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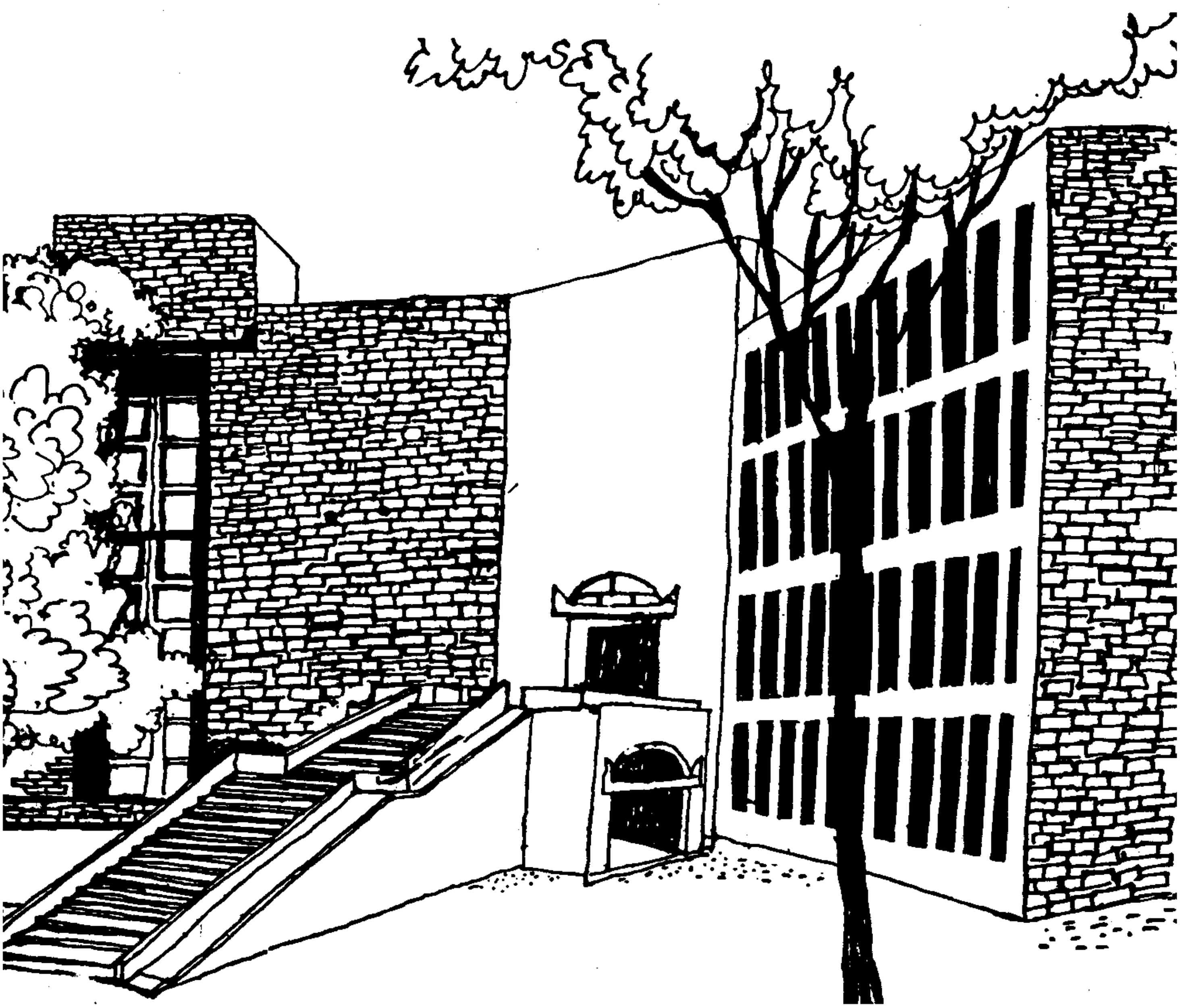

FERTILIZER PLANT MODELLING:
A SIMULATION STUDY

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W P No.1266
June 1995

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Fertilizer Plant Modelling: A Simulation Study

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Abstract

A simulation model of a fertilizer plant has been made. It includes activities from production to despatch, from the plant site. Input to the model is daily demand which comes to the plant as despatch instructions. The model includes provision for internal generation of realistic daily demand. Output gives the state of the system at any desired interval of time. Simulation reports can be used by managers for planning logistics and other operational aspects at the plant site. SLAM II has been used for modelling.

