Publication 5002

AGRICULTURAL MATERIALS HANDLING MANUAL

PART 1

SECTION 1.1

SYSTEMS ENGINEERING

Agriculture Canada

Publication 5002

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SECTION 1.1

SYSTEMS ENGINEERING

The Agricultural Materials Handling Manual is produced in several parts as a guide to designers of materials handling systems for farms and associated industries. Sections deal with selection and design of specific types of equipment for materials handling and processing. Items may be required to function independently or as components of a system. The design of a complete system may require information from several sections of the manual.

L.M. STALEY
BIO-RESOURCE ENGINEERING DEPARTMENT
UNIVERSITY OF BRITISH COLUMBIA
VANCOUVER, B.C.

PREPARED FOR THE CANADA COMMITTEE ON AGRICULTURAL ENGINEERING SERVICES OF CANADIAN AGRICULTURAL SERVICES COORDINATING COMMITTEE

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SECTION 1.1 SYSTEMS ENGINEERING

1.1.1 GENERAL

The seven sections of this manual have been organized to provide, in a concise manner, the essentials of engineering design for handling materials on or about the modern farmstead.

Part 1 deals with processes that may be used in assisting the materials handling designer to select the **best** combination of alternatives that are available to the modern farm manager. The design of a food or feed delivery system seeks either to provide an optimum amount of food delivery for a given farmstead, or minimize cost of the system for a final amount of material to be handled.

Part 2 discusses the many types of conveying and material carrying equipment available to the farming public. The emphasis is on intelligent equipment selection rather than the mechanical design of the equipment itself. Part 3 focusses on the many treatments and processes to which agricultural materials may be subjected on the farmstead and provides guidance in selecting equipment to carry out these treatments and processes. Part 4 deals with the selection and matching of electric power sources for the equipment treated in Parts 2 and 3. Part 5 focusses on the control equipment and control system design for a material handling installation. An additional feature of this section is a discussion of instrumentation useful for indicating to the operator the state of various parts of the controlled and controlling systems. These include electrical, liquid and air flow, humidity, light and weight changes. Part 6 is concerned with temporary and longer term storage of feed and food items. This includes the environmental conditions that the storage facility must create for safe efficient containment of the stored material. It also discusses the influence that the properties of the stored material have on the durability and safety of the storage, as well as the storage's loading and unloading characteristics.

Finally, Part 7 is a listing of the physical and mechanical properties of agricultural materials and various engineering formulae that will provide the materials handling engineer with a ready source of information.

A system contains hardware components and human components, and hence a man/machine interface and a society/system interface. Parts, 2, 3 and 4 then are more concerned with the hardware of an agricultural materials handling system while Part 5 provides some aspects of the man/machine interface and Part 6 provides some aspects of the society/system interface.

The design engineering of an agricultural materials handling system will find many tools of the industrial or production control engineer useful since there are many similarities between the modern farm and factory or business. Production process control, effective labor utilization and inventory control are examples. The application of operations research techniques are also useful in optimizing the economic performance of man-made systems or in selecting the best system from many alternatives. These techniques frequently require a digital computer to carry out the many computations (interactive processes). Most provincial extension engineering branches now have computer services available. This manual cannot treat in detail all the mathematical models now available and the serious user should consult the references, especially 15, for further information.

1.1.2 CHARTS AND DIAGRAMS

When designing a new materials handling system, or modifications to an existing one, it is always useful to depict the various stages with a flow chart or block diagram. The development should start with the initial conditions and end with the final condition as shown in Figure 1.1.1.

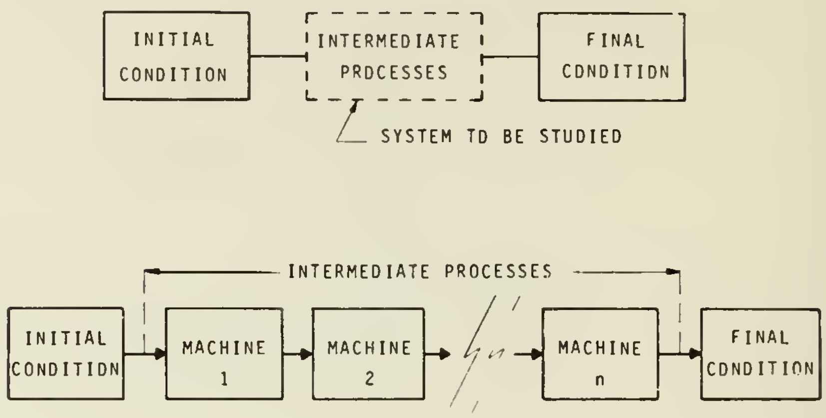

Figure 1.1.1 A planning flow diagram

Assume the initial condition is silage in a silo and the final condition is the silage blended with concentrates in a feed bunk. The intermediate processes then are some sequence of events, machines or tools that will accomplish the transition from initial to final condition. Several alternatives may exist for the intermediate processes. These alternatives should be laid out and evaluated for overall suitability. Quantities, physical and mechanical properties, required environmental conditions, etc., should be specified wherever possible.

One possible set of intermediate steps might be (1) remove silage from silo, (2) transfer silage to blender, (3) blend silage with concentrate, (4) transfer mixture to mechanical feed bunk, and (5) distribute feed into feed bunk.

1.1.2.1 Flow Process Chart

A flow process chart such as the one illustrated in Figure 1.1.2 is useful for detail study of the progression of material or a person through a materials handling system. These charts are frequently used along with a scaled plan view of the proposed elements in the system. Five symbols have been adopted by A.S.M.E. The ○ indicates an operation or modification to a material or product. It is usually carried out at one location, i.e. a grinder or hammermill. The ⇨ indicates movement or transportation of the product or material from one point to another, i.e. a belt conveyor. The □ indicates inspection of some type, i.e. weighing, counting, comparing against a standard. The D indicates a delay or waiting period. The ▽ indicates storage which may be either short term or long term.

Each step in a sequence is indicated by joining the appropriate symbols with a straight line. Each step is numbered and space is available for a short description. To design the most efficient system the questions Why?, What?, Where?, When? How? should be answered for each step. The objective is to eliminate or shorten travel,

FLOW PROCESS CHART

SUMMARY

	PRESENT		PROPOSED		DIFFERENCE	
	No.	Time	No.	Time	No.	Time
○ Operations						
⇨ Transportations						
□ Inspections						
D Delays						
▽ Storages						
Distance Travelled		Ft.		Ft.		Ft.

JOB ______________________

LOCATION ______________________

BEGINS AT ______________________

ENDS AT ______________________

CHARTED BY ____________ DATE ____________

STUDY NO. ______ PAGE ________ OF ________

WORKER □ OR PRODUCT □

DESCRIPTION [Present □ Proposed □]	Number	Operation	Transport	Inspect	Delay	Storage	ANALYSIS: Distance in feet	Time in minutes	WHY? What?	Where?	When?	Who?	How?	NOTES	ACTION: Combine	Chg. Seq.	Simplify
	1	○	⇨	□	D	▽											
	2	○	⇨	□	D	▽											
	3	○	⇨	□	D	▽											
	4	○	⇨	□	D	▽											
	5	○	⇨	□	D	▽											
	6	○	⇨	□	D	▽											
	7	○	⇨	□	D	▽											
	8	○	⇨	□	D	▽											
	9	○	⇨	□	D	▽											
	10	○	⇨	□	D	▽											
	11	○	⇨	□	D	▽											
	12	○	⇨	□	D	▽											
	13	○	⇨	□	D	▽											
	14	○	⇨	□	D	▽											
	15	○	⇨	□	D	▽											
	16	○	⇨	□	D	▽											
	17	○	⇨	□	D	▽											
	18	○	⇨	□	D	▽											
	19	○	⇨	□	D	▽											
	20	○	⇨	□	D	▽											

Figure 1.1.2 A typical flow process chart

reduce operations and inspections and avoid unnecessary delays.

Where alternative methods or equipment are suggested prepare a flow process chart for each alternative. Comparisons between alternatives can best be done by completing a summary for each. Engineering data for the handling characteristics of several classes of agricultural materials handling equipment are contained in succeeding sections of this manual.

The initial planning should consider long-term expansion and ultimate needs of a farmstead. Starting from current needs each addition can then be made according to the long-term plan. An example might be the random siting of grain storage bins (if no plan existed), compared to the circular layout of bins with a central hopper and radial loading auger illustrated in Figure 1.1.3. The latter economizes on equipment needs and labor requirements for filling. See Section 6.2.2.2 for further details.

Some typical flow patterns that can be used in agricultural materials handling systems are illustrated in Figure 1.1.4.

