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Analyzing the Receiving Operation of Different Grain Types in a Single-Pit Country Elevator

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ANALYZING THE RECEIVING OPERATION OF DIFFERENT GRAIN TYPES IN A SINGLE-PIT COUNTRY ELEVATOR

R. Berruto, D. E. Maier

ABSTRACT. *With the rise of value-added grains and oilseeds, many elevators need to segregate their incoming products into batches of different end-use quality (for example, high oil corn, genetically modified soybeans, high protein wheat), but often they are not designed to handle this task efficiently. The primary challenge is to segregate multiple grain streams during the receiving operation without increasing waiting times for all customers.*

This study utilized a system simulation model to investigate how queue management could help to improve the performance of a country elevator receiving multiple grain streams with a single unloading pit. In order to maintain the speed of the unloading operation, two queuing methods were investigated: the segregated BATCH versus the traditional FIFO (first-in, first-out) queue service method. A discrete event system simulation model was developed and validated utilizing data collected at a country elevator facility in Indiana. The simulation results showed that the BATCH queue management strategy reduced average waiting times per customer by up to 27% compared to the traditional FIFO queue management strategy when the daily grain receipt was near the maximum receiving capacity of the facility. For receiving rates below 72% capacity, the traditional FIFO service had shorter average waiting times per customer.

Keywords. *System model, Discrete event modeling, Grain quality, Grain segregation, Grain handling.*

With the rise of value-added grains and oilseeds, many country elevators are facing the problem of having to segregate their incoming grain streams into batches of different end use quality, for example: high-oil corn (HOC), high-protein soybeans, highly extractable starch corn, high-protein wheat, not-genetically modified (non-GM) grains, and other identity-preserved (IP) grains. Traditionally, country elevators in the Midwestern U.S. Corn Belt had to segregate only three products during the fall harvest: dry corn, wet corn, and soybeans. Not all elevators are designed for the efficient segregation of multiple products during the fall harvest rush (Hurburgh, 1994). The quantity delivered day by day to the elevator varies greatly due to yield, weather events, timeliness of harvest, and other factors. This variability influences the burden of the elevator, which is defined as the ratio of the total grain delivered per day divided by the daily design capacity of the receiving system. Generally, no two elevators are identical in receiving capacity. Thus, the problem of incoming grain segregation has to be solved for each elevator configuration. Existing receiving and segregation capacities have to be quantified and possible

solutions have to be evaluated to assure that a country elevator will be able to function efficiently under different future working scenarios (Vandenburg, 1999).

Many country elevators receive grain from farmers by truck, and ship grain by train or truck to a terminal elevator or directly to an end user. The majority of country elevators use the same scale to weigh full trucks and empty trucks. One or two receiving pits are often served by the same bucket elevator leg for the transfer of incoming products to wet grain storage before the dryer, or directly to dry grain storage. Traditionally, trucks are served by their order of arrival (first-in, first-out, or FIFO), which is the common approach to managing traffic. When the type of incoming grain into a pit changes, complete unloading and cleanout of the pit, bucket elevator leg, and subsequent conveyors is required before the new product can be unloaded into the pit. During this setup time, unloading is stopped and the waiting time increases for all customers currently in the queue. Reducing the frequency of the setup time by serving trucks with the same grain type in batches (BATCH queue management) increases the capacity of the unloading operation.

The objective of this article was to quantify and compare the effects of traditional FIFO versus BATCH queue management on the performance of the receiving operation of a country elevator using a discrete event system simulation model.

LITERATURE REVIEW

There are few references in the field of dynamic system simulation that apply directly to grain handling. Maier and Csaki (1993) developed an initial system model using SLAM II (Symix Systems, Inc.) to simulate the receiving operation

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of a grain elevator, which was expanded by Berruto and Maier (1996, 1999). King (1995) presented a grain elevator operations simulation model developed for use by Canadian wheat pools to analyze the efficiency of their operations. The work was never published and the software has remained inaccessible. Baker et al. (1997) conducted stopwatch time studies in order to calculate the design capacities of elevators in Kansas. Herrman (1999) developed a model using SIMAN (System Modelling Corporation) to evaluate whether enough idle capacity existed in Kansas elevators to segregate wheat in order to capture protein premiums. They showed that less than 45% of wheat receiving systems in Kansas operated at or above 70% of their burden. In their opinion, the residual capacity of grain receiving systems was large enough to carry out timely segregation of wheat during the harvest rush. They incorporated into their model a partial budget analysis and determined that the cost of segregating wheat into two quality categories at a 60% burden was \$2.05/tonne (\$0.079/bu), and into three quality categories was \$2.37/tonne (\$0.092/bu). As operating efficiency increased, the cost of segregation decreased. This was mainly due to decreased waiting time prior to unloading. However, the cost of segregating wheat at a country elevator with only a single receiving pit and bucket elevator leg never dropped below \$1.83/tonne (\$0.071/bu). Segregation of wheat based on end use quality enhanced the value of wheat received at the country elevators investigated by approximately \$10,000 per day (Herrman, 1999).