1. INTRODUCTION

Urea is produced in large continuously operating plants. Demand for it however is unevenly distributed during the year. Storage, therefore, becomes necessary. This is done in silos attached to the plant, and warehouses distributed enroute various demand centres. One of the important operational decisions is how much to store in silos and how much in leased-in/rented warehouses. Cost of warehousing [1], on one hand, and the ability to quickly transport the stock to the point of sale when demanded are the considerations that govern this decision.

Warehousing space needs to be booked in advance. Movement of urea from warehouses in one region to warehouses in another region is difficult. Producers therefore make great efforts to forecast demand. Forecasts made for the entire year are broken down into demand for each season and smaller periods within seasons. These forecasts are used to book warehousing space. As a result accuracy of demand forecasts assumes critical importance. Inaccurate forecasts could lead to unsold stock in one area and unmet demand in another [2],[4]. In this paper, we explore the use of simulation to supplement and improve upon the current practices.

One of the urea producing units in Gujarat was selected for the work. Operations of this unit are described first. It is followed by modelling of each operation including production, movement of urea to bagging unit or the silos, bagging operation, storage in the shed and despatch by rail and road. Past pattern of daily despatch are analysed to identify the underlying distributions. Using these as inputs, simulations are carried out. Usefulness of the model to managers is discussed.

2. OPERATIONS

Production

This plant uses natural gas as feedstock to manufacture ammonia. Urea is manufactured using Stamicarbon Stripping Process using ammonia and carbon dioxide. Naphtha, associated gas and LSHS (Low Sulphur Heavy Stock) are used as fuels. Details of the intermediate processes are not of interest here, only that granular urea is produced at the rate of 50 tons/hr. The plant works round the clock, except for scheduled shut down for maintenance once a year. Granular urea is sent to bagging unit, where it is filled into bags. When bagging unit is not in operation, urea is diverted through a flap valve to silo for storage.

Bagging

Bagging unit has 6 independent machines, each with capacity of 500 bags/hour. Bagging is normally done in 50 kg bags. Sometimes 25 kg bags are also made. The unit usually works in two shifts of 8 hours each, 6 am to 2 pm and 2 pm to 10 pm.

Usually, only two machines are in operation. More are switched on, when despatch requirement is large. Additional urea from silo is then brought to the bagging unit. This is called reclaiming. Bagged Urea is sent to the shed. If shed space is full, bagging is stopped and urea diverted to silo.

Silo

Silo in this plant has a capacity to hold 30,000 tons of granular urea. This represents 25 days of production.

Shed and Loading Platforms

Bagged urea is stored on platforms (shed) in ten high stacks. Platforms have a capacity of 1100 tons (22,000 bags), which can be augmented to 1500 tons (30,000 bags) if needed. This storage capacity amounts to about one day production.

Despatch

Information on the quantity of urea to be despatched and destination is received at the plant daily from Marketing Headquarters at Delhi in the form of despatch instruction (DI). On receipt of DI the Transport Manager requisitions trucks and rail wagons. Despatch to destinations within the state and nearby are usually made by trucks. Rail is used for far-off destinations.

A truck usually carries 10 tons (200 bags), a metre gauge rake 800 tons (16,000 bags) and a broad gauge rake 2000 tons (40,000 bags). Bags from the shed are manually lifted and loaded on the waiting transport. Despatch unit normally works from 8 am to 9 pm.

3. SIMULATION MODEL

Operations described above include both, the continuous processes (such as production and bag filling) and discrete processes (such as despatch). We selected SLAM II, because it can handle both the continuous and discrete processes. For definitions of terms and SLAM II elements used, see [3]. The flow chart of the simulation model is shown in figure 1.

Production

Quantity of urea produced in a given interval is easily obtained, by integrating the production rate over that interval.

$$P(t) = \int_0^t PR\, dt \qquad (1)$$

where P(t) quantity of urea produced (tons)
PR production rate (tons/hour)
t time (hours)

Granular Urea will normally go to bagging unit.

