Proceedings of the 2015 Winter Simulation Conference
L. Yilmaz, W. K. V. Chan, I. Moon, T. M. K. Roeder, C. Macal, and M. D. Rossetti, eds.

FROM FARM TO PORT: SIMULATION OF THE GRAIN LOGISTICS IN BRAZIL

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ABSTRACT

This paper presents a study about soybean and corn multimodal transportation and storage, from farm to port, considering the resources, locations and interferences. The harvest seasonality, climatic changes, road conditions, truck availability and warehouse options configure a very complex system with dozen of options. A simulation model was developed to evaluate and discover the better option under some future expected scenarios. Train, barges and ships were also considered as part of the logistic process. A localization study was made to feed the model with the best warehouse locations from the logistic point of view, and the model helped to choose which locations should be adopted. The simulation considering the complete chain provided a very precise and insightful answer about the system performance, guiding the future investments in the process.

1 INTRODUCTION

Brazil is one of the biggest world exporters of soybean and corn. Therefore, great part of the harvest has to be dispatched overseas through one of the available ports. Since the plantation areas are located in the countryside, the logistic transport is a challenge. Brazil is a continental sized country, with just few railroad options. At least for a while, since there are government initiatives to change this picture as explained in Valec's website (Valec 2015), explaining future Brazilian railroads.

Nevertheless, the country is favored by some navigable rivers, which offers convenient bulk transportation options. But the great part of the grain transportation happens by truck, which is affected by bad quality roads and hard-to-access farms. Also, the production in the harvest season has to be stored, since the demand does not match exactly with it. The complexity of all these factors together led to a simulation study to support a strategic decision to hire/build warehouses, dimension the truck fleet and barges, and define the contracts to be made with third-party trucks, ports, ships and freighter trains.

The study of grain transportation and other commodities using simulation is not new. But some of them focus on a specific modal, like the one made by Rea, Nowading and Buckholts (1973), describing a generalized model to simulate ship transportation through locks, lakes, reaches and ports. The study made by Anderson et al. (2003) have studied specifically the barges to perform oil transportation. Their model was used to optimize the system, finding the best configuration and schedule to deliver a list of

978-1-4673-9743-8/15/$31.00 ©2015 IEEE

transportation demands. It was possible due to the size of the model, very small, allowing the optimization tool to quickly run several scenarios in the search for the best solution. Others have a wider abrangency, like the one by Bushnell, Low and Pearsall (1980), that presents a model focused on finding the best path for a commodity transportation from origin to destination, through modal options like railroads, rivers and highways. Each option with its own costs associated. Nevertheless, they does not consider intermediary storage along the way. The study made by Halim, Tavassay and Seck (2012) proposes a framework to considers all modals available, but in a very abstractive way, focusing on worldwide transportation.

This study was motivated by a challenge faced by Multigrain, a invested company of Mitsui Group, one of the world biggest commodities trade, with activities in 66 countries, including Brazil.

In the context explained above, with many limitations in country logistics infrastructure, Multigrain had to move all the year's harvest from farm to ports, storing it in strategic locations in order to match production with demand, and use better transportation options. The company had many questions that wanted to be answered, like:

- How many warehouses should be built? And where? And what capacity ?
- How many owned trucks should be used to transport from warehouses to intermodal terminals and ports ?
- How many third-party trucks should be hired ?

These are simple questions to be answered in a small system, but Multigrain had a countrywide problem, dealing with 78 farms at different locations, 14 intermodal terminal options (some of them to trains and others to barges), 10 ports, and at least 57 warehouses whose locations were to be defined.

In addition, the company had to evaluate the processes inside a standard warehouse project, to determine its real capacity and later use this information in the global system study.

A simulation project was chosen as the best way to support internal decisions regarding the process.

2 THE SYSTEM

The whole system is represented by the chart in Figure 1. The farms, intermodal terminals (also called TSPs) and ports (also called TUPs) have known locations. The warehouses are not, with few exceptions for existing ones, already belonging to Multigrain.