Several solutions are available to improve the handling performance for grain segregation. One option that does not require a new investment for the elevator is the batch processing of trucks carrying the same type of grain. Numerous works cite related experiences in industrial engineering. Hall (1991) discussed several methods of scheduling activities by grouping together multiple items that have the same attribute (batching), and thus reducing the service–setup time of a manufacturing facility. Testing different queue management methods can be done with the help of discrete event system simulation models (Krahl, 1994; Pritsker, 1995; Banks, 1999; Berruto and Maier, 1996).

MATERIAL AND METHODS

ELEVATOR RECEIVING OPERATION

The country elevator used in this analysis has the following receiving system in place. A truck arriving at the elevator enters a common queue. While waiting, it is probed for a sample at a station about 100 m (310 ft) ahead of the integrated scale and unloading system. The sample is taken to the lab for grading, and the grade receipt is subsequently forwarded to the scale. The truck continues to wait in the FIFO queue until its turn to proceed to the weighing and unloading operation. The scale is integrated into a hydraulic lift unloading system, and thus is actually located after the pit. Once the truck enters the enclosed unloading area, it has to pull ahead of the pit and onto the platform scale. After

weighing, the truck has to back up a short distance. It can be unloaded either by opening a bottom gate (one at a time for a hopper–bottom semi–truck trailer) or by opening the rear gate and hoisting the truck. The entire contents of the truck are emptied into a receiving pit with a capacity of 37.5 t (1500 bu) within 3.3 minutes on average. Grain is transferred from the pit by a drag conveyor (475 t h^{-1}) into a vertical bucket elevator (475 t h^{-1}). Once emptied, the truck pulls ahead and is re–weighed. After weighing, the truck exits the unloading area and leaves the country elevator.

DATA COLLECTION

Data used to validate the system simulation model were collected during three days in November 1993 (3, 4, and 11 Nov.) at a large country elevator of 80,000 t (3.2 million bu) storage capacity in central Indiana (Maier and Csaki, 1993). The data recorded for each truck were: arrival time during the day, truck type, load weight, grain type, grain moisture content, start time, and length of service time for the weigh–unload–weigh operation. The only product received on those days was corn. “Dry” corn was any corn with a moisture content of less than 17% wet basis (w.b.), which went directly into storage. “Wet” corn was any corn with a moisture content of 17% w.b. or greater, which went directly into wet holding bins ahead of the dryer. The operating period of the facility was 11 hours each day (7 a.m. to 6 p.m.).

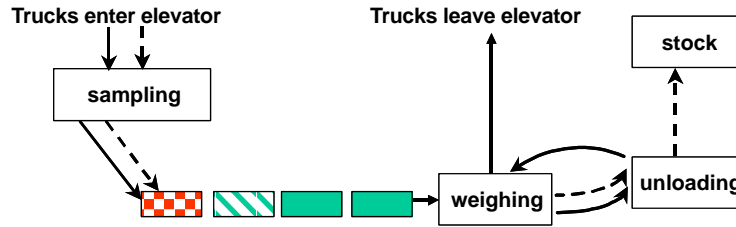
Clean–out time of the conveying system included the time required for the last kernel of grain to flow from the pit through the pit unloading conveyor, the vertical bucket elevator, the pre–cleaner, the distributor, and the drag conveyor into the wet holding bin, or into the final storage structure.

QUEUE MANAGEMENT

Whenever trucks arrive at the elevator, it is possible to pre–sort those carrying the same type of grain into batches in order to reduce the changeover frequency, and thus reduce the customer waiting times. The clean–out time of the pit and subsequent conveying system occurs only after the queue served is changed. This results in considerable savings in time and increases the daily unloading capacity of the elevator. On the other hand, non–optimal queue service can lead to longer waiting times for the trucks not served.

