CHAPTER III[1]

GRAIN STORAGE FACILITY MODELS, VERIFICATION AND VALIDATION

Abstract. *This work was developed with objective of verifying and validating stochastic and discrete models of grain storage facilities. Three models, facilities A, B, and C, were developed using the simulation package Extend^{TM} and a simulation toolset called "Grain Facility." The three modeled grain storage facilities belong to COAMO, an agricultural cooperative headquartered in Campo Mourão, Paraná, Brazil. The facility "A" model was used to carry out verification, and the model of facilities "B" and "C" were used in the validation study. In the verification, the correlation coefficient for the cumulative curves of the amount of received raw products, considering real system data and model outputs, presented the following ranges: (i) corn - first crop – from 0.90 to 0.96, (ii) soybean – from 0.94 to 0.97, (iii) corn - second crop – from 0.96 to 0.97, and (iv) wheat – from 0.92 to 0.97. The annual firewood consumption of facility "A" was 794.11 t. and the greatest difference between the simulated and the real system data was 7.4%. In the validation effort, it was found that the model for facility "C" satisfactorily predicted electrical energy consumption. The greatest difference in electrical energy consumption between simulated and real system data was 1.50 MWh (1.90%).*

Keywords. *grain storage facility, model verification, model validation, Extend^{TM}*

INTRODUCTION

A grain storage facility can be defined as a system designed for the appropriate receiving, cleaning, drying, storing and dispatching of grains and legumes (Flores, 1988; Loewer et al., 1994). In order to perform these operations, several types of equipment and structures, such as receiving pits, cleaners, dryers, conveyors, wet holding bins, bins, flat storage and dispatch bins, need to be linked in a logical sequence. This system is characterized by the fact that its performance is tied to random factors, such as the harvest process and the market demand for the product. Due to this behavior, simulation has been shown as one of the best tools for the system's analysis.

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[1] Silva, L. C. 2002. Stochastic Simulation of The Dynamic of Grain Storage Facilities. Ph. Dissertation. Universidade Federal de Viçosa. Viçosa, MG. Brazil

Considering this system and using the software Extend^{TM}, version 4.1.3C, a simulation toolset called *"Grain Facility"* was developed for modeling grain storage facilities. This paper presents the verification and validation of dynamic, stochastic, and discrete grain storage facility models built by using *"Grain Facility"*.

BACKGROUND

Balci (1997) states that three types of errors can occur during modeling. The Type I Error, called "Model Builder's Risk," occurs if simulation results are not accepted when, in fact, they are sufficiently credible. The Type II Error, termed "Model User's Risk," happens when invalid simulation results are accepted as if they were sufficiently valid. And, the Type III Error appears when the model is not well formulated, thus being the inappropriate model for the study by simulation. By verification and validation, these types of errors can be minimized.

Verification can be defined as a set of actions the target of which is to verify if a computerized model was correctly developed using the chosen simulation or programming languages (Sargent, 1999). In order to perform the verification, Balci (1997) and Maria (1997) suggest: (a) the involvement of two or more persons, (b) running the models considering known situations, (c) debugging the program and verifying that the procedures were executed properly, and (d) observing the model animation.

Validation can be explained as a set of actions to determine if the input-output transformations in the model represent the input-output transformations of a determined system with sufficient accuracy. Sargent (1999) describes sixteen validation techniques that can be classified as objective or subjective procedures. Objective procedures use statistic inferences, such as variance analysis, confidence interval determination, and hypothesis tests (Menner, 1995). Predictive validation, a type of objective procedure, consists of the comparison between the system's behavior and the behavior forecast by the model to determine if they are the same (Sargent, 1999). The system data can be obtained from designed experiments or from habitual operations.

The subjective validation procedures are used when it is not possible to conduct ideal incursions in the system. In this instance, for example, the Turing Test can be used. This test consists of: (a) obtaining information from a model and a real system, (b) formatting the information in the same configuration, and (c) submitting the formatted information to experts. If experts do not find any differences between the model's and the system's input-output transformations, the model is validated (Law and Kelton, 1991; Winston, 1994).

VERIFICATION AND VALIDATION PROCEDURES

Three grain storage facility models were built using the simulation toolset *Grain Facility,* created by this paper's author, and the software Extend^{TM}, version 4.1.3C (Krahl, 2000). The simulation toolset is a developed Extend^{TM} library that has a set of 102 blocks that simulate structures, equipment, and operational decisions associated to grain storage facilities. Figure 1 presents the main blocks of this library.

The three modeled grain storage facilities belong to COAMO, an agricultural cooperative headquartered in Campo Mourão, Paraná, Brazil. In this study, the grain facilities were identified as "A", "B" and "C." The model of grain storage facility "A" was used in the verification procedures because some information from "A" had been used to test a number of blocks during the *Grain Facility* library's development.

To build the models, the following information was collected: (*i*) the grain facility structures, processing machines, and conveyors technical specifications, such as type, static capacity (t), handling capacity (t/h), and electrical power rating (kW); (*ii*) the grain storage facility's operational flowchart; (*iii*) data from the 1999 harvest season; and (*iv*) data about the product dispatch plan.