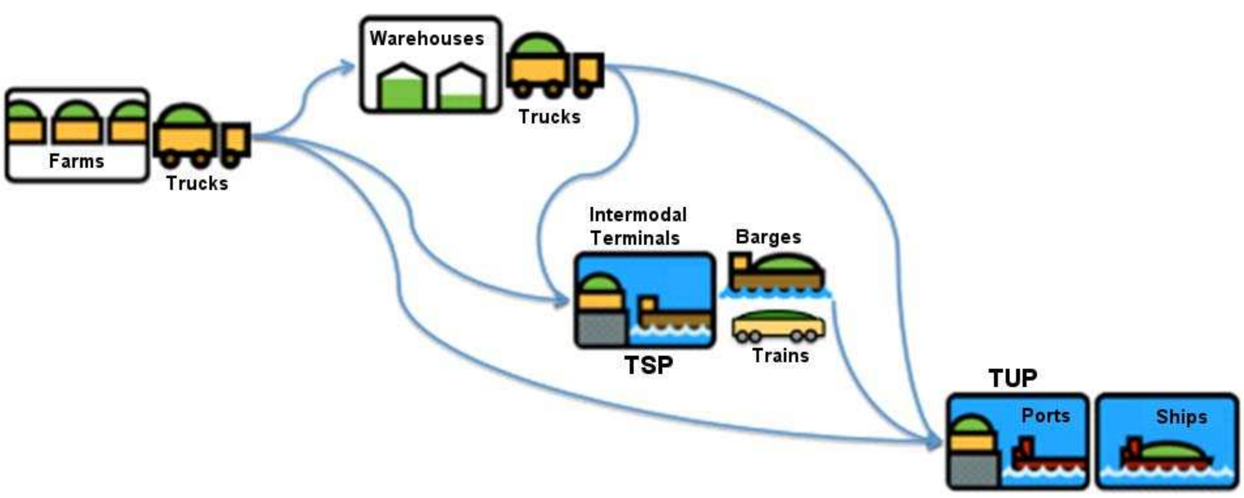

Figure 1: System overview.

2.1 Farms

The internal process happening into the farms are not important to the study. They only have to provide an amount of product (grains) to be transported to the next step of the system. This amount vary along the year, following the harvesting season of soybean and corn.

2.2 Truck Transportation

The truck transportation is made mainly by three types of fleet:

- Farm's trucks: Trucks belonging to farmers, responsible to transport the product to the nearest warehouse or terminal/port. This fleet has a great variety of truck sizes and capacities, and are subject to delays caused by bad weather, since they have to travel over dirt roads. Bad weather can also prevent the truck to leave the farm, since the humidity percentage on the grains may be too high, resulting in price penalties to the farmer. Also, the farmer is not very committed to the warehouse. If the truck finds a long line to unload, it may choose to give up and sell the product to a competitor warehouse nearby.
- Multigrain' s trucks: The company was planning to create its own truck fleet to transport the grains from warehouses to intermodal terminals and ports. A very standardized fleet, dedicated only to make this transport.
- Third-party trucks: Have the same function as the Mitsui's trucks, but are hired following the demand.

2.3 Warehouses

The warehouse is responsible to keep the product stored in good conditions to allow the company to deliver it at the best selling price. The warehouse process is illustrated at Figure 2. Basically, it receives loaded trucks from farms, unloads them and store the beans. Later, or even at the same time, it can load empty trucks and dispatch the grains. The layout of each warehouse may vary, but all have the same processes.

2.4 Intermodal Terminals: TSPs

The intermodal terminal (TSP) is responsible to receive the production from trucks and load it to barges or trains. Also acts as a warehouse with limited capacity. Each TSP has infrastructure to load barges or trains. Nevertheless, there aren't a TSP capable to load both modals.

2.5 Barges and Trains

These modals are responsible to transport the grains to some port. Since the company does not own barges nor trains, these processes have to be considered as the transportation capacity to be hired to reach the goal.

2.6 Ports (TUPs) and Ships

The ports (TUPs) are somewhat similar to TSPs. They have a limited storage capacity and unloading infrastructure to deal with trains, barges and trucks. Also, they have loading resources to load the ships. The ships are considered as infinite resources, and are always available to be loaded. The main goal is to determine how many ships would be necessary to transport the production.

