Logistic strategies for segregation of Identity Preserved grain during unloading operations: assessment by means of network simulation

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Abstract

The objective of this paper is to investigate the network modeling technique as an innovative system useful for analyzing the interaction between the grain elevator and the farmers who carry grain to the facility. In this investigation, network modeling was used to compare the performances of the four elevator strategies that characterize a large inland elevator in Delphi, IN, USA. The strategies examined were: baseline scenario, one-pit enlargement, two-pit enlargement, and traffic pattern change. The network model simulates unloading activities inside the elevator, farm activities (harvesting and transportation to the elevator), as well as the interactions between these two systems. The link between the elevator and traffic subsystem models allows for the analysis of the elevator performance by also taking into account the performance of the farmer and vice-versa. The software used to build the simulation model was Extend® (ImagineThat Inc., Palo Alto, CA, USA). The Average Service Time [AST] of the trucks was used as the indicator performance to compare the system performance with different strategies. The network model Scenario 1 predicted AST savings for a daily grain volume that could occurs during the season (average, busy and peak day). The savings were 32% for the one pit enlargement, 38% for the two pits enlargement, and 23% for the traffic pattern change compared to the baseline scenario. The network model Scenario 2 predicted near-maximum performance of the elevator strategies. The results showed that the two-pit enlargement was best and allowed for dumping of up to 76 loads.day-1 resulting in a 16.7% increase compared to the baseline scenario (i.e., The AST savings were 34.6 min.truck-1 vs. baseline scenario (i.e., 34.0%). The results showed that grain distribution also had important influence on the performance of unloading operations. The network modeling approach could be used to investigate the regional impact of harvest-transport operations (bigger combines, field-to-field yield variability, transportation speed effects, etc.), management practices and resources availability on farmers as well as the unloading operations of multiple grain facilities all simulated in one large-scale model. The performance of the system could be evaluated both on farm and elevator side.

Keywords: Logistics, network simulation, grain segregation

Introduction

Before the availability and common use of hopper bottom semi truck trailers, many Midwestern grain elevators improved their receiving capacities in the mid-1970s by adding hoisting stations that incorporated platform scales at their unloading pits.

Although pit holding capacities gradually increased to hold 10 t or more (a typical gravity wagon holds about 7.5 t, a single axle farm truck holds about 6 t, a two-axle truck about 10 t, and a straight semi trailer about 25 t), pit dimensions were designed to accommodate unloading from gravity wagons, trucks and trailers with rear gates.

The existing pit dimensions require that these trailers have to be moved during unloading at least once to align the hopper outlet over the pit. When trucks are weighed using existing hoist-based platform scales, they have to pass the receiving pit to be weighed full, then back up twice to align the first and then second hopper over the pit, and finally pull ahead again onto the platform scale to be weighed empty.

Multiple segregations of grain types require more cleanout cycles of the receiving equipment, which reduces unloading capacity and increases average service times (Berruto and Maier, 2001). Thus, in order to minimize them and maintain customer satisfaction, truck movement through the facility must be as efficient as possible. Longer service times must also be avoided in order to minimize the operating costs of the unloading system and for the elevator to remain competitive with respect to its local market share (Dooley and Wilson, 1987). Previously, the elevator system model began with the truck arriving at the elevator full and ended when it left empty (Berruto and Maier 2000, 2001). The time and frequency of truck travel from the elevator to the field and its impact on average service time and maximum elevator receiving capacity was not considered. In fact, if the elevator was serving the farmers faster, they would return more quickly and frequently. The fast service lowers the cycle times, increases the number of return trips per day, and results in more grain deliveries to the elevator.

The objective of this study was to utilize the network modeling approach to analyze the interaction between the grain elevator receiving operations and the travel time and arrival frequency of trucks carrying grain from fields to a large inland terminal elevator. Specifically, the following aspects were investigated:

- the expected maximum receiving capacity of the elevator as a result of the proposed logistic improvements;
- the effect of logistic improvements at the elevator on the reduction of the average service time and increase of the delivery frequency on individual customers.

Material and methods

Elevator description

The elevator consists of a single probing station near the main building, two 35 t receiving pits, two hoisting stations with integrated platform scales, 18 concrete silos (1250 t each), 5 welded steel tanks (12500 t each) and a 45000 t outdoor pile. The actual facility layout is presented in Figure 1.

