital was available (from average to high) 26.20 fewer hours were used, $1623 more capital was substituted and annual cost was reduced about $53.

On a per ton basis, changing from low to average capital quantities on the medium farm size, increased the labor use by 0.1 hours, capital invested by $13 per ton and achieved a decrease in annual total cost of about $1.60 per ton. Per ton changes were less significant when capital changed from average to high—in fact, costs decreased only $.17 per ton.

As quantity of capital moved from low to average, the large farm used 19 hours more labor and $13,522 more capital. Annual total costs were reduced about $1577 and costs fell $1.64 per ton. A high capital level reduced labor by about 68 hours and investment capital by $1349 and increased annual costs $60 per year or $ .06 per ton.

Annual cost per ton decreased as amount of capital expanded.[3] However, the greatest decrease was when capital increased from low to average, thus indicating a diminishing productivity for capital (and labor) in the activities studied as size increased. Cost per ton decreased as annual fixed costs are distributed over larger tonnages and would continue on tonnages larger than those studied until limits of capacity of components forced use of higher cost alternatives.

NON-USE OF COMPONENTS

Many popular and efficient components were not used in any of the optimum systems. Many factors had bearing on this; the method, the assumptions, as well as the input coefficients and prices all had varying degrees of influence on use or non-use of components.

Grain storage alternatives using different forms of artificial drying and those storing high moisture grain did not enter the optimum solutions for any farm size, labor or capital variations. For the small farm assumption, the small volume of grain limited use

[3]An exception is the large farm when capital increased from average to high and cost per ton increased slightly.

TABLE 12. LABOR AND CAPITAL REQUIREMENTS FOR VARIOUS FARM SIZES AND DIFFERENT CAPITAL LEVELS

Farm Size	Capital Availability	Hours Labor Used		Capital Used		Annual Cost	
		Total	Per Ton	Total	Per Ton	Total	Per Ton
Small	Low	70.05	.42	$1129.99	$ 6.88	$1152.69	$6.88
	Average	68.11	.41	2759.30	16.46	964.75	5.75
	High	68.29	.41	3672.13	21.91	944.62	5.64
Medium	Low	198.77	.50	$2946.29	$ 7.41	$2190.71	$5.52
	Average	201.77	.51	8132.48	20.46	1550.49	3.90
	High	174.97	.44	9755.06	24.55	1497.24	3.73
Large	Low	530.67	.55	$ 7200.46	$ 7.50	$4890.06	$5.09
	Average	549.71	.57	20722.37	21.58	3312.64	3.45
	High	481.82	.50	22071.04	22.99	3372.22	3.51

TABLE 13. CHANGES IN LABOR AND CAPITAL USE FROM LABOR QUANTITY FOR ALL FARM SIZES

	Small Farm Labor Level Change		Medium Farm Labor Level Change		Large Farm Labor Level Change	
	Low to Average	Average to High	Low to Average	Average to High	Low to Average	Average to High
Total Labor (hours)	−6.66	3.84	0	62.10	2.20	224.12
Total Capital ($)	0	821.17	0	−143.80	−341.57	−2852.34
Annual Total Cost ($)	0	−21.59	.33	−119.31	−57.47	13.82
Labor Per Ton (hours)	−.04	.09	0	.16	0	.23
Total Capital Per Ton ($)	0	4.90	0	−.36	−.36	−3.01
Annual Cost Per Ton ($)	0	−.13	0	−.30	−.06	−.34

TABLE 14. CHANGES IN LABOR AND CAPITAL USE FROM CAPITAL QUANTITY FOR ALL FARM SIZES

	SMALL FARM Capital Level Change		MEDIUM FARM Capital Level Change		LARGE FARM Capital Level Change	
	Low to Average	Average to High	Low to Average	Average to High	Low to Average	Average to High
Total Labor (hours)	−1.94	+.18	+2.40	−26.20	+19.04	−67.89
Total Capital ($)	+1529.31	+912.83	+5086.19	+1622.58	+13521.91	+1348.67
Annual Total Cost ($)	−187.94	−20.13	−640.22	−53.25	−1577.42	+59.58
Labor Per Ton (Hours)	−.01	0	+.01	−.07	+.02	−.07
Total Capital Per Ton ($)	+9.78	+5.55	+13.05	+4.09	+14.08	+1.41
Annual Cost Per Ton ($)	−1.13	−.11	−1.62	−.17	−1.64	.06

of high moisture storage. With the larger farm sizes, capital investment seemed, in most instances, to be restrictive. Improvement in storage efficiency was more than offset by the increase in the combined storage and handling investment and annual costs. The capacity to dry or store was a limitation in only a few combinations. If an additional penalty for storage losses had been imposed other alternatives would have been considered. Lower-cost high moisture storage units and flat and round steel bins with dryers at higher volumes would have been competitive. A flat rate loss charge per ton storage (as compared to a percentage or proportional loss) could also influence components selected. Furthermore, the restriction against multiple-use of storage facilities undoubtedly had its effect. Handling systems, too, were restricted by labor, capital and relative annual cost and by incompatability between some storage and handling systems.