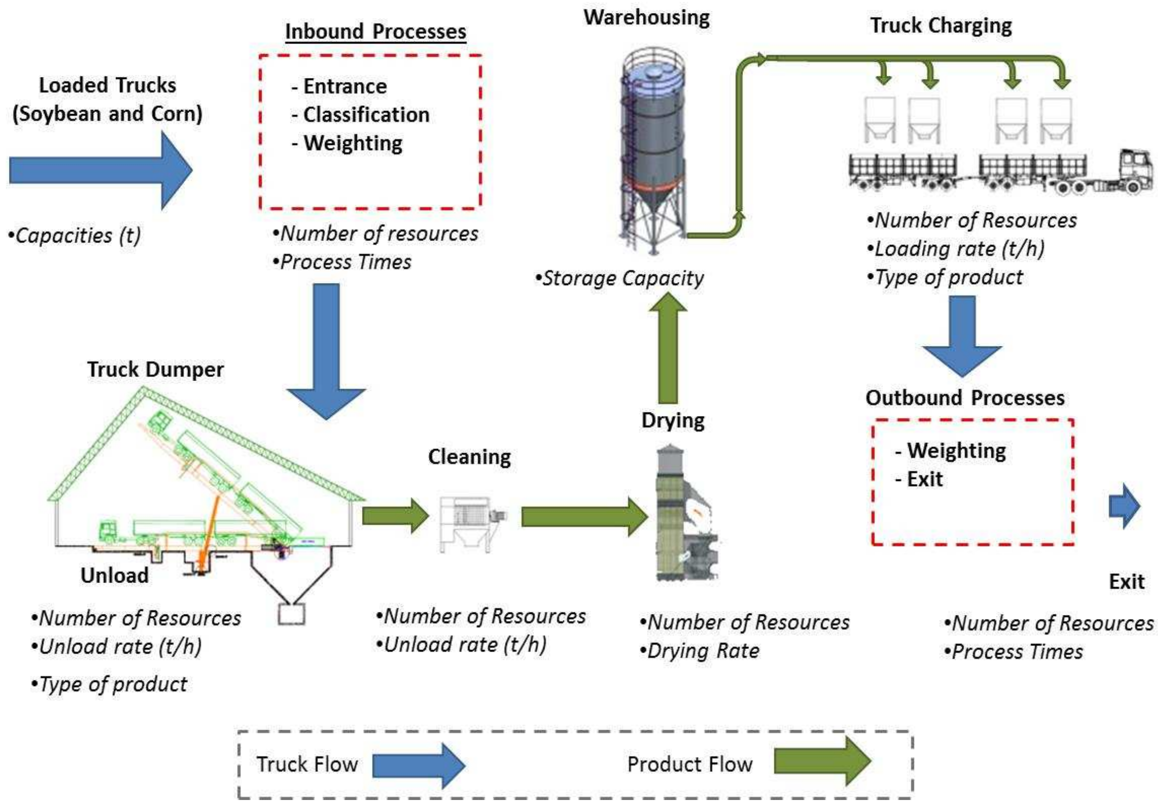

Figure 2: Warehouse internal processes.

3 SIMULATION STUDY

The study was divided in three parts: warehouse localization, warehouse simulation study and global system simulation study.

3.1 Warehouse Localization

In order to provide a starting point to the system study, a calculation was made to determine the best, or most convenient location of the warehouses. Ideally, a warehouse should attend the farms in a radius of 50Km, and located at the nearest highway. The selection of farms was made with an approximation using Google Earth, as presented in Figure 3.

The method explained by Chase, Jacobs and Rosemberg (2012) was applied to calculate the warehouses position taking into account the number of farms to be attended, and also its production. These are the equations used to locate the warehouses:

$$Warehouse\ Location = (Latitude, Longitude)$$

$$Latitude(Warehouse) = \frac{\sum(Latitude(Farms) * Production(Farms))}{\sum(Production(Farms))}$$

$$Longitude(Warehouse) = \frac{\sum(Longitude(Farms) * Production(Farms))}{\sum(Production(Farms))}$$

The localization results were used to estimate the distance between warehouses to other locations, which was an input to the simulation model.