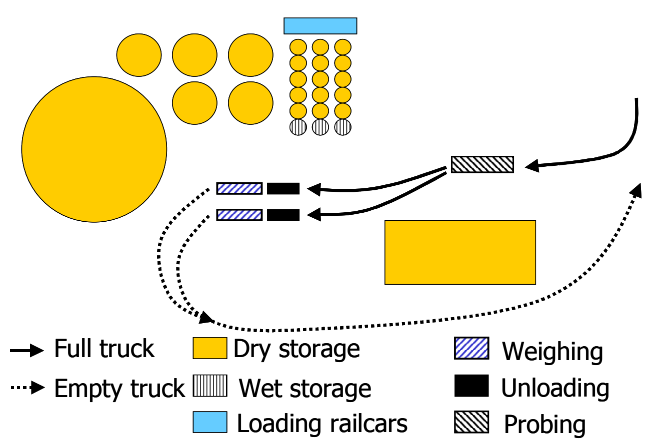

Figure 1. Layout of the commercial grain elevator surveyed in this study. The layout and the traffic pattern do not change for the enlargement of one or two pits.

In order to simulate the traffic outside of the elevator, the network model required three statistical distributions that defined the pattern of each daily traffic volume. Based on the analysis of the scale ticket data, the following distributions were estimated:

- the cycle time required for the trip to be made from the outbound gate of the elevator to the field and back to the inbound gate of the elevator;
- the inter arrival time between different trucks coming for the first unloading;
- the daily number of grain loads delivered per truck.

The goodness of fit test of the estimated distributions was done with the Kolmogorov-Smirnov test. The parameters related to the distributions that resulted from the statistical analysis using the SAS® software package are presented in Table 1.

Table 1. Parameter values for the statistical distribution related to the traffic model for three daily grain delivery volumes: average, busy and peak day.

Parameter	Units	Average	Busy	Peak
		Different trucks per day:		
Number		82	107	129
		Truck first arrival distribution:		
Type		Lognormal	Lognormal	Lognormal
Scale	(min)	9.73	8.11	6.62
Shape	(min)	4.48	3.94	3.32
		Cycle time distribution:		
Type		Lognormal	Lognormal	Lognormal
Scale	(min)	101.49	98.49	85.62
Shape	(min)	6.29	6.29	8.58
		Loads per day per truck distribution:		
Type		Poisson	Poisson	Poisson
Mean	(loads.day^{-1}.truck^{-1})	1.29	1.36	1.99
		Actual avg. number of loads per truck per day		
	(loads.day^{-1}.truck^{-1})	2.29	2.36	2.99
		Total number of load per day		
	(loads.day^{-1})	187	252	385

Proposed strategies to improve the grain receiving operation

Four receiving configuration and traffic management strategies were evaluated with the network simulation model:

- Strategy A. Actual configuration as depicted in Figure 1. The elevator had two pits and one probing station. The pits are not large enough to allow the unload of semi-truck without moving it. These pits allows to dump 13.1 trucks·hour^{-1}.
- Strategy B. One pit enlargement. where one pit was enlarged so that both hoppers of a semi truck trailer can be unloaded into the pit simultaneously. The enlarged pit could unload both trailer hoppers simultaneously, which increased its theoretical receiving capacity to 20.5 trucks·hour^{-1}. This resulted in a receiving capacity of 33.6 trucks·hour^{-1} for both pits.
- Strategy C. Two pits enlargement, where both of the available pits were enlarged in the manner described under Strategy B. Each pit could handle up to 20.5 trucks.hour^{-1}, which increased the simulated receiving capacity to 41 trucks·hour^{-1} for both pits combined.

- Strategy D. Traffic pattern change, which involves the relocation of the probing station and the addition of a scale for empty trucks. In this case, 15.1 to 16.7 trucks.hour^{-1} per receiving pit could be dumped based on a time motion study for the weighing full-unloading operation. This yielded 31 to 33.3 trucks.hour^{-1} considering both pits. The change in the layout of the elevator is presented in Figure 2.

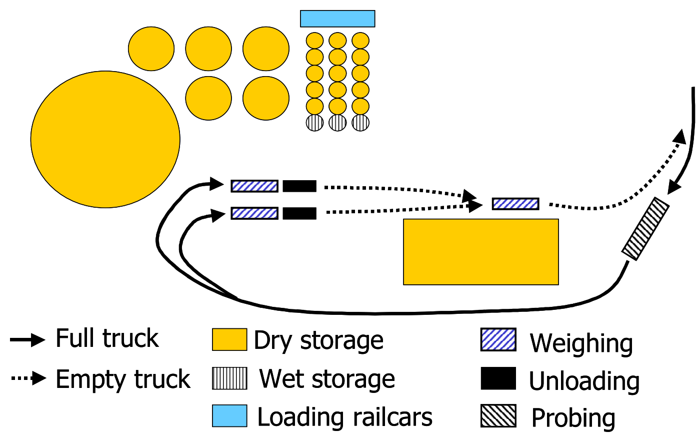

Figure 2. Layout of the elevator for the traffic pattern change. This layout presents a different traffic pattern and requires the relocation of the probing station and the addition of one scale for empty trucks.

