KP2-2

Engineering design and operation of equipment to assure grain quality and purity

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Abstract

The effective segregation of specialty grains (waxy maize, high amylase maize, non-GM soybeans) and maize types that are fully approved for food and feed use in the U.S. and Japan, but not yet in the EU at on-farm and commercial grain handling facilities has been the topic of much debate. How can on-farm and commercial systems designed and built to handle large quantities of low value commodities maintain the quality and purity of specialty crops and avoid contamination from genetic traits not desired by certain end users or approved in certain overseas markets? For years producers and commercial operators have been handling maize, soybeans, wheat and other grains in the same receiving systems. Cross contamination is minimized by allowing conveying systems to run empty between loads of different grain types followed by flushing the system of residual grain. According to industry sources, elevator deliveries of maize typically contain less than 0.1 % of soybeans, and deliveries of soybeans typically less than 0.1 % of maize. Thus, why should the same approach not work to maintain the genetic purity of grains and avoid cross-contamination on-farm and at elevators? The inability to successfully segregate multiple grain types is most often related to improper planting sequence and harvest planning, field-to-field pollen drift problems, poor sanitation practices of equipment, human errors during receiving and conveying, lack of trained personnel, poor utilization of available equipment, and poorly designed, maintained and operated equipment. In order to minimize the contamination potential and maximize quality, operators need to implement a strict cleanout program for each piece of equipment, field operation planning, or use dedicated equipment. Existing handling systems and equipment can be successfully used to maintain quality and purity as long as the same attention to detail is paid as to segregating maize from soybeans and vice versa.

Key words: Identity preservation, segregation, cross-contamination, genetically modified crops.

Introduction

With the rise of value added grains and oilseeds, grain handling facilities (grain elevators) across the world have been taking in an increasing number of differentiated crop types. This fact presents operations managers with a unique challenge. Originally, grain elevators were designed and built to take in large quantities of generic commodities. However today, they are expected to not only take in several different commodities, but to keep the identity of those commodities preserved throughout the receiving, storage, and shipping processes.

The term bottleneck refers to a point in the receiving operation that causes the whole

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operation to slow down. These bottlenecks could occur in the form of the weighing and probing operation taking a long period of time, bucket elevators with capacities (t/h) that cannot keep up with the incoming grain stream, or not having enough receiving pits to take in many different commodities in a timely manner. In the United States, many elevators had bottlenecks in their receiving system before the onset of value added crops in the marketplace. However, now more than ever, these bottlenecks need to be identified and eliminated so that elevators can improve operational efficiency in order to remain competitive.

At Purdue University, we have created a system simulation model called Elevator-SIM that can assist in the adoption of value enhanced grain handling and marketing strategies. Elevator-SIM was recently used to develop five site-specific grain elevator systems simulation models. Data for the development of the systems models was gathered at five Eastern Maize Belt elevators located in Indiana and Illinois during the 2002 and 2003 harvest seasons. The five site-specific grain elevator models were developed using EXTEND®, a powerful systems simulation software.

The intended purpose of the Elevator-SIM grain elevator system simulation model is to provide industry personnel, such as grain elevator operations managers, with a tool to use when making logistical decisions concerning their specific facilities. These logistical decisions focus on the identification and correction of receiving system bottlenecks. Additionally, Elevator-SIM could be used by facility planning and design engineers to evaluate proposed layout options for new or existing facilities given observed or expected site-specific grain receiving quantities and logistics patterns. It can also be used to quantify the potential for damage of grains and cross-contamination among multiple crops during handling operations.

The primary objective of this paper is to demonstrate the practical application of Elevator-SIM, which has been applied recently to a series of “what if” modification scenarios for five commercial country elevators in Indiana and Illinois (McGill, 2004). For example, “what if” a remote probe were added to the receiving system of an elevator? How would this affect the overall performance of the elevator in terms of average service time (AST)? Or, what if multiple grains are handled through the same receiving system? How much cross-contamination might be expected?

McGill (2004) evaluated 17 different “what if” scenarios. Space does not allow for the presentation of all “what if” scenarios investigated. Therefore, two primary examples will be presented in the following sections:

- Elevator A – What if…
    a) Traffic flow was improved by changing the facility layout?
    b) The number of trucks arriving at the elevators increased significantly?
- Elevator C – What if…
    a) The contamination of maize that does not need to be channeled could be predicted?
    b) The between truck clean-out time necessary to maintain predetermined purity levels and its effect on the contamination of maize could be predicted?