The main technical specifications of grain storage facilities "A", "B" and "C" are presented in Tables 1, 2, and 3 respectively. Tables 4, 5, and 6 present product input information, which is applied to each facility models' *Arrival Generator* block. The term *DHSI,* found in Tables 4, 5, and 6, relates to a distribution, which describes the variable "daily harvest success index." This variable defines the percentage by which the daily amount of a product received is below or above the average daily value of product received. This average is calculated based on the number of harvest days and the total amount of product to be harvested. Table 7 shows the dispatch plans for the cited facilities.

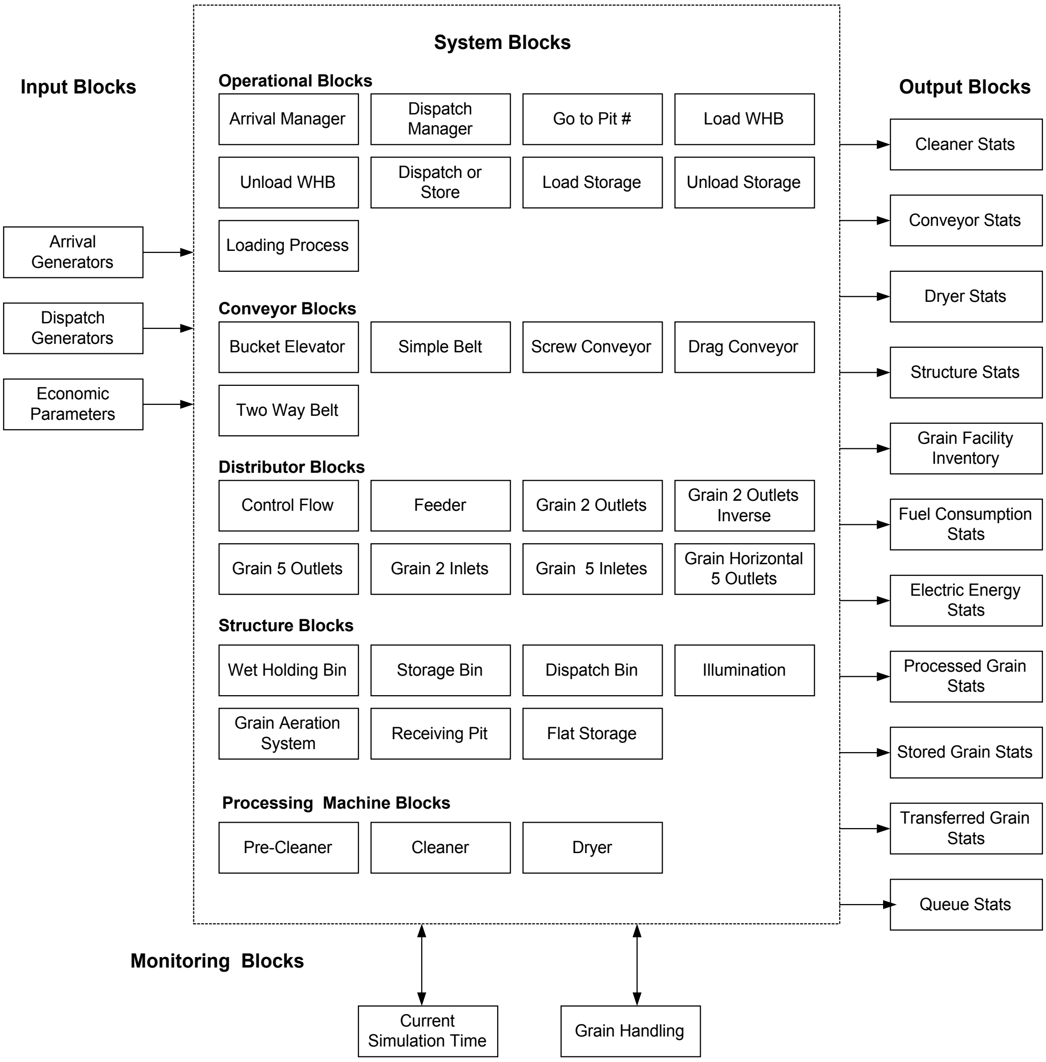

Figure 1 - *Grain Facility* Library schematic representation.

Table 1 – Main technical information of the modeled grain storage facility “A”

Structure	Quantity	Static capacity (t)
Receiving Pit	4	300
Wet Holding Bin	2	300
Flat Storage	1	
Cell-01		5,000
Cell-02		8,000
Cell-03		5,000
Dispatch Bin	1	80
Processing Machines	**Quantity**	**Hourly capacity (t/h)**
Pre-Cleaner	3	40
Dryer	1	80
Cleaner	4	30
Conveyors	**Quantity**	**Hourly capacity (t/h)**
Belt	4	120
Two way belt	1	120
Bucket elevator	7	120
Drag conveyor	2	120

Table 2 – Main technical information of the modeled grain storage facility "B"