The BATCH queue management strategy is illustrated in figure 1. It takes advantage of pre–segregation by assigning trucks filled with the same grain type into the same queues (e.g., dry corn queue, wet corn queue, soybean queue). The queue served by the receiving station will always be the one with the longest average waiting time (AWT) per truck. When one type of grain is served (e.g., dry corn queue), the unloading operation takes place either until all trucks carrying the same type of grain are served, or until the queue has been served for the service time calculated for that queue. When a queue is no longer served, the model chooses the next queue with the highest AWT.

FIFO queue service



BATCH queue service

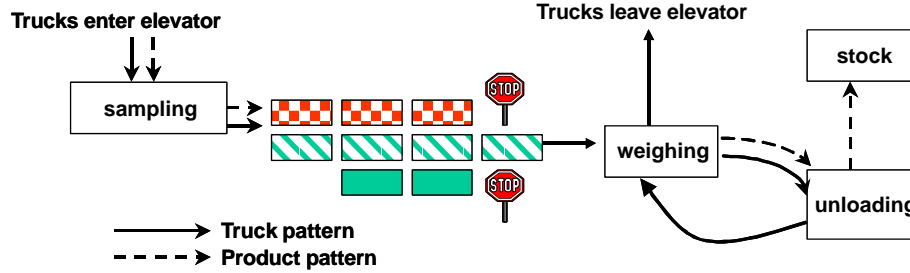


Figure 1. Flow diagrams of FIFO (first-in, first-out) vs. BATCH queue services.

The optimal time of service for each queue is calculated as a function of the unloading capacity of the pit, the setup time of the pit (clean-out of the pit and subsequent conveyors), and the arrival rate for each product. The hourly arrival rate, λ_i (trucks/h), of grain type i had a Poisson distribution that was calculated based on the data collected at the elevator (fig. 2) as follows:

$$\lambda_i = \frac{TP_i}{Hs} \quad (1)$$

where

TP_i = daily number of trucks arriving of grain type i (trucks/day)

Hs = service hours the elevator is open during the day for unloading operations (h/day).

The average load per truck, μ_L (t/truck), was calculated based on the data collected as follows:

$$\mu_L = \frac{TG}{TP} \quad (2)$$

where

TG = total grain delivered (summation of all product types) within one day in the same pit (t)

TP = total number of trucks arriving within one day across the same pit (trucks).

The average service rate, c (trucks/h), for each pit is calculated based on a modification from Hall (1991):

$$c = \frac{PFR}{\mu_L} \quad (3)$$

where

PFR = pit flow-rate ($t\ h^{-1}$).

The traffic intensity, r_i (dimensionless), for grain type i is calculated as follows (Hall, 1991):

$$r_i = \frac{\lambda_i}{c} \quad (4)$$

The traffic intensity, r (dimensionless), for all grain over the same pit is:

$$r = \sum_{i=1}^{i=n} r_i \quad (5)$$

where n represents the types of grain delivered to the same pit. For each day, the parameter r must satisfy the following restriction:

$$r \leq 1 \quad (6)$$

This restriction applies because the incoming flow of trucks cannot be larger than the number of trucks the pit can unload during the set operating hours of the facility. The setup time, a (minutes), can be calculated as follows:

$$a = \left\lceil 60 \left(\frac{PHC}{2} \right) \frac{1}{PFR} \right\rceil + s \quad (7)$$

where

PHC = pit holding capacity (t)

s = conveying system clean-out time after the pit is empty (minutes).

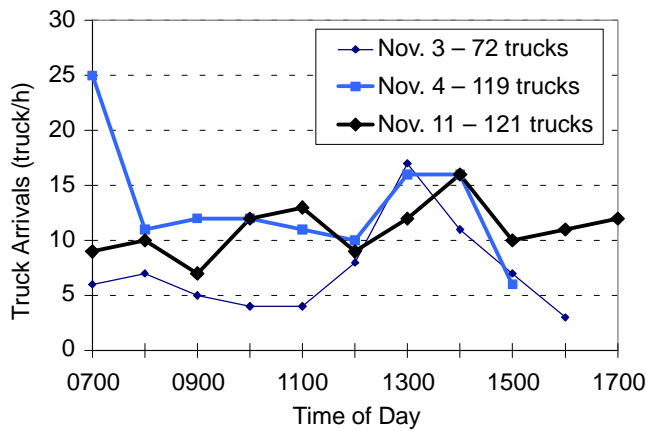


Figure 2. Distribution of truck arrivals at the country elevator on 3, 4, and 11 Nov. 1993.