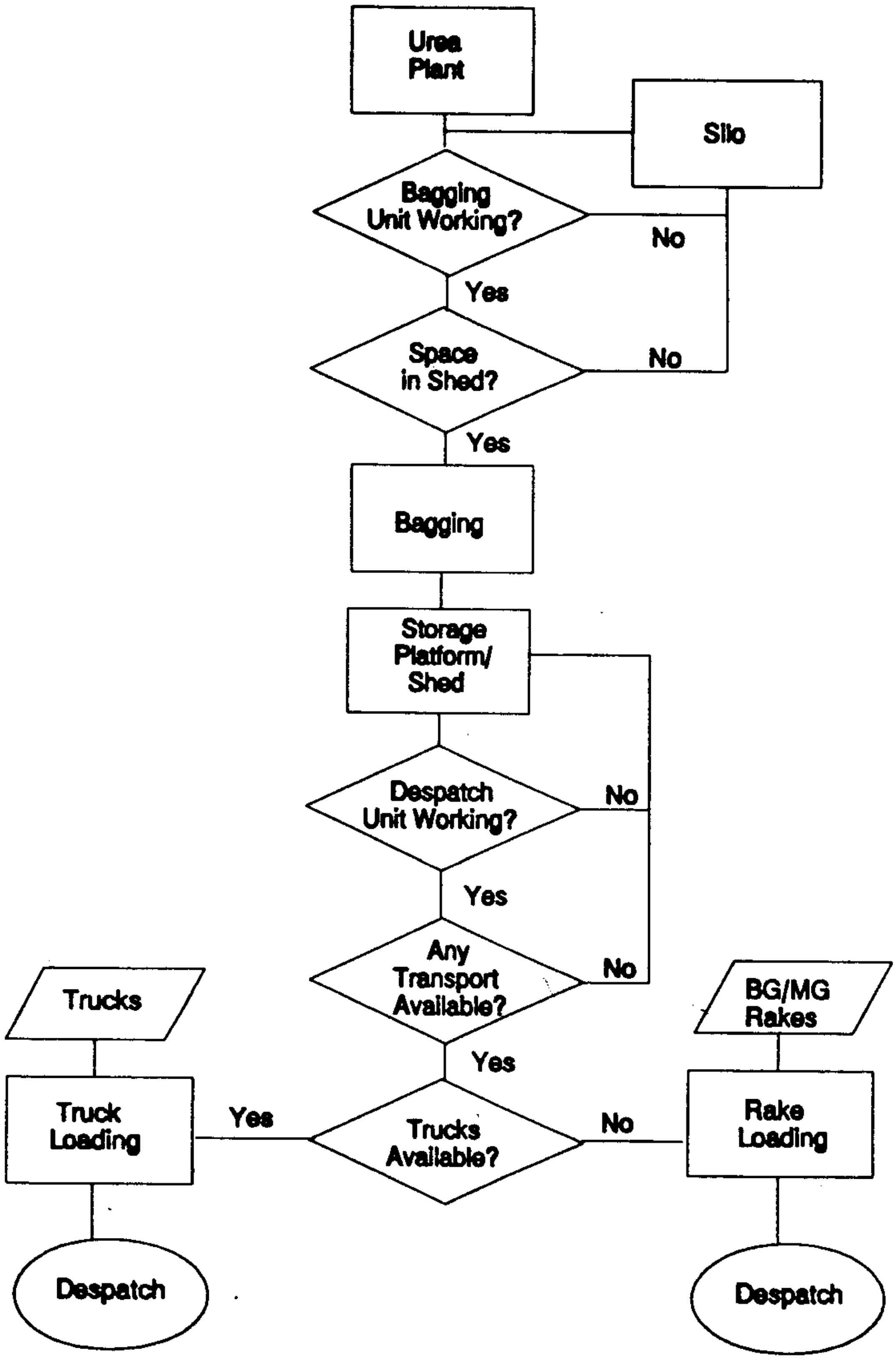

Fig. 1. Flow chart of the simulation model

Bagging Operation

Bagging unit starts at 6 am and closes at 10 pm. Closing and opening is accomplished by means of a time dependent variable, which operates cyclically. This is done in a 'disjoint network'. A DETECT node is placed in the flow path of bags to check if the shed is full. If so, bagging operations are suspended even if it is not the closing time for the unit. Operations are not resumed until the shed is at least 20% empty.

Bag Filling

A bagging machine is treated as a RESOURCE. The feedback control mechanism that stops the filling process when bag is full is represented by a DETECT node. Bags are treated as entities.