Network model

The term network model will subsequently be used to emphasize the importance of interactions between the components of the system model that are affected by the traveling speed and distance and the elevator operation (Figure 3).

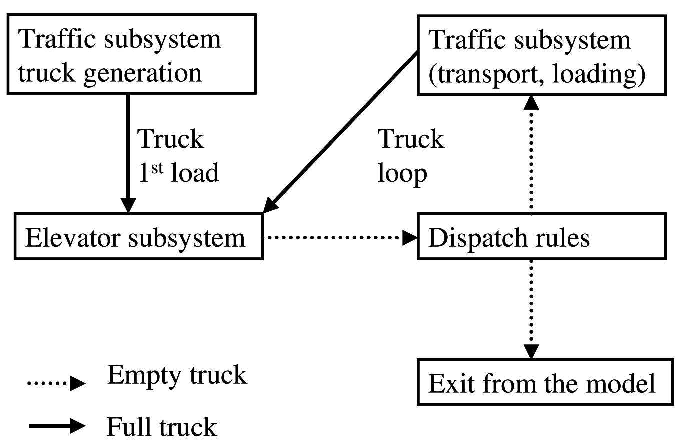

Figure 3. Schematic view of the grain elevator network model.

Network modeling considers the traffic outside of the elevator and generates arrivals over the day as a function of traffic parameters such as number of trips per day and traveling time for each trip. The link between the elevator and traffic subsystem models allows for the analysis of the elevator performance taking into account the farmer performance and vice-versa. The software used to build the simulation model was Extend® (ImagineThat Inc., Palo Alto, CA, USA). Extend is a discrete event simulation software (Law & Kelton, 2000).

The trucks are generated according to the first arrival distribution (see Table 1) by the traffic subsystem truck generation model.

The truck is then sent to the elevator subsystem for the grain unloading operation. When the truck arrives at the elevator inbound gate, it is moved through the elevator subsystem according to the elevator rules and resources during the unloading process.

At the exit of the elevator, the dispatch rules are verified, in order to check if the truck has to take another load to the elevator, or has to leave the model.

The dispatching rules, verified sequentially, provide two ways for limiting the loads carried by a single truck to the elevator:

1. Rule1. Each truck cannot bring more grain loads to the elevator than the loads assigned to it when it was generated, according to the parameters of Table 1. When the truck has delivered the assigned loads, it exits from the model.
2. Rule 2. Each truck has to reach the elevator inbound gate within the operation hours of the facility. If the rule is verified, the truck is sent to the traffic subsystem, otherwise it exits from the model.

The network scenarios simulated were the following:

- Network Scenario 1, in which both rules above described have to be satisfied.
- Network Scenario 2, resulting from the combination of Rule 2 with a maximum of 10 loads per day per truck, which was the maximum observed for the truck arrival frequency of any customer. Scenario 2 represents the theoretical maximum capacity of the grain harvest-transport chain that comes to the elevator on a particular day, assuming customers will deliver as much grain as they can to take full advantage of the available elevator receiving capacity. In this case, the model results predict the near maximum of the elevator-harvesting-transport system capacity.

<u>*Experiments*</u>

A summary of the simulation experiments is presented in Table 2.

Table 2. Simulation experiments and parameters used to test the elevator logistic strategies.

Parameter	Exp. 1-12	Exp. 13-24	Exp. 25-36	Exp. 37-48
Daily truck volume	Average, Busy, Peak	Average, Busy, Peak	Average, Busy, Peak	Average, Busy, Peak
Grain distribution	GrainA	GrainB	GrainA	GrainB
Network scenario	Scenario 1	Scenario 1	Scenario 2	Scenario 2
Elevator strategy (1)	A,B,C,D	A,B,C,D	A,B,C,D	A,B,C,D
Simulation runs	1200	1200	1200	1200

(1) A- Actual configuration, B-One enlarged pit, C-Two enlarged pits, D-Traffic pattern change

While Network Scenario 1 yielded a total number of loads per truck per day similar to those determined from the scale ticket data for average, busy and peak days (2.29, 2.36 and 2.99 loads per day per truck, respectively), Scenario 2 always predicted a day busier than the peak day.