We assumed that by the time the truck was reweighed and left the unloading station, the amount of grain in the pit was on average half of the total PHC. The time of service for two grain types can be calculated as follows (Hall, 1991):

$$T_1 = \frac{(1-r_2+r_1)}{1-r} \times a \quad (8)$$

$$T_2 = \frac{(1-r_1+r_2)}{1-r} \times a \quad (9)$$

where

T_1 = duration of the service time for queue with grain type 1 (minutes)

T_2 = duration of the service time for queue with grain type 2 (minutes).

Equations 8 and 9 were used to calculate the optimum duration of service time for each type of grain that arrived at the single-pit country elevator. Each day surveyed had different arrival patterns. Thus, for each day (3, 4, and 11 Nov.) an optimum set of batch service times was calculated (table 1). The calculated service times were used in the BATCH model to determine the length of the service period for each grain delivered on the same day and into the same pit.

MODEL IMPLEMENTATION

For the model implementation, Extend system simulation software (Imagine That Corporation) was used. Extend is a general-purpose package suitable for modeling discrete, continuous, and mixed systems. The graphical interface

allows the user to easily follow and understand the flow of the entities through the system represented.

The basic Extend software package contains 90 pre-built blocks. Third-party libraries are available for specific purposes, such as statistics and electronics, and other companies produce specific block libraries, such as a neural-network library and a financial library. Users can also build their own library blocks, including hierarchical blocks.

Standard blocks and custom designed blocks were used to build the model to simulate the unloading operation at a country elevator. The custom blocks developed by the authors for this purpose were (Berruto and Maier, 1999):

Truck Generator — This block simulates the grain arrival distribution at the elevator. Distributions of grain type, truck type, moisture content, load weight, and arrival times of trucks are included in this block. The block was set up to vary the mean inter-arrival time every hour in order to closely match the distribution of data collected at the facility during operating hours. The distribution of truck arrivals (as shown in fig. 2) is part of the data used to feed the truck generator block.

Sampling Operation — Used to set up the maximum queue length and the time required for taking a grain sample from the truck.

Queue Management Method — The two management methods developed were the FIFO (first-in, first-out) queuing strategy and the BATCH queuing strategy. New ModL code was written for the BATCH service method. This block can handle up to four grain types per pit without any modification (e.g., wet and dry corn, beans and non-GM beans).

Weigh-Unload Operation — Used to simulate truck weighing and unloading on a platform scale, as described earlier in the “elevator receiving operation” section.

Storage Structures — Used to simulate a series of storage structures (bins, tanks, silos, sheds, piles) in order to accumulate the amount of segregated grain received during the simulated time.

SIMULATION EXPERIMENT DESIGN

One model was developed and used to simulate the unloading operation at the single-pit country elevator, as described earlier in the “elevator receiving operation” section. The truck arrival distributions for 3, 4, and 11 Nov. were used to test the performance of the elevator during three days of harvest with the FIFO and BATCH queue management strategies. The time scale adopted was the minute (1 day = 1440 min), and all operating time

Table 1. Time of service (T1 = wet corn, T2 = dry corn) calculation for the BATCH queue (minutes per queue per product type) for the truck arrival distribution of 3, 4, and 11 Nov. 1993 for different pit flow rates.

Pit Flow Rate (t h ⁻¹)		150	175	200	225	250	275	300	325	350	375	400	425	450	475
3 Nov.	T1	79	79	42	29	22	18	16	14	12	11	10	10	9	9
	T2	42	42	24	18	14	12	11	10	9	9	8	8	7	7
4 Nov.	T1				185	169	60	37	27	22	18	16	14	13	12
	T2				120	115	42	27	20	17	14	13	11	10	10
11 Nov.	T1						172	172	70	44	33	26	22	19	17
	T2						71	71	31	21	16	14	12	11	10

distributions such as unloading, weighing, and probing were expressed in minutes. The output parameters “average waiting time per truck” (AWT) and “pit utilization” were chosen to interpret the performance of the system. Only AWT is discussed in this paper. AWT was used to compare the performance of the system model with that of the real system for which data was collected at the country elevator. Some manipulation was necessary both in the model design and in the set up of parameters to predict average waiting times that were not statistically different at the 95% confidence level from the collected data.