Additionally, varying opportunity costs for labor to reflect seasonal variation might have resulted in some different solutions. Inclusion of some of these factors would load to a huge matrix and added greatly to the computational burden.

Also many alternatives in grain storage and feed processing are affected less by annual cost, relatively, than by rationing of labor and capital via the opportunity cost concept. The model used considers the competitive nature of labor and capital within a given activity, but takes little note of total farm resource competition. For alls size farms essentially the same pattern of selection was observed. Capital tended to be limiting at high or average labor quantities but at low levels, labor and unit costs had more influence.

A number of factors determined the feed processing components used. Custom grinding at the elevator (40) had both the highest annual cost and labor input, hence, was never competitive under any circumstances programmed. All other processing methods were affected by economies of size so that varying levels of cost and capital were en-encountered.

The PTO mixer-grinder and PTO grinder-auger wagon-mixer were limited by insufficient capacity, capital supply and cost. The more pronounced limitation here, however, was labor. Custom processing was used extensively in the face of restricted capital conditions. Size and cost variations influenced the selection of custom processing when capital cost increased. The PTO mill-auger wagon entered solutions for medium and large size farms when labor was abundant to average and capital cost relatively high.

The automatic electric mixer-grinder with overhead bins was not considered when labor and capital levels were average or low. The PTO mill and auger wagon replaced the automatic mill when labor was abundant and capital relatively scarce. Here, capital input definitely appears the influencing factor.

High capital requirement was a major influence in some component cattle feeding systems being sub-optimal. All self-feeder alternatives had relatively high investments because of the non-divisibility of the investment. The same high capital investment limited those alternatives using a mechanized feeder. In both cases, increased use by feeding more than a single lot of cattle annually would lower the investment. These alternatives also have a relatively high annual cost, as a result of high fixed costs related to the investment.

Hog feeding systems offered little choice since the auger self-feeder system was lowest in requirements for labor and capital and annual cost.

In its most practical application, planning of a system for storing grain, processing feed and feeding livestock could consider multiple use equipment capabilities in several required processes. Thus, the duplication of an auger wagon for cattle feeding, a power take off mixer-grinder for processing, and an auger to fill hog self feeders, would not find practical support.

SUMMARY

Economies of size of operations appear at the higher tonnage levels used; some economics reflect the linearity of the input coefficients and others are related to non-divisibility of inputs. Hence, increased volume results in an actual decrease in fixed costs. At the tonnages used, economies of labor input per ton did not appear. The input per ton did, however, appear to be decreasing marginally and shows a possibility of decreasing some at still higher tonnages.

Labor and capital use appear to have a complementary relationship on small size operations. At larger sizes of operation these factors assumed a definite role as substitutes. The non-labor annual costs showed little variation regardless of opportunity cost of labor thus indicating that capital is a good substitute for labor.

Detailed examination of capital changes indicates that a substitution effect between labor and capital may exist at very small farm sizes of grain storage and feed processing. A size increased, a limited range of complementarity appeared, then disappeared to again assume the substitution relationship. A wide variation was noted on both capital and labor quantity within alternative components, depending on the relative level of these inputs.

The findings of this study substantiate a need for a reasonable estimate of earnings associated with alternative uses of labor and capital resources on the farm as a basis for selecting optimal least-cost systems. Further indicated was the importance of the total amount of resources available for selection of applicable component equipment. Important to the accuracy of the final decision is whether labor and capital would act as substitutes or complements at a particular level of anticipated use.

Implied but not explicit is a need for enough flexibility within a system to permit change in size of components as the costs and quantities of labor and capital change. It is always implied that the all costs and physical coefficients (i.e., labor and capital standards) need to be accurately evaluated. These data are difficult to assemble and not usually in the exact form needed for budgeting or linear programming. The system for a specific situation must allow for individual operator or manager restrictions which may result in a "sub-optimal" decision; there must be, however, an awareness of the opportunity cost of such self imposed limitations. Choice of some component equipment on farms is dictated by such items as local availability, individual preference and prestige values. These factors were not considered in this study. Neither, as indicated earlier, were the possible added economies of multiple use of storage units or other equipment, or use of components jointly with other necessary activities.

Finally, the overall decision making role of the manager forces him to ultimately evaluate the performance of the grain storage and feeding activity in relation to performance of other activities and the overall effect on farm resource earnings.