Structure	**Quantity**	**Static capacity (t)**
Receiving Pit	4	150
Wet Holding Bin	2	150
Flat Storage	1	
Cell-01		5,400
Cell-02		7,200
Cell-03		5,400
Dispatch Bin	1	60
Processing Machines	**Quantity**	**Hourly capacity (t/h)**
Pre-Cleaner	4	40
Dryer	2	40
Cleaner	3	30
Conveyors	**Quantity**	**Hourly capacity (t/h)**
Belt	6	120
Two way belt	1	120
Bucket elevator	11	60 and 120
Drag conveyor	2	120

Table 3 – Main technical information of the modeled grain storage facility "C"

Structure	**Quantity**	**Static capacity (t)**
Receiving Pit	4	60
Metal Storage Bin	2	300
Metal Storage Bin	2	3,000
Dispatch Bin	1	42
Processing Machines	**Quantity**	**Hourly capacity (t/h)**
Pre-Cleaner	2	40
Dryer	1	40
Cleaner	2	30
Conveyors	**Quantity**	**Hourly capacity (t/h)**
Belt	3	60 and 120
Bucket elevator	6	60 and 120
Screw Conveyor	5	60 and 120

Since built models are stochastic, the inputs are different for each replication (run); thus, model verification and validation were carried to evaluate: (i) the *Arrival Generators* block outputs, to determine these blocks predictive ability in regards to daily amounts of raw product received, according to information shown in Tables 4, 5, and 6, and (ii) the whole model output regarding firewood and electrical energy consumption. In the evaluations, five simulation replications were taken, each performed for one year (8,640 hours). In order to make the evaluations, the cumulative curves were examined using statistical analysis that determined confidence intervals and correlation coefficients.

Table 4 – Information used at the *Arrival Generators* block – grain facility “A”

Product	**Distribution types for predicting *the “daily harvest success index”* - DHSI**	**Received amount of products (t)**	**Harvest period**	**Moisture content**		**Foreign material content**	
				% w.b.	**% of loads**	**%**	**% of loads**
Corn	Beta Distribution	7,376	01/26/99	lower than 14.2	1.42	1.1 to 2.0	93.87
(1st Crop)	α_1 = 0.2287 α_2 = 0.5360		to	14.3 to 18.2	4.22	2.1 to 3	6.13
	Minimum = 0 Maximum = 317.18		03/06/99	18.3 to 24.0	57.60		
				higher than 24.0	36.75		
Corn	Exponential Distribution	7,804	07/17/99	lower than 14.2	1.64	lower than	3.37
(2nd Crop)	β = 101. 355		to	14.3 to 18.2	10.27	1.0	96.63
	Shift = -1.3697		09/30/99	18.3 to 24.0	55.12	1.1 to 2.0	
				higher than 24.0	33.96		
Soybean	Beta Distribution	53,179	02/26/99	lower than 14.2	55.02	1.1 to 2.0	92.54
	α_1 = 0.3665 α_2 = 1.7942		to	14.3 to 18.2	39.03	2.1 to 3.0	6.88
	Minimum = 0 Maximum = 686.70		04/30/99	18.3 to 24.0	5.85	3.1 to 6.0	0.56
Wheat	Exponential Distribution	5,118t	08/16/99	14.3 to 18.2	54.60	lower than	29.22
	β = 100.001		to	18.3 to 24.0	45.40	1.0	54.55
	Shift = -2.2728		09/29/99			1.1 to 2.0	16.24
						2.1 to 3.0	

Table 5 – Information used at the *Arrival Generators* block - grain facility “B”

Product	**Distribution types for predicting the “*daily harvest success index*” - *DHSI***	**Received amount of products (t)**	**Harvest period**	**Moisture content**		**Foreign material content**	
				% w.b.	**% of loads**	**%**	**% of loads**
Corn	Beta	5,830	02/05/99	18.3 to 24.0	2.52	1.0 to 2.0	87.39
(1st Crop)	$\propto_1$ = 0.1919 $\propto_2$ = 0.4865		to	higher than 24.0	97.48	2.1 to 3.0	6.72
	Minimum = 0 Maximum = 355.68		03/08/99			3.1 to 4.0	5.89
Corn	Normal	1,387	07/20/99	18.3 to 24.0	24.50	1.0 to 2.0	57.84
(2nd Crop)	μ = 101. 003 σ = 83.67		to	higher than 24.0	75.50	2.1 to 3.0	24.50
			08/25/99			3.1 to 4.0	17.66
Soybean	Beta	28,604	03/01/99	up to 14.2	0.05	Up to 1.0	1.48
	$\propto_1$ = 0.2049 $\propto_2$ = 0.7287		to	14.3 to 18.2	81.16	1.1 to 2.0	83.85
	Minimum = 0 Maximum = 555.3		04/30/99	18.3 to 24.0	18.79	2.1 to 3.0	14.67
Wheat	Beta	11,248	08/11/99	up to 14.2	0.39	Up to 1.0	0.78
	$\propto_1$ = 0..3265 $\propto_2$ = 1.576		to	14.3 to 18.2	49.50	1.2 to 2.0	39.29
	Minimum = 0 Maximum = 1230.1		10/22/99	18.3 to 24.0	49.70	2.1 to 3.0	36.54
				higher than 24	0.41	3.1 to 4.0	23.39

Table 6 – Information used at the *Arrival Generators* block - grain facility "C"

