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# A SIMULATION MODEL OF A WHEAT ELEVATOR SYSTEM USING SLAM

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ABSTRACT

This paper shows that simulation can be used as an analytical tool for agricultural marketing and the potential of the SLAM simulation language to model such systems. This analysis shows the effects upon the elevator complex from two different harvest season scenarios. The model also has the versatility of being able to derive the effects of different decision strategies on the elevator complex without designing a totally different model. The effects of elevator breakdowns, building of more elevator storage facilities, smaller and larger dumping areas, and different initial elevator inventory levels can be easily investigated. Also, different elevator systems (country, terminal, and export) can be developed from the existing model.

## 1. INTRODUCTION

The production and distribution system of grain in the United States is made up of several components. A specific part of the total system is the storage facilities for grain which have specific capacities at particular locations with an array of grain handling services. With improved grain varieties and harvesting equipment, higher grain yields and more rapid harvesting of mature grain has been realized which places strain on the fixed capacity levels of the commercial elevators to store the grain. Also, the export of American grain has increased in quantity and importance which adds stress to the elevator's ability to coordinate railway transportation and unload grain efficiently. The increased importance and activity in the agricultural grain sector in the economy has caused the decision making process of elevator management to become more dynamic and complicated.

## 2. THE ELEVATOR SYSTEM

Commercial elevators fall into two categories: country elevators and terminal elevators. Country elevators receive, store, merchandise, and procure transportation services for grain. Country elevators are dispersed across production regions to receive grain directly from the farmer. Since most country elevators receive more grain than the facility can hold, excess grain is shipped to terminal elevators where it is held until sold. Terminal elevators store grain which country elevators cannot handle, merchandise grain to final markets, blend grains produced from many areas to meet grade specifications of buyers, and procure transportation for domestic and export shipments.

For the country elevator, it receives nearly all of its grain for the year within the few days of the harvest period. The problems of the country elevators are elevator receiving capacity and outloading capacity. Elevator receiving capacity is the rate at which grain can be taken from farm trucks and placed in storage. The major elements determining the receiving capacity are the number of pits in which unloading can take place and the rate at which the elevator machinery conveys wheat from dump pit to elevator bin (leg capacity). As harvesting activities have increased with advances in grain varieties and harvesting equipment, the receiving capacities at country elevators have not changed which strains the capacities of the country elevator. To alleviate the capacity problem, either more efficient management of capacity storage will be required with more coordination between terminal elevators and transportation entities or additional dump pits and storage bins must be constructed which will require substantial outlays of capital.

Outloading capacity is the rate at which grain is taken out of the elevator and placed in appropriate transportation equipment. For country elevators, a limiting factor of outloading capacity is the length of rail siding. Rail siding for a particular elevator can accommodate only a certain number of railway cars, and this limits the out-loading rate. If grain is coming in faster than going out, the elevator must acquire trucks or run the risk of having to turn farmers away or dump wheat on the ground.

Terminal elevators also must be aware of in-coming capacities but their management problem is in the area of out-loading. Terminal elevators hold considerable quantities of grain in order to make up shipments to domestic millers and exporters. To put together 40 to 80 thousand tons of grain for a ship load with certain grade specifications requires sizable grain stocks and coordinated transportation management. The acquisition of railway cars for outloading from a terminal elevator is a problem and is a more acute problem during the harvest period when grain cars are spread around the country side.

The problems faced by management of country and terminal elevators are numerous and complex. The proper level and handling of inventory within the elevator is one such problem. If elevator inventory is too large before harvest, the elevator will be faced with an over capacity problem. If transportation facilities such as additional railway cars or trucks cannot be found, the elevator will be faced with either dumping the grain on the ground or turning away farmers from the grain receiving areas. The proper coordination of elevator capacity, in-coming rates of grain, and transportation service requires elevator management to take a systems view of their business in order to identify all entities and relate them.