Filling process is also represented by an integral.

where	QB(t)	quantity in the bag (tons)
	BR	flow rate from chute (tons/hour)

Silo

Silo is treated as a simple storage. Change in the quantity stored is the sum of rate of inflow and rate of outflow in the given interval. The rate of inflow is equal to the production rate. The outflow rate is equal to rate of reclamation. Both these are constant. Thus,

$$\frac{dQ}{dt} = PR - RR \quad (3)$$

$$Q = \int (PR-RR)\ dt \quad (4)$$

where	Q(t)	inventory of urea in silo (tons)
	PR	rate of inflow into the silo (production rate)
	RR	rate of reclamation

Shed

The storage shed (platform) is modelled as an AWAIT node. Monitoring of shed inventory is done continuously using another DETECT node. The flap valve that diverts urea to silo is activated by the DETECT node.

Despatch operations

Despatch unit also operates on shift basis, usually from 8 am to 9 pm. A GATE (say GATE 1) has been put at this unit, which will remain open during working hours and closed otherwise. Opening and closing of GATE is controlled using another disjoint network.

Availability of transport, trucks and rakes, is another condition that must be met for loading operation to begin and to continue. This is ensured using another GATE (GATE 2). GATE 2 will remain open when truck and/or rake is available and is closed otherwise. Thus, bags will be removed from the shed for loading only if both gates (1 & 2) are open.

Transport suppliers

The trucking firm and the railways are modelled as two separate CREATE nodes. Trucks and rakes are created as entities as per the despatch demand.

It has been assumed in this model that the rakes and trucks are available when required. This is true for trucks. There could be occasional delay in getting the rakes however. It is also assumed that trucks and rakes depart as soon as loaded. Again this will be true for trucks. But the loaded rakes may have to wait for the locomotive and for track clearance. Since the requirement of the railway rakes are fairly steady in most cases the rakes are available as per the despatch requirement. To that extent our assumption is realistic.

Loading Priority

When both trucks and rakes are available and are to be loaded, priority is given to the trucks. Priority can be readily altered when desired.

Loading is modelled as an ACTIVITY. TERMINATE node marks the departure of loaded trucks and rakes.

4. DESPATCH PATTERN

Data on quantity of urea despatched each month over a four year period was obtained. Examination of the data showed that there was very little variation in the yearly total [4], which worked out to an average of 393720 tons with coefficient of variation (C.V.) of only 3 percent (table 1).

Table 1: Summary of despatch data

Year (Apr-Mar)	Yearly Despatch (tons)	Mean monthly despatch (tons)	C.V. between months (%)
1989-90	3,92,778	32,731	26
1990-91	3,89,142	32,429	31
1991-92	4,11,448	34,287	17
1992-93	3,81,513	31,793	32
Mean	3,93,720	32,810	-
C.V. between years (%)	3	-	-

There is greater variation from month to month. This is because there are three main cropping seasons in the country, June to September, October to February, March to May. Crops grown in these seasons differ, so does the use of fertilizers. Moreover, fertilizer may be applied in several instalments.

The mean monthly despatch over the four year period is shown in **figure 2**. The horizontal line shows the rated monthly production (36,000 tons) of the plant. Two peaks are discernible, August and December. The August one is slightly higher than the December one. The month of November appears to be the leanest.

Daily Despatches

We are of course interested mainly in the pattern underlying daily despatches. Therefore, despatches in August (peak month) and November (lean month) were analysed

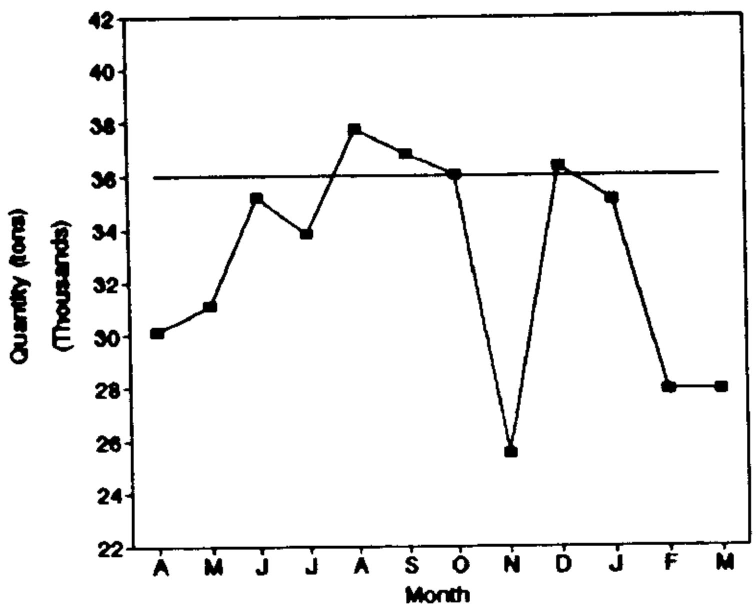

Fig. 2. Mean monthly despatch of urea

in detail. Three years ('90, '91 & '92) despatch data for August and November was obtained. Despatches by broad gauge rakes (BGR), metre gauge rakes (MGR) and trucks, were analysed separately. Frequency diagrams were plotted, likely distributions were tried, and goodness of fit tested. The results are given below.