Results and discussion of “what if” simulation scenarios applied to elevator A

Simulation Scenarios Investigated

The storage and receiving characteristics of Elevator A are summarized in Table 1.

The manager of grain Elevator A was well aware of the bottlenecks in this facility. As trucks came off of the scale and moved to the receiving pit, they were forced to make a sharp turn to the left or move across traffic streams often causing a major traffic jam in the town’s main street. As a result, the manger was weighing the pros and cons of altering the logistics of the receiving operation by purchasing an adjacent property, tearing down a building, and installing new equipment. The following is a list of proposed changes that were being considered for Elevator A (Figure 1):

1. The adjacent property is to be purchased and building A torn down.
2. The existing office is to be torn down and rebuilt on the adjacent property. The existing scale is to be moved in front of the new office.
3. A fourth receiving pit (P4) is to be added in order to increase the overall receiving capacity and improve grain segregating capabilities.

A remote probe station (R) is to be added ahead of the new scale.

Figure 2, Illustrates how the traffic would flow through Elevator A if the proposed changes were implemented at this particular facility.

Table 1. Storage and receiving characteristics of Elevator A, which has a total fixed storage capacity of about 50,000 tonnes.

Type of Structure	Number of Structure	Total Capacity of Storage Structure
Grain Storage		
Corrugated Steel Bins	5	28,000 t
Concrete Silos	4	2,500 t
Concrete Annex	25	19,000 t
Receiving Equipment		
Receiving Pit & Leg	5	675 t/h
Weighing/Probing Equipment		
Scale	1	1 Inbound / Outbound
Probe	1	1 Scale Probe

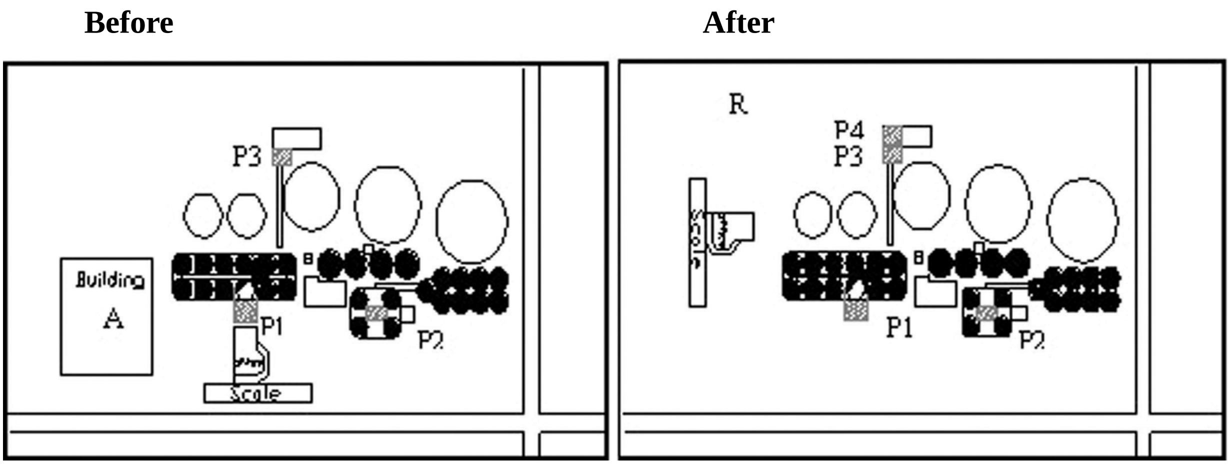
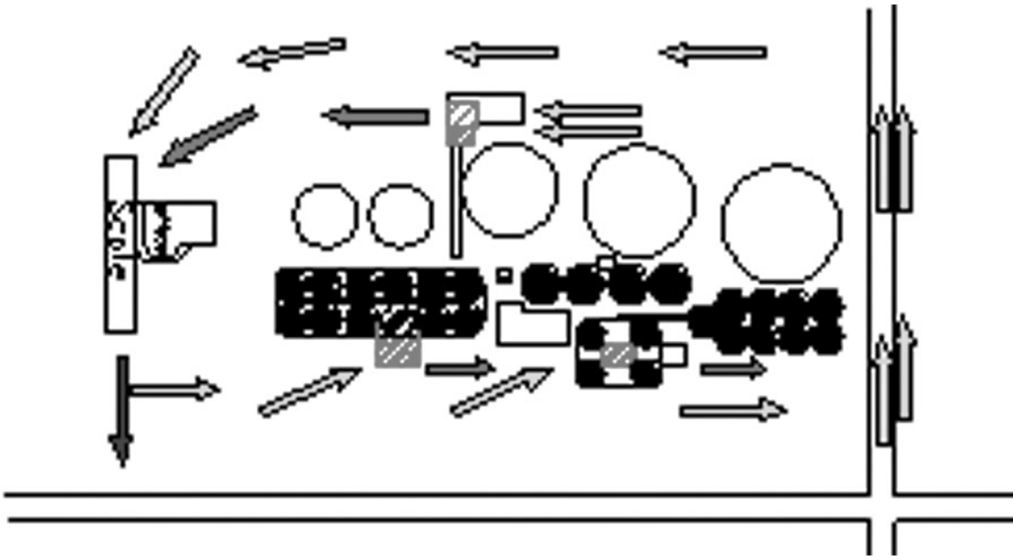