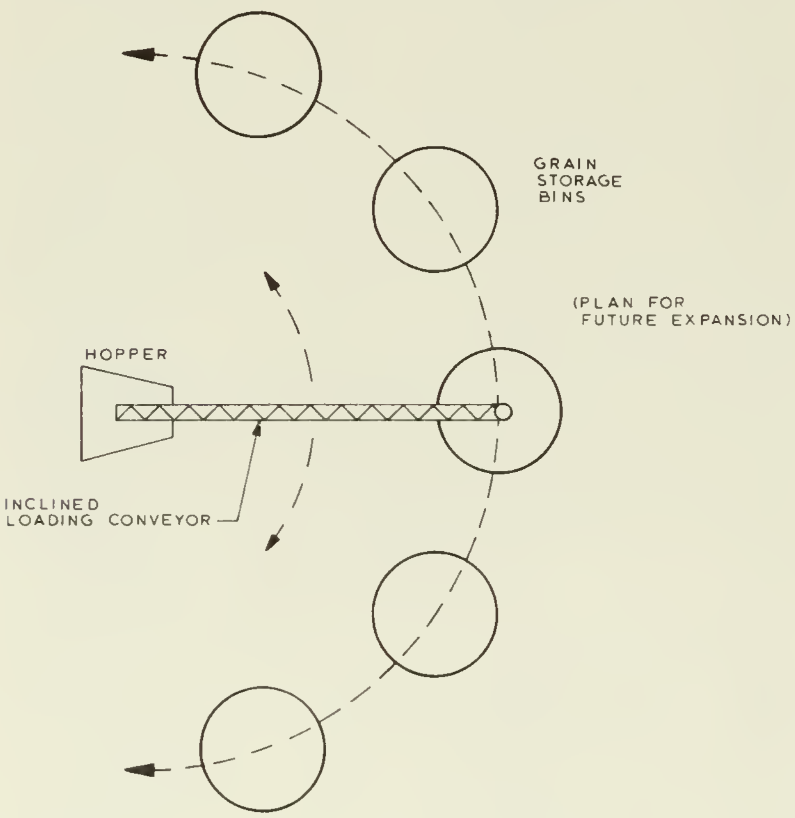

Figure 1.1.3 Plan for multiple use of equipment and future expansion

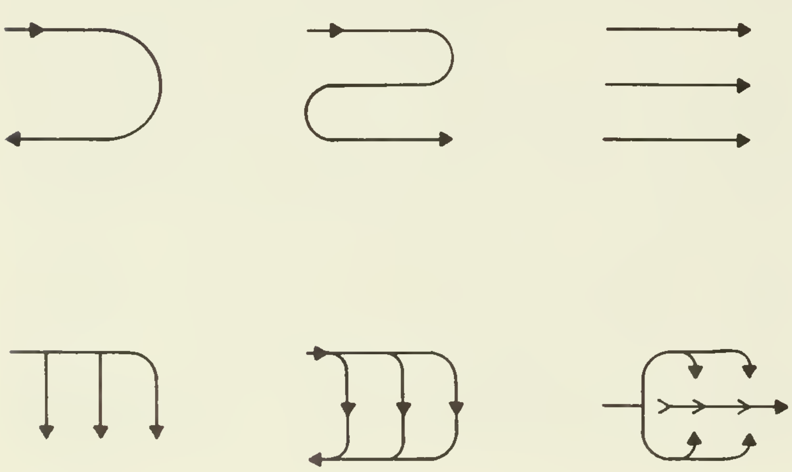

Figure 1.1.4 Typical material flow patterns

1.1.2.2 Principles of Materials Handling

The Materials Handling Institute Inc. (8) has adopted 20 principles of material handling. The following might be considered for agricultural material.

1. *Planning*. Plan all handling and storage activities for maximum overall efficiency.
2. *System*. Integrate as many handling activities as practical.
3. *Material flow*. Plan operation sequences and equipment layout to optimize material flow.
4. *Simplification*. Reduce, eliminate or combine movements and/or equipment.
5. *Gravity*. Use gravity to move material wherever possible.
6. *Space utilization*. Make optimum utilization of building space.
7. *Unit size*. Increase quantity or size of unit loads or flow rates.
8. *Mechanization*. Mechanize all handling operations.
9. *Automation*. Provide automatic controls where possible.
10. *Equipment selection*. Consider all aspects of the material handled including the movement and method to be used.
11. *Standardization*. Standardize handling methods, types and sizes.
12. *Adaptability*. Use methods and equipment that can best perform the variety of tasks where special purpose equipment is not justified.
13. *Utilization*. Plan for optimum utilization of equipment and manpower.
14. *Safety*. Provide suitable methods and equipment for safe handling.

1.1.2.3 Man-machine Chart

Many materials handling activities involve both machines and operator working together. The operator supplies the machine with material, starts the machine, makes necessary adjustments, and then removes the finished product from the machine. The operator is usually idle while the machine is running and the machine is idle while the operator loads and unloads material. By using man-machine charts such as seen in Figure 1.1.5 the reduction of idle time and scheduling can be studied. An appropriate time scale is chosen and the working periods are shaded in for the operator and the machines. The percentage of idle time at the end of a cycle can be computed and the chart studied to determine if any element or operation can be eliminated and if the percentage idle time can be reduced. An example of this type of study is the use of two or more milking machines in a milking parlor. To effectively use man-machine charts reliable data on the time required to perform farm tasks is necessary.

1.1.2.4 Standard Time Data

Standardized times for performing tasks in an industrial plant have been well established for some time. Only recently have data become available for agricultural tasks. Appendices A to D contain information for management activities in milking parlors, feed lots and piggeries.

Standard times are obtained by measuring the actual time to perform tasks either with stop watch or movie camera and later analysis of each frame on the film. A statistical sample of individuals and repetition of tasks is required. The results are averaged and usually a 15% allowance is added to the average observed time to allow for personal needs and work breaks. The resulting time is the standard time for the task.

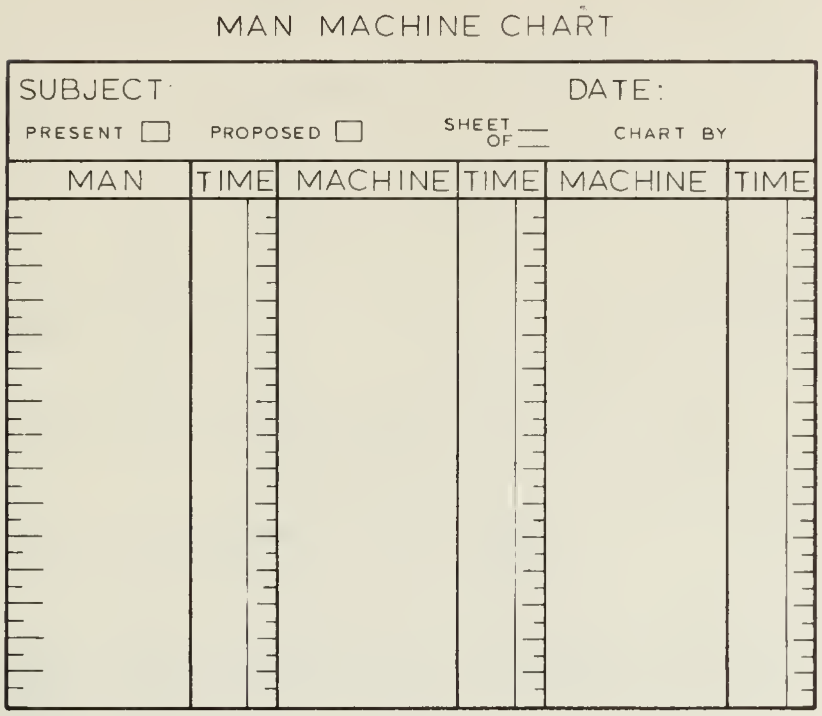

Figure 1.1.5 Man-machine chart

1.1.2.4.1 **Simulated Time**

Time for tasks for which standard time has not been established can be estimated reasonably accurately by utilizing Methods-Time Measurement (MTM) data. This data was established from detailed analysis of motion picture records of basic body motions. A time measurement unit (TMU) was standardized at 0.00001 hours or 0.036 seconds. A simplified summary of this data is shown in Table 1.1.1. It should be noted that this data contains a 15% allowance. Additional data for more complex movements is contained in reference (9).

This data can be used in two ways: (1) by visualizing an operation not yet existent; and (2) by observing an already established operation.

The first method requires the most care to get accurate results but allows the designer to compare methods of performing a task without entering into the expense of first setting up a real situation. Figure 1.1.6 is a block diagram of the steps involved. They are create, organize, plan, analyze, and compare.

1.1.2.5 **Break-even Charts**

Break-even charts can be used to indicate graphically the point at which fixed costs plus operating costs equal total sales or revenue. The vertical axis is usually expressed in

TABLE 1.1.1 Methods-time Measurement Application Data (Simplified Data[1])

Hand and Arm Motions			Body, Leg and Eye Motions	
REACH OR MOVE		TMU		TMU
25 mm		2	Simple foot motion	10
50 mm		4	Foot motion with pressure	20
75 to 300 mm		4 + length of motion	Leg motion	10
over 300 mm		3 + length of motion	Side step case 1	20
			Side step case 2	40
(For Type 2 reaches and moves use length of motion only)			Turn body case 1	20
			Turn body case 2	45
POSITION				
Fit	Symmetrical	Other	Eye time	10
Loose	10	15		
Close	20	25	Bend, stoop, or kneel on one knee	35
Exact	50	55	Arise	35
TURN-APPLY PRESSURE			Kneel on both knees	80
Turn		6	Arise	90
Apply pressure		20		
			Sit	40
GRASP			Stand	50
Simple		2		
Regrasp or transfer		6	Walk per pace	17
Complex		10		
DISENGAGE				
Loose		5		
Close		10		
Exact		30		

1 TMU = 0.00001 hour
= 0.0006 minute
= 0.036 second

[1]All times include 15% allowance.