Product	**Distribution types for predicting the "*daily harvest success index*" - *DHSI***	**Received amount of products (t)**	**Harvest period**	**Moisture content**		**Foreign material content**	
				% w.b.	**% of loads**	**%**	**% of loads**
Corn	Beta	6,682	02/20/99	14.3 to 18.2	10.83	Lower than 1.0	8.17
(1^{st} Crop)	$\propto_1$ = 0.2044		to	18.3 to 24.0	89.67	1.3 to 2.0	90.79
	$\propto_2$ = 0.9165		06/10/99			2.1 to 3.0	1.04
	Minimum = 0						
	Maximum = 686.5						
Corn	Exponential	3,002	08/24/99	18.3 to 24.0	15.00	2.1 to 3.0	67.50
(2^{nd} Crop)	β = 100. 00		to	higher than 24.0	85.00	3.1 to 4.0	17.50
	Shift = -2.7027		09/29/99			higher than 4.0	15.00

Table 7 – Dispatch plans for corn, soybeans, and wheat; facilities “A,” “B,” & “C”

Month	Stock portions to be dispatched (%)						
	Facility A			Facility B			Facility C
	Corn	Soybean	Wheat	Corn	Soybean	Wheat	Corn
1	0	0	0	0	0	0	0
2	20.35	0	0	0.26	0	0	0.80
3	29.82	47.18	0	78.86	3.18	0	2.00
4	0.15	14.52	0	0.50	33.46	0	6.58
5	0	20.58	0	0.48	0.63	0	8.70
6	0	0.67	0	8.08	17.89	0	10.85
7	0	6.52	0	8.81	23.37	0	2.89
8	20.45	7.81	0	3.01	2.75	0	2.45
9	0.55	0.54	69.96	0	17.19	9.44	12.25
10	0.55	0	0	0	0	0	10.89
11	7.03	1.32	0	0	0.07	0	11.40
12	21.10	0.86	30.04	0	1.46	90.56	31.19

VERIFICATION ANALYSIS

Figure 3 presents the cumulative curves for simulated and real system data on the amount of raw product received for grain storage facility “A.” Data refer to the real system and model outputs. The average curve refers to the average obtained from the five model replications. The dashed curves represent the 99% confidence interval boundaries for each harvest day.

The correlation coefficients were obtained by contrasting cumulative curves defined from the real systems’ data and from the models’ outputs. For each one of the five replications, the cumulative curve for the amount of grain arriving in the grain storage facility was plotted. The determined correlation coefficient ranges were: (i) corn - first crop: from 0.90 to 0.96, (ii) soybean: from 0.94 to 0.97, (iii) corn - second crop: from 0.96 to 0.97, and (iv) wheat: from 0.92 to 0.97. The second corn crop presented the best set of predicted values, with correlation coefficients above 0.96. The differences between the data from the real systems and from the simulated results were higher for the first days of the harvest, after which there was good agreement between simulated and real system data.

