Abstract: With the introduction of Genetically Modified seed [GMO], many grain elevators are facing the problem of having to segregate their incoming products in batches of different end use quality, in order to not mix GMO and non-GMO types of grain together. Existing receiving and segregation capacities have to be quantified and possible cost-effective solutions have to be evaluated to assure that an elevator will be able to function efficiently under different future working scenarios. The Authors have developed an object oriented library and model that evaluates the degree of flexibility of the elevator with respect to the GMO vs. non-GMO grain segregation. The model has been applied to some scenarios. It allows the user to track the service time per each type of product delivered, and the effect of non-GMO delivery on the waiting times of trucks carrying the other products. Copyright ©1999 IFAC

Keywords: object modeling techniques, discrete systems, Monte Carlo simulation, time-variability, randomness, GMO products

1. INTRODUCTION

With the rise of value-added grains and oilseeds, many grain elevators are facing the problem of having to segregate their incoming products in batches of different end use quality (for example, high oil corn [HOC], high protein soybeans, genetically modified crops [GMO], highly extractable starch corn, etc.) Traditionally, commercial elevators in the Midwestern U.S. Corn Belt had to segregate only three products during the fall harvest, namely dry corn, wet corn and soybeans. Few if any elevators are designed for the efficient segregation of many products during the fall harvest rush. Thus, the problem of incoming product segregation has to be solved for each individual elevator configuration. Existing receiving and segregation capacities have to be quantified and possible solutions have to be evaluated to assure that an elevator will be able to function efficiently under different future working scenarios.

Most 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. There are many configuration of the receiving system, with one or multiple scales, one or more receiving pits.

Although there generally exists enough room to store different types of grain, the system is often not designed to handle that much product variety. When the type of incoming product changes, complete unloading and cleaning of the pit and bucket elevator
leg has to be performed before the new product can flow into the pit.

Each operation takes time, and cumulatively can cause long waiting queues of trucks at the elevator facility. Service operations, like cleaning, increase the waiting time of all trucks in the queue, because nobody is served during the cleaning. The longer the queue, the longer the waiting time per customer.

The objectives of this work were (1) to model the receiving operation of a commercial elevator with two pits; and (2) to evaluate the influence of growing demand of non-GMO certified product on the unloading operations of that type of elevator.

2. MATERIAL AND METHODS

2.1 Literature review

There are few references in the field of dynamic system simulation that apply directly to grain handling. Csaki and Maier (1993) developed an initial system model using SLAM II® to simulate the receiving operation of a grain elevator. 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) developed a model using SIMAN® to evaluate whether enough idle capacity existed in Kansas elevators to segregate wheat in order to capture a protein premium. They showed that less than 45% of wheat receiving systems in Kansas were operating at or above 70% of their capacity. This percentage also describes the burden of the elevator, calculated as the total grain delivered per day divided by the theoretical capacity of the receiving system during the opening hours. In their opinion, the residual capacity of grain receiving systems was large enough to carry out the 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, and into three quality categories $2.37/tonne. 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 commercial elevator with only a single receiving pit and bucket elevator leg never dropped below $1.83/tonne. Segregation of wheat based on end use quality enhanced the value of the wheat received at the country elevators investigated by approximately $10,000 per day (Herrman, 1999).

The Authors have started a project that deals with the use of system simulation techniques for the improvement of both the operational process and the equipment adopted for GMO grain segregation and traceability at commercial elevators. The focus of this paper will be on the feasibility to effectively segregate non-GMO soybeans that will be tested by the elevator at the point of receiving.

At present, numerous Midwestern U.S. elevators have special premium programs that offer a grower an extra $4-8/t for soybeans that are free of the RoundupReady® gene. A grower who has planted non-RoundupReady® soybeans and is certain that the soybeans have not been contaminated during harvest, on-farm handling and storage, and transport to the elevator has the option to declare his load of soybeans to be “non-GMO”. This declaration initiates a testing process at the elevator on samples taken during the probing of his truck that takes approximately an extra 13 minutes and costs about $20 per truck load tested.

However, the extra time the grower has to wait prevents him from proceeding to the unloading station until the test is completed and affects the waiting times of other trucks also if they carry different types of grains. The increase in the types of grain increases the service times and thus raises the waiting times for all customers. The company surveyed, in certain facilities, pays to the customers the amount of service time exceeding 90 minutes. Thus, a longer operation time must be avoided in order to keep the operating costs of the unloading system to a minimum.

2.2 Data collection

The receiving pattern of a large Indiana country elevator (400,000 t/year of grain handled) was analyzed during the fall harvest 1999. The parameters registered are the scale time, the grain type, the moisture and the density of the product. As a total, 8304 truck were unloaded in the months of September and October, and 61.3% (106,467 t) of the

![Fig. 1. Weekly percentage distribution of grain delivered over 8 weeks of the harvest season](image-url)
total product delivered was maize, and 38.7% (67,273 t) was soybeans.