Figure 1. Elevator A before and after the proposed changes.

(a)



(b)

Symbol	**Explanation**
○ or ●	Corrugated Steel (open) or Concrete (solid) Grain Storage Structures
	Traffic Flow Pattern Into the Facility
	Traffic Flow Pattern To the Receiving Pits
	Traffic Flow Pattern From the Receiving Pits Back to the Scale
	Traffic Flow Pattern leaving the Facility
	Receiving Pits

Figure 2. (a) Layout of the proposed changes and traffic flow at commercial grain Elevator A. (b) Key to the layout of Elevator A.

The Elevator-SIM grain elevator systems simulation model allowed the manager to quantify the effects of the proposed changes on the average service time (AST) of his customers. This in turn allowed him to evaluate which changes would be most beneficial and cost effective to implement. AST was defined as the average of the total amounts of time each customer spends during each delivery at the grain facility from the time they arrive on the property until the time they leave.

What if traffic flow was improved by changing the facility layout?

Proposed changes 1-3 were implemented in the simulation environment. The traffic pattern data collected on October 10, 2002, which was used to validate the model for the existing Elevator A layout, was also used to model the proposed Elevator A layout. Table 2, summarizes the effect of the proposed changes on the AST of Elevator A. The results indicated that on a day with the same traffic characteristics, the proposed changes 1-3 would reduce AST by 3.3 minutes (from 8.7 to 5.4 min), a decrease of 37.5 %. The standard deviation was decreased by 1.7 min, a decrease of 48.5 %.

What if the number of trucks arriving at the elevators increased significantly?

In order to quantify the effect of the proposed changes on AST on days with larger traffic volumes, the models of the existing vs. proposed layouts were compared a second time. The number of trucks fed into the model was increased from 100 to 500 in increments of 50. The arrival pattern of the trucks remained unchanged. Table 3 and Figure 3 summarize the results of these simulation runs.

Table 2. Summary of the effects of the proposed changes 1-3 on the AST (in minutes) of Elevator A.

Elevator Layout	Number of trucks	Average service time (AST) (min per truck)	s.d. of service time (min)
Existing	218	8.7	3.6
Proposed	218	5.4	1.8

Table 3. Simulation results for the existing vs. proposed layouts of Elevator A as the number of trucks serviced increased from 100 to 500.

	Existing Layout		Proposed Layout	
Number of Trucks	Average service time (AST) (min per truck)	Standard deviation service time (min)	Average service time (AST) (min per truck)	Standard deviation service Time (min)
100	8.9	2.1	7.0	3.2
150	10.3	3.2	6.9	2.9
200	14.5	8.1	7.0	2.7
250	28.8	20.8	7.9	3.5
300	63.3	56.8	9.0	4.2
350	95.6	112.5	10.2	5.3
400	125.9	123.9	13.3	8.8
450	145.3	87.0	17.8	13.1
500	166.6	131.3	25.4	18.6