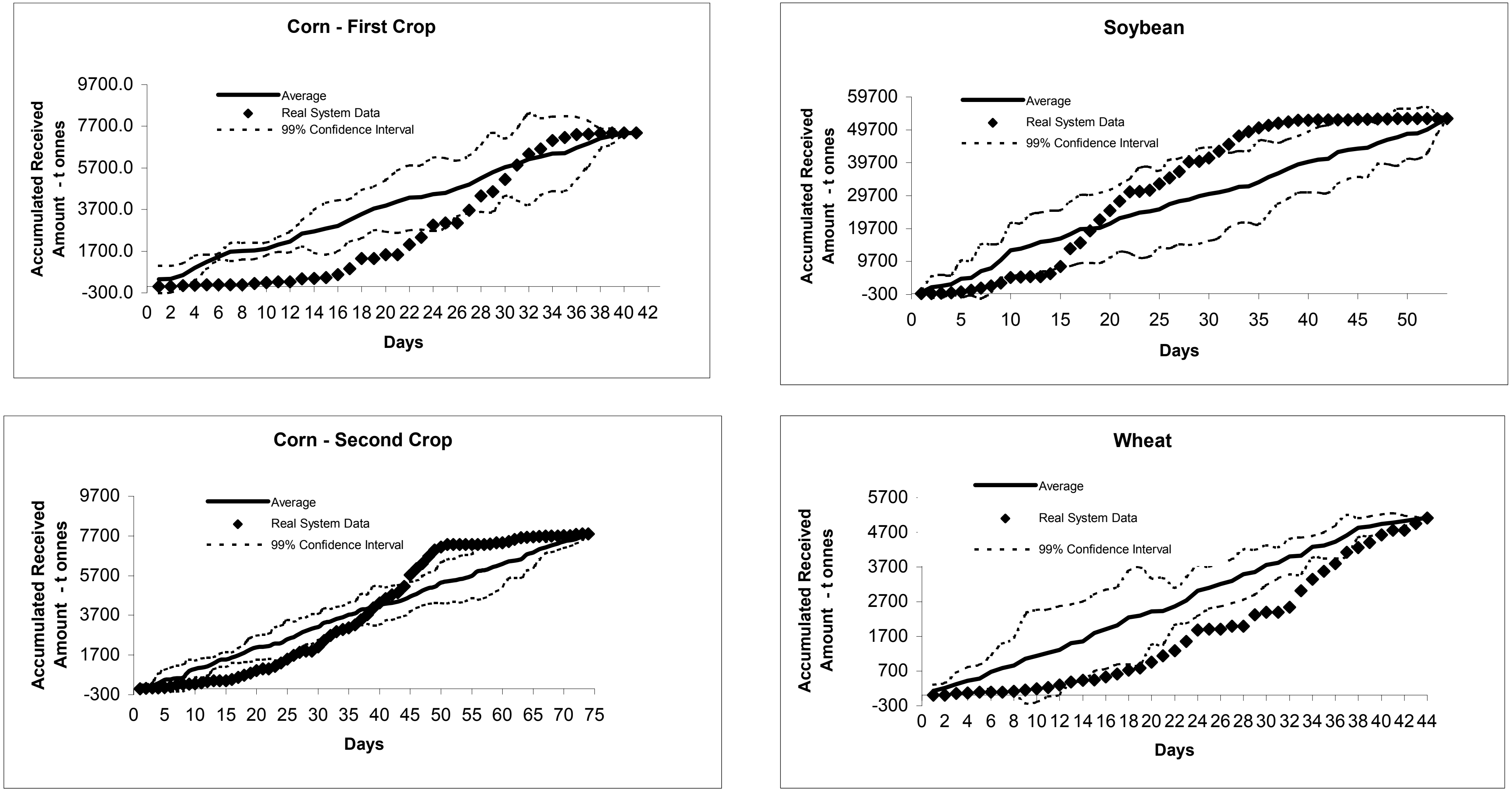

Figure 3 – The cumulative curves for received amount of raw products (Grain Storage Facility – “A”).

Figure 4 presents a plot showing the percentage differences between simulated and real system firewood consumption data for grain storage facility "A." Over the period of a year, 794.11 t of firewood was incinerated at this facility. Negative values mean that model's predicted consumption was lower than the real system's consumption. The low difference between simulated and real system data showed that the simulation model satisfactorily predicted firewood consumption. The greatest difference was found in the fourth replication, when the model's consumption figure was 58.97 t (7.42%) below real system consumption.

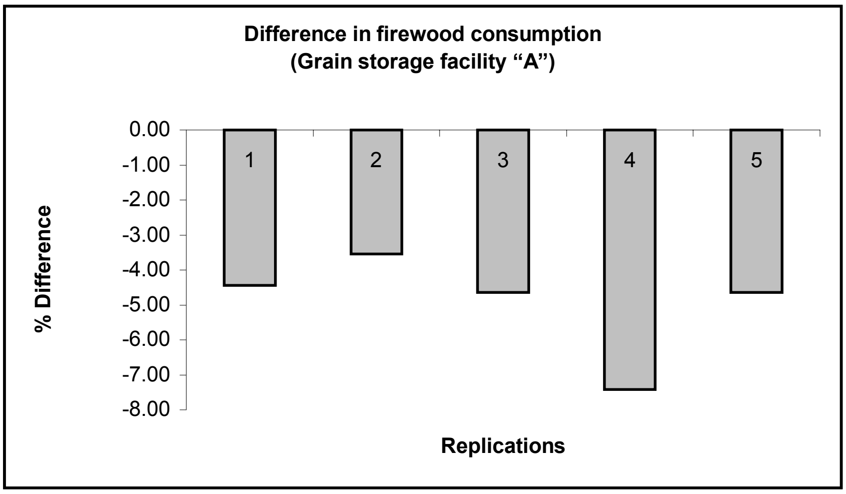

Figure 4 – Comparison between real system and model output for annual firewood consumption (Five replications, Facility "A").

VALIDATION ANALYSIS

Figures 5 and 6 present the cumulative curves for the amount of received raw products at grain storage facilities "B" and "C" respectively. The procedures and graphic representations that compare the output from models and the real systems are those used in the verification.

The correlation coefficient for the cumulative curves of the amount of products received at the real systems and at modeled grain storage facilities have the following ranges: (a) Facility "B": (i) corn - first crop: from 0.90 to 0.97, (ii) soybean: from 0.98 to 0.99, (iii) corn - second crop: from 0.91 to 0.95, and (iv) wheat: from 0.96 to 0.98; (b) Facility "C": (i) corn - first crop: from 0.83 to 0.90, and (ii) corn - second crop: from 0.95 to 0.99.