## 3. PREVIOUS STUDIES

A study by Crigler (1958) was on the economic analysis of the decision making criteria in cooperative elevator associations. Crigler's study centered on the proper charge to store grain by the elevator and did not look into the operations of the elevator system. Von Oppen and Hill (1970) derived factors affecting grain elevator numbers and location in Illinois. They found marginal capacity and marginal transporta-costs affected elevator numbers. Studies also have been done concerning the transportation of grain between elevators and between elevators and export terminals. These transportation studies have shown the use of transportation models and network analysis for grain shipments (Fedler and Heady 1976, Fuller and Sammughom 1978, Steglin 1979). A study by Johnson, Mennem, and Oehrtman (1976) looked at the efficiency of rail wheat transportation and detailed potential inefficiencies.

However for this analysis, the operation of a wheat elevator during the harvest season was developed through simulation techniques. Through a simulation model, the effects of different management decisions and harvest activities on waiting lines (queues) and elevator capacities can be derived. Waiting lines, busy periods, and queue sizes are characteristics which fall under queueing theory. If the system were such that analytical equations could be used, the elements of queueing theory would be adequate. However, real situations such as the one in question might not avail themselves easily to the assumptions of queueing theory. Simulation models are, therefore, used to depict complex systems and derive the effects on the system from different managerial decisions. The problem for this analysis is to build a model of a wheat elevator system using the SLAM simulation language and derive the effects of different harvest period scenarios.