The performance of the BATCH and FIFO queue management strategies was evaluated by conducting eight series of simulations for a total of 10,000 runs (table 2). In experiments A through F (six series), FIFO and BATCH were evaluated by comparing the three statistical distributions of truck arrivals on 3, 4, and 11 Nov. and by varying PFR from 150 to 475 t h⁻¹ (6000 to 19000 bu h⁻¹). In experiments G and H, the number of trucks was varied from 80 to 210 trucks/day based on the truck arrival distribution of 11 Nov. The PFR was held constant at 475 t h⁻¹ (19000 bu h⁻¹). Every configuration was simulated 100 times. The average of 100 runs was used to compare the performance of the two queue management strategies using ANOVA and the LSD test (SPSS Inc., Chicago, Illinois).

RESULTS AND DISCUSSION

TRUCK ARRIVAL DATA

As shown in table 3, the number and type of trucks arriving varied considerably during each day. The distribution of

truck arrivals was also different for each day (fig. 2). For example, the number of trucks arriving on 4 and 11 Nov. was almost identical (119 trucks and 121 trucks, respectively), but the average waiting time was almost half on 11 Nov. (0.67 hours vs. 1.2 hours on 4 Nov.). The cause for this difference was the presence of 25 trucks waiting in line at 0700 before the elevator opened for business on 4 Nov. combined with a less uniform distribution of truck arrivals throughout that day.

TRUCK UNLOADING AND WEIGHING DATA

Figure 3 shows the accumulated sum of the received and unloaded grain quantities on 4 Nov. During the early part of the day, the gap between the two curves was up to 500 t. At noon, only 200 t were waiting to be unloaded. The large amount of grain not being unloaded and the poor arrival distribution increased the AWT. On 3 Nov., the mean time for unloading and weighing was 7.5 min/truck with relatively few arrivals, compared to 4.6 min/truck on 4 Nov. with an initially high number of trucks at the beginning of the day. On 11 Nov., unloading and weighing was carried out in about 5 min/truck. The clean-out time of the pit and subsequent conveying system was determined to be about 2.8 min on each day.

ANALYSIS OF MODEL RESULTS

The results presented in the following sections are those obtained by the model simulations. It is noted that the simulated grain receipts were not significantly different at the 95% confidence level from the data collected at the country elevator (table 4).

Table 2. Simulated experimental design in order to investigate the FIFO vs. BATCH queue service methods.

Test Series	No. of Runs ^[a]	PFR ^[b] (t h ⁻¹)	Arrivals (trucks/day)	Arrival ^[c] Distribution Day	Service Queue Type
A	1400	150 – 475	73	3 Nov.	FIFO
B	1400	150 – 475	73	3 Nov.	BATCH
C	1200	200 – 475	116	4 Nov.	FIFO
D	1200	200 – 475	116	4 Nov.	BATCH
E	1000	250 – 475	122	11 Nov.	FIFO
F	1000	250 – 475	122	11 Nov.	BATCH
G	1400	475	80 – 210	11 Nov.	FIFO
H	1400	475	80 – 210	11 Nov.	BATCH

^[a] Only experiments with a burden less than or equal to 100% were carried out.

^[b] PFR = Pit flow rate, in tons per hour.

^[c] Hourly based distribution derived from collected data.

Table 3. Number of trucks and average weight by type delivered to the country elevator on 3, 4, and 11 Nov. 1993 (data from Maier and Csaki, 1993).

Day	Average Weight of Product Delivered by Type of Truck (t)			Truck Arrivals by Type of Truck			
	Double Axle (S.D.) ^[a]	Semi-truck (S.D.)	Single-axle (S.D.)	Double Axle	Semi-truck	Single-axle	Total
3 Nov.	14.3 (3.2)	25.2 (3.5)	9.3 (1.3)	22	44	6	72
4 Nov.	14.6 (3.7)	25.0 (3.4)	8.7 (1.8)	43	66	10	119
11 Nov.	16.0 (4.1)	24.5 (8.0)	7.6 (–)	13	107	1	121

^[a] Standard deviation of the truck loads.

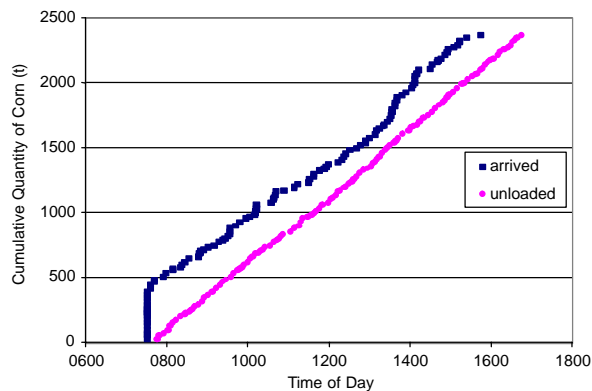


Figure 3. Actual corn delivered and unloaded at the country elevator on 4 Nov. 1993.