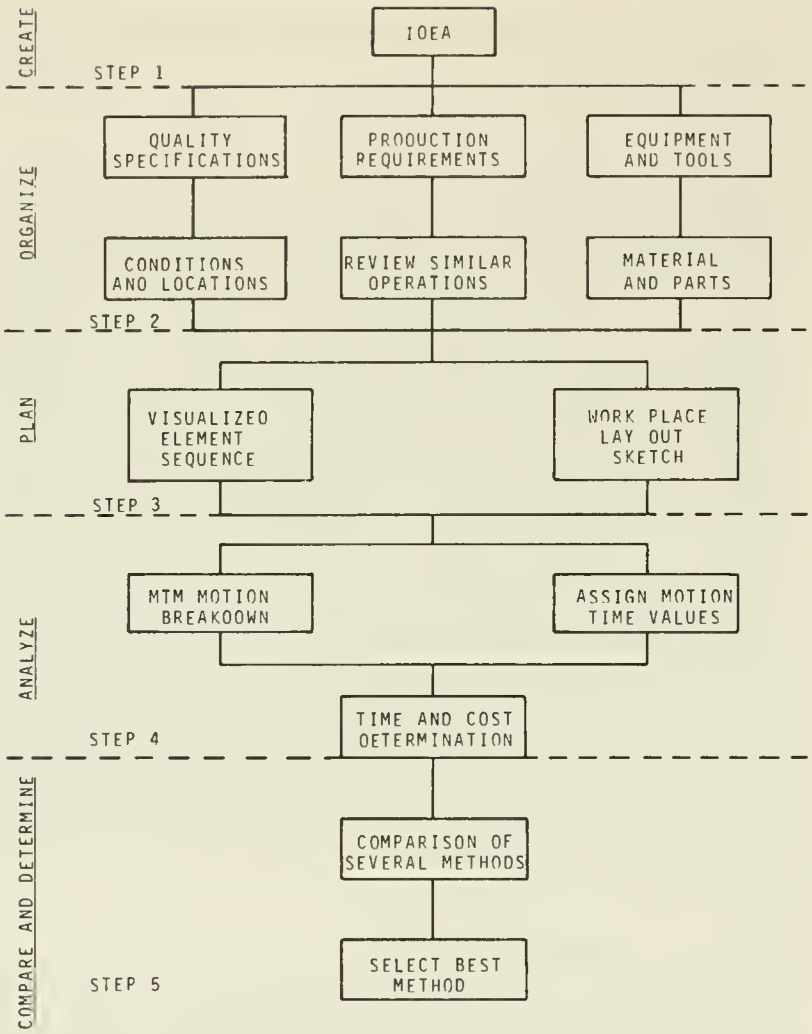

Figure 1.1.6 Five stages of planning a materials handling system

terms of costs or profits and the horizontal axis may express volume in terms of sales dollars or percent of capacity or years as shown in Figure 1.1.7. An alternate use is to illustrate a short payoff method for comparing machines or processes.

It is simply a rearrangement of the entries of a partial budget. In this method, the annual operating advantage anticipated through the purchase of new equipment is compared to the procurement, less trade-in, and installation cost of the proposed equipment. The point in time at which the saving in operating cost equals the net capital outlay is called the "break-even point". Figure 1.1.7 shows a break-even chart illustrating the short payoff method. Decisions to purchase are indicated when the break-even points falls within a "short-payoff period" of 3 to 6 years. Conversely, "don't buy" decisions are indicated when the break-even point falls outside the short payoff period. The decision making point, or short payoff period is determined by calculating the number of years required for interest and depreciation charges to equal 100% of a capital expenditure. For example, if interest and depreciation charges are each estimated at 10% per annum, then the payoff period

$$\text{in years} = \frac{100\%}{10\% + 10\%} = 5 \text{ years.}$$

Whereas this method has been explained on a basis of comparing a proposed system to an existing system, the method is equally valid in comparing two or more proposed systems. To do this, the proposed system having the lowest capital cost outlay is considered as the standard, or "old" equipment. Alternatives are then compared to this artificial standard.

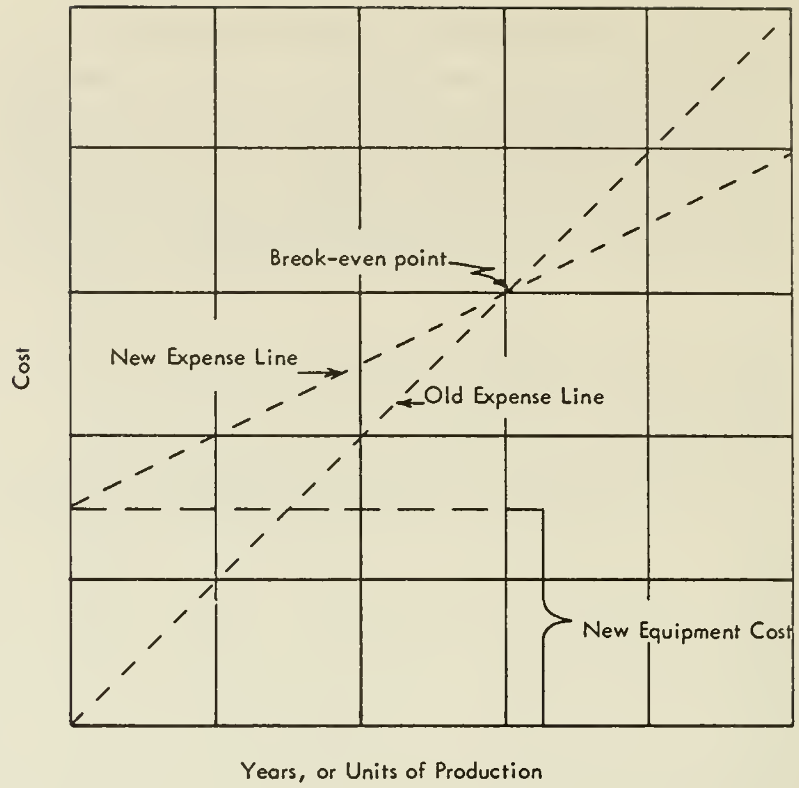

Figure 1.1.7 Break-even chart illustrating short payoff method

The short-payoff period method should be considered as roughly equivalent to the incremental cost budget method, and is extremely useful for rough discriminations. It should not however be considered a detailed analysis (7).

For more detailed analysis of machinery and mechanization planning the services of CANFARM is recommended. CANFARM is a cooperative program offered by provincial and federal governments and by agricultural faculties in universities across Canada. An example of an application form for *machinery planning: replacement* analysis is shown in Figure 1.1.8. Other computer services on machinery management are also offered by the Ontario Ministry of Agriculture and Food through a series of computer programs under the acronym COMSOLV.

1.1.3 MATHEMATICAL PLANNING MODELS

Models are devices used to depict or explain the workings of the real world. There are various types of models available to the engineer. Road maps, building plans or flow charts as shown in 1.1.2.1 are a pictorial or functional relationship. Dimensional models may be used to portray the spacial relationship of things. In systems planning the mathematical model has proven useful to define or predict how events in the real world will behave under given input and operational procedures. Once set up, the mathematical model can be more easily manipulated to predict the outcome of various events. The following sections are some examples of mathematical models that may be applied to designing materials handling systems. To approximate the real world however the number of variables involved usually precludes solving the mathematical model by hand. Therefore digital computers have become an essential part of mathematical modelling and many computer systems now have software packages for solving these.

CANFARM

MACHINERY PLANNING: REPLACEMENT

CONTACT NO

PURPOSE OF: 1 Farm Application 3 Promotion 2 Staff Training 4 Other

FARM I D NO (If on Farm Records) OR NAME

REPORTS TO BE MAILED TO: [1] Contact and Farmer (Print Farmer's Name and Address below) [2] Contact Only

REPORT IDENTIFICATION

(1)
(2)
(3)
(4)

REPORTS	NEW MACHINE	OLD MACHINE
(5) Listback of Your Problem Information	Summary of Average Annual Costs	Summary of Annual Costs
	Annual Costs for: Minimum Average Costs; All Other Years (Total of 9 Reports)	Annual Costs

GENERAL INSTRUCTIONS

Most of the information required for the program is self-explanatory but a few additional comments may be helpful

If a particular question does not apply to your problem enter a zero

Line 2	Whatever unit you choose to use must also be used in lines 16 20 to 24 28 and 33 to 36
Lines 3 and 4	A distinction is made between hired labor and owner labor since the cost of hired labor may result in a tax saving
Line 8	Your estimate of the average annual rate of inflation if you want to consider inflation otherwise enter zero
Lines 16 and 28	This refers to those machines which operate in conjunction with other equipment If applicable provide the operating costs per unit of the associated equipment
Lines 20 and 33	In cases where unit used is hour enter 1
Lines 18 and 30	This is actually the minimum resale value of the machine
Line 24	The value of additional losses or gains in yield resulting from using the new machine as compared to your old machine
Lines 26 and 38	You have a choice in this line either enter the letter for the value equation most representative of your type of machine (see beside) or enter your estimates of values expected for each of the next ten years
Lines 25 and 37	Similar to lines 28 and 38 see beside for selecting the most representative letter for the equation if equation type method is used