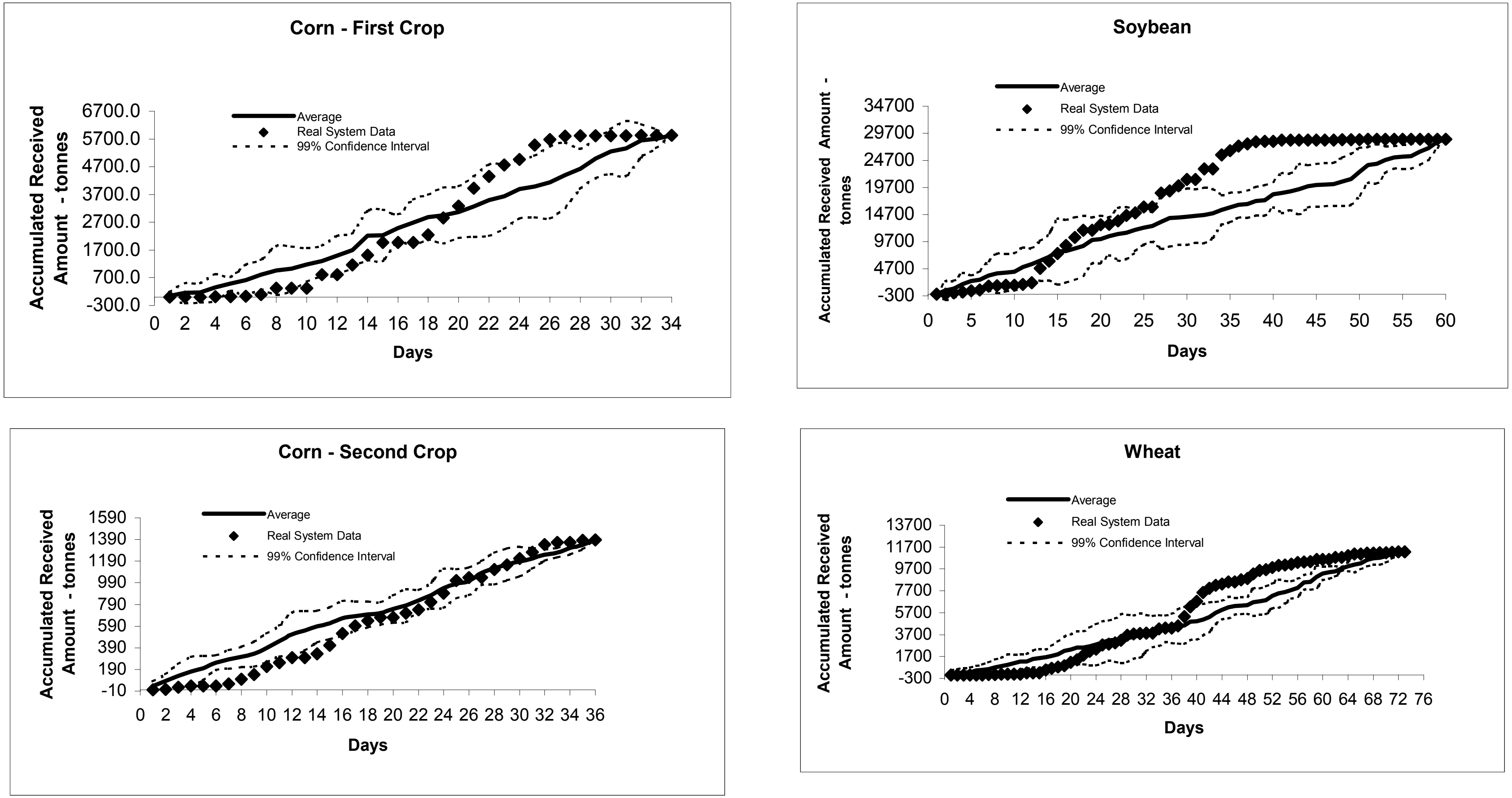

Figure 5 – Cumulative curves for received amount of raw products (Grain Storage Facility – “B”).