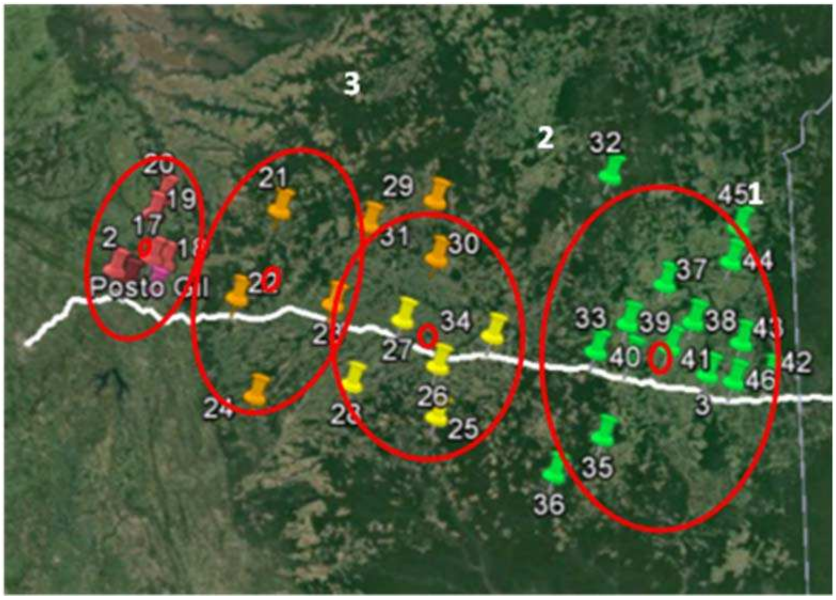

Figure 3: Selection of farms to be attended in an area.

3.2 Warehouse Simulation Study

An initial model was developed only to represent the warehouses internal processes. Each warehouse evaluated in the localization study was simulated, based in a standard layout that was able to represent all warehouse options. The standard layout was used in the model animation, shown in Figure 4.

Despite using the same layout, the warehouse model was able to try different configurations. The number of scales, unloading and loading docks, process rates and times were some of the configurable parameters.

This model was used to ensure each warehouse performance to receive the production and also deliver it to other components of the logistic chain. In addition to warehouse features, the model also had inputs regarding arriving trucks to load and unload, replicating the specific conditions to each location.

Figure 5 presents some of the KPIs gathered from this study.

3.3 Global System Simulation Study

The model should be able to represent the different process structures (farms, warehouses, TSPs, TUPs) and the various transportation options between them.

In a high abstraction level, the process structures in the global system had some similarities. Except farms, all structures share this features:

- Unload infrastructure for loaded trucks arriving. And also barges or trains in some cases.
- Limited storage capacity.
- Loading infrastructure for loading trucks, barges, trains or ships.