Figure 1 shows product delivery cycling during the season. At the beginning of the harvest period, in the first 5 weeks, the amount of soybeans delivered is bigger than that of corn, and late in the season, the trend is opposite. The high number of trucks per day occurs late in the season, but more important is the distribution of them regarding the opening hours of the elevator.

The distribution of Oct. 1, 1999 is presented in figure 2. Each segment of the bar expresses the percentage of the number of trucks delivering each product in the specific hour and the total number of trucks that arrived. On that day, 149 trucks were unloaded from 7 a.m. to 8 p.m., with an arrival distribution that varied from 5 to 14 trucks per hour, where 69.5% on average was maize (29.4% dry -defined as maize dry than 16% moisture and 40.1% wet - with a moisture higher than 16%) and 30.5% was soybeans. On a busy day, late in the season, 235 trucks were unloaded, with 56% on average dry corn, 22% wet maize (total 78%), and 22% soybeans. In that case, the number of arrivals ranged from 7 to 27 trucks per hour.

2.3 Model implementation

For the model implementation, the Extend® simulation software from ImagineThat, Palo Alto, California was selected.

Extend® is a powerful general-purpose package suitable for modeling or reengineering continuous and discrete systems. It uses an iconic language and a model is built by connecting user-developed or standard blocks.

The blocks have their own code, written with the ModL® language. The source code of each block in the Extend® library is viewable and the user can modify that code to customize a block to fit the needs of the model. The ModL® language is similar to the C language, has the ability to handle events and the flow of entities, and is powerful and easy to use.

The basic Extend® software package contains 90 pre-built blocks. The most useful ones are the discrete-event blocks for activities, queues, schedules, gates and timers. Other useful blocks are contained in the generic library, such as input random data, input function, file input and output. Third-party libraries are available for specific purposes (statistics, electronics). A library for material handling purposes (SDI Industry® from SimulationDynamics), was purchased as part of this project.

Even with a powerful simulation tool like Extend®, it usually takes significant time to build a system model, check the model, and set up the parameters of the model correctly. For that reason, a new object oriented library has been developed as part of this work. The size of the main view of the model is reduced and made by blocks of the library, which it makes easier to understand the flow of grain and the path of trucks in the system. The user is able to easily change each parameter of the system. The blocks used in the current model are:

- **Truck Generator:** Used to set up the grain characteristics, the truck size, the size of the grain load, and the arrival times of trucks. Arrival times of trucks are based on a random distribution function related to the actual operating hours (military time) of the facility. The truck generator was set up to vary the mean inter-arrival time every hour in order to match the distribution of the simulated hour.

- **Sampling Operation:** The sampling operation occurs for each truck. For non-GMO product, in order to make a correct analysis, it is necessary to take samples twice. This involves two more minutes in sampling, and lowers the efficiency of the sampling system, used for all the grains collected at the elevator.

- **GMO Test System:** The current GMO test operation requires at least 13 min to be completed, and during that time the trucks are waiting in the staging area, occupying part of the space before the pit, which is in our example facility was sized for 14 loaded trucks.

- **Queue Management before Unloading:** In the actual configuration, there are two unloading pits available. The manager, based on his own experience, dedicated to the greatest flow of product one pit, in order to reduce the cleaning time of the legs and of the long belt conveyors (about 4 minutes for each cleaning). The other minor flows come to the second pit. In this study, all the incoming non-GMO grains were directed to the second pit.

- **Weighing and Unloading Operation:** Used to simulate truck unloading. This block is quite complex because of the additional time required to clean the system when another type of grain is falling into the pit.
- **Cleaning Operation**: This occurs when the type of grain unloaded is different from the preceding one. Since the elevator is quite big, there is a safety system that locks the unloading of the pit for 3 to 4 minutes, depending on the grain path from the pit to the storage bins.

- **Storage Structures**: Used to simulate a series of storage structures (bins, tanks, silos, piles) in order to accumulate the amount of product received during the simulated time.

- **Utility Blocks**: Some additional and useful output for the type of analysis performed was provided by means of this blocks.

In order to connect the outputs to the SPSS® package, additional Visual Basic Executables allow for more flexibility in preparing preformatted files for SPSS®.

**2.4 Validation of the model**

The model was verified and validated with the manager of the facility, in order to verify the sequence of the activities and the flow of the trucks and of the grain. The average times for each operation surveyed in the plant were used as a duration of each corresponding operation in the model. Also the unloading strategy simulated was the same as the real one in order to fit the real situation. The model was validated against the performance observed at the facility during the 1999 fall harvest, based on three days known from direct survey.