Table 4. Product delivered to the country elevator on 3, 4, and 11 Nov. 1993 (data from Maier and Csaki, 1993).

Day	Wet Corn (t d ⁻¹)	Dry Corn (t d ⁻¹)	Total (t d ⁻¹)
3 Nov.	982 (68%) ^[a]	497 (32%)	1479
4 Nov.	1446 (60%)	922 (40%)	2368
11 Nov.	1757 (65%)	1079 (35%)	2836

[a] Percentage of the total product delivered.

EFFECT OF PIT FLOW RATE ON AVERAGE WAITING TIMES

Figure 4 shows the predicted AWT for FIFO vs. BATCH for the 3 Nov. data. The amount of grain delivered was comparatively small (1545 t d⁻¹). Thus, the burden of the elevator was relatively low (only 30% at 475 t h⁻¹) and no significant differences were encountered between the two queuing strategies for 200 to 475 t h⁻¹ PFR. At PFRs less than 200 t h⁻¹, the BATCH strategy performed significantly better than FIFO based on a LSD comparison at the 95% confidence interval. The reduction in AWT ranged from 8% (9 min) to 9% (7 min) at 150 and 175 t h⁻¹ PFR, respectively.

On 4 Nov., the BATCH system performed significantly better at a PFR below 350 t h⁻¹ (fig. 5). The improvement in AWT with respect to FIFO queue management ranged from 25% (59 min) to 10% (15 min) at 225 and 300 t h⁻¹, respectively. Between 375 and 425 t h⁻¹, FIFO performed significantly better than the BATCH strategy, reducing AWT from 7% (6 min) to 17% (15 min).

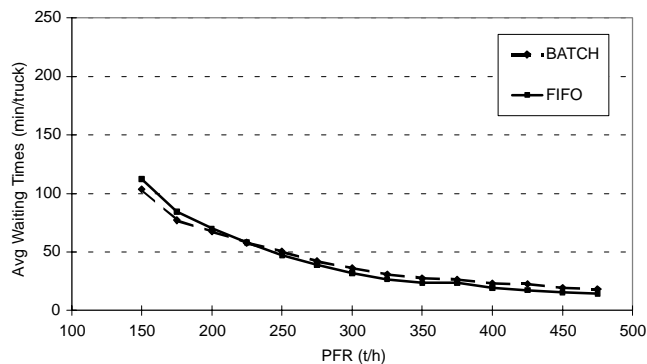


Figure 4. Average waiting times for simulated experiments A (FIFO) and B (BATCH) vs. pit flow rate (PFR) variation for the 3 Nov. truck arrival distribution.

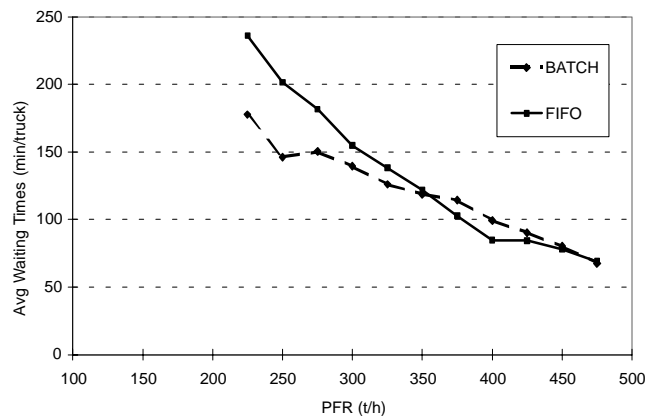


Figure 5. Average waiting times for simulated experiments C (FIFO) and D (BATCH) vs. pit flow rate (PFR) variation for the 4 Nov. truck arrival distribution.

At higher PFRs (425 to 475 t h⁻¹), there was no statistically significant difference in the AWT between the two strategies. At PFRs of 250 and 275 t h⁻¹, the AWTs of the BATCH strategy were statistically equal. Similarly, the AWTs of the FIFO strategy at PFRs of 400 and 425 t h⁻¹ were statistically equal. This implies that if it were possible to manipulate the truck arrival distribution, additional reductions in AWT could be achieved. A country elevator could accomplish this, for example, by utilizing scheduling windows for the delivery of specific products (Berruto and Maier, 2000).