Two grain type distributions (defined as GrainA and GrainB) were used in the simulated experiments. They were chosen based on scale ticket data gathered from the elevator surveyed, and pit management was decided by the operations manager as follows:

- GrainA represented a grain type distribution of 55.6% dry corn, 22.4% wet corn and 22.0% soybeans, which was typical for the late harvest season when fewer soybean acres were harvested. In this case, pit #2 was reserved for the dry corn and pit #1 was designated for wet corn and soybeans. Thus, about 56% of the incoming grain volume was served by pit #2, while 44% was served by pit #1.
- GrainB represented a grain type distribution of 29.1% dry corn, 40.4% wet corn and 30.5% soybeans, which was typical for the middle of the harvest season. In this case, pit #2 was reserved for the wet corn and pit #1 was designated for dry corn and soybeans. About 40% of the incoming grain volume was served by pit #2, while 60% was served by pit #1. For Strategy B, the assignment of the pit was different than for the other strategies. The enlarged pit was reserved for dry corn and soybeans (59.6% of the total flow) and the regular pit for wet corn (40.4%).

Results

<u>*Network model Scenario 1*</u>

In this scenario, the daily number of loads per truck was fixed and so was the daily receiving capacity of the elevator. For this scenario, only the AST savings for the proposed elevator configuration and management strategies are shown in Table 3 where the data are presented according to the day volume - average, busy and peak day.

Table 3. Average service times (min.truck^{-1}) for the four elevator strategies for Scenario 1 and AST savings (min.truck^{-1} and percentage).

		GrainA			GrainB	
Scenarios	Average	Busy	Peak	Average	Busy	Peak
A[(1)]	9.5 a[(2)]	10.6 e	19.5 h	9.8 l	13.6 p	44.1 t
B	7.7 bc	8.2 fg	10.7 j	8.3 m	10.0 qr	29.0 v
C	6.8 c	7.2 g	9.1 k	7.3 m	9.3 r	27.6 w
D	8.1 b	8.9 f	13.4 i	8.5 lm	10.9 q	33.1 u
A-B (min) [(3)]	1.8	2.4	8.8	1.5	3.6	15.1
A-C (min)	2.6	3.4	10.4	2.5	4.3	16.4
A-D (min)	1.3	1.7	6.1	1.3	2.7	11.0
A-B(%)[(4)]	19.2%	23.0%	45.2%	15.5%	26.7%	34.2%
A-C(%)	28.0%	32.2%	53.2%	25.7%	31.5%	37.3%
A-D(%)	14.0%	16.0%	31.5%	13.0%	19.9%	24.9%

[1]A- Baseline, B-One enlarged pit, C-Two enlarged pits, D-Traffic pattern change. AST are presented in min.truck^{-1}

[2]Values with the same letter are not significantly different at the 95% confidence level within the same incoming grain stream. Statistical comparison is valid just within the same incoming grain stream and thus the same column (same grain type and daily traffic volume).

[3]AST savings vs. Strategy A (min.truck^{-1})

[4]AST savings vs. Strategy A (%)

For what concern the different elevator strategies, the network model for the Strategy A (baseline, no modification in the elevator) yielded 20.0 min.truck^{-1}.

The proposed new strategies yielded overall the following average service times:

- the one enlarged pit (Strategy B) yielded 13.5 min.truck^{-1} (32% reduction vs. Strategy A);
- the two enlarged pits (Strategy C) yielded 12.4 min.truck^{-1} (38% reduction vs. Strategy A);
- the traffic pattern change (Strategy D) yielded 15.4 min.truck^{-1} (23% reduction vs. Strategy A).

The traffic pattern change yielded the lowest percentage savings, while enlarging both pits resulted in the greatest AST savings for all strategies evaluated.

Network model Scenario 2

This scenario identified the theoretical maximum capacity of the networked elevator-farmers system as a function of the elevator strategies and of the incoming grain stream. The number of daily loads received by the elevator is the first result that has to be pointed out for Scenario 2 of the network model. Therefore, the average number of load per day (Table 4) is much higher than the one presented in Table 1 (187, 252 and 385 respectively for average, busy and peak days parameters).

In this case, the number of daily loads delivered by the customers was not an input parameter as it was in the elevator model, and it was not limited per truck as in network Scenario 1.