The number of trucks waiting in the staging area and the time of the last unloading were some of the parameters used to validate the model, because it was easier for the operators involved to keep track of that data than some other parameters (e.g. waiting times, service times, etc). The results of the model validation were discussed with the manager of the facility in order to have feedback not just on the results, but also on the model verification. Subsequently some modifications were made in the unloading operation and in the unloading queue management to improve the model prediction further.

**2.5 Experiment design**

Once validated, the model was used for the following experiments, as shown in table 1:

- **Grain type distribution arrival**: Two days were considered, one defined as an average day with 140 loads delivered per day and a busy day with 235 trucks unloaded. Those two scenarios were adopted based on real data gathered from the elevator surveyed.

- **GMO vs. non-GMO distribution of arrivals**: The hypothesis was to segregate an incoming flow of non-GMO soybeans, which ranged from 0% (absence of non-GMO soybeans) to 100% of that product on the soybeans delivered. The runs were done in increments of 10% variation in incoming non-GMO arrivals, with a total of 11 levels of non-GMO and of common grain.

A set of pseudo-random numbers was used in order to compare different solutions. Every solution was tested for the average day of the harvest season. Each set of options was tested with a 100 runs using pseudo-random seeds (Banks, 1995). In that way the truck arrivals were the same, and it was possible to exclude the effect of interarrival times on the system performance. In total, 2200 runs were made.

The average service time (Hall, 1991) per each product segregated at the elevator was chosen as a key factor to evaluate the performance of the system. This takes into account both the waiting times and the activities at the elevator. Also in some elevators it is accounted for as a cost for the company if service of each customer takes more than 90 min per truck.

The results were analyzed using SPSS® ANOVA procedure, in order to evaluate significant differences between mean truck service times.

**3. RESULTS**

The result of the experiments are presented in figures 3 and 4. In each of these figures, the average service time per truck and per grain type is presented. Service time is the total time the truck stayed at the elevator, from entering the queue to the exit from the plant. The X-axis represents the amount of non-GMO flow related to the theoretical maximum capacity of the pit (pit #1) where the non-GMO product is flowing into.

In both cases, three of the four products flowed into the same pit:

<table>
<thead>
<tr>
<th>parameter</th>
<th>units</th>
<th>exper. #1</th>
<th>exper. #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>truck/day</td>
<td>(#)</td>
<td>149</td>
<td>235</td>
</tr>
<tr>
<td>avg. load/truck type</td>
<td>(t)</td>
<td>25.2</td>
<td>25.2</td>
</tr>
<tr>
<td>avg. load/truck type 2</td>
<td>(t)</td>
<td>11.9</td>
<td>11.9</td>
</tr>
<tr>
<td>dry corn(1)</td>
<td>(%)</td>
<td>29.1</td>
<td>55.6</td>
</tr>
<tr>
<td>wet corn(1)</td>
<td>(%)</td>
<td>40.5</td>
<td>22.4</td>
</tr>
<tr>
<td>soybeans(1)</td>
<td>(%)</td>
<td>30.5-0</td>
<td>22-0</td>
</tr>
<tr>
<td>non-GMO(1)</td>
<td>(%)</td>
<td>0-30.5</td>
<td>0-22-0</td>
</tr>
<tr>
<td>runs</td>
<td>(#)</td>
<td>1100</td>
<td>1100</td>
</tr>
</tbody>
</table>

(1) number of loads per day over the total number of loads daily.
− for experiment #1, dry corn, soybeans and non-GMO soybeans went to pit #1. The greatest flow, the wet corn, had pit #2 reserved.
− for experiment #2, wet corn, soybeans and non-GMO soybeans went to pit #1. The greatest flow, the dry corn, had pit #2 reserved.

3.1 Influence of non-GMO segregation on service times during an average day (experiment #1).

The results are negatively affected by the introduction of the non-GMO segregation operation. Particularly, at 10% non-GMO soybean flow over the total soybean flow (2.5% of the maximum theoretical flow of pit #1) the service times increase are:
− dry corn (unloaded in the same pit as non-GMO) by 1.76 min;
− wet corn (unloaded in the other pit) by 1.45 min;
− soybeans (unloaded in the same pit as non-GMO) by 1.8 min;
− non-GMO soybeans compared to common soybeans (including double probing and strip test) by 16.7 min;

It should be noted that the number of loads is the same for the situation with 0% non-GMO. Thus it shows the true effect of introducing the non-GMO test.

At 50% non-GMO soybean flow over the total soybean flow (12.5% of the theoretical maximum flow of pit #1) the service times increase are:
− dry corn (unloaded in the same pit as non-GMO) by 5.4 min;
− wet corn (unloaded in the other pit) by 4.9 min;
− soybeans (unloaded in the same pit as non-GMO) by 6.4 min;
− non-GMO soybeans compared to common soybeans (including double probing and strip test) by 21.5 min;

In this case, the cleaning times are reduced, because all the soybeans are non-GMO. Each product in the same pit is served with an increase similar to the 10% situation. Also testing 100% non-GMO soybeans required per truck the same amount as for the 10% non-GMO situation.

