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Application of Operations Research in Agriculture

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Abstract: Operations Research is the practice of relating advanced logical theories and models to aid in better decision making and optimum utilization of resources. Applications of operations research techniques in the field of agriculture have been the theme of this study. They are applied to various aspects of agriculture like day-to-day decisions of farmers like choosing the right type of grain, farm planning, cost minimization and profit maximization on an individual farm and even production and shipment of crop. This research paper illustrates various Operations Research theories and models applied to agriculture, demonstrating them with cases and problems.

This field of study is a detailed one therefore we would primarily be focusing on 4 major techniques

1) ***Linear programming model***
2) ***Network analysis***
3) ***Game theory***
4) ***Waiting line theories***

Keywords: Linear Programming Model, Network Analysis .Game Theory, Waiting Line Theories, Agriculture, Operations Research, Profit, Optimal.

I. METHODOLOGY AND INTRODUCTION

Agriculture has been long a low profitability and high risk occupation. Specific to the scenario in the Indian agriculture sector, the sector suffers loses, improper resource management and lack of modernisation.

In this research paper, our aim is to throw light on modernising the approach towards the agricultural sector via the knowledge of Operations Research.

Through secondary research it came to light that there is a need to focus on agricultural management through various techniques such as linear programming, game theories, network analysis etc, this would induce a shift from the traditional approach and ensure optimal use of resources and maximum profits for the labour involved.

For the purpose of the study, we have taken up 4 major techniques that are both easy to comprehend and implement. The study involves individually focusing on every technique, its relevance, practicality and its mathematical derivation.

Every technique will also talk about various areas of farming enterprises where that technique can be utilised with a significant advantage.

II. LINEAR PROGRAMMING MODEL AND IT'S APPLICATION IN THE AGRICULTURAL SECTOR

Agriculture is the backbone of any country, keeping in line with this many European countries, Japan and limited parts of the USA are highly invested in using the linear programming model approach also called "programme planning" in order to optimise their produce and for an optimal running of their resources.

CONCEPT USED FOR A LINEAR PROGRAMMING MODEL

I. Finding values of the objective function at the extreme points

1) The problem that arises while solving a linear programming problem is to find an efficient set of extreme points of a convex polyhedral set determined by the objective function.
2) In a linear programming problem every extreme point is a basic feasible solution under the set of constraints,
3) similarly every basic feasible solution is also an extreme point of the set of feasible solutions

II. Choosing the optimum value

Furthermore the maximum or minimum optimum value of C^t, as x varies over j, will be one or more of the extreme points of n.

Maximize Z = $c_1x_1 + c_2x_{2+} \dots c_nx_n$

Subject to:

$a_{11}x_1 + a_{12}\ x_2 \dots + a_{1n}x_n \leq b1$

$a_{21}x_1 + a_{22}\ x_2 \dots + a_{2n}x_n \leq b2$

.

.

$a_{m1}x_1 + a_{m2}\ x_2 \dots + a_{mn}x_n \leq bm$

$x_j \geq 0$, j= 1, 2, 3....n

Can be also written as

Max Z = C^t**X**

Subject to

AX≤ b

X ≥ 0

X represents the vector of variables (to be determined) while C and b are vectors of known matrix of coefficient. The expression to be maximized is called the objective function (C^t in this case). The equation **AX ≤ b** is the constraint which specifies a convex polyhedral set over which the objective function is to be optimized. The coefficients $(c_{1,}c_2, c_3 \dots c_n)$ are the unit returns for the coming from each production process $(x_{1,}x_2 \dots . x_n)$.

MATHEMATICAL FORMULATION

To formulate the problem mathematically, the following notations are used

Z = The objective function to be maximize

X_j = Input Variables

c_i = Cost coefficients of the objective function Z

b_i = Maximum limit of the constraints

a_{ij} = Coefficients of the functional constraint equations

Maximise Z = $\sum_{i=1}^{n} c_i x_j$

Subject to constraints

$\sum_{j=1}^{n} A_{ij} x_j \leq b_i$

$x_j \geq 0$

$A_{ij} = [a_{ij}]_{m*n}$

$x_j = [x_{ij}]_{m*n}$

$b_i = [b_{ij}]_{n*1}$

$$\sum_{i=1}^{n} c_i x_j$$

$x_{ij}, c_i, b_i \in \mathrm{R}$

APPLICATION OF LINEAR PROGRAMMING IN AGRICULTURAL SECTOR

Linear programming finds its application in a vast array of fields. Since its inception, operations research is being utilised for

1) **The problem of minimization of costs of feed:** The optimal function becomes the total cost incurred while the prices and quantity become the constraints.
2) **On the Choice of a Crop Rotation Plan:** The model can be used to pick an optimal crop rotation pattern to gain maximum profit while the cost incurred at producing them becomes the constraints.
3) **Field of feed-mixing for nutritional requirements:** The model uses various combinations of feed in order to obtain an optimal feed combination keeping in mind the nutritional requirements for the animals.