For the 11 Nov. data, the BATCH strategy performed significantly better than the FIFO strategy at PFRs below 375 t h⁻¹ (fig. 6). The improvement in AWT vs. FIFO queue management ranged from 23% (46 min) to 12% (12 min) at 250 and 350 t h⁻¹, respectively. Above 375 t h⁻¹, there was no statistically significant difference in the AWT between the two strategies.

EFFECT OF TRUCK ARRIVAL DISTRIBUTION ON AVERAGE WAITING TIMES

The number of truck arrivals on 4 and 11 Nov. was nearly the same (119 vs. 122 trucks/day, respectively), but the amount of grain delivered was 20% greater on 11 Nov. than on 4 Nov. (2855 t d⁻¹ vs. 2384 t d⁻¹, respectively), primarily because of the larger number of semi-trucks (107 vs. 66,

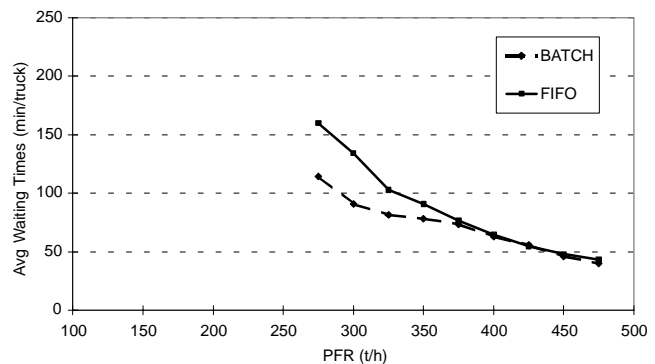


Figure 6. Average waiting times for simulated experiments E (FIFO) and F (BATCH) vs. pit flow rate (PFR) variation for the 11 Nov. truck arrival distribution.

Table 5. Simulated burden of the country elevator, calculated as the ratio between the total product delivered and the design capacity of the unloading system, expressed as a percentage of the maximum receiving capacity. The asterisk indicates significantly better performances at the 95% confidence level for the BATCH compared to the FIFO queue management strategy.

PFR ^[a]	150	175	200	225	250	275	300	325	350	375	400	425	450	475
3 Nov.	94*	80*	70	62	56	51	47	43	40	37	35	33	31	30
4 Nov.	—	—	—	96*	87*	79*	72*	67*	62	58	54	51	48	46
11 Nov.	—	—	—	—	—	94*	87*	80*	74*	69	65	61	58	55

[a] PFR = Pit flow rate, in tons per hour.

respectively). The effect of the truck arrival distribution on AWT was significant. The AWTs for the BATCH strategy on 11 Nov. were on average 39% (49 minutes) lower compared to 4 Nov., while the AWTs for the FIFO strategy were on average 33% (49 minutes) lower. Specifically, at the same PFR of 300 t h⁻¹ for 4 and 11 Nov., the BATCH strategy reduced AWT on 11 Nov. by 35% compared to 4 Nov. (from 139 min/truck on 4 Nov. to 91 min/truck on 11 Nov.). Similarly, the FIFO strategy reduced AWT on 11 Nov. by 14% compared to 4 Nov. (from 155 min/truck for 4 Nov. to 134 min/truck for 11 Nov.). Thus, the BATCH queue management strategy appears to be influenced more by truck arrival distribution than is the FIFO strategy.

EFFECT OF BURDEN ON AVERAGE WAITING TIMES

The burden of the country elevator was calculated as the ratio between the total amount of grain unloaded each day divided by the design capacity of the unloading system for that day. The burdens up to 100% for each simulated scenario are summarized in table 5.

The performance of the BATCH queue management strategy was significantly better when the burden was greater than or equal to:

- 80% for the 3 Nov. arrival distribution, which corresponded to a PFR of 175 t h⁻¹ when 1545 t d⁻¹ were unloaded
- 67% for the 4 Nov. arrival distribution, which corresponded to a PFR of 325 t h⁻¹ when 2384 t d⁻¹ were unloaded
- 74% for the 11 Nov. arrival distribution, which corresponded to a PFR of 350 t h⁻¹ when 2855 t d⁻¹ were unloaded.

Thus, the BATCH queue management strategy appeared preferable whenever the receiving burden of the country elevator was on average above 72%. At lower burdens, the FIFO strategy was the better and simpler solution for incoming traffic management.