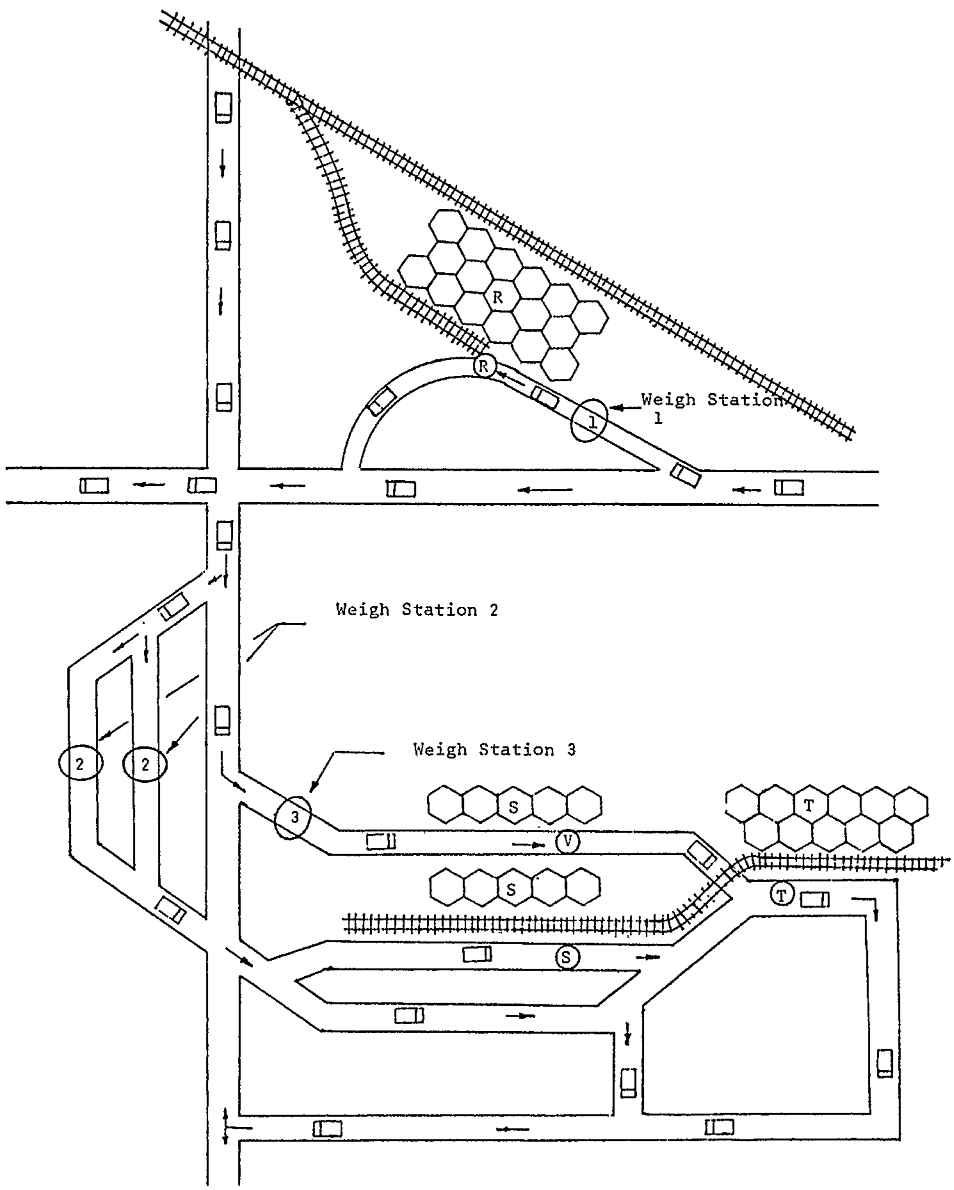
## 4. SYSTEM DESCRIPTION

For this model, a wheat elevator complex similar to a terminal elevator was used with three different storage elevators. Wheat can be delivered to the elevator complex by hopper trucks, flat bed semi-tractor trailer trucks, self hydraulic semi-tractor trailer trucks, and farm trucks. Twice daily at 12:00 noon and 5:00 p.m. a train leaves with 60 hopper railway cars. Fig. 1 shows the elevator complex for the analysis.

Elevator R is offset from the other elevators and can only service hopper trucks. A hopper truck will enter elevator R only if weigh station 1 has the smallest numbers current in queue as opposed to weigh station 2. Also, weigh station 1 has only one scale or server. After being serviced, the hopper truck moves to dumping area R. The queue line capacity for dumping area R is four trucks, after which the queue for area R is blocked. When a hopper truck enters area R, the hopper truck dumps its load of wheat and leaves. However, if elevator R is full of wheat, the wheat carried by the hopper truck is dumped on the ground.

For elevators S and T, hopper trucks, semis, and farm trucks can dump their wheat. For dumping areas S and T, only hopper trucks and semis can enter. Farm trucks have a special dumping area at V. A hopper truck or semi entering dumping areas S and T must first pass through weigh station 2. At weigh station 2 there are two scales or servers, and after weighing, the trucks select either dumping area S or T on the selection rule of the queue which has the current smallest number of entities (trucks) in it. Also, dumping areas S and T have queue line capacities of four trucks, respectively. When queue capacity for either or both dumping areas is reached, the queue is blocked. As with elevator R, if storage of wheat in either or both elevators S and T are full, the wheat is dumped on the ground. For the farm truck, a special dumping facility is used in which wheat goes to elevator S. For an entering farm truck, it must go through weigh station 3, where there is one scale or server. After weighing, the farm truck goes to dumping area V, where the wheat is dumped. For dumping area V, the capacity of the queue is four trucks, after which the queue is blocked. Also, if storage in elevator S is full, the wheat is dumped on the ground.

As wheat is being delivered, wheat is also being transported from the elevator. For this analysis, a train which has 60 hopper cars, each carrying 3000 bushels of wheat, leaves the elevator




Fifure 1. The Elevator Complex

complex twice daily at 12:00 noon and 5:00 p.m. The allocation of railway cars among elevators R, S, and T was derived on the percentage of capacity of the elevator relative to the other elevator percentage capacities. That is, if elevator R was 80% full, elevator S was 50% full, and elevator T was 30% full, then elevator R would get 30 railway cars, elevator S would get 18 railway cars, and elevator T would get 12 railway cars. The model was run for 30 days under two different harvest scenarios to derive the effects on the elevator complex.

5. MODELING WITH SLAM

A SLAM network flow diagram of the wheat elevator model is shown in Fig. 2. The network diagram is very helpful in depicting the flow of wheat through the system. From the diagram, the creation of truck entities is derived through create nodes. For hopper cars, these entities are created from an exponential distribution with a mean of 2.7 minutes. After creation, the entities go through an assign node where attribute values as to truck type, quantity of wheat carried by the truck, and service time are determined. The entity then travels to a select node to select which queue to enter. A hopper car will pick either weigh station 1 or 2 by the smallest number of entities in either queue which is depicted by SNQ. If the entity picks weigh station 1, it will go to queue node WST1 where it takes 0.50 minutes to weigh. After weighing, and if queue node QUE-R is not blocked, the truck enters the dumping area QUE-R. The time to dump the wheat is an attribute designated by ATRIB(4), after which, control goes to the event node EVT1 to determine if the wheat went to elevator R or was dumped on the ground.