QUANTITATIVE MEASURES OF AGRICULTURAL SECTOR IN LINEAR PROGRAMMING PROBLEM

- **Optimal crop pattern** and **production of food crops** with **maximum profit** is important information for agricultural planning using optimization methods. **Crop yield, man power, production cost** and **physical soil type** are required to build the method.
- This technique can be highly useful for individual farmers if the **quantitative measure,** as mentioned above, of various **alternative methods** and **resource use** can be provided. Moreover, if implemented properly the **benefits obtained from the implementation exceeds the cost incurred** by the farmer for implementing the said technique.
- On a large scale or a macro level, this technique **helps** the farming population in **agricultural management and spatial analysis.**
- **Spatial linear programming analysis** can help studies related to inter regional production and major crop adjustments. Transportation models are the simplest of linear programming models applied in agriculture.

SIMPLEX METHOD

The simplex method is another technique of finding out the corner positions (extreme values). In this method, the slack variables, introduced to convert the inequalities to equalities and the coefficients of these slack variables in c vector are zero.

$$\text{Maximise } Z = \sum_{i=1}^{n} c_i x_j$$

Subject to

$$\sum_{j=1}^{n} A_{ij} x_j + x_{n+i} = b_i$$

$$x_j \geq 0$$

LINEAR FRACTIONAL PROGRAMMING

The problem is to optimize the objective function which is the ratio of two linear functions of the decision variable with the constraints being linear. The linear fractional function programming technique is applied wherever the objective function is defined as a ratio.

MATHEMATICAL FORMULATION

Maximize

$$f(X) = \frac{h' \cdot X + \alpha}{g' \cdot X + \beta}.$$

Subject to

$$A \cdot X \leqslant a,$$
$$B \cdot X \geqslant b,$$
$$E \cdot X = e,$$

and

$$X \geqslant 0,$$

where the matrices A, B, E, as well as the vectors h, g, a, b and e, have appropriate dimensions while α and β are scalars. Without loss of generality we assume that a, b and e are non-negative. Various authors e.g. Charnes and Cooper [6], Isbell and Marlow [7], Mortos [8], Wolf [9] and Anstreicher [10] have evolved algorithms for solving LFP problems. All these algorithms start with the following three assumptions:

(1) the denominator of $f(x)$ does not vanish in the feasible region;
(2) the denominator of $f(x)$ is positive;
(3) the feasible region is bounded.

APPLICATION OF LINEAR FRACTIONAL PROGRAMMING IN THE AGRICULTURAL SECTOR

- **Maximising various macroeconomic determinants** such as rate of growth, per capita income etc with respect to the agricultural sector is one of the objectives of economic planning. These can be depicted as ratio concepts therefore linear fractional programming serves as an essential technique to maximise such determinants.
- Furthermore on a **microeconomic level** also this technique can be used for individual farmers as well using various measures of profits such as **net returns, family labour income, income from farm business** etc using an appropriate denominator For e.g. maximising returns per hour of labour used on the farm, maximising profits per dollar invested etc.

III. NETWORK ANALYSIS AND ITS' APPLICATION IN THE AGRICULTURAL SECTOR

The past years have witnessed a growth and improvement of the old and emergence of the new management planning and control tools being grouped under the head of 'network* or 'flow' plans, these were independently and simultaneously developed by the military and the industry and include PERT (Program Evaluation and Review Technique), CPM (Critical Path Method), etc. The 'network' consists of a series of related events and activities and their relationship is sequential. PERT was advanced by the U.S. Navy in connection with the Ballistic Missile Program whereas CPM was developed under the patronages of the industry in the United States of America. Defining some terms that would be frequently encountered in connection with the 'network analysis' and will assist in understanding the tools are-

Activity: It is a time-consuming constituent and occurs between two events. In simple words, an activity depicts a 'thing' that is required to be done in order to go from one event to another. The activities are denoted in a network diagram via an arrow.

Events; They are the goals or milestones that need to be done. Any 2 events are connected by an activity that is an arrow; they are at the starting as well as at the end of it. In a network diagram their representation is through a node or a box.

