

LUÍS CÉSAR DA SILVA

STOCHASTIC SIMULATION OF THE DYNAMIC BEHAVIOR OF GRAIN
STORAGE FACILITIES

Thesis submitted to Universidade
Federal de Vicosa, as the requirement
of Agricultural Engineering Graduate
Program for obtaining the title of
Doctor Scientiae.

VIÇOSA
MINAS GERAIS – BRAZIL
2002

LUÍS CÉSAR DA SILVA

STOCHASTIC SIMULATION OF THE DYNAMIC BEHAVIOR OF GRAIN
STORAGE FACILITIES

Thesis submitted to Universidade Federal de Vicosa, as the requirement of Agricultural Engineering Graduate Program for obtaining the title of *Doctor Scientiae*.

APROVED: May 21, 2002.

Dr. Pedro Amorim Berbert

Dr. José Helvecio Martins

Dr. Carlos Arthur Barbosa da Silva
(Advisory Committee Member)

Dr. Evandro Castro de Melo
(Advisory Committee Member)

Dr. Daniel Marçal de Queiroz
(Major Professor)

*To my wife, Sônia,
and my children,
Humberto and Raphael.*

ACKNOWLEDGEMENTS

First, I would like to thank God for the protection and blessings I have received.

My sincere appreciation goes to my major professors, Dr. Daniel Marçal de Queiroz and Dr. Rolando Arturo Flores, for their professionalism, strong guidance, support, time, patience, and advice. Also, I want to thank Dr. Evandro Castro de Melo and Dr. Carlos Arthur B. Silva, members of my advisory committee, and Dr. Ekramul Haque for their assistance and support, and Drs. Pedro Amorim Berbert and José Helvecio Martins for their important suggestions.

My special thanks goes to the Universidade Federal de Viçosa (UFV), Brazil, Kansas State University (KSU), USA, and the Universidade Estadual do Oeste do Paraná (UNIOESTE), Brazil, for providing me this training opportunity. Furthermore, I would like to thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - CAPES, Brazil, my sponsor.

I am thankful to my friends and colleagues, especially Monica Pirozi and family, for their strategic and essential support during my stay in Manhattan, Kansas, United State of America.

I am very thankful to the staffs of the Grain Science & Industry Department at Kansas State University and Agricultural Engineering Department at Universidade Federal de Viçosa, Brazil.

I would like to thank the Brazilian “*Cooperativa Agropecuária Mourãoense Ltda.*” (COAMO) and the “*Cooperativa de Cafeicultores e Agropecuaristas de Maringá Ltda.*” (COCAMAR) for allowing me to collect data, and for their staff’s amiability and cooperation.

Last but not least, I would like to express my sincere acknowledgements to my wife Sônia and my sons Humberto and Raphael for their essential support and incommensurable sacrifice, which allowed me to achieve my objectives.

VITA

LUÍS CÉSAR DA SILVA, son of Sebastião José da Silva and Maria do Carmo Araujo da Silva, was born in Viçosa, Minas Gerais, Brazil, on May 27, 1963.

He received his Bachelor in 1985; Master of Science in 1990, and, in 2002, his Ph. D from the Universidade Federal de Viçosa (UFV). Part of his Ph. D was conducted at Kansas State University in Manhattan, Kansas.

Mr. Silva has been worked at the Universidade Estadual do Oeste do Paraná (UNIOESTE) since March 1986 as a professor of Agricultural Engineering. From September 1992 to December 1997, Mr. Silva was head of the Engineering Department of UNIOESTE.