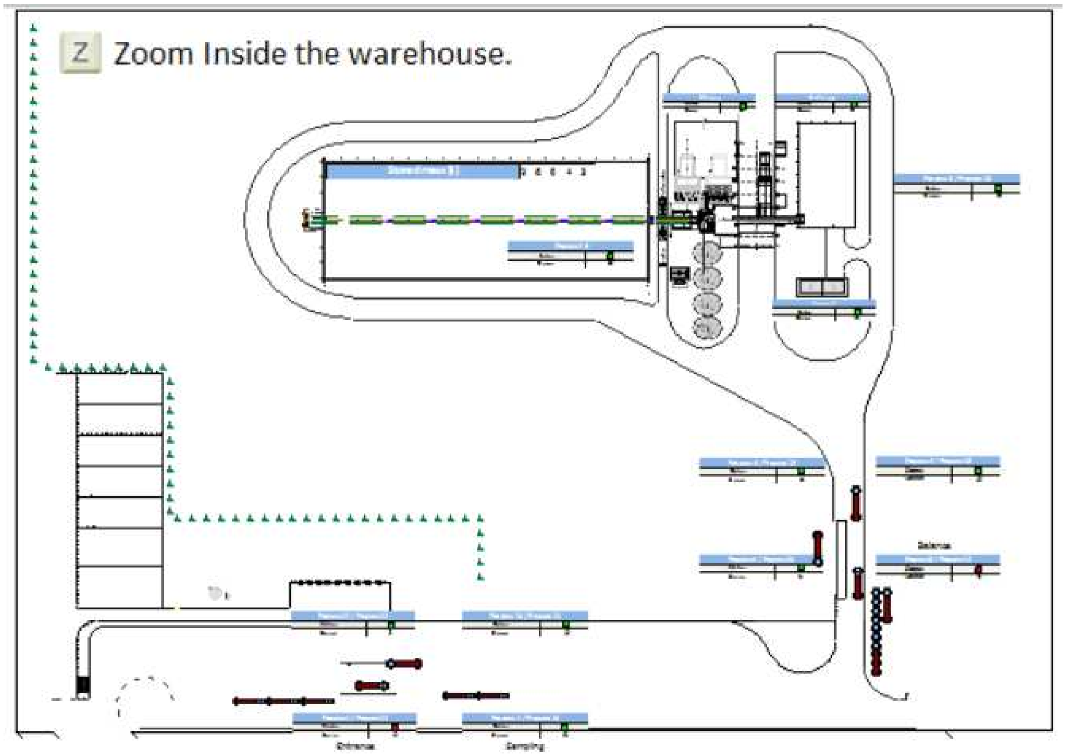

Figure 4: Warehouse simulation.

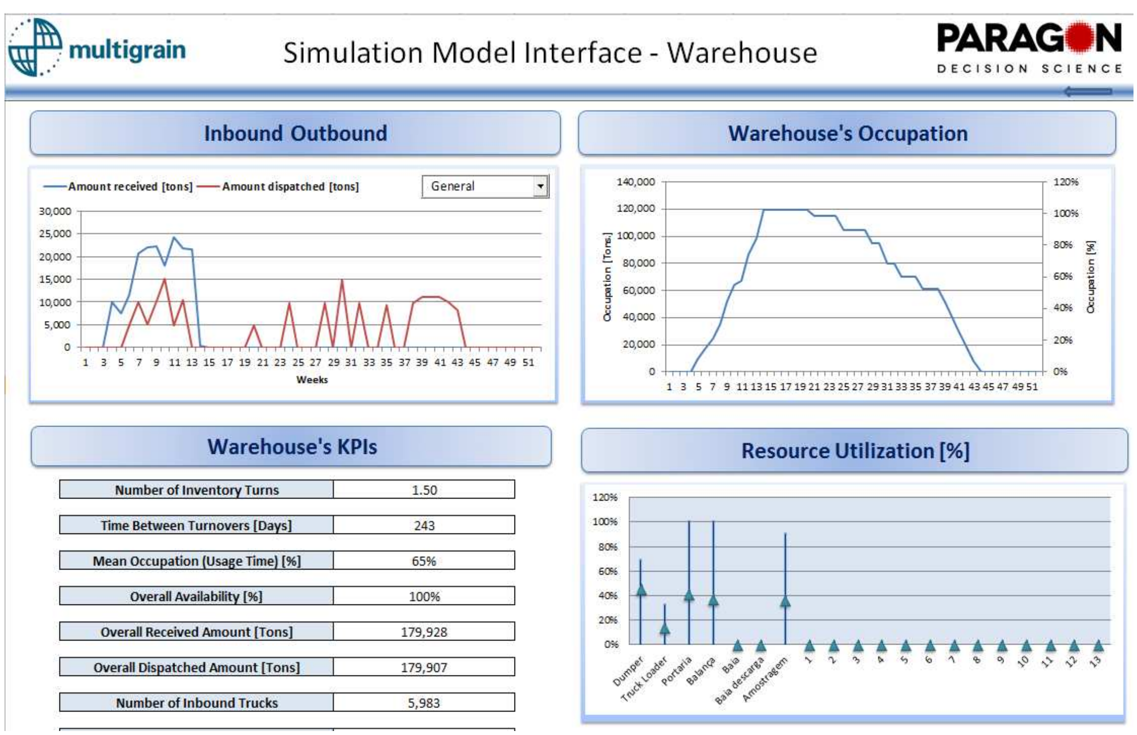

Figure 4: Part of the warehouse KPIs.

In addition, they should record the same KPIs, like queue sizes and waiting times, resources utilization, storage space occupation, product delivered, etc. Also considering the high number of instances of each structure, this led to a construction of a generic, configurable object, able to represent any structure. This object was nicknamed as "GPU": Generic Processing Unit. The GPU schematic is presented in Figure 5, with all main components considered in the model.