Positive Slack: It is the cap of additional time available to the firm to perform activities in a given slack path and still allows the activity to be completed within the needed time.

Negative Slack: It is the amount of time, which is not available to the firm to conduct the series of activities in a given slack path and still allow the activity to be completed within the required time.

Critical Path: Critical Path is a path having the largest amount of negative or the smallest number of positive slack.

A network consists of a sequence of related activities and events. It is a flow plan or a pictorial representation of the activities with the events that lead to the attainment of the ultimate objective and also illustrates a plan with activities and events arranged in an order of precedence. Hence with the assistance of this simple tool, the management can attain a position to plan the best possible use of resources in a manner that the milestone is achieved within the required time and given costs.

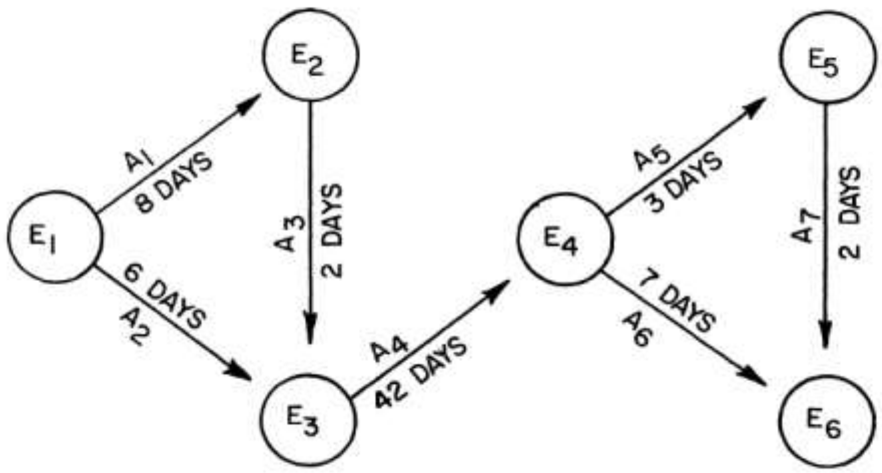
Network Analysis has been broadly used in industries for planning, scheduling and estimation of the projects. A very few applications of this analysis have been put to use in agriculture.
The most elaborate application of this has been done to solve the problem of labor.
Critical path algorithm was used to find out the solution to the problem of selecting a machine for corn production and also in making the contrasts in the costs of different systems of production.

Taking an illustration

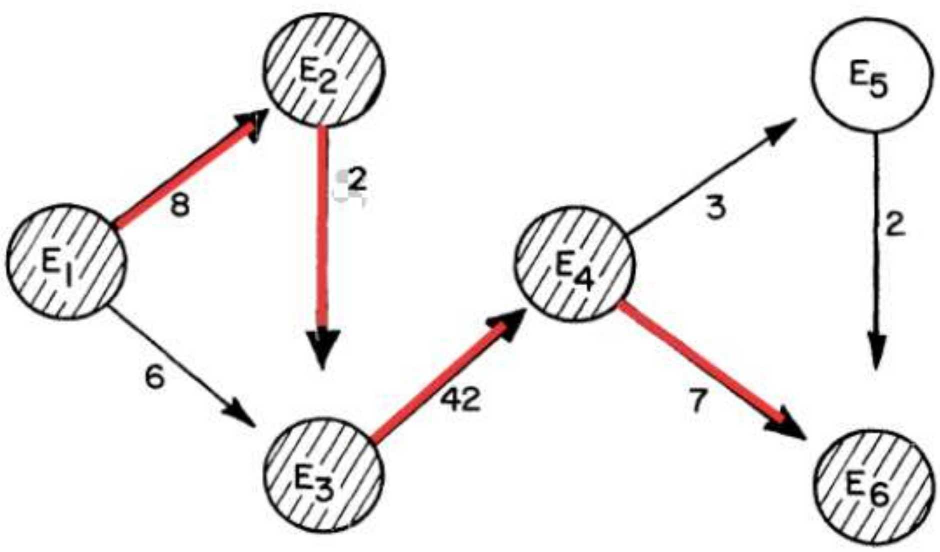
An Indian farmer intends to follow a one-year rotation of green manure taking the crop as wheat. Leguminous crops like sun hemp seeds are sown in the 'Kharif' season and ploughed in the soil at their applicable period of growth to aid as a green manure for the subsequent wheat crop. Typically, this is to be functioned from the middle of August to the first week of September because at this point of time the manure plants are moist to quickly release nutrients in the soil and there is adequate time for soil to engage the nutrients. The farmer can cultivate in the manure either with the assistance of a tractor if he owns one or can rent it and even bullocks can be used.