SUGGESTED TYPICAL INFORMATION

Machine Type	*Depreciation Equation	Capital Cost Allowance Rate %	Repair Equation	Estimated Wearout Life (Hours)
Tractors 4 wheel drive	A	30	A	12 000
Tractors 2 wheel drive	A	30	B	12 000
Combines Self propelled	B	30	C	2 000
Combines PTO	B	20	E	2 000
Manure spreaders	C	20	C	2 500
Trucks	C	30	C	3 000
Forage harvestor self propelled	D	30	C	2 000
Forage harvestor PTO	D	20	D	2 000
Corn picker	C	20	D	2 000
Potato harvestor	C	20	D	2 500
Baler	D	20	D	2 500
Blower ensilage	D	20	D	2 000
Swather self propelled	B	30	E	2 500
Hay conditioner	C	20	E	2 500
Rake side delivery	C	20	E	2 500
Seeding equipment	C	20	E	1 200
Fertilizer equipment	C	20	F	1 200
Tillage equipment (plows cultivators harrows etc)	C	20	G	2 500

Typical insurance and housing rates are 2% of list price

0058-504 1 (7751) 48a

MACHINERY PLANNING - REPLACEMENT

GENERAL INFORMATION

	Sample Machine	Your Machine
1 MACHINE NAME UP TO 10 LETTERS	Swather	(6)
2 UNIT USED e.g. ACRE HOUR ETC.	Acre	(7)
3 HIRED LABOUR COST PER MACHINE HOUR	2.50	(8)
4 OWNER LABOUR COST PER MACHINE HOUR	0	
5 FUEL COST IN DOLLARS PER GALLON	0.41	
6 CAPITAL COST ALLOWANCE RATE (%)*	30	
7 ANNUAL INSURANCE AND HOUSING RATE (%)*	2.5	
8 INFLATION FACTOR (%)	10	(9)
9 TAX RATE EXPECTED (%)	18	
10 INTEREST RATE OF BORROWING MONEY (%)	15.5	
11 REQUIRED RETURN ON EQUITY	9.5	
FOR NEW MACHINE		
12 PURCHASE PRICE	8000	(10)
13 MONEY TO BE BORROWED	6000	
14 REPAYMENT PERIOD OF BORROWED MONEY (IN YEARS)	6	
15 AGE OF MACHINE IN YEARS (0 FOR NEW MACHINE)	0	
16 ASSOCIATED COST PER UNIT	0	
17 ESTIMATED WEAROUT LIFE (IN HRS)*	2500	(11)
18 SALVAGE OR SCRAP VALUE	350	
19 FUEL CONSUMPTION (GALS PER HR)	3	
20 ESTIMATED PERFORMANCE (UNITS PER HOUR)	3	
21 UNITS OF OWN USE PER YEAR	600	
22 UNITS OF CUSTOM WORK DONE FOR OTHERS PER YEAR	45	(12)
23 CUSTOM RATE PER UNIT	3.75	
24 GAIN OR LOSS PER UNIT	0	

	Sample Machine	Your Machine
25 DEPRECIATION EQUATION ABC or D OR EXPECTED VALUE OF MACHINE FOR EACH OF THE NEXT 10 YEARS	B	(13)
(13) YOUR MACHINE 1 2 3 4 5 6 7 8 9 10		
26 REPAIR EQUATION A B C D E F or G* OR EXPECTED REPAIR COSTS FOR EACH OF THE NEXT 10 YEARS	E	(14)
(14) YOUR MACHINE 1 2 3 4 5 6 7 8 9 10		
FOR THE OLD MACHINE (Optional)		
27 AGE OF MACHINE IN YEARS	4	(15)
28 ASSOCIATED COST PER UNIT	0	
29 TODAY'S VALUE OF MACHINE	1600	
30 SALVAGE OR SCRAP VALUE	300	
31 REMAINING UNDEPRECIATED CAPITAL COST	840	
32 FUEL CONSUMPTION (GALS PER HOUR)	3.0	(16)
33 ESTIMATED PERFORMANCE (UNITS PER HOUR)	2.75	
34 UNITS OF OWN USE PER YEAR	600	
35 UNITS OF CUSTOM WORK DONE FOR OTHERS PER YEAR	45	
36 CUSTOM RATE PER UNIT	3.75	
37 DEPRECIATION EQUATION (ABC or D) OR EXPECTED VALUE OF MACHINE FOR EACH OF THE NEXT 10 YEARS		(17)
38 REPAIR EQUATION A B C D E F or G* OR EXPECTED REPAIR COSTS FOR EACH OF THE NEXT 10 YEARS		(18)

Line 37:

	1	2	3	4	5	6	7	8	9	10
SAMPLE MACHINE	1300	1150	1000	900	800	700				
YOUR MACHINE (17)										

Line 38:

	1	2	3	4	5	6	7	8	9	10
SAMPLE MACHINE	200	210	220	230	240	250				
YOUR MACHINE (18)										

0058-504 1 (7751) *SEE FRONT OF FORM 48b

Figure 1.1.8 Computerized machinery management - replacement analysis (Courtesy of CANFARM)

1.1.3.1 Linear Programming (LP)

Linear programming refers to a group of mathematical techniques whose aim is to optimize performance in terms of combination of resources. Linear refers to the requirement that the relationship between variables is a straight line when these variables are plotted on a graph. If the rental relationship is not linear then the range of the independent variable may be restricted to provide a linear approximation between the variables, or more complex techniques beyond the scope of this manual may be required. A general formulation of the problem is:

$$\sum_{j=1}^{m} A_{ij}\, x_j \leqslant b_i, \quad i = 1.....n$$

and we wish to maximize as objective function

$$Z = \sum_{j=1}^{m} c_j\, x_j$$

where $x_j \geqslant 0, \quad j = 1.....m.$ (1)

For j=2 the problem can be solved graphically but for j>2 a computer solution is essential.

Each activity such as growing corn, raising beef, etc., is designated the X variable and the coefficients form the columns of a matrix that are read into the computer. Each restraint such as hours of labor, dollars of capital, etc., make up a row of the matrix. The major task of the planning engineer is to formulate the problem and determine realistic coefficients.

The following example is given to illustrate problem execution and interpretation.

1.1.3.1.1 Example Problem

A broiler producer wishes to add a specialty line of roasting chicken and Cornish game hens to supply a local urban market. Buildings and a feed-mixing plant, that will supplement his existing housing and mixing plant, are available to him on an adjacent farm. To maximize his profits he wishes to know if both feed plants should be modified to handle the three different feed rations or if only one ration should be produced in one mill and hence confine one of the feeding activities in the buildings associated with the special purpose mill. Before the materials handling engineer can recommend modifications to conveyors, processing equipment, control devices and storage facilities a study of the alternatives must be made.

The engineer decides that a linear programming model might be appropriate for this situation and begins to obtain operational costs of the two mills, available hours of operation, feed requirements, expected revenue and sales potential of the three planned activities. Since there are three groups to be fed and two sources of feed there are six identifiable activities which can be labled as:

x_1 broilers fed from mill A
x_2 broilers fed from mill B
x_3 roasters fed from mill A
x_4 roasters fed from mill B
x_5 Cornish game fed from mill A
x_6 Cornish game fed from mill B

Time requirements to mix 100 kg of feed, variable hourly costs and total available time for the mills A and B are:

Group	Hours/100 kg of feed	
	A	B
Broilers	0.25	0.20
Roasters	0.40	0.25
Cornish game	0.35	0.40
Variable cost/hour	$250	$300
Max. hours/week	100	100

Sales and demand was expected to be:

	Sales revenue ($/100 kg feed)	Max. demand (100 kg feed units/wk)
Broilers	$100	310
Roasters	$120	300
Cornish game	$150	125

The net profit Z will be the difference between revenue and variable costs, hence:

$$Z=100(x_1+x_2)+120(x_3+x_4)+150(x_5+x_6)-250(0.25x_1+0.4x_3+0.35x_5)-300(0.2x_2+0.25x_4+0.4x_6).$$

Collecting terms

$$Z=37.5x_1+40x_2+20x_3+45x_4+62.5x_5+30x_6=\text{max}.$$

This is the objective function of the linear programming model. The limitations on this objective function are available hours of operation of the two mills and demand of the product from the mills. These limitations can be written as inequalities.

$$\begin{aligned}
0.25x_1 + 0.4x_3 + 0.35x_5 &\leqslant 100\\
0.2x_2 + 0.25x_4 + 0.4x_6 &\leqslant 100\\
x_1 + x_2 &\leqslant 310\\
x_3 + x_4 &\leqslant 300\\
x_5 + x_6 &\leqslant 125
\end{aligned}$$

The objective function and the above inequalities are now in a form for computer solution using the linear programming model that is available at most computing centers.