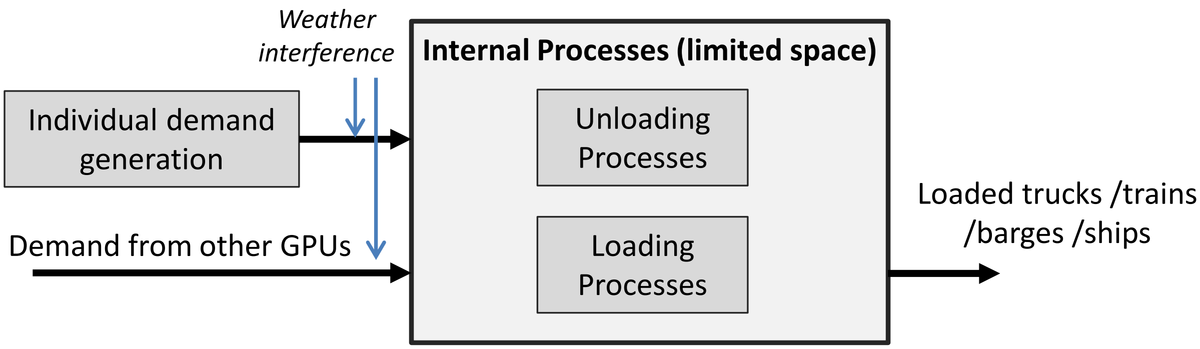

Figure 5: General Processing Unit schematic.

Since the warehouse was already modeled, it was used as a matrix to create the GPU. Based on input data, the object is instructed to act as a warehouse, a TSP or a TPU. All internal parameters, like unloading/loading times, storage space and other data, are also passed to the object via its input data.

The transportation options between components of the system were individually modeled, considering different types of trucks, trains and barges, its individual capacity and percentage of the total fleet. The model was designed to read all necessary data from an MS Excel spreadsheet, prepared to describe the desired scenario. Some input examples are presented in Figure 6.

Pirapora - MG — Type: TSP

Outbound Fleet

Type	Capacity	Probability
Train 1	1860	30%
Train 2	2250	30%
Train 3	1650	15%
Train 4	1950	10%
Train 5	1920	15%
		100%

Porto Velho - RO — Type: TSP

Outbound Fleet

Type	Capacity	Probability
Barge 1	14500	30%
Barge 2	14500	30%
Barge 3	14500	15%
Barge 4	14500	10%
Barge 5	14500	15%
		100%

Sorriso - MT — Type: Warehouse

Inbound Fleet

Type	Capacity	Probability
Truck 1	30	30%
Truck 2	27	30%
Truck 3	29	15%
Truck 4	32	10%
Truck 5	25	15%
		100%

Outbound Fleet

Type	Capacity	Probability
Truck 1	50	30%
Truck 2	32	30%
Truck 3	37	15%
Truck 4	27	10%
Truck 5	34	15%
		100%

Figure 6: Some inputs for the global system model.

The model has also an animated interface, that can visually inform what is happening in the system, key features of the scenario, like warehouse locations and active TSPs or TPUs. Part of the animation is presented in Figure 7.

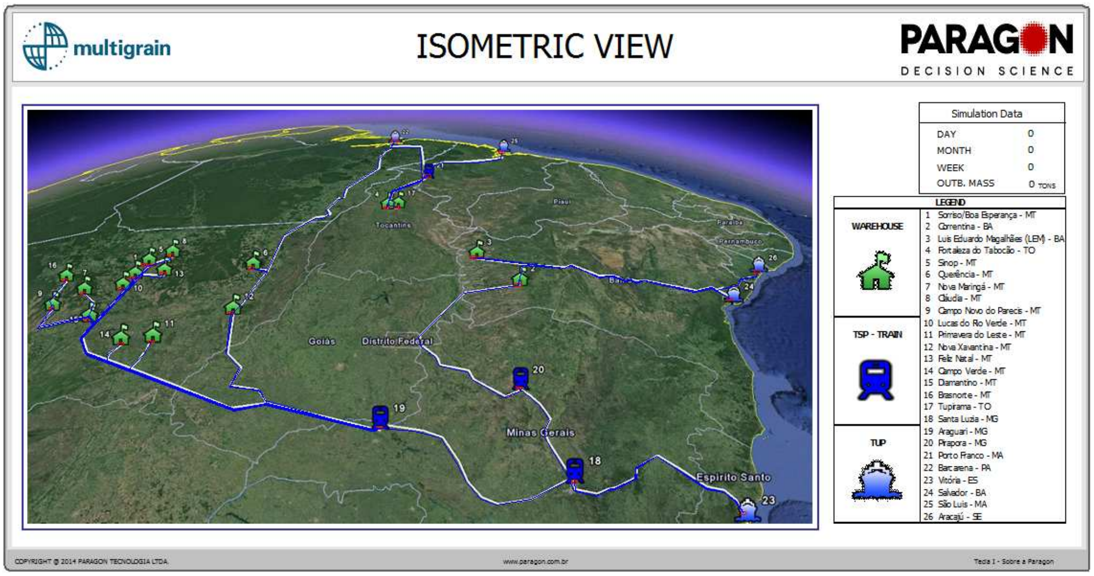

Figure 7: Model animation.