Ploughing in by the tractor will take nearing two days, whereas ploughing in by the bullocks is bound to take six days. Considering the heavy demand for the tractor, its availability is questionable and it might take up to 8 days to be available. His land properly cannot be prepared and get on with the succeeding activities till he has ploughed the green manure in. Furthermore, sowing can be done earliest only after six weeks of ploughing in the green manure and at the latest by the last week of October. He can sow with the bullock-drawn seed penetrate or in rows behind the plough, but again if he does not own the seed drill but has to take it on rent, which might take up to a good number of three days again.

The events, activities and the expected time required by each are stated here. They are:
A1 = Obtaining the tractor
A2 = Ploughing in the green manure through the means of bullocks
A3 = ploughing in the green manure crop via a tractor
A4 = Arrangement of the field for sowing by bullocks
A5 = Obtaining the drill for the process of sowing
A6 = Scattering/ Sowing behind the plough
A7 = Scattering/ Sowing via the seed drill
The corresponding events are:
El = Initiation/ Start (August 21)
E2 = Tractor obtained
E3 = Field being green manured
E4 = Field prepared and made ready for sowing
E5 = Drill obtained
E6 = Sowing finished/ completed (October 23)
Figure: Network Diagram of the farmer with expected time required for each activity



The diagram shows that the longest path which takes the maximum number of days is: E1-E2-E3-E4-E6, in the number of days: 8+2+42+7=59 days. The figure below shows the critical path for this example.



Time and motion studies in agriculture, which have occurred for a prolonged time, are similar to these techniques.

CPM has evidenced to be quite helpful in the construction industry and, hence, can be used with advantage for construction of huge storage plants for storage of agricultural supplies. In places where farmers depend on moneylenders and organizations like government for the supply of fertilizers, and rent machinery and equipment from for cultivation, a plan can be drawn to make the most efficient use of the machinery by larger number of members in a particular period of time. There are regions where the farmer has to wait for days and even weeks for his turn to fetch water from canals or tube wells to irrigate his crops and sustain them where this tool could be used to improve the situation. These techniques are of too useful only if put to use.

IV. GAME THEORY AND ITS' APPLICATION IN THE AGRICULTURAL SECTOR

What is 'Game Theory'?

The term game theory was invented by the mathematicians John Nash, John Von Neumann and the economist Oskar Morgenstern. Game theory is the study of mathematic models of human conflict and cooperation of humans in a competitive situation. Game theory is meant for situations where decision makers are affected by the interaction of other players and their own behaviour. Game theory is applicable to problem solving. Game theory captures real life concepts like “bargaining” and “reputation” in situations like a land owner and a potential renter bargain over a potential contract.

Game theory in agriculture is mainly used in fields of international trade and political economy. Besides these two sectors game theory is rarely seen in agriculture this is because it is difficult to use it as a basis of estimation. Game theory helps model situations that cannot be modelled without it to help evaluate its role.

Basic models

The Two-Person, Zero-Sum Game

Two players or persons oppose each other in this type of game each having a finite number of actions called a strategy set.

Sl = [a1, a2, •••, am] and

S2 = [b1, b2, ••• , bn]

Assuming s1 and s2 are strategy sets for players 1 and 2 respectively. The rule for the game is that the players must take one move at a time and the moves must be taken simultaneously.

Considering each player made a move there is a playoff. The playoff matrix shows the profit to player 1 for every strategic pair. Ojj . All possible pairs of strategies form a matrix of outcomes, (0ij) . The 0ij (i = 1, . . . , m and j = 1, . . • , n) entry in this matrix is the outcome of Player 1 choosing his ith strategy and Player 2 choosing his , jth strategy.

		Player 2		
		1	2	3
Player 1	1	3	5	1
	2	6	-3	0

The above matrix is a pay-off matrix which shows the strategies of player 1 and 2. So we can read the above matrix as follows if player 1 plays strategy 1 the playoffs will be 3,5 and 1. And if player 2 plays strategy 3 the play-offs will be 1 and 0.

In the above example the strategy 1 of player1 and strategy 2 of player 2 gives us the outcome of -3. The negative sign shows a loss for player1 and a gain for player 2.

Thus the game is called a zero sum game because the gain of one player is the loss of the other. This theory points out the strategies that a player can play to obtain the lowest loss or the highest return. This is called the security level. The playoff matrix is always written in the viewpoint of player 1.