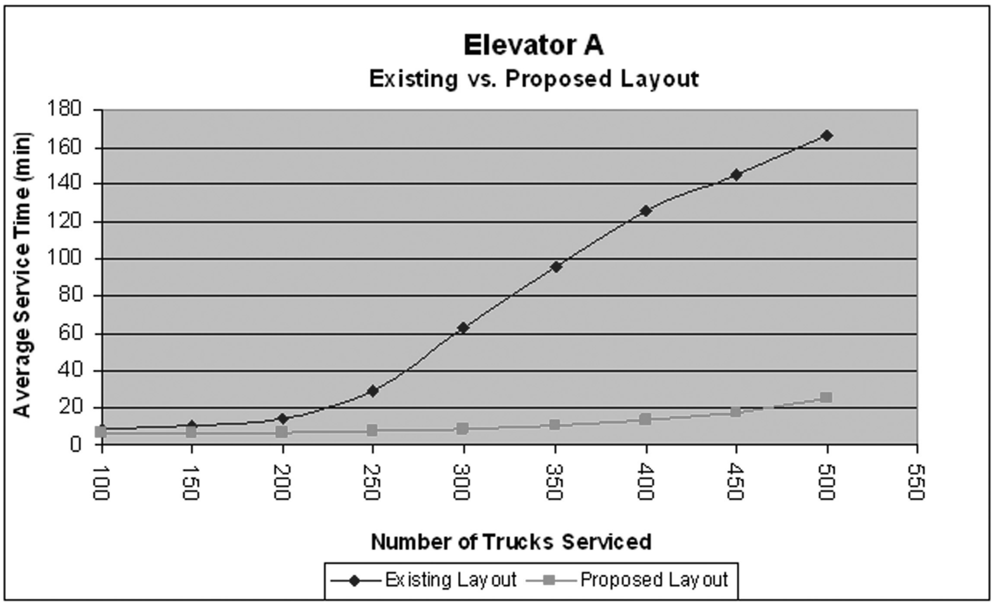


Figure 3. Effect of the proposed changes 1-3 on the AST of Elevator A.

This set of simulation runs indicated that the proposed changes would allow Elevator A to service more trucks per day more efficiently than the existing layout. There was not that large of a difference in AST between the existing and proposed layouts when servicing 100-150 trucks in a day (10.3 min - 6.9 min, respectively). However, the differences in AST increased sharply beginning with 200 trucks. The proposed layout would allow up to 300 trucks to be serviced with an AST of less than 10 min and up to 450 trucks with an AST of less than 20 min.

Another important consideration is the standard deviation of the AST for each data point. The results indicated that the existing layout had a higher s.d. when compared to the proposed layout. Smaller s.d. indicated that trucks were serviced at the elevator in a more consistent time frame, which is a more desirable result. Larger standard deviations indicated a greater variability in the AST, which implied that some trucks had to wait very long periods of time to be serviced. For example, for 200 trucks, 66% of them would be serviced between 6.4 and 22.6 min with the existing layout vs. between 4.3 and 9.7 min with the proposed layout.

Currently, this facility rarely services more than 300 trucks per day. However, if Elevator A aimed at expanding its business, and more regularly drew 300 + trucks on peak harvest days, producers would unlikely be willing to wait for an hour or more to dump their grain. Thus, by changing the traffic flow and adding a fourth pit, Elevator A could service 300 trucks in an AST of 9.0 min vs. 63.3 min, which is a reduction of over 600 % in AST.

Results and discussion of "what if" simulation scenarios applied to elevator C

Simulation scenarios investigated

Elevator C is a new facility that was designed with a high capacity receiving system to accommodate primarily semi truck deliveries. This elevator utilized a remote probe and an automated ticketing system to minimize service times further. The receiving characteristics of this particular system are summarized in Table 4.

Given that few improvements could be made to this particular elevator, it was chosen for the evaluation of the contamination effect due to channeled maize. The Elevator-SIM site-specific system simulation model for Elevator C was modified as discussed by McGill (2004) to predict grain contamination during segregated handling. The rationale behind these simulation experiments lie in the recent industry debate about the effective segregation of specialty grains (for example, waxy maize, high amylose maize,

Table 4. Storage and receiving characteristics of Elevator C, which has a total fixed storage capacity of about 5.3 million bushels.