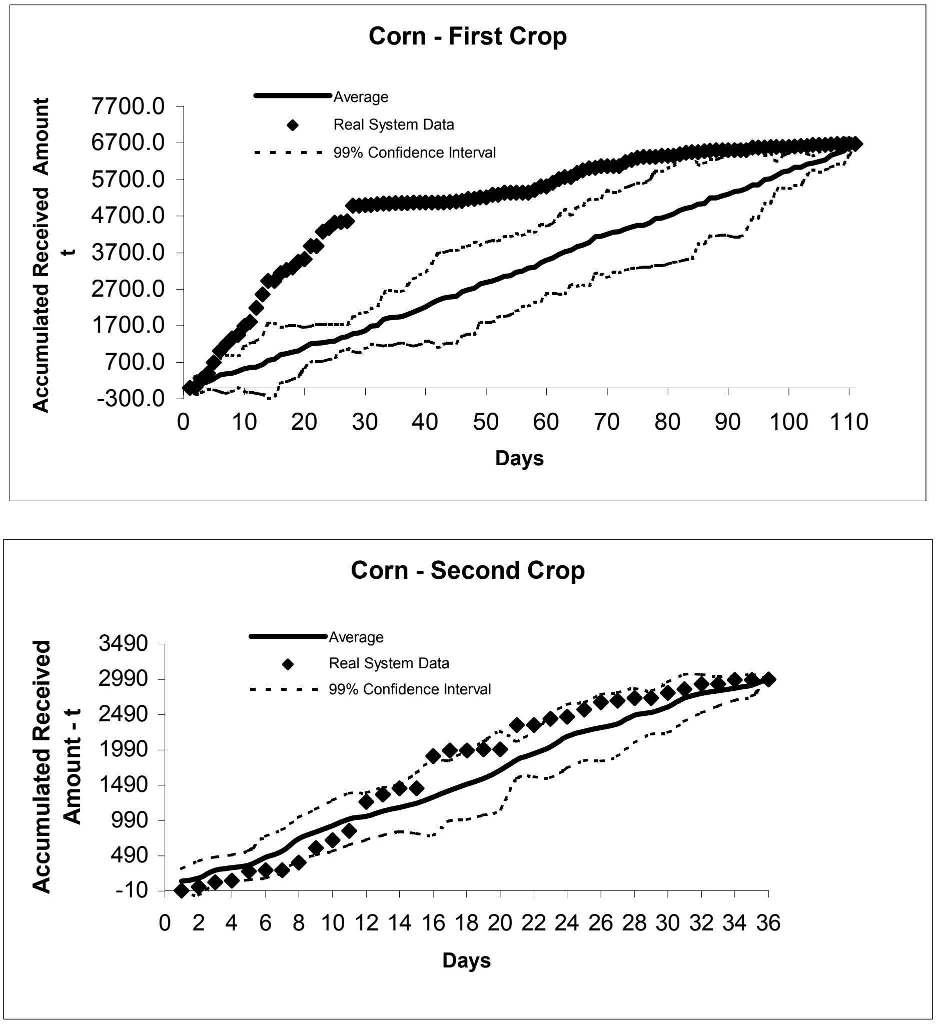

Figure 6 – Cumulative curves for received amount of raw products

(Grain Storage Facility "C")

Considering information presented for facility B," it can be concluded that the developed model satisfactorily predicted the cumulative curves of received amounts of raw material: the correlation coefficients for the cumulative curves were higher than 0.90.

For facility C, the first crop of corn had the lowest correlation coefficient (Figure 6). This can be explained by the fact that 75% (5,002 t) of raw product was received in the first 30 days of the 111 day harvest period. Over the harvests last 81 days only 25% (1,180 t) of the product was received. To minimize this discrepancy, the toolset's description of the harvest season should be divided into two or more parts, and a different fitted distribution should be used for each part. To attending to this suggestion, during development of the *Arrival Generators* block, the variable *DHIS* per received product should have more than one fitted distribution.

Figure 7 shows firewood consumption output differences between the models of facilities “B” and “C” and the real systems. It shows that the models’ firewood consumption figures were lower than those from the real systems. Annually, facility “B” consumed 883.61 t of firewood and Facility “C” consumed 410.08 t. For facility “B,” the greatest percentage difference between the real and the simulated systems was -23.27% (209.97 t), and the smallest difference was -17.32% (153.03 t). For facility “C,” the corresponding values were –17.33% (71.06 t) and –14.52% (59.53 t). Negative percentage values mean that simulation outputs are lower than systems outputs.

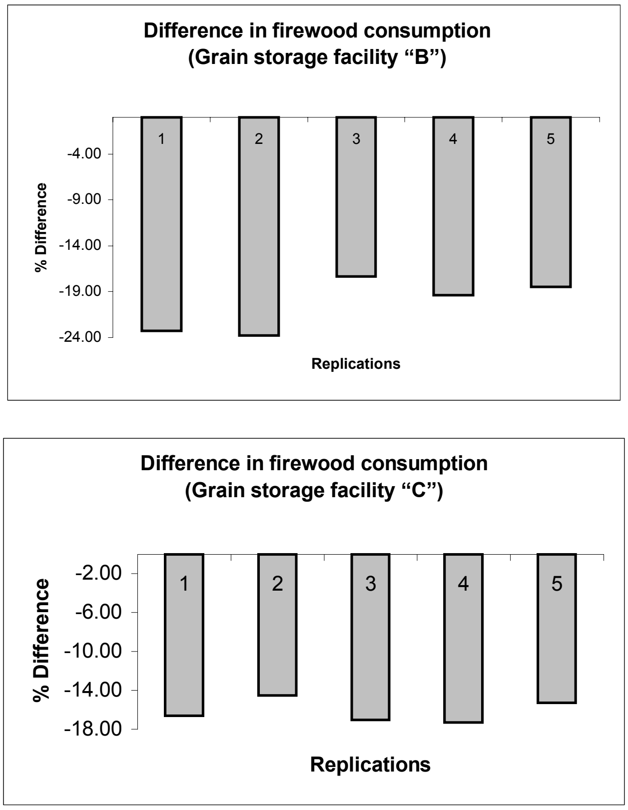

Figure 7 – Comparison among system and model outputs for annual firewood consumption.

The discrepancies found between actual and simulated facility firewood consumption might be associated with dryer specific heat-energy consumption. The value used for the simulated dryers' capacities was 40 t/h in accordance with actual dryer capacity in facilities "B" and "C." As defined by Weber (2001) citations, a dryer of this capacity uses 3,551.36 kJ of energy to evaporate each kg of water. Possibly, this value is not appropriate for these dryers.

Figure 8 presents monthly electrical energy consumption for grain storage facility "C." It was decided to perform the analysis only for facility "C" since it was not possible to obtain data exclusively related to grain handling for facilities "A" and "B." The yearly electrical energy consumption for facility "C" was 78.60 MWh.The predicted model outputs, considering the five replications, ranged from 77.10 to 78.13 MWh. The greatest difference between modeled and actual consumption was 1.50 MWh (1.90%).