The Maxi- mini and Mini-maxi strategies

Given below is the playoff matrix of player A and player B

Player A's strategies	Player B's strategies				Row Minimum(Maxi-mini)
	T1	T2	T3	T4	
S1	5	8	7	9	5
S2	15	12	9	17	9
S3	11	6	8	7	6
Column maximum(Mni-maxi)	15	12	9	17	

Row minimum column or the Maxi-mini column symbolizes the minimum payoff for player A's strategies.

Player A has to maximize his gains and the aim of player B is to reduce his losses and risk.

So if a plays his first move that is S1 and B plays T1 the playoff will be 5 to A. so if a has to choose a strategy we will notice that A will choose to play s2 because in this case he is assured of a pay-off of at least 9. If he plays any strategy other than S2, his gain can be reduced to as low as 5 (if he plays s1). Thus the others are less than 9. Therefore 9 is the maximum of the minimum (called maxi-min) and S2 is A's maxi-min strategy.

In the above table 9 is called the saddle point of the game as if you observe 9 is the maximum in its column and minimum in its row thus also called the value of the game where the Maxi-mini and Mini-maxi value is the same.

Game Against Nature

The main application of the game theory in agriculture is done in the "game against nature". Nature out here can be defined as weather, insects, pests' diseases In plants, climatic conditions and social and political situations. Thus the term nature is applicable to all situations except when a farmer is directly in conflict with another farmer. When a farmer is against another farmer/ landlord it is called game against "person". The difference between nature and person being that against nature the farmer is the only one who makes losses/gains. Whereas against a person the famers loss will be the persons again and the other way around .Thus when we apply game theory to game against nature the pay-off matrix will always be in the view point of the farmer therefore all the operations shall be conducted on the rows and not the columns unless required.

DIFFERENT CRITERIA OF CHOICE WALD MAXIMIN CRITERION

This criterion assumes the farmer to be pessimistic and helps us find out the minimum return (security level). Wald creation act is the act of selecting the security level. Let's assume X1, X2,…Xm to be situations and Y1, Y2,…. Yn to be states.

	Y1	**Y2**
X1	**(2**	**3)**
X2	**(4**	**1)**

We see that 2 is the security level for X1 and 1 is the Security level for X2. In the above example if X1 are the farmer strategies and Y1 are the acts of nature. In the above example can be taken as a game the farmer is playing against nature. The game is exactly like that of a two-Person, zero-sum game. It can be shown that the maximum strategy for a two-person zero-sum game is the best strategy against the worst an opponent can do. Nature will not consciously do its worst against the farmer. Hence the Wald criterion is a model for decision-making under uncertainty. As we all know farmers with limited resources may go bankrupt and loose all that they have if an uncertainty.

Thus the Wald crition suggests various precautions a farmer could take to avoid uncertainties.

Wald crition would suggest growing alternative crops or growing mixed crops to ensure minimum fixed income every year. It may also advise to increase use of fertilizer to increase the security level.

Similar to the Wald Maximum Criterion are also the Laplace's criterion , regret criterion, Hurwicz' criterion decision models. Application of these various decision models to agricultural problems can result in recommendations suited to a wide range of farmer situations.

Summary

Thus we see how various models of game theory help in agriculture in various decisions that are made by the farmer. The game theory helps the farmer make various choices in his day to day life like choice of crop enterprises, choice of pasture mixtures, etc. Farmers can follow a several models specifying how to plan under uncertainty. They may apply the models to their own problems directly to find out precautions to take.

V. APPLICATIONS OF WAITING LINE THEORIES IN AGRICULTURE

Everybody is versed in the upheaval of waiting. It may be buying tickets for a cricket match, waiting for baggage at an airport, being put on hold by a customer care executive, in a line for car wash or in traffic. In general waiting line has these attributes:

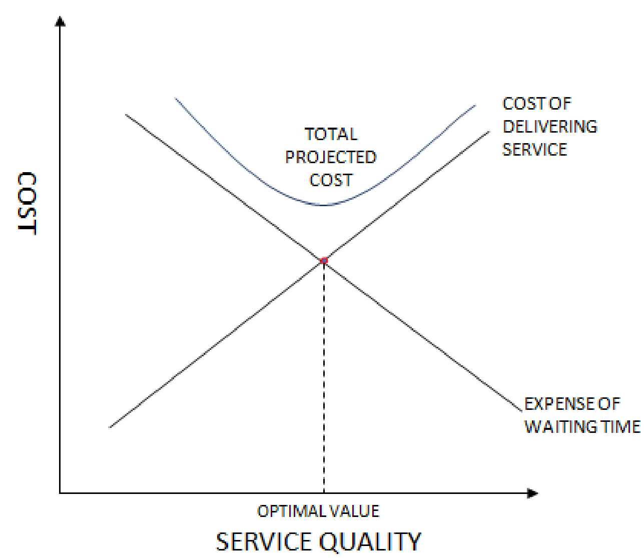
a. Someone or something that needs the use of a service, often referred to as a 'customer'
b. The service
c. The idleness of:
I. Customer to be serviced
II. The service
d. The definite function of providing the service

X axis represents service quality & y axis represents cost of providing the service.