Type of structure	Number of structure	Total capacity of storage structure
Grain Storage		
Corrugated Steel Bins	4	64,000 t
Concrete Silos	11	1,850 t
Receiving Equipment		
Receiving Pit & Leg	2	675 t/h
Weighing/Probing Equipment		
Scale	2	1 Inbound / 1 Outbound
Probe	1	1 remote probe

non-GM soybeans) and Market Choices[SM] maize types (products that are fully approved for food and feed use in the U.S. and Japan, but not yet in the EU) at commercial grain facilities. How can grain elevators that were designed and built to handle large quantities of generic commodities maintain the purity of specialty crops and avoid contamination from genetic traits not desired by certain end users or approved in certain overseas markets?

For years grain elevators have been receiving maize and soybeans in the same receiving systems. Cross contamination is minimized by assigning trucks as much as possible to designated receiving pits and allowing conveying equipment to run empty between loads of different grain types. The grain industry maintains that shipments of maize typically contain less than 0.1 % soybeans and shipments of soybeans typically contain less than 0.1 % maize. Thus, why should this same approach not work to maintain the identity of grains and avoid cross-contamination at commercial grain handling facilities?

The system simulation model of Elevator C was modified to predict purity levels of grain receipts and the contamination due to commingling. Recent research conducted at the U.S. Grain Marketing & Production Research Center (Manhattan, KS) provided data for the residual amount of grain left in a 75 t/h receiving system, and the effect of running the conveyer system clean on the observed contamination in maize (Ingles et al., 2002). Based on that data, a corresponding cumulative commingling function was developed relating the level of impurity due to residual grain commingling with new grain in a 75 t/h conveying system. That function was used to determine the percent of commingling in the received load due to residual grain left in the conveying system (McGill, 2004).

The system simulation model of Elevator C was modified to simulate a worst case contamination scenario, i.e., when each truck that entered the elevator carried a different grain type than the truck ahead of it. For example, for a single pit receiving system and two grain types, the first truck carried maize approved for all market destinations, the second one maize to be channeled away from the E.U. market, and with the third truck the cycle repeated. This maximized the frequency of the self-cleaning period, and thus the potential commingling effect (as long as no other contamination contributing factors such as human error were considered).

In order to maintain the separate identity of multiple grain types being dumped into one pit it is necessary to run the receiving system clean between loads of different grain types. This procedure entails running all of the bucket elevators and conveyors free of grain before dumping the next load of grain into the pit. The time that it takes to clean the system out is referred to as the between truck clean-out time. This delay is not easily decreased due to the fact that it is directly related to the time it takes grain to get from the receiving pit to the bin the grain is being dumped in. However, using the system simulation model it is possible to predict how long the between truck clean-out time would have to be in order to achieve a desired purity level.

It is important to keep in mind that these simulations and this study as a whole did not take into consideration contamination effects due to seed impurity, pollen drift, and on-farm planting, handling and harvesting practices. The systems simulation model made the assumption that the genetic purity of each delivered truck load of grain was an unrealistic 100 %. This assumption was made so that the contamination effects of commingling alone could be studied. Contamination of grain is a cumulative effect and thus, genetic impurity ahead of the receiving pit would have to be added to the results of this study. Recent work by Fleck (2005) expanded the current Elevator-SIM model to account for the cumulative contamination effect from the seed bag to the delivery from multiple farms to a commercial grain receiving facility.

What if contamination of maize that does not need to be channeled could be predicted?

In order to isolate the effect of a worst case scenario of commingling of grain, the model of Elevator C was modified so that all of the traffic serviced by the elevator was forced through one receiving pit. The simulation model predicted that the contamination of non-channel maize accumulated in a designated storage bin never exceeded 0.6 % as the amount of Market Choices^{SM} maize increased from 0 to 100 % of the incoming truck loads (Figure 4). Additionally, if the amount of Market Choices^{SM} maize was less than 20 % in the main drawing area of this single pit country elevator, simply allowing the conveying system to run empty between these two incoming maize types could keep the potential contamination to less than 0.4 % in this worst case scenario example.

The simulation results shed new light on an elevator's potential ability to maintain the genetic purity of channeled and non-channeled maize. As previously mentioned, elevators have been successfully segregating maize and soybeans in the same receiving system for years. Cross contamination of crops is minimized by the discussed method of designating receiving pits and allowing conveying systems to run empty between different grain loads. Although the practice is not as common, flushing the grain receiving system of residual grain and discarding the flushed grain into a mixed grain tank could also be utilized to maintain genetic purity even more effectively.