The results were also recorded in the same MS Excel spreadsheet, containing massive data about the simulation:

- Comparison between scheduled and accomplished production, month by month, for all 57 warehouses, 14 TSPs and 10 TPUs.
- Inventory data regarding all 57 warehouses.
- Queue sizes and waiting times for all 57 warehouses. Inbound and outbound.
- The same information for TSPs and TPUs.
- Global consolidated data regarding the system

The Multigrain team had a previous deterministic study regarding the necessary infrastructure to run the system. It was a reference to compare results and design the KPIs, making both compatible.

Besides the test and validation scenarios, several other scenarios were simulated to test interference hypothesis and to determine the real cause of any discrepancy between the deterministic study and the simulation results.

Due to the size of the model and number of variables considered, the model required more than 2 hours to run in a computer equipped with an Intel i5 processor and 8Gb of RAM.

Part of the results are presented in Figure 8, and the global consolidated data is presented in Figure 9.

Warehouse	Modal	Warehouse KPI's: Number of Inventory Turns (Quantity)	Overall Received Amount (Tons)	Overall Dispatched Amount (Tons)	Number of Inbound Trips (Quantity)	Number of Outbound Trips (Quantity)	Queue Inbound: January Avg.	January Max.	February Avg.	February Max.	March Avg.	March Max.	Avg
Warehouse 1	Truck	1.5X	185107	174555	6554	4662	6	81	164	574	647	1,004	53
Warehouse 2	Truck	1.6X	95296	95095	3374	2622	-	-	-	-	1	94	
Warehouse 3	Truck	1.5X	123016	122998	4356	3390	-	-	-	-	1	110	
Warehouse 4	Truck	1.3X	90132	89780	3191	2474	2	34	1	42	0	37	-
Warehouse 5	Truck	0.6X	35019	34705	1240	956	-	-	-	-	1	60	-
Warehouse 6	Truck	1.5X	90150	89928	3192	2480	3	39	1	71	2	78	
Warehouse 7	Truck	1.0X	60336	60060	2136	1656	2	37	0	25	-	-	-
Warehouse 8	Truck	1.5X	88058	87886	3118	2423	3	39	0	35	0	47	-
Warehouse 9	Truck	1.1X	16052	16043	568	442	1	16	0	27	-	-	-
Warehouse 10	Truck	1.0X	75125	74945	2660	2065	13	146	8	98	-	-	-
Warehouse 11	Truck	1.0X	15084	14838	534	408	-	-	-	-	-	-	-
Warehouse 12	Truck	1.0X	10056	9892	356	272	-	-	-	-	-	-	-
Warehouse 13	Truck	1.0X	20112	19604	712	539	1	15	0	27	-	-	-
Warehouse 14	Truck	1.0X	30168	30012	1068	835	-	-	-	-	-	-	-
Warehouse 15	Truck	0.6X	23056	22763	816	626	0	8	0	8	-	-	-
Warehouse 16	Truck	0.0X	0	0	0	0	-	-	-	-	-	-	-
Warehouse 17	Truck	1.5X	15084	14658	534	403	-	-	-	-	-	-	-
Warehouse 18	Truck	0.0X	0	0	0	0	-	-	-	-	-	-	-

Figure 8: Partial view of the results spreadsheet.