Table 1.1.2 is an illustration of the output from the UBC computing center. It shows that the optimal value of the objective function or maximum profit is $33,250 and that from our original definition 185 units of broiler feed should be produced from mill A, 125 units from mill B for a total demand of 310 which agrees with our input. Our total demand of 300 units of roaster feed should all come from mill B, hence roasters should not be located at the site of mill A, and finally 125 units of Cornish game feed should come from mill A. It is also noted that the computer program has added a variable x_7=10 hours of unused time at mill A. It should be emphasized that the inequality equations must be changed to equalities by adding what is known as a slack variable to the equation. On some computer linear program models these may have to be included in the input data file. Mill A then is operated at 90% capacity and mill B is operated at 100% capacity.

If coefficient ranging can be performed as in this example we see that the profit coefficient from activity x_1, provided the other coefficients remain the same, can vary between 20 and 40 before any change in activities would be required to give us an optimal solution. The profit coefficient from x_3 (producing roaster feed from mill A) would have to exceed 41.87 before this activity would enter our optimal solution.

For values on the right-hand side of the inequalities the output shows that mill B can work between 92 and 137

TABLE 1.1.2 Computer Output of Linear Programming Example Problem

```
FEED PLANT SIZING

DATA LOADED

INPUT TABLEAU:
  FIRST ROW CONTAINS OBJECTIVE FUNCTION
  NEXT    5 ROWS CONTAIN INEQUALITY CONSTRAINTS



           COL.  1      COL.  2      COL.  3      COL.  4      COL.  5      COL.  6      COL.  7
ROW  1     37.500       40.000       20.000       45.000       62.500       30.000      0.0
ROW  2     0.25000      0.0          0.40000      0.0          0.35000      0.0          100.00
ROW  3     0.0          0.20000      0.0          0.25000      0.0          0.40000      100.00
ROW  4      1.0000       1.0000      0.0          0.0          0.0          0.0          310.00
ROW  5     0.0          0.0           1.0000       1.0000      0.0          0.0          300.00
ROW  6     0.0          0.0          0.0          0.0           1.0000       1.0000      125.00

ITERATION LOG:
ITERATION      OBJ.FUN.          VAR.IN   VAR.OUT

PHASE II BEGINS
FEASIBLE
    1            7812.50            5        11
    2           21312.5             4        10
    3           26312.5             2         8
    4           33250.0             1         9


OPTIMAL VALUE OF THE OBJECTIVE FUNCTION=          33250.00


PRIMAL SOLUTION VECTOR:
VARIABLE            VALUE

    1              185.0000
    2              125.0000
    4              300.0000
    5              125.0000
    7              10.00000      SLACK   1


THE REDUCED COSTS:
VARIABLE            VALUE

    3              21.87500
    6              37.50000


    DUAL SOLUTION VECTOR:
    VARIABLE            VALUE

        2              12.50000
        3              37.50000
        4              41.87500
        5              62.50000

    OBJECTIVE FUNCTION COEFFICIENT RANGING:
     COEFF.          LOWER BOUND          COST/PROFIT          UPPER BOUND

        1              20.00000             37.50000             40.00000
        2              37.50000             40.00000             57.50000
        3             -INFINITY             20.00000             41.87500
        4              23.12500             45.00000            +INFINITY
        5              25.00000             62.50000            +INFINITY
        6             -INFINITY             30.00000             67.50000

    RIGHT HAND SIDE RANGING:
     NUMBER          LOWER BOUND             RHS              UPPER BOUND

        1              90.00000            100.0000            +INFINITY
        2              92.00000            100.0000             137.0000
        3              125.0000            310.0000             350.0000
        4              152.0000            300.0000             332.0000
        5             0.0                  125.0000             153.5714

    *** END-OF-DATA REACHED
```

hours before any change in activities would be indicated. It also indicates the demand for feed for Cornish game hens would need to exceed 153.57 units with all other right-hand-side values remaining constant before any change in activities would be warranted.

The materials handling engineer can now proceed with plans to modify the mills to handle only two feed formulations each and mill A will need to operate only 90 hours per week. This is a very simplified example but the results are not obvious from a less detailed study of the data. A more detailed discussion of linear programming is available in numerous books and publications such as references 1,2,4,5. It should be remembered that the results obtained from a mathematical model such as LP will only be as accurate as the input coefficients one can obtain for the objective function and inequality equations.

1.1.3.2 Network Models

There are several special forms of network models that have been applied in agricultural mechanization. One model that is widely used for construction projects is critical path scheduling, or CPS. Most computing centers have this model in their program library.

1.1.3.2.1 Critical Path Method

The critical path method is based on the following principles:

1. projects can be organized into components;
2. components have a magnitude measured in time units; and
3. some components must precede others to successfully execute the project.

Any activity which, if increased in duration, increases the total project by a like amount is called a critical activity. The path which connects these critical activites in a time sequence is the critical path.

Associated with each activity is an earliest start time (EST) and an earliest finish time (EFT). The EST for an activity is the latest EFT of all its preceding activities. The EFT for an activity is the EST plus its duration. The EFT for an activity is the EST for all its successor activities. The latest start time (LST) for an activity is its latest finish time (LFT) minus its duration. The free float (FF) is the maximum delay that an activity can have from its EST before other activities are affected. The total float (TF) is the maximum delay that an activity can have from its EST before the project duration is increased.

The activities are represented by arrows which form a network that has a beginning node or point in time and a terminal node which marks the completion of the project. The times are calculated automatically by existing computer algorithms when the activities, their performance time and precedence relationships (as indicated by the numbering of their tail and head arrows) are inputed.

1.1.3.2.2 Shortest Path Network Analysis

The production of an agricultural commodity usually involves a set of many possible alternative methods or components. These alternatives can be depicted as a directed network with a unique initial and terminal point or node. If values can be established for each activity making up the alternate pathways, such as time, cost, distance, energy used, etc., then an optimum solution can be found. An algorithm called Shortest Path Network Analysis (SPNA) has proven advantageous for this type of problem. The program was initially formulated by Preston (13) and modified with computer documentation provided by Lievers (6). Ogilvie et al (10) gives the following advantages of the algorithm: (a) the network is an integral part of the approach and once constructed relates directly to the program input; (b) the SPNA program is easy to use with algebraic relationships input as FORTRAN equations to assign values to each arc of the network; (c) nonlinear functions can be used without linear approximation; (d) initial output of the analysis includes a valuation and ranking of all possible alternatives (not just the optimal as given by LP); and (e) the network and the SPNA application provide a basis for later simulation of selected alternatives involving stochastic parameters such as weather.

Section 3.5 shows examples of simplified networks for handling wastes from dairy and swine units using SPNA. Figure 1.1.9 is an abbreviated computer flow chart provided by Ogilvie (11).

SPNA FLOW CHART

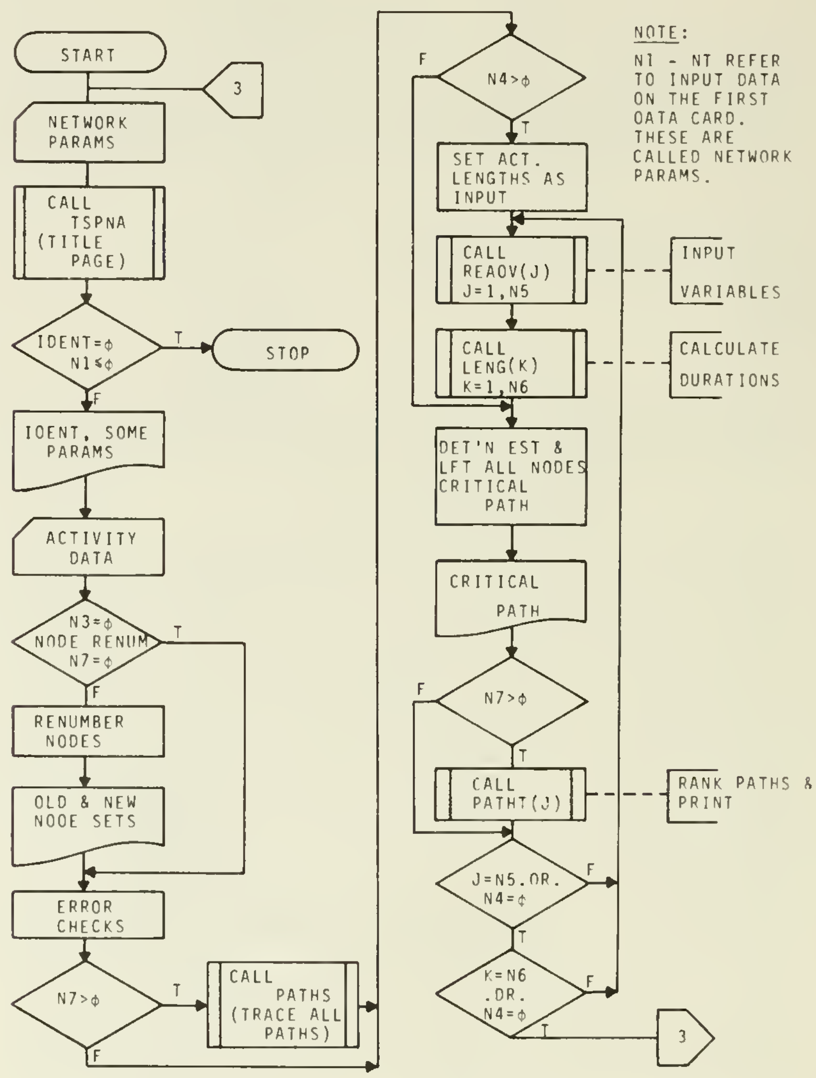

Figure 1.1.9 Computer flow chart for SPNA analysis (Courtesy Dr. J.R. Ogilvie)

1.1.3.3 Waiting Lines

The theory of waiting lines (or queuing theory) was first developed by Erlang, a Danish telephone engineer, prior to World War I. It has been widely used by industry since World War II and recently is gaining attention in agricultural and food processing situations.