This practice of flushing the receiving system clean and discarding the flushed grain could easily be adapted for use with incoming streams of Market Choices^{SM} maize. However, it would not be necessary to discard the flushed grain into a mixed grain tank. Instead the load of non-channeled maize (following the load of Market Choices^{SM} maize) used for flushing out the receiving system would simply be run into the same tank as the previous load of Market Choices^{SM} maize. This adaptation of the flushing practice could help to ensure that non-channel maize remains free of any genetic material from Market Choices^{SM} grain types.

Additional simulation experiments indicated that the contamination at Elevator C was directly related to the number of grain types delivered

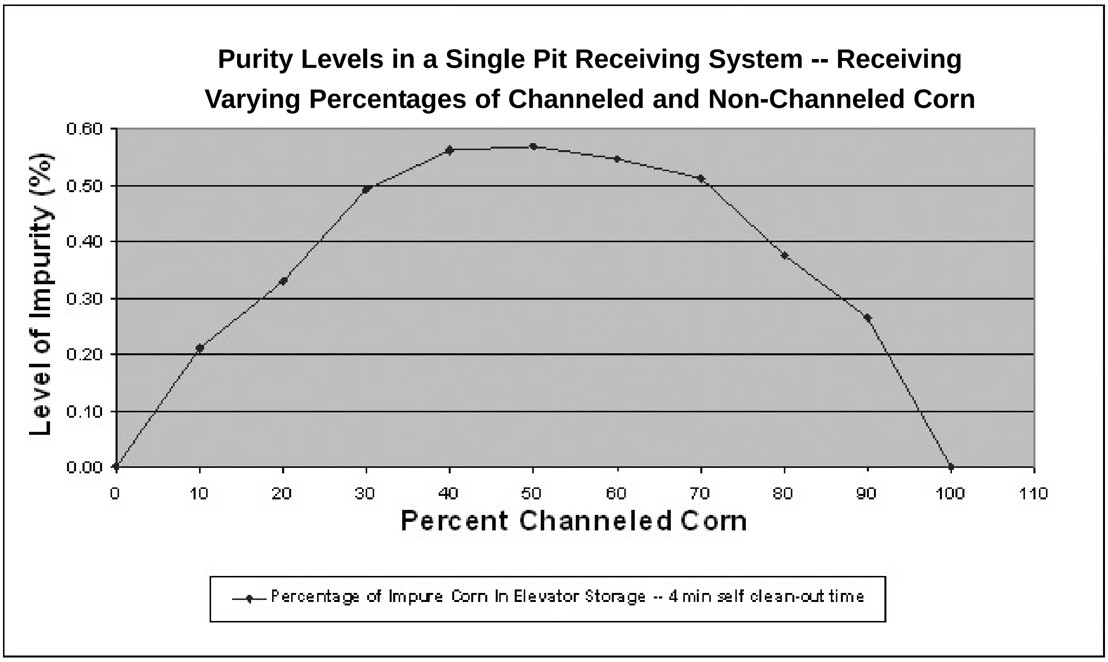


Figure 4. Predicted levels of contamination in maize approved for all market destinations as a function of the amount of maize containing genetic traits that have to be channeled away from E.U. market destinations delivered to Elevator C when using a single receiving pit.

and receiving pits available. For example, when an elevator with one receiving pit takes in two grain types, the worst case scenario predicted that the contamination potential would reach a maximum and remain constant when additional grain types were added (Figure 5).

Similarly, if Elevator C had two or three receiving pits, the worst case contamination potential would increase with each additional segregation until a maximum was reached for four or six segregations respectively, then remained constant beyond that level (Figures 6 and 7). The Average Service Time at the elevator seems to mirror this trend as well. Thus, absent of other factors (such as human error), the maximum contamination potential for an elevator was reached when the number of grain type segregations was twice the number of receiving pits. In a worst case scenario example, as described above, the elevator is receiving a different grain type on every truck that it dumps. So when the elevator has only two pits, and is taking in four or more grain types, it is switching crop types every time it receives a truck thereby maximizing the contamination level.