As the service quality improves, the cost of providing a service will also increase. With an increase in service quality, the cost of waiting time falls as people or items will have lesser time to wait in a queue and they will be serviced quickly.

By adding the 2 curves, total projected cost is obtained.

The point of optimal value represents the most economical value with optimum total cost and service quality



The model can be illustrated with an example, showing how costs help to optimise service quality.

Example**:**

Let the service cost be $8/hour, Arrival = 300/8 = 37.5/hr

	No. of clerks			
	1	2	3	4
A) No. of customers	300	300	300	300
B) Waiting time per customer	0.17	0.10	0.07	0.05
C) Total waiting time per shift (AxB)	50	30	20	15
D) Cost per hour of waiting	10	10	10	10
E) Value of lost time per shift (CxD)	500	300	200	150
F) Total pay of clerks each shift	64	128	192	256
Total expected cost (E+F)	564	428	392	406

Here, the optimal value is 392 which shows that operating with 3 clerks provides the lowest cost.

FEATURES OF WAITING LINES:

1. ARRIVALS:
   Arrivals depend on the following:
   a) Size of the calling population – Unlimited or Limited
   b) Pattern – Poisson Distribution
   c) Behaviour – Balk, Renege, Jockey

2. QUEUE
   a) Length – Unlimited or Limited
   b) Discipline - FIFO or LIFO

3. SERVICE FACILITY
   a) Configuration
   b) Pattern – Constant or Random

SINGLE SERVER WAITING LINE MODEL

This model includes single-server, single-phase, single-line system.

The following assumptions are made:

1. The customers are patient and come from a finite population
2. Customer arrivals are reported by a Poisson distribution with an average arrival rate of λ (lambda). The time between consecutive customer arrivals supports the exponential distribution with a mean of $1/\lambda$
3. The customer service rate is recounted by an average service rate of μ (mu) & Poisson distribution. This means that the service time for one customer is followed with exponential distribution with a mean of $1/\mu$
4. The waiting line priority rule often utilized is first come, first serve basis

FORMULAE:

λ = mean arrival rate of customers (mean of customers arriving per unit of time)

μ = mean service rate (mean of customers that are served per unit of time)

p = *the* mean usage of the system

L= *the* mean number of customers in the service system

L_Q pL the mean number of customers waiting in queue W^1 the average time passed waiting in the system,

W_Q pW the mean time passed waiting in queue

P_n $(1p)$ p^n the probability that *n* customers are in the service system

EXAMPLE

The PVR Cinema at Juhu has a ticket counter to help customers purchase tickets. The customers form one single queue in front of the counter for assistance. Around 15 customers enter per hour. Customer arrivals are illustrated by a Poisson distribution. The server helps 20 customers per hour (calculated through an exponential distribution). Calculate:

a) The average utilization of the ticket counter server

b) The mean no. of customers in the system

c) The mean no. of customers waiting in the queue

d) The average time a customer passes in the system

e) The average time a customer passes waiting in the queue

f) The probability that there are more than 4 customers in the system

Solution:

Under the assumptions of single server waiting line model,

a) Average utilization: p = λ/μ = 15/20 = 0.75 or 75%

b) Average no. of customers: L = λ/μ-λ = 15/20-15 = 3

c) Mean no. of customers waiting in queue: L_Q = pL = 0.75 x 3 = 2.25 customers

d) The mean time customer passed in the system: W = 1/μ-λ = 1/20-15 = 0.2 hours or 12 minutes

e) The mean time customer passed waiting in the queue: $W_Q = pW$ = 0.75 (0.2) 0.15 hours, or 9 minutes

f) The probability that there are more than four customers in the system equals one minus the probability that there are four or fewer customers in the system. We use the following formula.