If the hopper car chooses weigh station 2, it goes to queue node WST2, as does created flat bed semis and self hydraulic semis. At weigh station 2, two scales or servers are used in which 30 seconds are required to weigh individual trucks. After weighing, the entities go to a queue selection node in which selection of either queue S or T is done through the SNQ priority rule. The SNQ priority rule gives priority to the queue node which has had the current smallest number of entities in it. After choosing a node and if the queue is not blocked, the entity enters and dumps its wheat. As for farm trucks, they are created and enter the weigh station three queue node. After weighing the entity, it travels to queue node QUE-V to dump its wheat.

After the service activities to dump the wheat, the entities travel to event nodes to determine if the wheat goes to the elevators or is dumped on the ground. The enter nodes entitled 8, 5, 6, and 7 in Figure 2 transfer the entities to an ALTER Node which adds the wheat from the trucks to the selected elevators. From enter node 4, the wheat of the trucks is added by the ALTER node to wheat which has been dumped on the ground. This completes the network flow which delivers wheat to the elevators. An important facility of the SLAM language is the EVENT node. This node makes it possible for the routine to jump out of the network go to a FORTRAN written subroutine which makes management decisions.

The network flow diagram for transport of wheat from the elevator is modeled in the last five disjoint networks. The first three alter the elevator levels by the quantity of wheat to be shipped out of each elevator which is determined by global variable XX(1). The first three disjoint networks are not activated until a train is ready to leave. At this point the AWAIT node TRAN allows entities to travel to the alter nodes. The fourth disjoint network determines when the unloading of wheat will occur. It is assumed that the 60 hopper cars are at the complex. The dumping of wheat is inacted at a time period where all cars can be filled before the train leaves. The train departures are determined in the fifth disjoint network in which the train leaves at 12:00 noon and 5:00 p.m. daily. The simulation was started at 6:00 a.m. of the first day and, therefore, the first train which leaves at 12:00 noon is scheduled to be created six hours into the simulation run.

6. RESULTS

This model was run for two harvest scenarios which lasted for 30 days. The first run or Scenario I depicts the entities of trucks to the elevator system as in a normal harvest season. The second scenario depicts a much busier harvest period as realized when a bumper crop is produced. For Scenario II, the same number of trucks that entered in 30 days in Scenario I enter in just 24 days for this scenario. The truck creations are assumed to be from an exponential distribution with mean value shown in Table 1.

From Table 1 for the same number of hopper trucks to arrive at the elevator in 24 days for Scenario II as in Scenario I, the time between creations is reduced from 2.7 minutes to 2.2 minutes. Unloading times for the trucks were from an uniform distribution with hopper trucks ranging from 4 1/2 to 5 minutes, flat-bed trucks 5 to 6 minutes, self-hydraulic trucks 5 1/2 to 6 1/2 minutes, and farm trucks 3 to 4 minutes. The quantity of wheat carried by each truck is also assumed to be from an uniform distribution and is shown in Table 2.

The capacities for the elevators were 8,000,000 bushels for elevator S, 10,000,000 bushels for elevator T, and 14,000,000 bushels for elevator R. Initially, elevators R and T were assumed half full with elevator S being one-quarter full. The elevator complex was in operation 24 hours a day throughout the simulation.

A preliminary run of the model was made where results at specific time intervals were printed out. This information was used to detect the occurrence of the steady state condition which helps in the collection of more reliable statistics. It was determined that after 3 days, or 4,320 minutes, steady state occurred, and with the use of MONTR statement, statistics were cleared and collected again in which transient state effects were eliminated.

Table 3 shows the average storage level in each of the elevators for each of the scenarios. Also in Table 3 are the maximum and minimum storage levels for each elevator.