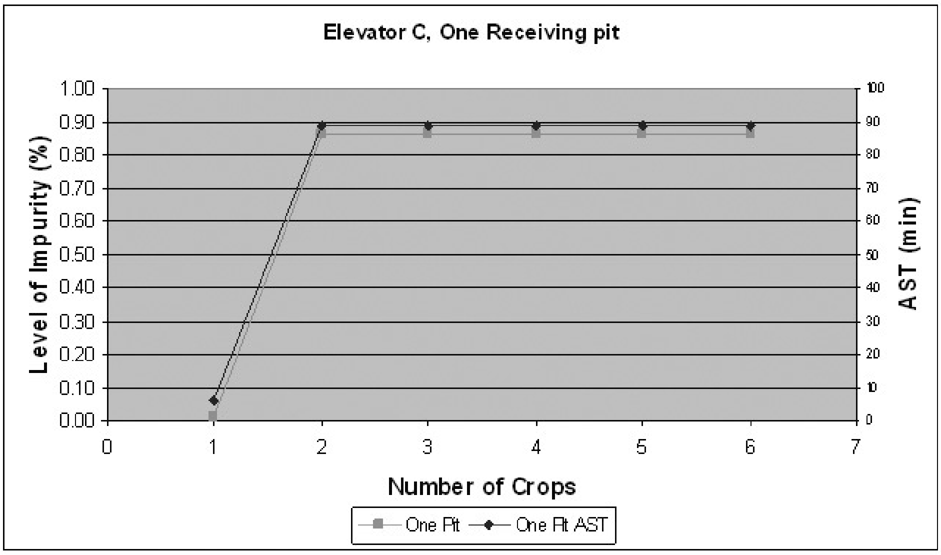


Figure 5. Predicted levels of contamination and average service times as a function of the number of grain types at a country elevator with one receiving pit.

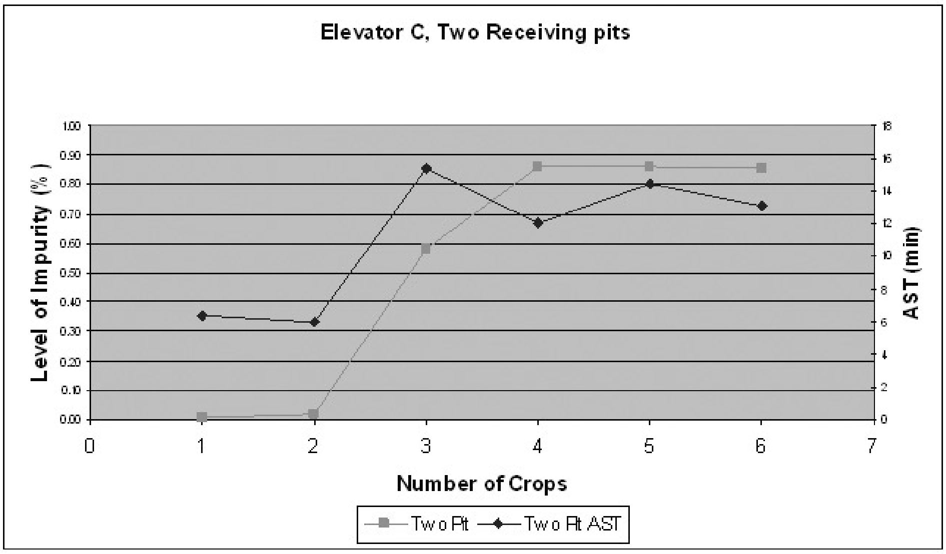


Figure 6. Predicted levels of contamination and average service times as a function of the number of grain types at a country elevator with two receiving pits.