Using the information shown in Figure 8, the cumulative curves for electrical energy consumption were determined. These curves are presented in Figure 9. The correlation coefficients obtained by contrasting the cumulative curves related to system and model outputs ranged from 0.98 to 0.99.

Data refer to the real system and to the model outputs. The model outputs come specifically to the outputs of the *Electric Energy Stats* block (Figure 1). The model outputs are shown in Figures 8 and 9 as the averages of the predicted values for the five model replications. The dashed lines represent the band of the 99% confidence intervals for each month, encompassing data obtained from the five replications.

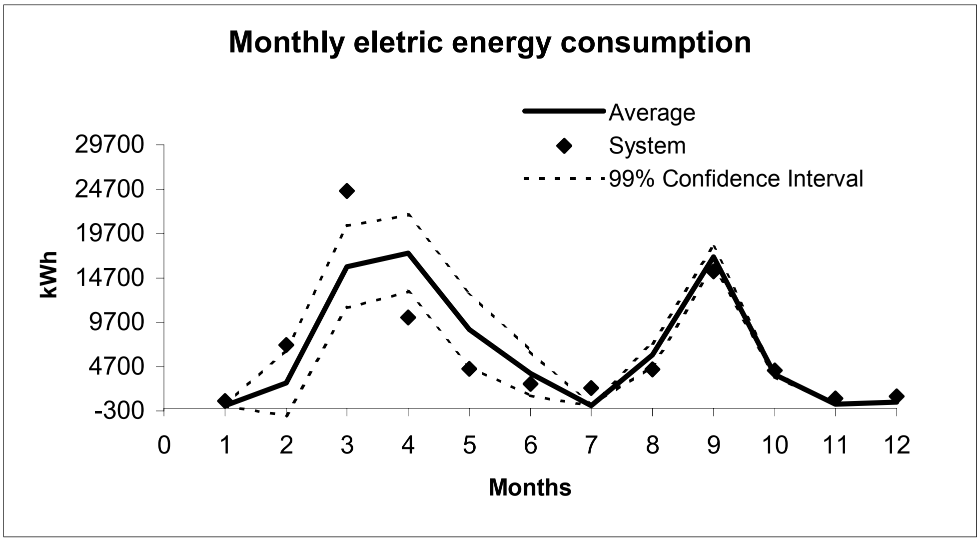

Figure 8– Comparison among system and model outputs for monthly electrical energy consumption – (Grain Storage Facility – “C”)

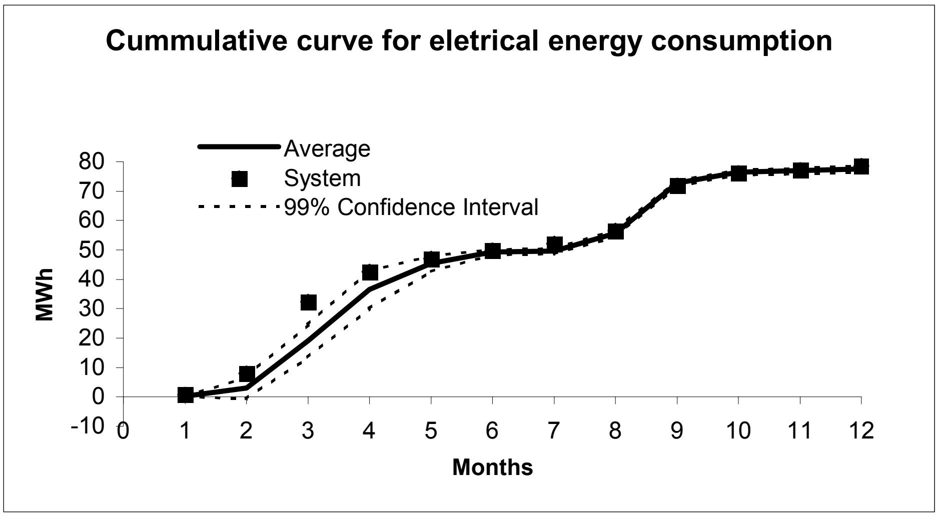

Figure 9 – Cumulative electrical energy consumption curves (Grain Storage Facility – “C”).

According to Figures 8 and 9, the greatest difference between the real system and the modeled electrical energy consumption was in March. This variation was probably caused by the discrepancies observed in the cumulative curve for the first crop of corn (Figure 6). However, according to the cumulative curves' high correlation coefficients and the noted narrowness of the differences in annual electric energy consumption between the real and the modeled systems, it is clearly shown that the model for facility "C" satisfactorily predicted electrical energy consumption.

CONCLUSION

This article deals with procedures carried out in the verification and validation of the simulation models created by using the simulation tool "*Grain Facility*." In the verification, the model for grain storage facility "A" satisfactorily predicted firewood consumption. The greatest difference found between the system and the model data occurred when model output was 735.14 tonnes. This value was lower than the system output by 58.97 t (7.42%).

In the validation study, it was found that the model for grain storage facility "C" satisfactorily predicted annual electric energy consumption. The model's predicted outputs, considering the five replications, ranged from 77.10 to 78.13 MWh, with 1.50 MWh (1.90%) being the greatest difference between real and modeled systems.

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