The number of broad gauge rakes despatched on a typical day in August was found to follow Poisson distribution.

$$P(x=k) = \frac{(0.35)^k e^{-0.35}}{k!} \quad (5)$$

where k number of rakes

$\chi^2_{1,0.90} = 2.706$ $\chi^2_{computed} = 0.010$

Figure 3 shows the comparison of computed and observed values, for illustration.

The number of metre gauge rakes despatched on a typical day in August was also found to follow Poisson distribution.

$\chi^2_{2,0.90} = 4.605$ $\chi^2_{computed} = 2.022$

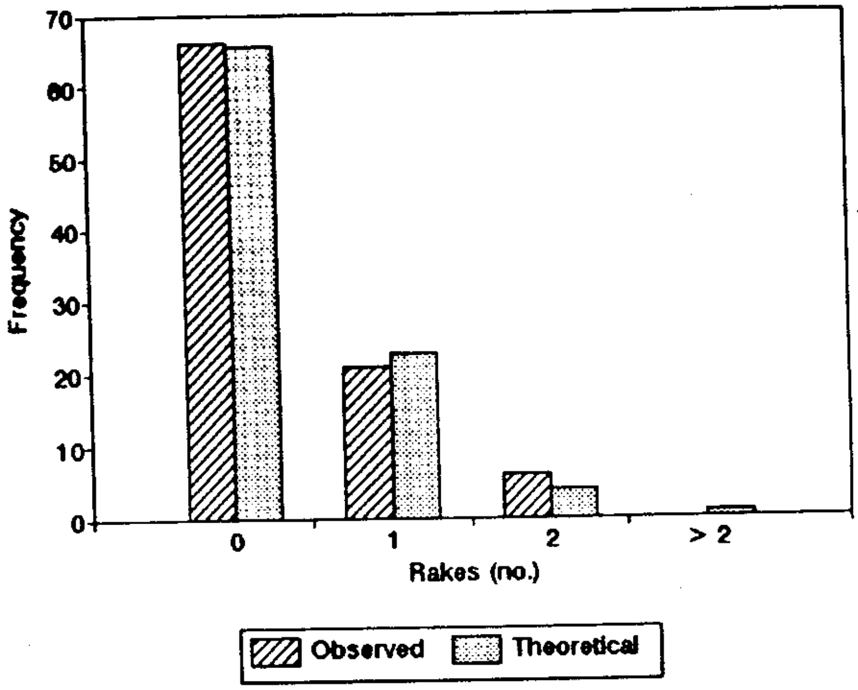

Fig. 3. Urea despatched by broad gauge rakes

$$P(x=k) = \frac{(0.38)^k \, e^{-0.38}}{k!} \tag{6}$$

The quantity of urea despatched daily by trucks in August was found to be Normally distributed.

$$f_x(y) = \frac{1}{\sqrt{2\pi\sigma}} \exp\left[-\frac{1}{2}\left(\frac{(y-\mu)}{\sigma}\right)^2\right] \tag{7}$$

for $-\infty < y < \infty$

where	y	quantity of urea despatched (tons)		
	σ	= 233.57 and		= 593.00
	$\chi^2_{6,0.90}$	= 10.645	$\chi^2_{computed}$	= 8.552

Figure 4 shows the observed and computed quantity of urea despatched daily by trucks for the month of August.

Similarly for November the results are as follows.