Statistically, the service times were significantly different at the 95% probability level for:
− wet corn (delivered to pit #2) vs. all other products (all simulations);
− both dry corn and common soybeans vs. non-GMO beans (all simulations);
− dry corn vs. common soybeans at 10% non-GMO soybean flow over the total soybean flow;
− dry corn vs. common soybeans at 90% non-GMO soybean flow over the total soybean flow (just 10% of the soybeans is common type);

Considering these results the product with the lowest flow into pit #1 is significantly affected by a more frequent cleaning operations, because of the lower occurrence of two trucks with the same grain in a row compared to the other products delivered into the same pit.

3.2 Influence of non-GMO segregation on service times during a peak day (Exp.#2). The results show a similarly trend as in experiment #1 but the service times were higher than those found in exp. #1, and the big influence was due to the higher number of...
truck arrivals (235 in exp. #2 compared to 149 in exp. #1). This is the factor that has the greatest influence over the performance of the unloading operation system.

The increase truck service time due to the non-GMO effect for exp. #2 is presented in table 2.

Table 2. Increase in truck service time in a peak day vs the amount of non-GMO bean deliveries, exp#2 (235 truck deliveries)

<table>
<thead>
<tr>
<th>type of grain delivered</th>
<th>non-GMO 10% (1)</th>
<th>non-GMO 50% (1)</th>
<th>non-GMO 100% (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>dry corn (min)</td>
<td>2.9</td>
<td>9.5</td>
<td>5.2</td>
</tr>
<tr>
<td>wet corn (min)</td>
<td>3.2</td>
<td>10.0</td>
<td>5.7</td>
</tr>
<tr>
<td>soybeans (min)</td>
<td>3.4</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>non-GMO beans (min)</td>
<td>18.4</td>
<td>26.4</td>
<td>19.7</td>
</tr>
</tbody>
</table>

(1) ratio between non-GMO soybeans delivered and the total amount of soybeans delivered.

Comparing exp#1 vs. exp #2, the increase in waiting times due to the non-GMO delivery is nearly proportional to the number of trucks unloaded for the commodity grains but shows a small rise for the non-GMO product (just 1.4 min at 10%, 4.9 min at 50%, and 2.4 min at 100% non-GMO beans), probably due to the amount of time spent for the non-GMO test.

In exp. #1, considering the absence of non-GMO product, with just 149 trucks per day, the average waiting times were significantly lower (17.1 min/truck) than those in exp. #2 (35.7 min/truck), where the number of trucks unloaded was 235. A 67% flow increase at the probing station (just 25% increase of traffic at pit #1) caused the average service time to increase by 108% in exp. #2 compared to exp. #1.

3.3 Influence of non-GMO segregation on waiting time costs. Considering experiments #1 and #2, with the event where the flow of non-GMO delivered is 50% of the total flow of beans arrived during the day, the results in terms of waiting costs are the following (table 3):

- if the elevator would pay farmers (and some do) one dollar each minute for waiting over 60 min at the elevator, it would cost 13 times more on a peak day vs. an average day.

<table>
<thead>
<tr>
<th>Waiting time policy</th>
<th>exp #1 ($)</th>
<th>exp #2 ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 minutes</td>
<td>228</td>
<td>3037</td>
</tr>
<tr>
<td>90 minutes</td>
<td>37</td>
<td>1328</td>
</tr>
</tbody>
</table>

- if the elevator would pay one dollar each minute for waiting over 90 min at the elevator, it would cost about 36 times more on a peak day vs. an average day.

These are, of course just simulated cases and the amount may vary. However, the model allows the user to understand the expected costs of different strategies and options that can be considered to improve segregation and customer relations.

4. FINAL REMARKS

The model shows the possibility of monitoring the system under different flows of product, and particularly allows the elevator manager to better understand the effect on the unloading system due to segregation of non-GMO declared soybeans from generic products.

Considering the existing receiving system as it is, without change in the actual configuration, the model allows to keep track of each truck's waiting times and service time. This makes it possible to calculate the costs due to the non-GMO collection operation compared to the other products. Further studies will be done in order to reduce the overall cost of segregating non-GMO products.

Now that the model is available, it will be relatively easy to explore the effects of various system component changes, such as different management of the queues ahead of the unloading gate, scheduling of non-GMO arrivals with dedicated resources, use of rental truck trailers by the customers, or the upgrade of the actual unloading equipment. These are some of the possible options that can be explored with the model in order to increase the efficiency of the system and reduce the cost of additional segregation processes.

Further investigation of quantitative methods to reduce the number of experiments and to understand the results of the model better are also needed.

REFERENCES