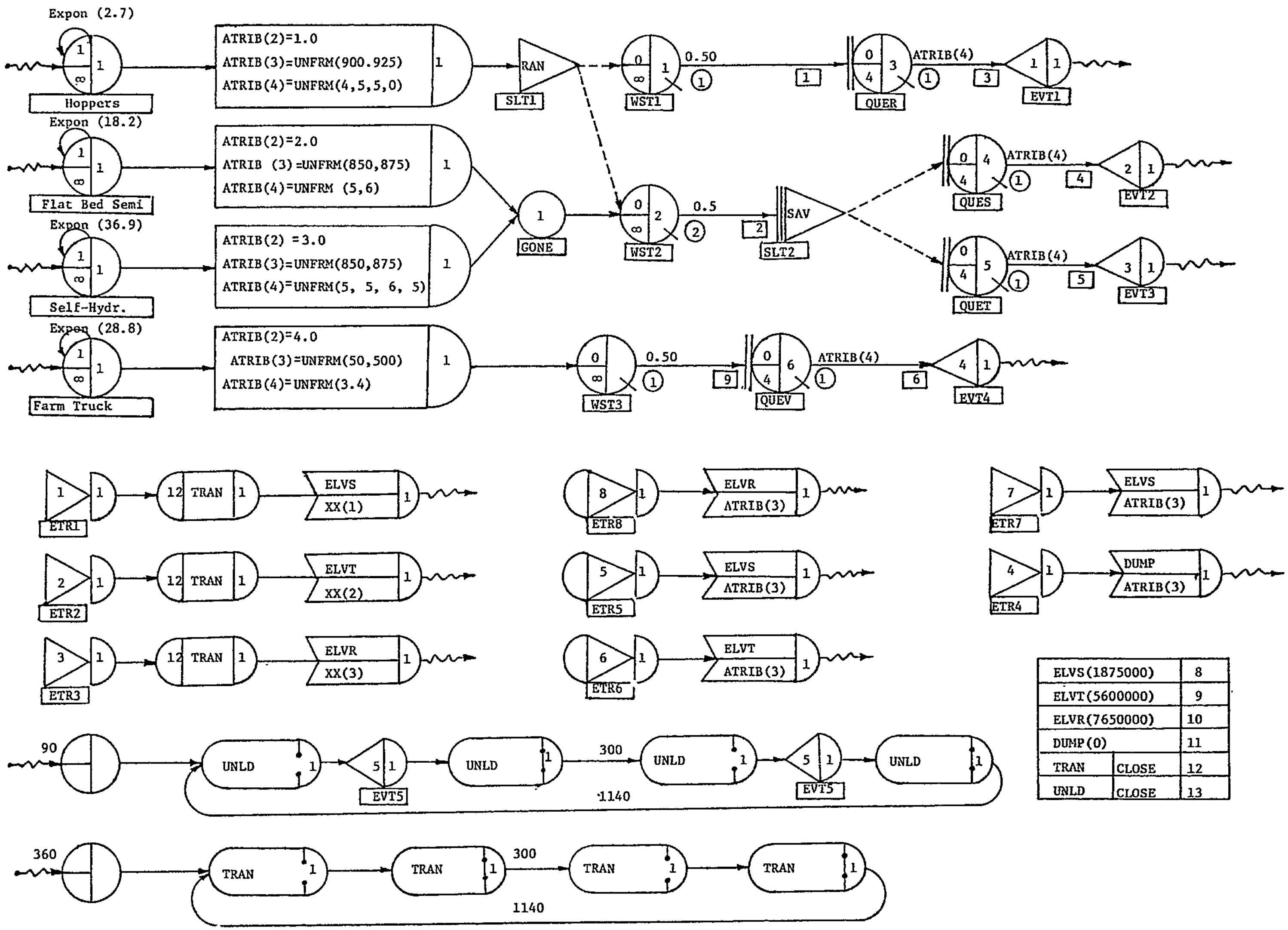



Figure 2. SLAM Network Flow Diagram of Elevator Complex

Scenario II, with more truck creations, has a larger average inventory in each of the elevators, but it is interesting to note that the current facility even with a busier harvest season can adequately store the grain. However, with a different initial elevator inventory level, occurrence of a railway strike, or greater truck creations, there could be storage capacity problems.

The difference in congestion for the elevator complex from the two scenarios is shown in Table 4.