Mr. Silva's research interests include modeling and operations research applied to agro-industrial systems. His address is: UNIOESTE – Campus Cascavel; Caixa Postal #701; 85.814-110 Cascavel – PR, Brazil; e-mail: silvalc@unioeste.br

TABLE OF CONTENTS

ABSTRACT	VIII
RESUMO	X
CHAPTER I	1
INTRODUCTION	1
1.1 BACKGROUND	1
1.2 PROBLEM STATEMENT	4
1.3 OBJECTIVES	4
1.4 ORGANIZATION OF THIS STUDY	5
1.5 LIMITATIONS AND SCOPE	6
1.5.1 LIMITATIONS	6
1.5.2 SCOPE	6
1.6 REFERENCES	7
CHAPTER II	9
A SIMULATION TOOL FOR MODELING GRAIN STORAGE FACILITIES	9
ABSTRACT	9
INTRODUCTION	9
BACKGROUND	10
THE EXTEND™ SOFTWARE	11
GRAIN FACILITY LIBRARY DEVELOPMENT	12
APPLICATION OF THE GRAIN FACILITY LIBRARY	34
MODEL OUTPUTS DISCUSSION	35

CONCLUSION	41
REFERENCES	42
CHAPTER III	44
GRAIN STORAGE FACILITY MODELS, VERIFICATION AND VALIDATION	44
ABSTRACT	44
INTRODUCTION	44
BACKGROUND	45
VERIFICATION AND VALIDATION PROCEDURES	46
VERIFICATION ANALYSIS	53
VALIDATION ANALYSIS	55
CONCLUSION	61
REFERENCES	61
CHAPTER IV	63
SENSITIVITY ANALYSIS USING A GRAIN STORAGE FACILITY MODEL	63
ABSTRACT	63
INTRODUCTION	63
BACKGROUND	64
EXPERIMENT ORGANIZATION	65
RESULTS AND DISCUSSIONS	68
CONCLUSION	72
REFERENCES	72
CHAPTER V	74
SCENARIO ANALYSIS OF THE DRYING SECTOR'S CONFIGURATION	74
ABSTRACT	74
INTRODUCTION	74
BACKGROUND	75
EXPERIMENT ORGANIZATION	76
RESULTS AND DISCUSSIONS	80
CONCLUSION	84
REFERENCES	85
CHAPTER VI	86
CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH	86
APPENDICES	90

ABSTRACT

Silva, Luís César da, D. S., Universidade Federal de Viçosa, May, 2002.
Stochastic simulation of the dynamic behavior of grain storage facilities. Adviser: Dr. Daniel Marçal de Queiroz. Committee Members: Dr. Rolando Arturo Flores Galarza, Dr. Evandro Castro de Melo, and Dr. Carlos Arthur Barbosa Silva.

A grain storage facility may be defined as a designed and structured system for receiving, cleaning, drying, storing, and dispatching grains and legumes. To perform these tasks appropriately, structures, processing machines, and conveyors are logically linked and management decisions are made. Due to the dynamic of grain storage facilities and external random factors, such as the harvest process and market demand, evaluation and analysis using static techniques are not recommended. Static methodologies may lead decision makers to erroneous conclusions or put them in an awkward position when trying to correlate the several variables involved. For these reasons, simulation proves to be a more than adequate method to better understand the studied decision parameters; and it is ideal for conducting sensitivity analysis, scenario analysis, optimization, and Monte Carlo simulation. Thus, a simulation toolset was developed to allow engineers, designers, managers, and other decision makers to model the dynamic behavior of new and existing grain storage facility and conduct related experiments and

feasibility analyses. This toolset, called “*Grain Facility*,” was developed by using Extend™ software, version 4.1.3C. “*Grain Facility*” is an Extend™ library holding a set of blocks that enable the user to: (i) input information which rules system operations, (ii) simulate unit operations related to the grain storage facility environment, (iii) collect and display information during the simulation process, and (iv) generate reports and graphics. For the development of models using the “*Grain Facility*” library and for the following study’s verification and validation sections, data were obtained from the *Cooperativa Agropecuária Mourãoense Ltda.* (COAMO), an agricultural cooperative headquartered in Campo Mourão, Paraná State, Brazil. The data refer to: (i) monthly electric energy consumption, (ii) annual consumption of firewood used in the grain drying process, (iii) daily quantity of product received, (iv) monthly quantity of product dispatched, (v) a flowchart of the grain storage facilities visited, and (vi) technical information about processing machines, conveyors, and structures. This study’s outcomes show that *Grain Facility* has significant problem solving potential. It allows the structuring of models that have various applications, such as (i) conducting grain storage facility feasibility analyses, (ii) estimating electric energy and fuel consumption at grain storage facilities, (iii) acting as teaching tools to make cases under study more readily understandable, and (iv) analyzing new and existing systems to make them more efficient or to provide direction for facility remodeling and technological updating.