1.1.3.3.1 **Single Channel Waiting Lines**

The general waiting line situation has three primary components: (1) an arrival mechanism, (2) the waiting line or queue proper and (3) the service provided or departure mechanism. Each may be simple or very complex. The question usually asked is how to balance the cost of providing a service against the economic returns provided by the service. For example, is it worthwhile to spend money speeding up service by providing more labor, service equipment, etc., in terms of the savings in production, inventory or delay costs?

To answer the above question it is usually first necessary to answer such questions as: What is the average length of the line of waiting units? How long will an arrival at the service facility have to wait before being served? How long will an arrival have to wait before its service is completed? What is the probability that a unit will even wait for service? What is the utilization of the service facilities? And what is the utilization of the units being serviced?

Table 1.1.3 lists some examples of waiting lines that occur in production agriculture.

For the case of a single queue with a first-in, first-out discipline and random arrival and service rates the following formulae can be used to calculate attributes of a waiting line. Assumptions and definition of terms are:

1. arriving population is ∞ with arrival random at a rate, λ
2. single service channel, first-come, first-served, service rate is random with a value, μ.
3. the queue can be infinite

n = number of units in the queue and in the service facility
Pn(t) = probability of n units in the system at time, t.
Pn = probability of n units in the system at any time after start-up transients have dropped out.
λ = arrival rate or reciprocal of time between arrivals
μ = service rate or reciprocal of average service time, not the time between service completions since there are times when the service facility is not engaged.
$\bar{n}$ = average number in the system
$\bar{q}$ = average number in the queue
1-Po = probability the service channel is in use or utilization of the service system
Po = probability the service is empty

Some useful queuing formulas selected from Page (12) are:

Probability that the system is empty
Po $= 1-(\lambda/\mu)$ (1)

Probability that the service channel is in use
$= \lambda/\mu$ (2)

Average queue length
$= \lambda^2/\mu(\mu-\lambda)$ (3)

Average length of non-empty queue
$= \mu/(\mu-\lambda)$ (4)

Average waiting time of an arrival
$= \lambda/\mu(\mu-\lambda)$ (5)

Average number of units in the system
$= \lambda/(\mu-\lambda)$ (6)

Average time an arrival spends in the system
$= 1/(\mu-\lambda)$ (7)

1.3.3.2 **Example Problem**

During harvesting operations it is noted that trucks arrive at the crop storage building at the average rate of one every 0.83 hours and the arrival times are random. The men and equipment used to transfer the load from the truck to storage take an average of 0.5 hours. This service time is also noted to be random. Trucks waiting to unload must park in the service yard to wait their turn on a first-come, first-served basis. The cost of having trucks wait and unload is found to be $20 per hour. The men and equipment used to unload the trucks cost $15 per unloading hour. By changing the unloading equipment the farm operator has been told that the service rate or unloading rate can be reduced to 0.25 hours per truck but the unloading costs will triple to $45 per hour. Should the materials handling system be modified to incorporate the faster but more expensive system?

Present method:

$\mu = 1/0.5h = 2/h$
$\lambda = 1/0.83h = 1.2/h$

the average time a truck is in the system
$1/(\mu-\lambda) = 1/(2-1.2) = 1.25$ hours

average total cost per truck
= 1.25 (20) + 0.5 (15)
= $32.50

Proposed alternative:
$\mu = 1/0.25h = 4/h$
$\lambda = 1/0.83h = 1.2/h$

Average time a truck is in the system
$1/(\mu-\lambda) = 1/(4-1.2)$=0.36 hours

TABLE 1.1.3 Typical Agricultural Situations Involving Waiting Lines

	Arriving Unit	Service or Process Facility
Maintenance and repair of farm machines	machine breakdowns	repair crew
Load grain bins	trucks loaded with grain	grain auger
Drying grain	damp grain	grain dryer
Grain, forage and orchards	crops ripening in fields	combine or harvester
Eggs on grading belt	eggs	egg candler
Milking cows	cows	milking parlor
Livestock feeding	livestock	feeding conveyor

New total cost per truck
= 0.36 (20) + 0.25 (45)
= $18.45

Since there is a saving of $14.05 per truck the new equipment should be recommended for use in this situation.

1.1.3.4 Simulation or Monte Carlo Methods

There are many situations where exact relationships or interactions between variables do not exist or a mathematical description of the real-world situation is too complex or difficult to solve. In these situations simulation and the use of random numbers (hence the term Monte Carlo Techniques) can be used to advantage.

When applied to waiting line situations with known mean service rate and standard deviation and the use of a table of random normal numbers such as those in Table 1.1.4 then the nature of the waiting line can be examined.

Most computer facilities will have random number algorithms as part of their capabilities so that many more replications can easily be made. Generally the more replications that are made the greater will be the reliability of the simulation.

1.1.3.4.1 Example Problem

A simple example that can be calculated easily without a computer will illustrate an approach to the use of Monte Carlo Methods.

Consider a problem of choosing a suitably sized storage bin for feed delivered to a livestock enterprise. Feed is normally delivered every 7 days but because of holidays and impassible roads on occasion during the winter a

TABLE 1.1.4 Random Normal Numbers*

			$\mu = 0, \sigma = 1$				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	0.464	0.137	2.455	−0.323	−0.068	0.296	−0.288
2	0.060	−2.526	−0.531	−1.940	0.543	−1.558	0.187
3	1.486	−0.354	−0.634	0.697	0.926	1.375	0.785
4	1.022	−0.472	1.279	3.521	0.571	−1.851	0.194
5	1.394	−0.555	0.046	0.321	2.945	1.974	−0.258
6	0.906	−0.513	−0.525	0.595	0.881	−0.934	1.579
7	1.179	−1.055	0.007	0.769	0.971	0.712	1.090
8	−1.501	−0.488	−0.162	−0.136	1.033	0.203	0.448
9	−0.690	0.756	−1.618	−0.445	−0.511	−2.051	−0.457
10	1.372	0.225	0.378	0.761	0.181	−0.736	0.960
11	−0.482	1.677	−0.057	−1.229	−0.486	0.856	−0.491
12	−1.376	−0.150	1.356	−0.561	−0.256	0.212	0.219
13	−1.010	0.598	−0.918	1.598	0.065	0.415	−0.169
14	−0.005	−0.899	0.012	−0.725	1.147	−0.121	−0.096
15	1.393	−1.163	−0.911	1.231	−0.199	−0.246	1.239
16	−1.787	−0.261	1.237	1.046	−0.508	−1.630	−0.146
17	−0.105	−0.357	−1.384	0.360	−0.992	−0.116	−1.698
18	−1.339	1.827	−0.959	0.424	0.969	−1.141	−1.041
19	1.041	0.535	0.731	1.377	0.983	−1.330	1.620
20	0.279	−2.056	0.717	−0.873	−1.096	−1.396	1.047
21	−1.805	−2.008	−1.633	0.542	0.250	0.166	0.032
22	−1.186	1.180	1.114	0.882	1.265	−0.202	0.151
23	0.658	−1.141	1.151	−1.210	−0.927	0.425	0.290
24	−0.439	0.358	−1.939	0.891	−0.227	0.602	0.973
25	1.398	−0.230	0.385	−0.649	−0.577	0.237	−0.289
26	0.199	0.208	−1.083	−0.219	−0.291	1.221	1.119
27	0.159	0.272	−0.313	0.084	−2.828	−0.439	−0.792
28	2.273	0.606	0.606	−0.747	0.247	1.291	0.063
29	0.041	−0.307	0.121	−0.790	−0.584	0.541	0.484
30	−1.132	−2.098	0.921	0.145	0.446	−2.661	1.045
31	0.768	0.079	−1.473	0.034	−2.127	0.665	0.084
32	0.375	−1.658	−0.851	0.234	−0.656	0.340	−0.086
33	−0.513	−0.344	0.210	−0.736	1.041	0.008	0.427
34	0.292	−0.521	1.266	−1.206	−0.899	0.110	−0.528
35	1.026	2.990	−0.574	−0.491	−1.114	1.297	−1.433
36	−1.334	1.278	−0.568	−0.109	−0.515	−0.566	2.923
37	−0.287	−0.144	−0.254	0.574	−0.451	−1.181	−1.190
38	0.161	−0.886	−0.921	−0.509	1.410	−0.518	0.192
39	−1.346	0.193	−1.202	0.394	−1.045	0.843	0.942
40	1.250	−0.199	−0.288	1.810	1.378	0.584	1.216

*This table is reproduced in part from a table of the RAND Corporation.

standard deviation of 3 days is to be expected. The feed requirements are 1600 kg/day with a standard deviation of 400 kg. Based on extreme values one would expect the answer to be between 4 days x (1200 kg/day)=4800 kg, to 10 days x (2000 kg/day)=20 000 kg.