Broad Gauge Rakes (Poisson)

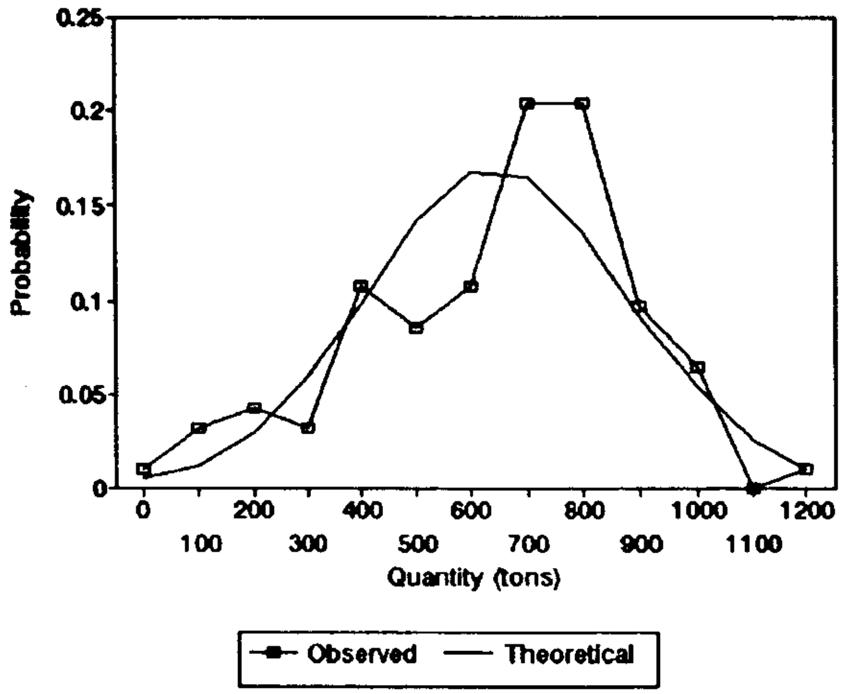

Fig. 4. Urea despatched by trucks

$$P(x=k) = \frac{(0.12)^k e^{-0.12}}{k!} \tag{8}$$

$\chi^2_{1,0.90} = 2.706$ $\chi^2_{computed} = 0.152$

Metre Gauge Rakes (Poisson)

$$P(x=k) = \frac{(0.50)^k e^{-0.50}}{k!} \tag{9}$$

$\chi^2_{2,0.90} = 4.605$ $\chi^2_{computed} = 0.109$

Quantity despatched by trucks (Normal)

$$f_x(y) = \frac{1}{\sqrt{2\pi * 167.37}} \exp\left[-\frac{1}{2}\left(\frac{(y-239.16)}{167.37}\right)^2\right] \tag{10}$$

$\chi^2_{5,0.90} = 9.236$ $\chi^2_{computed} = 7.498$

5. SIMULATED RESULTS AND DISCUSSION

For simulation, it is necessary to first customise the model to the specific plant. This is done by specifying the operational parameters of the working units and the distribution of arrival patterns of despatch instructions. The other inputs are the initial conditions, span of time for which simulation is desired (run length), reporting interval and the items on which report is desired. The output report can be obtained either as a detailed one or as a summary at suitable interval (hourly, daily etc.).

Simulations given below were done on Sun IPC work station.

Simulation Runs

<u>Operating Parameters</u>

Production rate - 50 tons/hr

Baggers - 6 nos; 25 tons/hr capacity; working hrs 6 am to 10 pm

Shed - 22000 bags of 50 kg each (or 1100 tons)

Loading & despatch working hrs - 8 am to 9 pm

<u>Loading Times</u>

Truck (10 ton)	45 crew-minutes; 5 crews
BG rake	8 hrs
MG rake	5 hrs

Loading is manual. For loading a fixed quantity using fixed number of crew, the time taken is fairly constant.

<u>Initial Conditions</u>

Silo inventory	5000 tons
Shed	empty
Despatch backlog	0
Run length	8 days
Input	Daily despatch instructions internally generated using the distributions, for August
Reporting - interval	24 hrs

The usual SLAM II report contains statistics for time persistent variables, file statistics, regular activity statistics, service activity statistics, resource statistics, gate statistics and values of state and derivative variables. Here certain aspects have been selected from the detailed results to discuss the utility of the simulation. These are shown in **table 2**.