RESUMO

Silva, Luís César da, D. S., Universidade Federal de Viçosa, maio de 2002.
Stochastic simulation of the dynamic behavior of grain storage facilities. Orientador: Daniel Marçal de Queiroz. Conselheiros: Rolando Arturo Flores Galarza, Evandro Castro de Melo e Carlos Arthur Barbosa Silva.

Unidades armazenadoras de grãos podem ser definidas como sistemas projetados e estruturados para receber, limpar, secar, armazenar e expedir grãos e oleaginosas. Para alcançar essas metas apropriadamente, estruturas, máquinas de processamento e transportadores são interligados, segundo um fluxograma lógico, e tomadas decisões operacionais. Devido à dinâmica do sistema da unidade armazenadora de grãos e a influências de fatores aleatórios externos, como o processo de colheita e a demanda do mercado, não são recomendados o emprego de métodos estáticos em estudos de avaliações e análises para este tipo de sistema. Isso se deve ao fato de que os métodos estáticos podem levar os tomadores de decisões a cometer erros, como também colocá-los em situações embaraçosas ao procurar estabelecer correlações entre as variáveis envolvidas. Por essa razão, a simulação se apresenta como a técnica mais adequada, por permitir um melhor entendimento dos parâmetros selecionados para a tomada de decisão, além de propiciar a condução de experimentos, como: análise de sensibilidade, análise

de cenários, otimização e simulação de Monte Carlo. Dessa forma, visando permitir engenheiros, projetistas, gerentes e demais tomadores de decisões simularem a dinâmica operacional, conduzirem experimentações e realizarem análises de viabilidade, considerando-se unidades armazenadoras existentes e novas, foi desenvolvida uma ferramenta para estruturação de modelos de simulação. Essa ferramenta, denominada *Grain Facility*, foi desenvolvida utilizando-se o software ExtendTM, versão 4.1.3C. *Grain Facility* é classificada como uma biblioteca do ExtendTM, que contém um conjunto de blocos que propiciam: (i) introduzir dados que governam o sistema, (ii) simular as operações unitárias associadas ao ambiente das unidades armazenadoras de grãos, (iii) coletar e apresentar informações durante a simulação e (iv) gerar relatórios e gráficos. Para o desenvolvimento da biblioteca *Grain Facility*, dos modelos e dos estudos de verificação e validação, dados foram obtidos na Cooperativa Agropecuária Mourãoense Ltda. – COAMO, com sede em Campo Mourão, Paraná, Brasil. Os dados referem-se a: (i) consumo mensal de energia elétrica, (ii) consumo anual de lenha utilizada no processo de secagem, (iii) quantidades diárias de produtos recebidas, (iii) quantidades mensais de produtos expedidas, (iv) fluxogramas das unidades armazenadoras visitadas e (v) informações técnicas sobre equipamentos e estruturas. Com base nos resultados, pode-se concluir que *Grain Facility* possui significativo potencial para solução de problemas, uma vez que essa ferramenta permite a estruturação de modelos que são úteis em aplicações como: (i) análises de viabilidade, (ii) entendimento dos casos em estudo, (iii) estimativa do consumo de energia elétrica e combustível no processo de secagem e (iv) avaliação de sistemas novos e existentes, bem como das necessidades de expansão, remodelação e inovação tecnológica.

CHAPTER I

INTRODUCTION

1.1 BACKGROUND

According to Flores (1988) and Loewer et al. (1994), grain storage facilities are systems designed for the appropriate receiving, cleaning, drying, storing, and dispatching of grains and legumes. 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. These systems should also be designed, operated, and managed in a way that product characteristics can be preserved and profits can be earned.