A 3 month winter period simulated is shown in Table 1.1.5 based on random normal numbers selected from Table 1.1.4. From this one winter simulation it is seen that a 17 500 kg storage would be needed. Five or ten years of results should be generated to determine the frequency with which this figure may be exceeded. Additional information on Monte Carlo simulations can be obtained from Churchman (3).

1.1.4 MEASURES OF EFFECTIVENESS

The designer of an agricultural material handling system should develop a clear understanding with his farmer client on how the final system should be judged. Waymore (14) discusses the development of a "measure of effectiveness" that can be used to determine the acceptability of a system for a particular farmstead. Generally there will be two sets of measures of effectiveness, one based on the input/output specifications and the other based on the available technology. Those measures of effectiveness that are common to both sets are the measures that should be used to judge the acceptability of the design.

Items to be considered in a measure of effectiveness are such things as dependability, availability, repairability, durability, capability, vulnerability, etc.

A "figure of merit" can be developed to provide some numbered rating to these "-ilities". For example durability might be years of service, repairability might be the inverse of anticipated annual repair costs. Capability might be the weight or volume of material handled per unit time. Other figures of merit might be numbers from 1 to 10 where the higher number is used to rate the most desirable aspect of the particular measure of effectiveness. Summing all these figures of merit and choosing the maximum value attributable to a particular piece of equipment or system would ensure that the system designer has met the original expectations of his client.

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TABLE 1.1.5 Monte Carlo Simulation of Feed Storage Capacity

(1) Random Normal No. Table 1	(2) Feed Consumed (kg/day) 1600 + 400 (1)	(3) Random Normal No. Table 1	(4) Days since last delivery 7 + 3(3)	(5) Total Feed required kg (2) (4)*
0.768	1907	0.542	9	17160
0.375	1750	0.882	10	17500
-.513	1394	-1.210	4	5580
0.292	1716	0.891	10	17160
1.026	2010	-0.649	5	10050
-1.334	1066	-0.219	7	7460
-0.287	1485	0.084	8	11880
0.161	1664	-0.747	5	8320
-1.346	1061	0.790	10	10610
1.250	2100	0.145	8	16800
0.137	1654	0.034	8	13230
-2.526	589	0.234	8	4710

*Quantities have been rounded to nearest 10 kg.

Engineering (PERCAE). Contr. no. I-112, Engineering and Statistical Research Institute, Agriculture Canada, Ottawa K1A 0C6. Latest ed., June 1979, revised periodically.

1.1.6 APPENDICES

Appendix A Standard Time Data For Side-entering and Herringbone Milking Parlors

Elements	Stall Type: Side Entering min	Stall Type: Herringbone min
1. Open headgate	0.025	0.040
2. Close headgate	0.036	0.042
3. Close tailgate	0.040	0.049
4. Open tailgate	0.023	0.034
5. Feed chop by lever/crank	0.013	0.034
6. Feed chop by rope/pull		0.024
7. Dip teatcups	0.056	0.042
8. Install machine		0.119
9. Install machine (bucket)	0.247	
10. Install machine (pipeline)	0.201	
11. Remove machine		0.036
12. Remove machine (bucket)	0.088	
13. Remove machine (pipeline)	0.046	
14. Dump rollo-measure		0.024
15. Right rollo-measure		0.036
16. Pour bucket into carrying pail	0.080	
17. Fill chop pail from bin	0.032	
18. Dump chop into feeder	0.038	
19. Walk (per step)	0.012	0.012
20. Wash rag	0.036	0.036
21. Wash cow with rag	0.120	0.120
22. Wash cow with hose	0.087	0.087
23. Machine strip	0.257	0.257
24. Hand strip	0.061	0.061
25. Dry udder with paper towel	0.112	0.112
26. Grease udder after milking	0.067	0.067
27. Strip check into hand	0.112	0.112
into cup	0.137	0.137
28. Hold door open by rope	0.171	
by vacuum	0.124	
29. Open door by rope		0.045
30. Close door by rope		0.040
31. Record milk weight	0.090	0.090
32. Dry hands	0.036	0.036
33. Reset Milko-meter to zero	0.041	0.041
34. Hang up cluster	0.020	0.020

Appendix B Standard Milking Time Data for Herringbone Milking Parlors and Stanchion Barns

STANDARD TIME DATA FOR HERRINGBONE MILKING PARLORS

Element	Average min/cow
Prepare to milk	0.21*
Let cow in	0.17
Feed concentrate	0.04
Let cow out	0.12
Wash udder with rag	0.29
Dry udder	0.06
Put on milker	0.22
Take off milker	0.08
Dry cow	0.62
Dip milker	0.08
Record milk weight	0.22
Wash udder with hose	0.21
Treat udder after milking	0.15
Clean up utensils	0.37*

*These elements varied according to the number of animals being milked. That is: 1. the average total time for a herd of 33 animals is 6.33 minutes or 0.19 min/hd; 2. the average total time for a herd of 84 animals is 9.12 minutes or 0.11 min/hd.

Average total time per milking = 2.84 min/cow.

STANDARD MILKING TIME DATA FOR STANCHION BARNS

Element	Average min/cow
Prepare to milk	0.25
Wash cow	0.39
Put on milker	0.67
Strip cow	0.80
Elapsed time	0.58
Take off milker	0.16
Dump milker	0.18
Clean up	0.29

Average total time per milking = 3.94 min/cow.

ELEMENT DESCRIPTION - STANCHIONS

Prepare to milk: This is the total time taken by the operator to prepare the rinse water, milkers, filters and step saver and to move equipment to the stable.

Wash cow: This element involves wetting the cloth in rinse water, washing cow's udder and returning cloth to the bucket.

Put on milker: The operation beginning from the time the milker top is replaced on the milker, put on the cow, and the operator returns to the middle of the walkway.

Strip cow: This is the time from when the operator moves to the milker until he shuts off the vacuum.

Take off milker: This is the time from when the vacuum is shut off until the operator has reached the dump station in the center of the walkway.

Dump milker: The time involved from taking the top off the milker and dumping the milk to when the top is replaced on the milker.

Elapsed time: This is the time that the operator is performing a task not directly related to milking or is idle while waiting for a task to be performed.

Clean up: The total time the operator is cleaning milkers, buckets, bulk tank and step saver.

Concentrate Handling

1. Pick up and fill two 5-gal pails with grain	0.12	min
2. Distribute two 5-gal pails of grain, setting one pail down	0.10	min

Roughage Handling

9. Remove twine and spread one bale by hand	0.37	min
13. Cut two twines on bale and pull out twine	0.032	min

Appendix C Standard Time Data For Feedlot Operations

	Time in Minutes
Concentrate handling	
1. Pick up and fill two 5-gal. pails with chopped grain	0.132
2. Walk with two filled 5-gal pails (per pace)	0.013
3. Walk (per pace)	0.012
4. Pick up and fill one 5-gal. pail	0.077*
5. Distribute two 5-gal. pails of chop without setting down	0.080
6. Distribute two 5-gal. pails of chop, setting one pail down	0.111
7. Fill two 5-gal. pails with a shovel	0.619
Roughage handling	
8. Pick up one bale and walk (per pace)	0.019
9. Remove twine and spread one bale by hand	0.367*
10. Distribute one bale with a fork	0.516
11. Walk per pace with one bale and toss	0.024
12. Walk per pace with one bale, toss and cut twine	0.027
13. Cut two twines on bale and pull out twine	0.078
14. Slip two twines off bale	0.093
15. Pull out two cut twines and discard into pile	0.093*
16. Feed one bale into hammermill with a fork	1.206
17. Pick up a forkful of roughage	0.122
18. Walk per pace with a forkful of roughage and dump	0.165**
Unloading box operations	
19. Mount tractor, start motor, put in gear, release clutch	0.165
20. Mount tractor, put in gear, release clutch (motor running)	0.019
21. Mount tractor, engage PTO, put in gear, release clutch (motor running)	0.167
22. Mount tractor	0.072
23. Put tractor in gear, release clutch (motor running) (based on one operator only)	0.023**
24. Stop tractor, turn engine off, dismount	0.117
25. Stop tractor and dismount (engine running)	0.075
26. Dismount tractor	0.059
27. Hook on wagon	0.183
28. Slip on PTO drive	0.136
29. Slip off PTO drive	0.143
30. Unhook wagon	0.157
31. Mount feed box	0.105
32. Dismount feed box	0.102
33. Spread roughage on feed box with a fork	0.410
34. Spread grain on feed box with a shovel	0.599
35. Position belt feed conveyor for unloading	0.083
36. Swing belt feed conveyor for transport	0.080
37. Position unloading auger on power box	0.103*
38. Load roughage onto feed box with 0.5 m elevator	186 kg/min*
39. Load grain onto feed box with 150 mm auger	211 kg/min
40. Load one bucket of silage onto feed box using front end loader	1.716**
41. Throw one forkful of roughage on feed	0.056**
42. Unload grain with up to 25% roughage or silage using tractor drawn unloading wagon at speed of 0.8-2.4 km/h,	0.075-0.025 min/m
43. Unload roughage & grain or silage & grain, with power box on truck at speed of 2.4-4.0 km/h (3-6 passes required per bunk)	0.025-0.015 min/m
44. Mount truck, put in gear, release clutch	0.112
45. Stop truck & dismount (engine running)	0.088
Miscellaneous operations	
46. Unhook & open board gate	0.144
47. Close board gate	0.112
48. Open wire gate	0.155
49. Close wire gate	0.265
50. Start air-cooled motor	0.418
51. Stop air-cooled motor	0.050**
52. Position tripod auger to bin	1.633**
53. Open bin door	0.077**
54. Close bin door	0.125**
55. Position tractor for belt work	0.560**
56. Position truck for unloading	1.117**
57. Weight wagon and set scales for load	0.472**
58. Set scales for load	0.167**

*Based on fewer than 10 times

**Based on fewer than 5 times

Appendix D Standard Time Data for Piggery Chores

Notes

Chopped Grain

Capacities, etc., are based on 520 kg/m³.