$P = 1 - \sum_{n=0}^{4} P_n = 1 - \sum_{n=0}^{4} (1-p)p^n$

= 1 – 0.25(1+ $0.75^2 + 0.75^3 + 0.75^4$)

= 1 – 0.7626 = 0.2374

There is 23.74% chance of having more than four customers in the system.

MULTI SERVER WAITING LINE MODEL

This model includes multi-server, single-line, single-phase system. The customers are served by the first server available. Assumptions:

1. There are s identical servers
2. The service time is 1/μ

FORMULAE:

s = the number of servers in the system

$p = \lambda/s\mu$ = the average utilization of the system

$P_0 = \left[\sum_{n=0}^{s-1} \frac{\left(\frac{\lambda}{\mu}\right)^n}{n!} + \frac{(\frac{\lambda}{\mu})^s}{s!}\left(\frac{1}{1-p}\right)\right]^{-1}$ = the probability that no customers are in the system

$L_Q = \frac{P_0 (\frac{\lambda}{\mu})^s p}{s!(1-p)^2}$ = the average number of customers waiting in line

$W_Q = \frac{L_Q}{\lambda}$ = the average time expended waiting

$W = W_Q + \frac{1}{\mu}$ = the average time spent in the system, including service Q

$L = \lambda W$ = the average number of customers in the service system

$$P_n = \begin{cases} \frac{(\frac{\lambda}{\mu})^n}{n!} P_0 & \text{For } n \leq s \\ \frac{(\frac{\lambda}{\mu})^n}{s!\, s^{n-s}} P_0 & \text{For } n > s \end{cases}$$

= the probability that n customers are in the system at a given time

Example:

PVR Juhu has increased the number of screens and is concerned about the service counters. Instead of a single service counter, the theatre is considering having 3 identical service counters. According to a Poisson distribution, the theatre expects 45 customers per hour. According to exponential service times, the counter can serve 18 customers per hour. Calculate:

a) The average utilization of the ticket counter server

b) The probability of having no customers in the system

c) The average no. of customers waiting in the queue

d) The average time a customer passes waiting in the queue

e) The average time a customer passes in the system

f) The mean no. of customers

Solution:

Under the assumptions of multiple server waiting line model,

a) Average utilisation = λ/sμ = 45/(3x18) = 0.833 = 83.3%

b) Probability that there are no customers in the system

$$P_0 = \left[\sum_{n=0}^{s-1} \frac{\left(\frac{\lambda}{\mu}\right)^n}{n!} + \frac{(\frac{\lambda}{\mu})^s}{s!}\left(\frac{1}{1-p}\right)\right]^{-1} = \left[\frac{(\frac{45}{18})^0}{0!} + \frac{(\frac{45}{18})^1}{1!} + \frac{(\frac{45}{18})^2}{2!} + \left(\frac{\left(\frac{45}{18}\right)^3}{3!}\left(\frac{1}{1-0.8333}\right)\right)\right]^{-1} = \frac{1}{22.215} = 0.045 = 4.5\%$$

c) The average number of customers waiting in line

$$L_Q = \frac{P_0\,(\frac{\lambda}{\mu})^s\, p}{s!(1-p)^2} = \frac{0.045(\frac{45}{18})^3\ X\ 0.833}{3!\ X\ (1-0.833)^2} = \frac{0.5857}{0.1673} = 3.5$$

d) The average time a customer spends waiting
$W_Q = \frac{L_Q}{\lambda} = \frac{3.5}{45} =$ 0.078 hour or 4.68 mins

e) The average time a customer spends in the system
$W = W_Q + \frac{1}{\mu}$ = 0.078 + 1/18 = 0.134 hour, or 8.04 mins

f) The average number of customers in the system
$L = \lambda W$ = 45(0.134) = 6.03

VI. APPLICATION OF WAITING LINE THEORIES & MODELS IN AGRICULTURE

Lu (60) applied the queuing theory to determine the ideal counter facilities at a famous chain food store in Detroit. Simmons (91) attempted to determine suitable plant stacking facilities for fleet milk distribution trucks with the use of this theory under the conditions of Poisson probability distribution of arrivals, variable average arrival rates, constant service times and a first-come-first-served discipline. The Waiting Line models are illustrated with 2 examples:

Illustration 1: SINGLE CHANNEL MODEL

Cotton is a cash crop, grown in many regions of India. Cotton is sent to various factories and mills. It is the producer’s responsibility to deliver the cotton at the collection centres of the factories. He delivers it the cotton in trucks. But there is only one weighing machine so the farmer has to wait for long to get his cotton weighed and get the weight receipt which is taken to the cashier to receive his payment.