Due to the grain storage facility system's characteristics, such as the complexity of unit operations, stochastic effects regarding external and internal factors, and high long-term investment demand, the design of grain facilities is a difficult task for which the simulation of facility characteristics has become an important tool. According to Lower et al. (1994), improved simulation of grain pre-processing has made it possible to better evaluate the grain drying process, the facility layout and design, and the complete grain storage system.

For the grain drying process, Loewer et al. (1994) lists the following simulation models:

(a) CROSSFLOW (Thompson et al., 1968) simulates drying time, drying rate, cost, and energy requirements for drying either corn or sorghum. This model was programmed using the FORTRAN language for the mainframe environment.

(b) FANMATCH (Thompson, 1975a) determines the fan horsepower requirements needed to move a given volume of air per bushel of grain and selects the fan according to type of bin chosen and type of grain to be dried.

(c) NATAIR (Thompson, 1975b) calculates how long it takes to dry the top grain to a specified final moisture content given either natural air or low temperature drying conditions and evaluates the airflow produced by the dryer system. NATAIR was formulated to consider corn or grain sorghum characteristics and was originally run using mainframe computers running FORTRAN. Parts of this model have been included in several others.

(d) CONTBN (Bridges et al., 1984), developed using GASP IV simulation language, makes it possible to evaluate the drying performance of continuous in-bin drying systems.

(e) LAYERD (Bridges et al., 1982) provides a filling schedule for a layer-drying bin based on dry matter decomposition and the possibility of aflatoxin contamination. LAYERD can be used to simulate corn and grain sorghum drying based on input information, such as ambient temperature and relative humidity, drying air temperature, initial and desired final grain moisture content, fan performance data, drying bin diameter and height, and whether the system is to be controlled by a thermostat or a humidistat.

(f) STIRDRY (Bridges et al., 1984), used by decision makers, provides management information and analyzes the advantages of the use of stirring devices in individual layer and batch-in-bin corn systems.

For facility layout and design, Loewer et al. (1994) list the following models:

(a) BNDZN (Loewer et al., 1976a), which is static design model programmed in FORTRAN. It provides the layout dimensions, bill of materials and estimated fixed annual costs for centralized grain storage facilities.

(b) CIRCLE (Loewer et al., 1976b) is a spreadsheet model employed to layout a circular arrangement of storage bins.

(c) FLASTOR (Loewer et al., 1989) gives the facility geometric layout and purchase cost information for a flat storage system. It is a spreadsheet model that can be run on a microcomputer.

(d) DUCT (Bridges et al., 1988) determines duct sizes and duct spacing for aeration of rectangular storage facilities. The design is based on the configuration of the grain mass, desired airflow rate, grain volume, and duct spacing criteria that provide a relatively uniform distribution of air throughout the grain mass.

For total system evaluation, Loewer et al., (1994) presents the following models:

(a) CHASE (Bridges et al., 1979) is a static design model that simulates the optimization of the delivery, drying, and storage components for 60 different types of systems and ranks them according to purchase price and annual cost. Physical layout information is also provided. The optimum situation is defined according to the input data, which includes cultivated acreage, yield per acre, row width, harvest season (days), harvest time (hours/day), energy cost, portable drying time (hours/day), travel distance from the field to the facility, labor cost (\$/hour), and initial and desired grain moisture content.

(b) SQUASH (Benok et al., 1981) is structured using FORTRAN and GASP IV and allows the identification of bottlenecks in the system that may arise during harvest, transport, delivery, drying, or storage. This model provides a list of events and a graphic output of grain flow and vehicle activities for a set of equipment and management strategies.

(c) EXSQUASH (Loewer et al., 1990) is an expert system model that helps to identify bottlenecks in the harvesting/delivery and handling/drying/storage systems. This model was developed using EXSYS software.

Several models that simulate part or all of the grain pre-processing system have been developed and implemented in Brazil.

(a) Queiroz et al. (1984) created a simulation of the corn drying process in concurrent flow dryers with countercurrent flow cooling using the Michigan State University drying simulation model.