Baled Straw

One bale usually sufficient for 4-5 stalls or small pens per day.

Pen Sizes

Small pen - approximately 5 m²
e.g. farrowing stalls or pens and weaner pens.

Medium size - Approximately 14 m²
e.g. weaner and grower pens.

Large pen - Approximately 56 m²
e.g. grower and feeder pens.

Manure

Farrowing stall - no bedding = 1 shovelful/day
shavings = 2 shovelsful/day
straw = 3 shovelsful/day

Weaner & grower pens
no bedding 4 m² = 1 shovelful/day

One wheelbarrow load = 7-9 shovelsful.

Paces

Walking -	1 pace = 0.75 m
Carrying pail, bale, etc. -	1 pace = 0.75 m
Pushing wheelbarrow, cart, wagon, carrier -	1 pace = 0.6 m

Floor Space Requirements

These can be obtained from the various floor design types, or from the Canadian Farm Building Code (1977).

Water Requirements

Water requirements vary according to the season of the year and may be assessed by allowing 0.2 L of water for each kg of food consumed.

Feeding

Batch Handling	Standard Time in Minutes
Fill container	
1. Burlap sack (70 L)	
(i) Position sack	0.114
(ii) Fill from spout	0.311
(iii) Remove	0.128*
2. 23 L pail	
(i) Fill from spout	0.160
(ii) by dipping in bin	0.148
(iii) by shovel	0.240
(iv) from sack	0.252
3. Cart or wheelbarrow	
(i) Fill by shovel (per 100 kg)	0.205**
(ii) from spout (per 100 kg)	0.190**
Transport	
1. Load sack	
(i) Onto carrier	0.146
(ii) Onto back	0.236
2. Travel	
(i) Push wheelbarrow (average of) (per step)	0.013
(ii) Push cart of wagon	0.023
(iii) Pull track mounted carrier (1 pace = 0.6 m)	0.046
3. Walk & carry	
(i) Walk with two 23 L pails (pace) (1 pace = 0.75 m)	0.013
4. Open sack	
(i) Burlap (by string)	0.474*
(ii) Paper (23 kg) by tearing end	0.249
(iii) Paper (23 kg) by cutting	0.032
Distribute	
1. Burlap sack (70 L)	
(i) Pour into self feeder	0.313
2. Paper sack (23 kg)	
(i) Pour into self feeder	0.253
3. 23 L pail	
(i) Pour all or part into self feeder	0.179
(ii) Pour into trough or in pile	0.191
(iii) Pour approximately 5 L portion into stall	0.190
(iv) Spread two 23 L pails on pad while walking	0.387
4. 11 L pail	
(i) Scoop, pivot and pour into trough	0.160
5. 5 L hand scoop	
(i) Scoop from sack or	0.132
Scoop from cart or wagon	0.050
(ii) Pivot & pour into stall	0.092
6. Scoop shovel	
(i) Scoop, pivot, spread on pad (per shovelful)	0.179

Mechanical Feed Handling

1. Operate motor	
(i) Switch on or off	0.096
(ii) Plug in or unplug	0.172
2. Set spouts	
(i) Open or close valve	0.235
(ii) Change location of spout	0.256

3. Auger times (per 100 kg of chop)

These auger times are based on varying conditions and operating speeds. They are intended only as a guide for time and motion work. For more accurate work, formulas or charts should be used.

(i) 100 mm auger - horizontal	2.74*
(ii) 40-50 degrees	3.81
(iii) vertical	4.69**
(i) 125 mm auger	
(ii) 40-50 degrees	0.904*
(iii) vertical	2.66 **
(i) 150 mm auger	
(ii) 40-50 degrees	0.65 *

Watering

Fill	
1. 23 L pail	
(i) Dip into tank	0.073
(ii) Fill from tap	0.259
Distribute	
2. 23 L Pail	
(i) Pour part or all into trough	0.157

Cleaning

Farrowing Stall Cleanout

1. Floor-level stall with solid floor; cleaned with hoe; bedded with straw or shavings	
(i) Scrape manure from either side to area behind sow	0.245
ii) Lift out rear panel and set aside	0.089
(iii) Scrape sow manure into alley	0.242
(iv) Replace rear panel	0.103
(v) See manure removal	
Total =	0.679
2. Pedestal-type stall elevated 0.3 m and with 0.6 m of mesh along back; no bedding used	
(i) Scrape manure through mesh on either side of sow	0.524
(ii) Raise rear panel	0.075
(iii) Scrape sow manure over mesh	0.493
(iv) Lower rear panel	0.047
(v) Wash rear mesh with hose	0.546
(vi) Flush manure into gutter	0.757
Total =	2.442

Weaner, Grower & Feeder Pen Cleanout

1. Solid floor pen; bedded with straw or

shavings; undivided (small pens).

(i) Scrape manure out of pen (per m²) 0.11

2. Solid floor pen; bedded with straw or shavings; divided into sleeping & manure areas (medium or small pens).

(i) Scrape dirty bedding into manure area (per m²)	0.11
(ii) Scrape manure area into gutter (per m²)	0.21
Total =	0.32

3. Solid floor pen; no bedding used; divided into sleeping & manure areas (medium or large pens); cleaned with snow shovel & hose

(i) Scrape sleeping area (per sq ft)	0.008
(ii) Scrape manure area (per sq ft)	0.012
(iii) Open gate to gutter or	0.115
Lift mesh off gutter	0.210
(iv) Push manure into gutter (per ft)	0.051
(v) Close gate or	0.116
Replace mesh	0.275
(vi) Hose down floor (per sq ft) or	0.015
Wet down floor (per sq ft)	0.010
Dry floor with rubber scraper (sq ft)	0.009
Total =	0.821

Manure Removal

1. Shovel and wheelbarrow

(i) Load manure into wheelbarrow (per shovelful - see notes)	0.211
(ii) Push wheelbarrow (per step)	0.019
(iii) Dump wheelbarrow	0.131
Total =	0.361

2. Mechanical barn cleaner (0.45 m wide) conveyor type

(i) Cleaning time (per m of travel) 0.19

3. Mechanical cleanout by auger (125 mm auger)

(i) Cleaning time (per m of travel) 0.30

4. Sloped gutter & running water (no manual time required)

Cleaning Gates

1. Two-way gates one m wide
Used (1) to divide manure alley
and (2) to close hogs into sleeping area while
manure is removed from gutter

(i) Position gate for manure removal	0.261
(ii) Position gate across alley	0.153
Total =	0.414

Sanitation

1.

(i) Rinse scraper in disinfectant	0.068
(ii) Wash & rinse rubber boots	0.617
(i) Flush watering bowl with hose	0.250
(ii) Scrape trough with hoe	0.199
(i) Sweep alley with stable broom (per m²)	0.20
(ii) Wash down alley with hose (per m²)	0.34

Bedding

1. Distribute bedding by hand;
material within reach
(time required to talk & open bales excluded)

(i) Bed a stall or small pen with shavings	0.090
(ii) Bed a stall or small pen with baled straw	0.274
Total =	0.364

2. Bale handling

(i) Pick up and walk (per pace)	0.019
(ii) Cut two twines and pull out	0.078
(iii) Slip two twines off bale	0.093
Total =	0.190

Miscellaneous

Movements of Operator

1. Step over wooden pen partition (3 ft high)

(i) Step over partition	0.104
(ii) Step over partition while carrying hose	0.148

2. Open, walk through & close gate

(i) Without latching	0.120
(ii) And, securing latch	0.178

3. Open or close gate or door

(i) Unlatch and open	0.115
(ii) Close and latch	0.116

4. Stairs (3 m)

(i) Climb	0.409
(ii) Descend	0.312

5. Walk (per pace) (1 pace = 0.75 m) 0.012

Handle Equipment

1. Handle water hose

(i) Uncoil hose and attach nozzle	0.535
(ii) Turn tap on or off	0.232
(iii) Recoil hose	0.627

2. Hand tools (e.g. shovel, hoe)

(i) Grasp tool	0.139
(ii) Set down tool	0.104

*Element based on fewer than 10 observations
**Element based on fewer than 5 observations

Appendix E Flow Process Chart of Pig-feeding Operations