The number of loads per truck and the daily loads were generated by the network model and represented the near-maximum performance of the inter-connected elevator-harvest-transport chain. The traffic subsystem (i.e., transportation and harvesting operations) is the same for the four elevator configuration strategies within the same incoming grain stream (i.e., daily traffic volume and grain type distribution). The number of loads received daily is directly influenced by the elevator performance. So, the better the strategy performs, the higher the number of daily loads delivered by the customers.

All new strategies yielded significantly better results than Strategy A.

The enlargement of one (Strategy B) or two pits (Strategy C) allowed for important increases in daily receiving capacity compared to the actual configuration, which was valuable information for the elevator manager.

Also, the grain type distribution and pit management had an important effect on the number of loads received daily:

- for the GrainA distribution the delivery increase due to the enlargement of one (Strategy B) or both pits (Strategy C) vs. Strategy A (actual configuration) was about 11.0 to 16.7% while the traffic pattern change (Strategy D) accounted for a 3.3-3.9% gain in grain received daily. The best strategy was enlargement of the two pits, with an increase up to 16.7% (76 loads.day^{-1}) compared to the actual elevator configuration performance (Strategy A). For the busy day, strategies B and C were not significantly different;
- for the GrainB distribution, the pit enlargement yielded a 5.7 to 7.2% increase (up to 30 loads.day^{-1}) vs. the actual configuration, while the traffic pattern change allowed for a 4.0 to 5.4% (up to 22 loads.day^{-1}) increase vs. the actual configuration. Strategy C was significantly better (α=0.05) than Strategy D but not significantly different than Strategy B. For the peak day, the strategies B and D were not significantly different from each other.

The number of daily loads delivered to the elevator was also an important result with respect to the results related to the Average Service Times [AST].

Table 4. Daily receiving capacity of four elevator strategies for network Scenario 2 (loads.day^{-1}).

	GrainA			GrainB		
Scenarios	Average	Busy	Peak	Average	Busy	Peak
A[(1)]	373.8 d[(2)]	413.4 g	455.2 k	347.6 n	382.9 r	416.4 v
B	414.9 b	463.5 f	519.2 i	369.3 l	404.6 p	443.2 tu
C	420.7 a	469.2 f	531.2 h	371.1 l	408.2 p	446.4 t
D	388.0 c	427.0 e	473.1 j	362.6 m	398.0 q	438.9 u
B-A[(3)]	41.0	50.1	64.0	21.8	21.8	26.9
C-A	46.9	55.8	76.0	23.5	25.3	30.0
D-A	14.2	13.5	17.9	15.0	15.2	22.5
B-A(%)[(4)]	11.0%	12.1%	14.1%	6.3%	5.7%	6.5%
C-A(%)	12.5%	13.5%	16.7%	6.8%	6.6%	7.2%
D-A(%)	3.8%	3.3%	3.9%	4.3%	4.0%	5.4%

[1]A- Baseline, B-One enlarged pit, C-Two enlarged pits, D-Traffic pattern change
[2]Values with the same letter are not significantly different at 95% confidence level within the same incoming grain stream. Statistical comparison is valid just within the same incoming grain stream (same grain type daily traffic volume)
[3]Receiving capacity increase vs. the strategy A (loads.day^{-1})
[4]Receiving capacity increase vs. the strategy A (%)

The three new strategies evaluated returned statistically significant (α=0.05) lower AST values than the actual configuration (Strategy A), and the differences were significant among the strategies (Figure 4).