(b) Silva (1991) developed a drying model for an intermittent counter flow coffee dryer. The model was according to Thompson et al. (1968).

(c) Rezende (1997) developed a spreadsheet model that can be applied to the design, simulation, and economic evaluation of on-farm grain storage facilities with a receiving capacity of between 500 to 6,000 tonnes. The ideal layout was adopted using corn grain characteristics to develop the model.

1.2 PROBLEM STATEMENT

Due to the influence of external and internal stochastic variables on the performance of grain storage facilities, the use of deterministic simulation models and static methods of analysis can lead to erroneous decisions. Therefore, models are needed that allow simulation of the dynamic behavior of grain storage facilities under the influence of stochastic variables. These types of models allow a better understanding of grain storage facility operations. Moreover, using this type of model, sensitivity analysis, scenario analysis, optimization, and Monte Carlo simulation can be performed to find the best design for a new facility, and the best way to operate or renovate an existing facility.

1.3 OBJECTIVES

This research consists of the development of a simulation tool that will assist decision makers who work in the grain handling industry to: (i) assemble their models according to the configuration of their grain storage facilities, and (ii) modify pre-assembled models to determine the best configurations and operation plans for optimum system effectiveness in terms of (1) electrical energy and firewood consumption, (2) conveyor and processing machine efficiencies, and (3) structure utilization indices.

Due to the characteristics of the simulation language, Extend™, used to develop of the simulation tool, users, according to their background and study purpose, will be able to select several types of information from the model reports. This information will allow one to (i) conduct grain storage facility feasibility analyses, (ii) make economic evaluations, and (iii) estimate operational impacts resulting from modifications in the system's configuration and product flow.

Academically, the general objective of this research was to develop stochastic models that simulate the dynamic behavior of grain storage facilities, thereby permitting feasibility analyses. To achieve this objective, the following specific objectives were defined: (a) Develop a group of computational routines

for simulating unit operations and processes related to grain storage systems; (b) Implement models that group developed routines for simulating the dynamic behavior of grain storage facilities; (c) Verify and validate developed mathematical models using experimental data obtained at pre-processing grain enterprises located in the western region of the state of Paraná, Brazil; (d) Conduct a sensitivity analysis to verify the impact on firewood and electric energy consumption caused by changes in the quantity of grain handled and the initial moisture content of this grain; and (e) Analyze the configuration of the grain storage facility's drying sector through use of scenarios.

1.4 ORGANIZATION OF THIS STUDY

This thesis contains six chapters. Chapter I, INTRODUCTION, presents an outline of the general vision of this study, previous studies in this area, the reasons for doing this research, the organization of this work, and the study's limitations and scope. Chapter II, A SIMULATION TOOL FOR MODELING GRAIN STORAGE FACILITIES, describes the development of the "*Grain Facility*" simulation tool and gives an example of its use. Chapter III, VERIFICATION AND VALIDATION OF THE GRAIN STORAGE FACILITY MODEL, delineates the procedures used to verify and validate the model's output. Chapter IV, SENSITIVITY ANALYSIS USING A GRAIN STORAGE FACILITY MODEL, presents a study that shows that the quantity and initial moisture content of raw product received can affect grain storage facility performance. Chapter V, SCENARIO ANALYSIS RELATED TO DRYING SECTOR'S CONFIGURATION, shows how changes in the drying capacity can affect grain storage facility performance according to engineering parameters. Chapter VI, CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH, contains the main conclusions arrived at from this study and recommendations for future work. Appendixes and supporting information are included at the end of the study.

Chapters II, III, IV, and V were written as a research paper.

1.5 LIMITATIONS AND SCOPE

1.5.1 LIMITATIONS

This study has the following limitations: (a) Only data related to the crop year of 1999 was made available by the agricultural cooperative COAMO – “*Cooperativa Agropecuária Mourãoense Ltda*”. Therefore, in the verification and validation studies, there is a comparison between simulated and experimental data for only one year of grain storage facility operation. (b) In the developed model, there are options for corn, soybeans, and wheat only (c) Data related to moisture content, foreign material content, truck capacities, and interval between truck arrivals were considered according to empirical distributions defined according to modeler experience and informal data. (d) Simulation time is restricted to the maximum of 1 year (8640 hours). (e) In the simulation process, one year was considered to be 360 days, made up of 12 months each 30 days long, and each day has 24 hours.