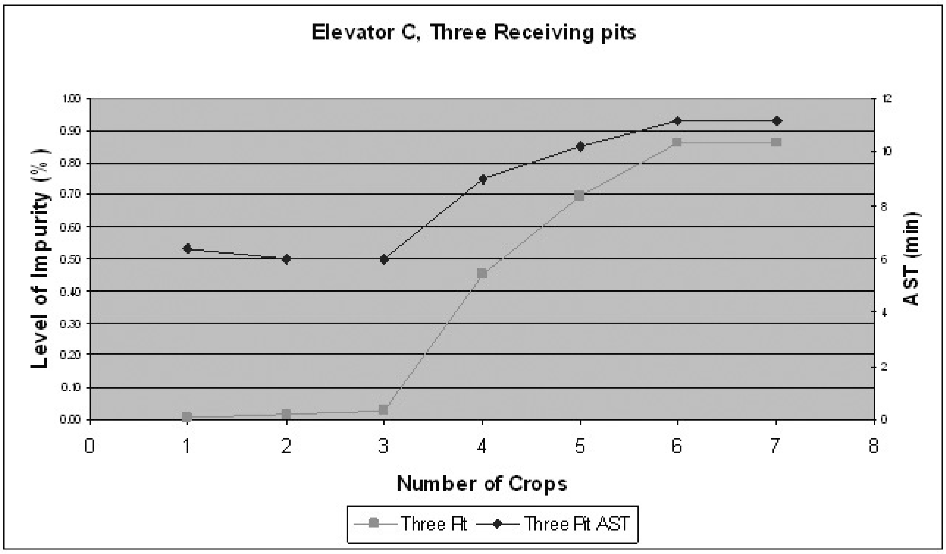


Figure 7. Predicted levels of contamination and average service times as a function of the number of grain types at a country elevator with three receiving pits.

McGill and Maier (2003) found that 89 % of elevators in the Eastern Maize Belt operated with two or more receiving pits and bucket elevators. Consequently, 89 % of Eastern Maize Belt elevators will reach a maximum contamination level when segregating four or more crop types. On the other hand, 48 % of the country elevators surveyed operated with three or more receiving pits and bucket elevators. Thus, 48 % of Eastern Maize Belt elevators will reach a maximum contamination potential when segregating six or more crop types.

The inability to successfully segregate multiple streams of incoming grains at a grain elevator is thus most often related to poor logistical management of incoming trucks during the harvest peak period, lack of trained personnel, and poor allocation of available resources (such as not assigning trucks to designated receiving pits), labor, equipment, and time. In order to minimize the contamination potential (and maintain high genetic purity levels during commercial grain handling), operations managers need to reduce the number of times self clean-out is needed implementing traffic management tools such as assigning trucks with certain grain types to designated receiving pits and accumulating multiple trucks of the same grain type into batch queues ahead of receiving pits when the number of segregations exceed the number of available pits. Above all else, grain operations employees need to avoid human errors at the receiving pit and when conveying grain into storage bins.

Existing receiving systems at U.S. elevators can be successfully used to segregate specialty grain and Market Choices^{SM} maize types as long as the same attention to detail is paid as to segregating maize from soybeans and vice versa. The contamination levels of incoming grain streams from farmers' fields and storage bins have to be added to the contamination caused by commercial grain handling when estimating the achievable genetic purity for end use contracts.

Conclusions

The practical application of Elevator-SIM was demonstrated in this paper through the example of a series of "what if" modification scenarios for two commercial country elevators. In the case of Elevator A, the proposed layout would decrease AST by 37.5 %. Additionally, the maximum number of trucks that could be serviced in the proposed layout while keeping the AST under 10, 20, and 30 minutes would be 303, 434 and 500+, respectively. In the case of Elevator C, Elevator-SIM was used to estimate the amount of contamination that occurs between channeled and non-channeled maize due to commingling at the elevator. The model predicted that the contamination of non-channeled maize never exceeded 0.6 %. Furthermore, additional simulation experiments indicated that the amount of contamination at the elevator was directly related to the number of grain types delivered and receiving pits available. Overall, the Elevator-SIM simulation tool proved to be an effective method for evaluating the efficiency and performance of the grain elevators modeled.

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References

Ingles, M.E., Casada, M.E., Maghirang, R.G., (2002). Commingling effects and residual grain during grain receiving ASAE Paper No. 02-6111; ASAE, St. Joseph, MI.

Mcgill, J., 2004. An infrastructure analysis of grain elevators and the development of system simulation models. M.S. thesis, Purdue University, West Lafayette, IN.

Mcgill, J., Maier, D.E., 2003. Capability of Eastern Corn Belt country elevators to segregate crops during harvest. ASAE Paper No. 03-6001, ASAE St. Joseph, MI.

Fleck, N., 2005. Grain production system analysis to improve the purity of food grade corn delivered to a masa flour mill. M.S. thesis, Purdue University, West Lafayette, IN.