Let there be one service counter, Let the average number of arrivals be 30 trucks per hour. Let the rate of servicing be 40 trucks per hour. Then

Solution:

Under the assumptions of single server waiting line model,

a) Average utilization: p = λ/μ = 30/40 = 0.75 = 75%

b) Average no. of trucks: L = $\lambda/\mu-\lambda$ = 30/40-30 = 3 trucks

c) Average no. of trucks waiting in queue: L_Q = pL = 0.75 x 3 = 2.25 trucks

d) Average time a truck passed in the system: W = $1/\mu-\lambda$ = 1/40-30 = 0.1 hours or 6 mins

e) Average time a truck passed waiting in queue: $W_Q = pW$ = 0.75 (0.1) = 0.075 hours or 4.5 mins

Illustration 2: MULTIPLE SERVER MODEL

For the convenience of farmers, the factories have brought 2 more weighing machines. This was done so that the farmers waiting time lessens. Now, the average number of arrivals expected are 90 trucks per hour and each weighing machine can serve 35 trucks per hour.

Solution:

Under the assumptions of multiple server waiting line model,

a) Average utilisation = $\lambda/s\mu$ = 90/(3x35) = 0.8571 = 85.71%

b) Probability that there are no trucks in the system

$$P_0 = \left[\sum_{n=0}^{s-1} \frac{\left(\frac{\lambda}{\mu}\right)^n}{n!} + \frac{(\frac{\lambda}{\mu})^s}{s!}\left(\frac{1}{1-p}\right)\right]^{-1} = \left[\frac{(\frac{90}{35})^0}{0!} + \frac{(\frac{90}{35})^1}{1!} + \frac{(\frac{90}{35})^2}{2!} + \left(\frac{\left(\frac{90}{35}\right)^3}{3!}\left(\frac{1}{1-0.8571}\right)\right)\right]^{-1} = \frac{1}{29.0145} = 3.45\%$$

c) The average number of trucks waiting in line

$$L_Q = \frac{P_0\,(\frac{\lambda}{\mu})^s\, p}{s!(1-p)^2} = \frac{0.0345(\frac{90}{35})^3\ X\ 0.8571}{3!\ X\ (1-0.8571)^2} = \frac{0.5027}{0.1225} = 4.1 \text{ trucks}$$

d) The average time a truck spends waiting
$W_Q = \frac{L_Q}{\lambda} = \frac{4.1}{90} =$ 0.045 hours or 2.73 mins

e) The average time a truck spends in the system
$W = W_Q + \frac{1}{\mu}$ = 0.045 + 1/35 = 0.074 hours or 4.41 mins

f) The average number of trucks in the system
$L = \lambda W$ = 90(0.074) = 6.66 trucks

Therefore, the waiting time of the farmer will be lesser if 2 more weighing machines are introduced. It is seen from the above 2 illustrations that the waiting time per truck reduces from 4.5 minutes to 2.73 minutes,

The two applications undertake to demonstrate the way in which the problems can be solved with the help of queuing theory. The queuing theory models can be applied to several types of problems and aspects in agriculture like glitches of loading and unloading, Upkeeps and maintenance evaluation, manufacture and delivery of crop, and manufacture of feed. The queuing theory can be applied in the exact same manner in industries similar to agriculture like fertilizer, tractor, etc.

CONCLUSION

From the beginning of use of operation research in the First World War to the advance use of operations in various fields. Array of application where the use of operation research reaches is vast from education, health, welfare, urban affairs to even agriculture. The use of operation research to the problem of decision making in agriculture has hardly been 20 years old. The most used technique in agriculture is linear programming. Besides linear programming Game theory, simulation, time-network analysis, queuing theory, inventory control and other techniques are frequently used. Most of these tools can be used in all the fields of agricultural economic activities, viz., production, consumption, exchange and distribution.

There is no doubt that the future would see increasing and diversified applications of operations research techniques in agriculture with the sudden increase in population and demand for more food. Every country is facing the problem of shortage of resources. Hence operation research can be used in agriculture in

- Optimum utilization of land and growing crops according to the given climatic conditions of the region.
- Optimum and correct utilization of water.

The past two decades have shown us the phenomenal growth of operation research in agriculture and as we agree the potential use of operation research in agriculture is vast and far greater than what we realise. Soon the scope of operation research would broaden from the use of agricultural industry to farm management.

If farmers are educated of the scope of operations research and enough brainstorming takes place on agricultural management by various economies of the world, the risk associated with this sector and the problem associated with the low returns can be solved and can pave way for a profit making occupation.

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