1.5.2 SCOPE

The general subject matter covered in this thesis includes computer simulations, modeling procedures, grain storage facility descriptions, and a simulation applied to pre-processing grain system. The major focus is Brazilian grain storage facility systems with storage capacities of more than 6,000 tonnes. In general, these systems belong to private enterprises, agricultural cooperatives, or governmental agencies and grain is stored in flat storage structures made of concrete or cylindrical bins made of concrete or corrugated metallic sheets.

1.6 REFERENCES

- Benock, G., O. J. Loewer, T.C. Bridges, and D. H. Loewer. 1981. Grain flow restrictions in harvesting-delivery systems. *Trans. ASAE* 24(5): 1151-1161
- Bridges, T. C., D. G. Overhults, S. G. McNeil, and G. M. White. 1988. An aeration duct design model for flat grain storage. *Trans. ASAE* 27(5): 1283-1288.
- Bridges, T. C., D. G. Colliver, G. M. White, and O. J. Lower. 1984. A computer aid for evolution of on-farm stir drying systems. *Trans. ASAE* 27(5): 1549-1515.
- Bridges, T. C., G. M. White, I. J. Ross, and O. J. Loewer. 1982. A computer aid model for management of on-farm layer drying systems. *Trans. ASAE* 25(3): 811-815
- Bridges, T. C., O. J. Loewer, Jr., J. N. Walker, and D. G. Overhults. 1979. A computer model for evaluating corn harvesting, handling, drying and storage systems. *Trans. ASAE* 22(3): 618-629
- Flores, R. A. 1988. Quality is chief priority in grain storage units. *Agribusiness Worldwide* 11(10): 9-16.
- Law, A. M. and W. D. Kelton. 1991. *Simulation modeling and analysis*. 2nd Edition. New York: McGraw Hill, Inc.
- Loewer O. J., T. C. Bridges, and R. A. Bucklin. 1994. *On-farm drying and storage systems*. ASAE Publication 9, American Society of Agricultural Engineers.
- Loewer, O. J., M. K. Koecher, and J. Solamianian. 1990. An expert system for determining bottlenecks in on-farm grain processing system. *Applied Engineering in Agriculture* 6(1): 69-72.
- Loewer, O. J., I. L. Berry, and T. J. Siebenmorgen. 1989. Geometric and economic considerations in the design of circular grain storage systems. *Applied Engineering in Agriculture* 2(1): 114-122.
- Loewer, O. J., T. C. Bridges, D. G. Overhults. 1977. Using the computer to analyze grain storage facilities. *Agricultural Engineering* 58(1): 42-43.
- Loewer, O. J., T. C. Bridges, and D. G. Overhults. 1976a. Computer layout and design of grain storage and handling facilities. *Trans. ASAE* 19(6): 1130-1137.