The second scenario with more trucks coming to the elevator has greater queue lines. Blockage of the queues is realized for weighing stations 1 and 2 under the second scenario which could suggest the allocation of more space. Also the utilization of dumping areas is more intense and the queue line for weigh station 1 and 2 has increased substantially under the second scenario which would suggest potential difficulties for the elevator complex if some part of the elevator system broke down.

In using the SLAM language, alternative management decisions can be used to derive their effects upon the system. In an earlier model, the priority selection criteria used for hopper trucks to decide whether to enter weigh station 1 or weigh station 2 was the random priority sequence. The random priority rule assigns equal probability to each queue node that has an entity in it. With this type of priority rule the average queue length for weigh station 1 increased to 406.6 entities for Scenario II. This suggests that the elevator complex should retain some management overview in order to direct hopper cars to weigh station 1 or 2 based on smallest number in queue. Also some of the elevator operators would like to keep elevators S and T equally busy throughout the harvest season. The priority rule for this decision would be the SAV code. The SAV code designates priority to the queue node which has had the smallest average number of entities in it to date. When the SAV priority is used to select either queue S or T, the average utilization for S and T under Scenario I is 61% and 62%, respectively, and for Scenario II is 87% and 87%, respectively. This type of priority would require more active management and would be more costly than the smallest number in queue (SNQ) at the current time priority.

Another facet of elevator operations which should be investigated is the occurrence of a railway strike. To investigate a railway strike, the original SLAM model of the elevator complex was altered by using a gate. For this analysis, the elevator complex was operating for 7 days until a strike occurred. The strike lasted for 14 days and Scenario II truck creations were used. Therefore, the railway strike for 14 days would occur during the busier harvest season and with initial inventory levels as stated earlier in the paper. Inventories did increase from the railway strike and are shown below in Table 5.

When inventory levels in Table 5 are compared to Table 3, the railway strike causes average inventories and maximum inventories to increase. As can be seen in Table 5, maximum inventory levels do come close to storage capacity. If the strike lasted longer or initial inventory levels were greater, then dumping of wheat on the ground would occur which would be costly because the wheat grade would be lowered and reloading the wheat to be dumped into a storage bin would be expensive.

## 7. MODEL FLEXIBILITIES

The elevator SLAM model presented in Figure 2 is a representation of a terminal elevator. However, the SLAM codes can be changed which can investigate other elevator systems such as country and export elevators or can add or delete services of the current depicted terminal elevator system.

For a country elevator, the model in Figure 2 may be too large. The number of dumping areas, storage bins, and elevator capacity can be reduced. Country elevators, also, used railroad hopper cars and trucks for out-shipments to the terminal elevators. Therefore a proper number of railroad cars for out-shipments sufficient for railside capacity can be used as well as a system to simulate truck out-shipment activity. Additionally the number, arrival times, and capacity of railway cars and trucks used for out-shipments can be depicted as a random variable.

The SLAM network flow diagram of the terminal elevator in Figure 2 can be changed to depict different elevator situations and services. Many terminal elevators receive grain by railroad cars. These railway in-shipments are stored in a separate elevator with a specific storage capacity. The network model, therefore, can be changed to add the in-shipments of grain by railway cars. In addition, the grain from the railway elevator and its capacity will enter into the decision process of allocating railway cars for out-shipment.

The current procedure used by railroad companies is that railway cars bringing grain to the terminal elevator cannot be used to ship grain out of the terminal elevator. These in-shipment railway cars are assigned to country elevators and are for their use. Railroad cars used for out-shipments from the terminal elevator come directly to the terminal elevator. The number of cars used in the Figure 2 model is set at a constant 60 railway cars. This number, however, could be random depicting the difficulty of coordinating transportation service.

The quantities of grain removed from the elevator also can be more complex. For shipments out of the elevator, different blends of grain can be used to make a single shipment. Using different attribute numbers for the grains stored in the elevator, a desired grain blend could be derived for an out-shipment. Also when grain is poured out of the elevator for transport, vast quantities of grain dust escapes into the air which reduces the elevator storage level.