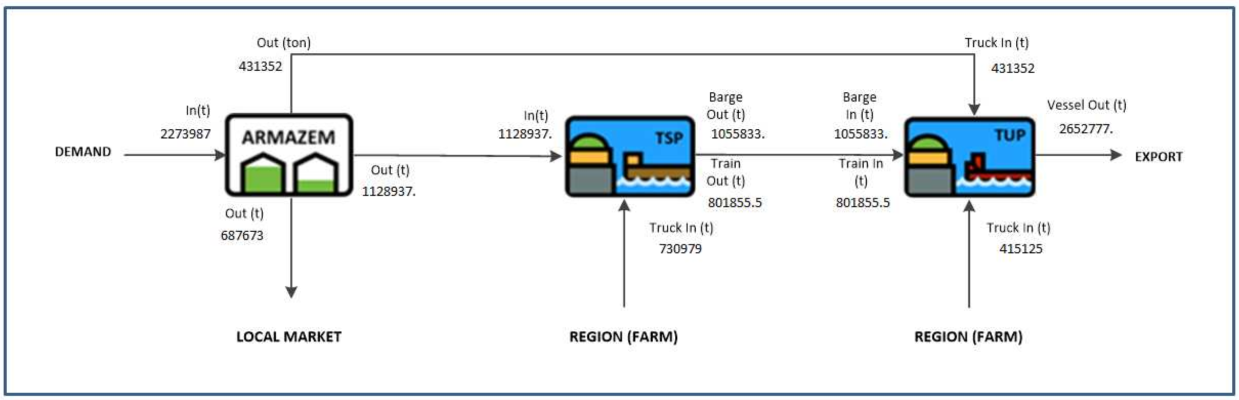

Figure 9: Global consolidated data.

4 RESULTS

The main goal of the study was to simulate year 2019, with the forecasted demand for this year, and determine the necessary infrastructure to deliver the scheduled production to the ports. The demand in 2019 is expected to be 84% higher than 2015, turning it into a significant challenge to the company.

Basically, simulation scenarios were created based on deterministic estimations, providing data for warehouses, TPUs and TSPs capacities, expected demand in each one of them, and fleet sizes responsible to move the product between these GPUs.

The validation was made using data from 2014

Several scenarios were simulated to adjust the fleets and GPUs capacities, giving many insights about the process. Some of the facts uncovered by the simulations are:

- Due to the impact of weather interferences and long queues in some warehouses (third-party trucks give up from Mutigrain warehouses if they face a long entry queue, and go to the competition), some of the most important intermodal terminals (TSPs) will receive less product than expected, from 6% to 18%, allowing an adjustment in building investments or third-party barges contracts. This will probably only happen if the barges fleet is correctly dimensioned like the one considered in the simulation. Also, the train schedule has to be well planned to achieve that

- Some ports (TPUs) will require less warehouse space than expected, varying from 6% to 15%. This also depends on the ship arrival plan. The model has the assumption that the ship schedule is well planned. That was a consequence of what was explained in the last topic regarding TSPs, since they are some of TPU's providers.
- At least one of the ports will require 2% more space than expected. This can be a point of attention to look for alternatives in the area, or reshape the investments in that port. This result was considered a little adjustment in the expected demand, revealed by the combination of destination alternatives from each TSP and warehouse in that area.

5 CONCLUSIONS

The model was considered a valuable tool to evaluate investment decisions regarding the grain transportation and storage processes for Mitsui. In general, the main purpose of this tool is to mitigate investment risks, anticipating the effects of many possible logistic decisions like:

- Building a new warehouse in some location
- Changing the truck fleet pattern from owned trucks to third-party trucks
- Choosing one port instead of other
- Changing the barges provider for another with smaller or bigger barges
- The effects of seasonal weather on the system and how to react to that, etc.

The tool was considered valid and a precise enough to represent the system behavior, and despite being used to evaluate calculated warehouse positions, any geographic position could be used, giving a great flexibility to later make adjustments, or even simulate a completely different situation.

The tool is also capable to consider products other than soybean and corn, in a maximum of five different types. This important feature allow Multigrain to keep using it even if facing changes in the portfolio.

Despite all that, it's still a regular train-and-error what-if tool, that requires considerable effort from the user side on creating a feasible or good scenario. This process could be improved using an optimization tool, which could run with deterministic values and less restrictions or sophisticated decisions, allowing to quickly try a large amount of scenarios, just to find out the best volumes and locations. The optimized result would be a good starting point scenario for the simulation model, allowing it to fine-tune it and uncover constraints or problems not detected by the optimization.

ACKNOWLEDGMENTS

The authors thanks Multigrain by supporting this project and by authorizing the use of its information in this paper.

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