- Loewer, O. J., T. C. Bridges, and D. G. Overhults. 1976b. CHACHE: Computer model for the analysis of the economics of corn harvesting and processing systems. *Technical Series No. 10. Agr. Eng. Dept.*, University of Kentucky, Lexington
- Queiroz, D. M., V. A. Dalpasquale, J. A. M. Pereira. 1984. Simulação de secagem de milho em secadores de fluxos concorrentes de múltiplos estágios com resfriamento em fluxos contracorrentes [*Corn drying simulation in multi stages concurrent flow dryers with countercurrent flow cooling*]. *Revista Brasileira de Armazenamento*. Viçosa, MG: Centro Nacional de Treinamento em Armazenagem, 9(1): 30-34.
- Rezende, R. C. 1997. Modelo computacional aplicado a dimensionamento, simulação e análise econômica de unidades pré-processadoras de grãos. [*A computational model applied to the design, simulation, and economic analysis for pre-processing grain facilities*]. MS Thesis, Universidade Federal de Viçosa, Viçosa: MG, Brazil.
- Silva, L. C. 1991. Desenvolvimento e avaliação de um secador de café (*Coffea arabica* L.) intermitente de fluxos contra-correntes. [*Design and performance assessment of an intermittent counter-flow dryer for coffee (Coffea arabica L.)*]. MS Thesis, Universidade Federal de Viçosa, Viçosa: MG, Brazil.
- Thompson, T. L. 1975a. FANMATCH: Fan performance computer programs. Presented at the 1975-Grain Storage Computer Workshop, University of Kentucky, Lexington.
- Thompson, T. L. 1975b. NATAIR: Natural air drying program. Presented at the 1975-Grain Storage Computer Workshop, University of Kentucky, Lexington.
- Thompson, T. L., R. M. Peart, and G. H. Foster. 1968. Mathematical simulation of corn drying – A new model. *Trans. ASAE* 11(4): 582-586.

CHAPTER II

A SIMULATION TOOL FOR MODELING GRAIN STORAGE FACILITIES

Abstract. *This work was carried out with the objective of developing a simulation toolset for performing analyses and evaluations of grain storage facilities that consider dynamic behaviors. This toolset, a library called “Grain Facility,” developed using the simulation package Extend™, has a set of blocks that allows simulation of (i) receiving and dispatching activities, (ii) grain processing unit operations, (iii) operational decisions, and (iv) electrical and heat energy uses. To demonstrate the simulation toolset’s application, a grain storage facility that received 73,473.00 t of raw product was modeled. Simulated results show that: (i) after processing unit operations, 12,205.02 t of corn, 47,451.81 t of soybean, and 4,356.88 t of wheat were cleaned and dried, (ii) the maximum amount of product stored occurred in April, when the final monthly balance was 14,409.20 t of soybeans, (iii) the amount of firewood consumed in the drying operation totaled 766.02 t, with 27.0 kg, 13.0 kg, and 16.0 kg of firewood consumed to dry each tonne of corn, soybeans, and wheat respectively, and (iv) that annual electrical energy consumption was 181.98 MWh, 34.78% of which was used in the drying sector.*

Keywords. *grain storage facility, simulation, model, Extend™*

INTRODUCTION

Several authors have indicated the need for grain drying and storage system simulations. Lower et al. (1994) describes several computer models applied to (i) grain drying systems – Thompson et al. (1968), Bridges (1984) and Bridges et al. (1982); (ii) facility layout and design – Loewer et al. (1976) and Lower et al. (1990); and (iii) total system evaluation – Bridges et al. (1979) and Benok et al. (1981). These models are characterized as deterministic and are applied for system static analysis. Moreover, the models for system evaluation were developed using specific layouts.

According to Flores (1988) and Loewer et al. (1994), a grain storage facility can be defined as a system designed, structured, and equipped for the

appropriate receiving, cleaning, drying, storing, and dispatching of grains and legumes. To perform these operations, several types of equipment and structures, such as receiving pits, cleaners, dryers, conveyors, wet holding bins, silos, flat storage containers, and dispatch bins, need to be linked in a logical sequence. It is also required that these systems should be designed, operated, and managed in a way that wanted product characteristics can be preserved and profit can be accomplished.

The operation of a grain storage facility is complex and affected by many factors, some of which demonstrate stochastic behavior that impacts the product-handling process. This type of facility is a high cost, long-term investment. To maximize potential gain from such an investment, structured models that accurately simulate the dynamic behavior of grain storage facilities would be of use. This indicates the need for a simulation toolset to create models that accurately reflect reality, able to consider the influence of stochastic factors and a range of grain facility layouts.

This article was written to present the development of the simulation toolset “*Grain Facility*,” which allows the modeling of existing and proposed grain storage facilities.