If an export elevator is to be modeled, changes to the Figure 2 network flow diagram will be required. The number of elevators, dumping areas,

Table 1. Time Between Arrivals for Each Truck Type Under the Two Scenarios.

| Truck Type | Time Between Arrivals | |
|---|---|---|
| | Scenario I | Scenario II |
| | (Minutes) | |
| Hopper Trucks | 2.7 | 2.2 |
| Self-Hydraulic Semis | 36.9 | 29.5 |
| Flat-bed Semis | 18.2 | 14.6 |
| Farm Trucks | 28.8 | 23.0 |

Table 2. Quantity of Wheat Carried by Each Truck Type.

| Truck Type | Quantity of Wheat | |
|---|---|---|
| | Low | High |
| | (bushels) | |
| Hopper Trucks | 900 | 925 |
| Self-Hydraulic Semis | 850 | 875 |
| Flat-bed Semis | 850 | 875 |
| Farm Trucks | 50 | 500 |

Table 3. Average, Maximum and Minimum Inventory*

| | Scenario I | Scenario II |
|---|---|---|
| Elevator S | | |
| Average | 3,707,000 | 4,579,000 |
| Maximum | 4,942,000 | 6,504,000 |
| Minimum | 2,360,000 | 2,528,000 |
| Elevator T | | |
| Average | 5,173,000 | 6,418,000 |
| Maximum | 5,549,000 | 7,750,000 |
| Minimum | 4,917,000 | 5,180,000 |
| Elevator R | | |
| Average | 9,068,000 | 9,247,000 |
| Maximum | 10,810,000 | 11,230,000 |
| Minimum | 7,358,000 | 7,366,000 |

*Levels are in bushels.

Table 4. Average Queue Lengths and Facility Utilization for the Different Scenarios.

| | Average Queue Length | | | Average Utilization | | | |
|---|---|---|---|---|---|---|---|
| | WST1 | WST2 | WST3 | R | S | T | V |
| Scenario I | 0.0047 | 0.0001 | 0.0002 | 0.99 | 0.71 | 0.52 | 0.12 |
| Scenario II | 0.2154 | 0.1492 | 0.0003 | 1.00 | 0.91 | 0.83 | 0.15 |

Table 5. Average, Maximum, and Minimum Inventory Levels Under the Railway Strike Scenario.*

| | Average | Maximum | Minimum |
|---|---|---|---|
| Elevator S | 5,065,000 | 7,164,000 | 2,528,000 |
| Elevator T | 7,051,000 | 8,608,000 | 5,180,000 |
| Elevator R | 9,963,000 | 12,230,000 | 7,366,000 |

*Levels are in bushels.

and elevator capacity levels will need to be changed. Export elevators receive wheat by railway cars and trucks. Therefore proper quantities of delivered grain, railway and truck creations, and time to dump grain are needed. Grain is dumped by the export elevator into ships which have different storage capacities. Ships are also queued outside the port to enter as soon as a ship leaves.

In all these models, the elevators are assumed to be open 24 hours a day. This may not occur in practice so the model can be developed to open at a specific time and close at a specific time. Also trucks can be queued to arrive before the gates of the export elevator open. This type of creation would create waiting lines of trucks in front of the export elevator.

## 8. REFERENCES


Crigler, T. P. (1958) A Method of Economic Analysis for Decision Making by Cooperative Elevator Associations, unpublished Ph.D. dissertation, Oklahoma State University.

Fedler, Jerry A. and Earl O. Heady (1976) Grain Marketing and Transportation Interdependencies: A National Model, American Journal of Agricultural Economics, LVIII, pp. 224-235.

Fuller, Stephen and Chiyyorath Sammughom (1978) Network Flow Models: Use in Rural Freight Transportation Analysis and a Comparison With Linear Programming, Southern Journal of Agricultural Economics, pp. 183-188.

Johnson, Marc A., Gary M. Mennem, and Robert L. Oehrtman (1976) Railway Wheat Transportation Efficiency Study (Problem Assessment), Stillwater; Oklahoma State University, Department of Agricultural Economics, Paper No. AE 7708.

Steglin, Forrest E. (1974) Methodological Analyses of the Export Transportation Network Flows: Hard Red Winter Wheat, unpublished Ph.D. dissertation, Oklahoma State University.

von Oppen, Matthias and Lowell Hill (1970) Grain Elevators in Illinois, Factors Affecting Their Number and Location, Urbana-Champaign, University of Illinois, Agricultural Experiment Station, AERR Number 108.