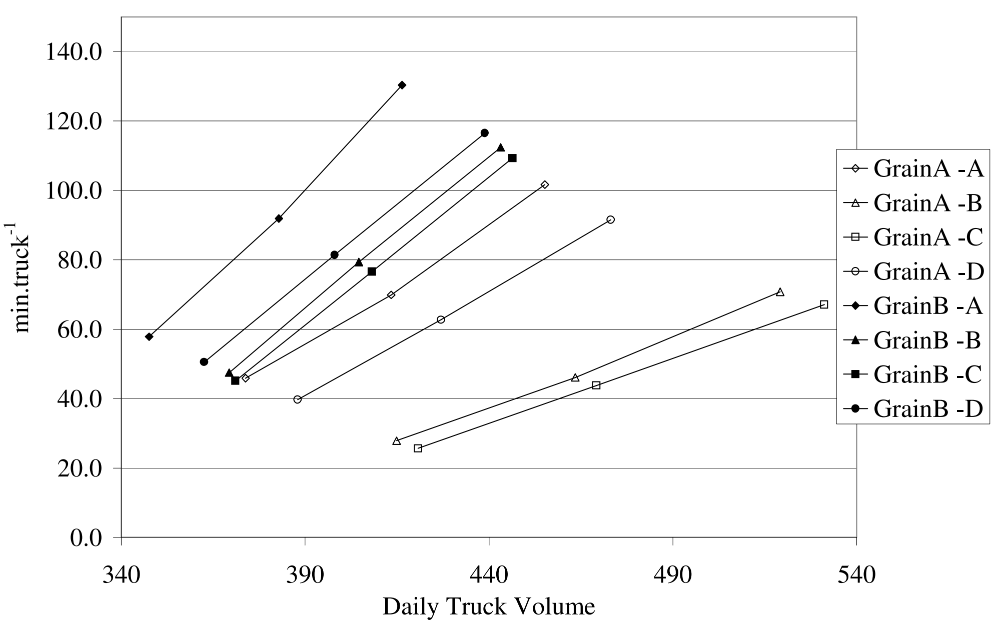

Figure 4. AST values for Scenario 2 and GrainA and GrainB distributions, for four simulated elevator strategies: baseline (A), one pit enlargement (B), two pits enlargement (C) and traffic pattern change (D).

Particularly:

- for the GrainA distribution, the AST savings due to the enlargement of one (Strategy B) or both pits (Strategy C) vs. Strategy A (actual configuration) was about 30.4 to 44.1% while the traffic pattern change (Strategy D) accounted for 10.0-13.4% AST reduction. The best strategy was the two pits enlargement, with AST savings up to 34.6 $min.truck^{-1}$ compared to the actual elevator configuration performance;
- for the GrainB distribution, the pit enlargements yielded up to 21.9% in AST savings vs. the actual configuration (Strategy A), while the traffic pattern change allowed for 10.6-12.6% in AST savings vs. the actual configuration;
- the savings in AST were larger for larger incoming grain flows.

Conclusions

The research presented the implementation of a network model to simulate the interaction of elevator grain receiving operations and grain truck deliveries from fields and farms. Four elevator configuration and traffic management strategies (baseline, one pit enlargement, two pits enlargement and traffic pattern change) were tested using the network model as a function of two different grain distributions and three daily traffic volumes.

The results of the simulation experiments showed that:

- the network model Scenario 1 predicted AST savings during a simulated grain flow that could occurs during the season. The savings were 32% for the one pit enlargement, 38% for the two pits enlargement, and 23% for the traffic pattern change compared to the baseline;
- the network model Scenario 2 predicted near-maximum performance of the elevator strategies for GrainA distribution given a delivery limit of 10 loads per day per truck. The results showed that the enlargement of two pits was best and allowed for dumping of up to 76 $loads.day^{-1}$ (i.e., 16.7% increase) more than Strategy A (actual elevator configuration). The AST savings were 34.6 $min.truck^{-1}$ vs. Strategy A (i.e., 34.0%);
- the network model Scenario 2 predicted maximum performance of the elevator strategies for GrainB. The results showed that the enlargement of two pits was best and allowed for dumping of up to 30 $loads.day^{-1}$ more than Strategy A (i.e., 7.2% increase). The AST savings were 21.1 $min.truck^{-1}$ vs. Strategy A (i.e., 16.2%).

The network modeling approach could be used to investigate the regional impact of harvest-transport operations (bigger combines, field-to-field yield variability, transportation speed effects, etc.), management practices and resources availability on farmers as well as the unloading operations of multiple grain facilities all simulated in one large-scale model. The performance of the system could be evaluated both on farm and elevator side.

References

Berruto, R., and D. E. Maier. 2000. Using modeling techniques to test the feasibility of GMO grain segregation and traceability at commercial elevators. IFAC Conference: Modeling and Control in Agriculture, Horticulture and Post-harvest Processing. 12-14 July 2000. Wageningen, The Netherlands: 339-344

Berruto, R., and D.E. Maier. 2001. Analyzing the receiving operation of different grain types of grain in a single pit commercial country elevator. Transactions of the ASAE, 44(3): 631-638.

Dooley, F., and. W. Wilson. 1987. The effect of elevator competition upon market areas. In Journal of the Transportation Research Forum. Volume XXVIII, 1987.

Law, A., and D. Kelton. 2000. Simulation modeling and analysis. Mc Graw Hill, MA.