EFFECT OF PIT FLOW RATE ON MAXIMUM WAITING TIMES

Another question that arises from BATCH queue management is the distribution of the maximum waiting times (MWT). One might expect these to be greater for BATCH management than for the FIFO strategy because some trucks may be in a batch queue longer than if they had been served on a first-in, first-out basis. However, based on the results of all simulation runs (experiments A, C, and E for FIFO, and B, D, and F for BATCH), the MWTs were significantly lower whenever the AWTs of the BATCH

strategy were significantly lower. Thus, on busy days when the burden on the receiving system of the elevator was greater than 72% on average, the use of the BATCH queue service method allowed for a significant reduction in both the AWT and MWT compared to the traditional FIFO strategy.

EFFECT OF NUMBERS OF TRUCKS UNLOADED ON AVERAGE WAITING TIMES

In test series G and H, an increase in the amount of the grain delivered per day was simulated while maintaining the PFR of the elevator fixed at 475 t h⁻¹. The BATCH strategy performed consistently better above a burden of 72% (fig. 7). This was equivalent to 3760 t delivered per day during 11 hours of facility operation and resulted in a 7-min AWT reduction per truck served. This difference increased up to 40 minutes when the utilized capacity reached 85% to 90% burden. The 72% burden is an average value that implies 100% utilization of the receiving system during some hours of the day and a lower utilization during other hours. In the common situation where truck arrival is unpredictable, it is not possible to obtain 100% of machinery and plant utilization (burden) without causing a steady increase in the average and maximum customer waiting times.

The experiment was repeated for 3 and 4 Nov. to evaluate whether truck distribution arrival had a significant effect on results. The simulation results confirmed the 72% burden limit for switching from FIFO to BATCH queue management independent of truck arrival distribution (data not shown).

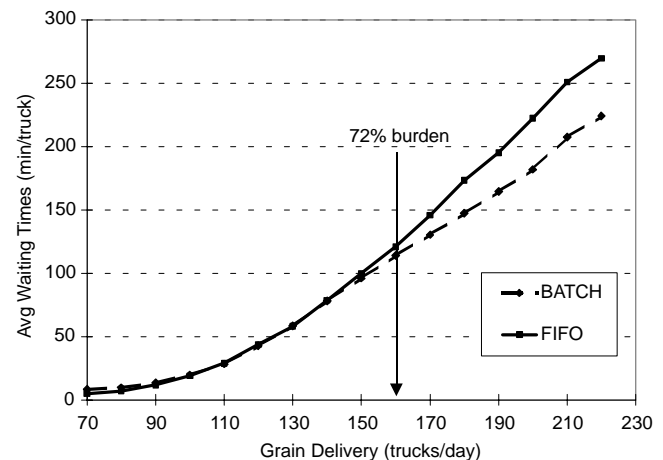


Figure 7. Average waiting times for simulated experiments G (FIFO) and H (BATCH). Total grain delivered was 3760 t d⁻¹ at 72% burden, and 5225 t d⁻¹ for 100% theoretical burden. (11 Nov. truck arrival distribution data.)

CONCLUSIONS

This study has shown the benefits of switching the management of incoming truck traffic for a single-pit country elevator from FIFO queue management to a more efficient segregated BATCH strategy during high burden periods. Advantages for BATCH management are greatest at burden levels greater than 72% of the full receiving capacity of the unloading operation, independent of the truck arrival distribution. The BATCH queue method reduced average waiting times by up to 27% per customer compared to the traditional FIFO strategy when the incoming flow of grain was near the maximum receiving capacity of the facility. For flow rates below 72% of the full receiving capacity, the traditional FIFO queue management strategy proved adequate. This analysis could also be applied to the receiving operation of multi-pit country elevators.

The time savings incurred by the BATCH queue strategy will be even more significant when more incoming grains and oilseeds have to be segregated because the probability of different products in the same row of a single-pit unloading system would be much greater. This greater product mixture would dramatically increase the accumulated setup times between different products, and consequently increase the AWT (and MWT) per customer with the traditional FIFO strategy.

Another recommendation that arises from this work is that the burden of the elevator should be calculated more realistically by taking into account the setup time as a part of the unavoidable work in the elevator. Thus, the actual burden will be higher when the number of grains to be segregated increases because of the more frequent pit and conveyor cleanout operations.

Based on this investigation, the unused capacity of the single-pit country elevator would be much lower than the difference between the theoretical 100% capacity and the actual burden, if the goal of the elevator is to keep the waiting times for customers reasonably low.

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