Table 2: Run One - Summary Output

End of day	Despatch instructions			Despatch fulfilled by end of day			Detention time of rakes		Shed space (% full)	Silo inv. (tons)	Despatch backlog		
	BGR (no)	MGR (no)	Tr (no)	BGR (no)	MGR (no)	Tr (no)	BGR (hrs)	MGR (hrs)			BGR (no)	MGR (no)	Tr (no)
0	-	-	-	-	-	-	-	-	-	5000	-	-	-
1	0	1	50	-	1	50	-	15	103	3859	-	-	-
2	0	0	30	-	-	30	-	-	103	4759	-	-	-
3	1	0	85	-	-	85	86	-	91	5088	1	-	-
4	0	1	59	-	-	59	-	78	48	5066	1	1	-
5	0	0	82	-	-	82	-	-	101	4817	1	1	-
6	0	1	57	1	-	57	-	35	61	4840	-	2	-
7	0	0	0	-	2	0	-	-	101	4336	-	-	-
8	1	0	40	-	-	40	-	-	28	4072	1	-	-

Table 3: Run Two - Summary Output

End of day	Despatch instructions			Despatch fulfilled by end of day			Detention time of rakes		Shed space (% full)	Silo inv. (tons)	Despatch backlog		
	BGR (no)	MGR (no)	Tr (no)	BGR (no)	MGR (no)	Tr (no)	BGR (hrs)	MGR (hrs)			BGR (no)	MGR (no)	Tr (no)
0	-	-	-	-	-	-	-	-	-	5000	-	-	-
1	0	1	50	-	1	50	-	13	103	3859	-	-	-
2	0	0	30	-	-	30	-	-	103	4759	-	-	-
3	1	0	85	-	-	85	38	-	50	4811	1	-	-
4	0	1	59	1	-	59	-	39	26	4051	-	1	-
5	0	0	82	-	1	82	-	-	94	3332	-	-	-
6	0	1	57	-	1	57	-	14	101	3137	-	-	-
7	0	0	0	-	-	-	-	-	101	4337	-	-	-
8	1	0	40	1	-	40	14	-	34	3795	-	-	-

The first row (day 0) shows the initial conditions. The silo had 5000 tons of urea, sheds were empty and there was no backlog of despatch instructions.

Columns (2), (3) & (4) show the despatch instructions for a sequence of days, generated internally. For instance, it is desired that one MG rake and 50 truck load of urea be despatched on the first day. By the end of the (24 hours) day the desired despatches had been made as indicated in columns (5), (6) & (7) against day 1. This is confirmed in columns under backlog which indicates zero.

Note, the shed now has some bags stored. The silo inventory has reduced indicating that some of it was reclaimed during the past 24 hrs, to fulfil the despatch instructions. The rake was detained for 15 hrs.

The first backlog occurs on day 3. Columns (10) & (11) show that this was despite the fact that there was bagged urea lying in the shed. The backlog was caused because bags could not be loaded due to lack of time. It could be reduced or removed by deploying a larger number of loading crew and/or extending the working hours of this section.

This was tried in the next run whose results are shown in **table 3**. The loading unit works from 8 am to 9 pm (13 hrs) normally. In this situation, as can be seen from columns (12) & (13) there were 8 occasions when rakes had to be held up overnight. If working hours of this unit are increased by say, 3 hrs (6 am to 10 pm), same as for the bagging unit, the number of rakes held up overnight got reduced to 2 during 8 days of simulation.

The model was run under varied conditions and the output of the model was checked with operating managers for validation. The managers expressed confidence in the model.

6. SUMMARY AND CONCLUSION

A simulation model of a urea plant was built using features of SLAM II. Operations included in the model are production, bagging, storage in silo, despatch through road and rail. There is provision to generate synthetic despatch instructions internally.

Simulations can be done for as long a span of time as desired. Report on the state of the system at plant site can be obtained at any interval (hourly, daily, weekly etc.) desired. Items on which report is desired can be specified. The report can be detailed account or in a summary form.

The model can be used as a planning tool for the managers. It can be used to anticipate transport requirement, loading crew requirement, bag requirement, need for extra working hours etc. The silo inventories can be used for planning warehouse requirement. It can be used to foresee likely occurrences of despatch backlogs. It can serve as a regular planning tool for proper management of inventories and despatch. Expected occupancy of silos can be obtained by through repeated runs.

The model can be used for other plants with similar processes. It can also be extended to find the arrival pattern at primary and secondary warehouses.

Acknowledgement

This work was done under a grant from Union Ministry of Agriculture to Centre for Management in Agriculture (CMA), Indian Institute of Management, Ahmedabad (IIMA). This is gratefully acknowledged. Authors are thankful to the fertilizer unit in Gujarat who provided the data. They also thank IIMA and CMA for the facilities provided for this study.

The authors are thankful to Profs. G. Raghuram and V. Venkata Rao of IIMA who gave useful comments on the draft manuscript.

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