BACKGROUND

A simulation model can be classified as: (i) *static* or *dynamic*, (ii) *stochastic* or *deterministic*, and (iii) *discrete* or *continuous*. The static model does not consider the time variable when predicting the state of the system, while the dynamic model does. The stochastic model involves one or more random variables while the deterministic does not. Finally, in the discrete model, time progresses according to event occurrence; in the continuous model, time advances according to a predefined increment, which determines how frequently the model's state variables are recalculated during simulation (Law and Kelton, 1991; Imagine That, Inc., 1997).

The following options can be used to develop a simulation model in digital computers: (i) programming languages such as FORTRAN, Pascal, C, or Visual Basic™, (ii) simulation languages such as Arena™, Extend™, and

SLAM™ or (iii) a simulation package such as @Risk™ that works together with a spreadsheet (Roberts and Dessouky, 1998; Maria, 1997; Palisade Corporation, 2000).

THE EXTEND™ SOFTWARE

Extend™ is a graphically oriented simulation package developed by Imagine That, Inc., which can be used for performing discrete and continuous simulation (Krahl, 2000). Users can apply this package in three different ways: (i) to run pre-assembled models; (ii) to assemble their models using the standard blocks that comes with Extend™, or (iii) to program a new code or modifying the code of existing blocks (Rivera, 1997; Krahl, 2000).

Extend™ models are structured using blocks that are stored in libraries. Each library has a set of blocks that exhibit similar behavior, such as Discrete Event, Generic, Manufacturing, Plotter, and Business Process Reengineering (Rivera, 1997). An Extend™ block can be programmed to model processes, to carry on calculations, to send information, or to plot graphics. It generally is composed of (i) an icon that refers to the block's appearance in the worksheet, (ii) dialog windows that enable users to define behaviors as well as to access output reports, and (iii) connectors that work as interface points and allow blocks to be connected to other blocks (Krahl, 2000).

An Extend™ block can be classified as code or hierarchical. Code blocks are programmed using ModL, Extend™'s internal programming language. A hierarchical block is assembled using previously constructed blocks. This type of block allows models to be subdivided into sub-models that can represent the system elements. In addition, they enable the user to add documents to the models by nesting text, graphics, and pictures (Imagine That, Inc., 1997; Rivera, 1997).

To build Extend™ models, blocks need to be dragged from the libraries and placed on the worksheet. Next, they need to be logically organized and connected. Through the connections, two types of information flows can be established. The first, exclusively applied to the discrete simulation, refers to items that represent objects or entities that move among the system elements.

The second relates to value changes and can be a single number or an array (Rivera, 1997; Krahl, 2000).

Items can have attributes and priorities associated with them. An attribute is a type of variable that describes the item's characteristics. The value of the attribute can be modified during simulation. By assigning priorities the item's importance is specified. This is useful in queue modeling (Krahl, 2000).

Information exchanges among Extend™ blocks can also be established by means of global arrays and global variables. Any block in the model can read the data stored in the global arrays and variables. The user can create global arrays while global variables are predefined by Extend™ (Imagine That, Inc., 1997).

GRAIN FACILITY LIBRARY DEVELOPMENT

The "*Grain Facility*" library was developed using Extend™ software, Version 4.1.3C. This library was developed from the conceptualized model shown schematically in Figure 1. Two types of external stochastic phenomena that affect the grain storage facility system, the grain harvest and the market demand, are assumed to exist and are responsible for the occurrence of the Arrival and Dispatch events. The arrival events refer to the appearance of loaded trucks at the receiving sector. These trucks come from the field, loaded with raw products that must be cleaned and dried. The dispatch events are the arrival of empty trucks at the dispatching sector, which must be loaded with cleaned and dried products. The products in this study are corn, soybeans, and wheat.

The grain storage facility environment, Figure 1, was divided in the following sectors: receiving, wet holding in bins, pre-cleaning, drying, cleaning, storing, and dispatching. These sectors, according to their functions, can have: (i) structures, such as receiving pits, wet holding bins, storage bins, flat storage pads, and dispatch bins, and/or (ii) processing machines, such as pre-cleaners, cleaners, and dryers. The structures and machines are linked by conveying equipment, such as bucket elevators, screw conveyors, belts, and drag conveyors.

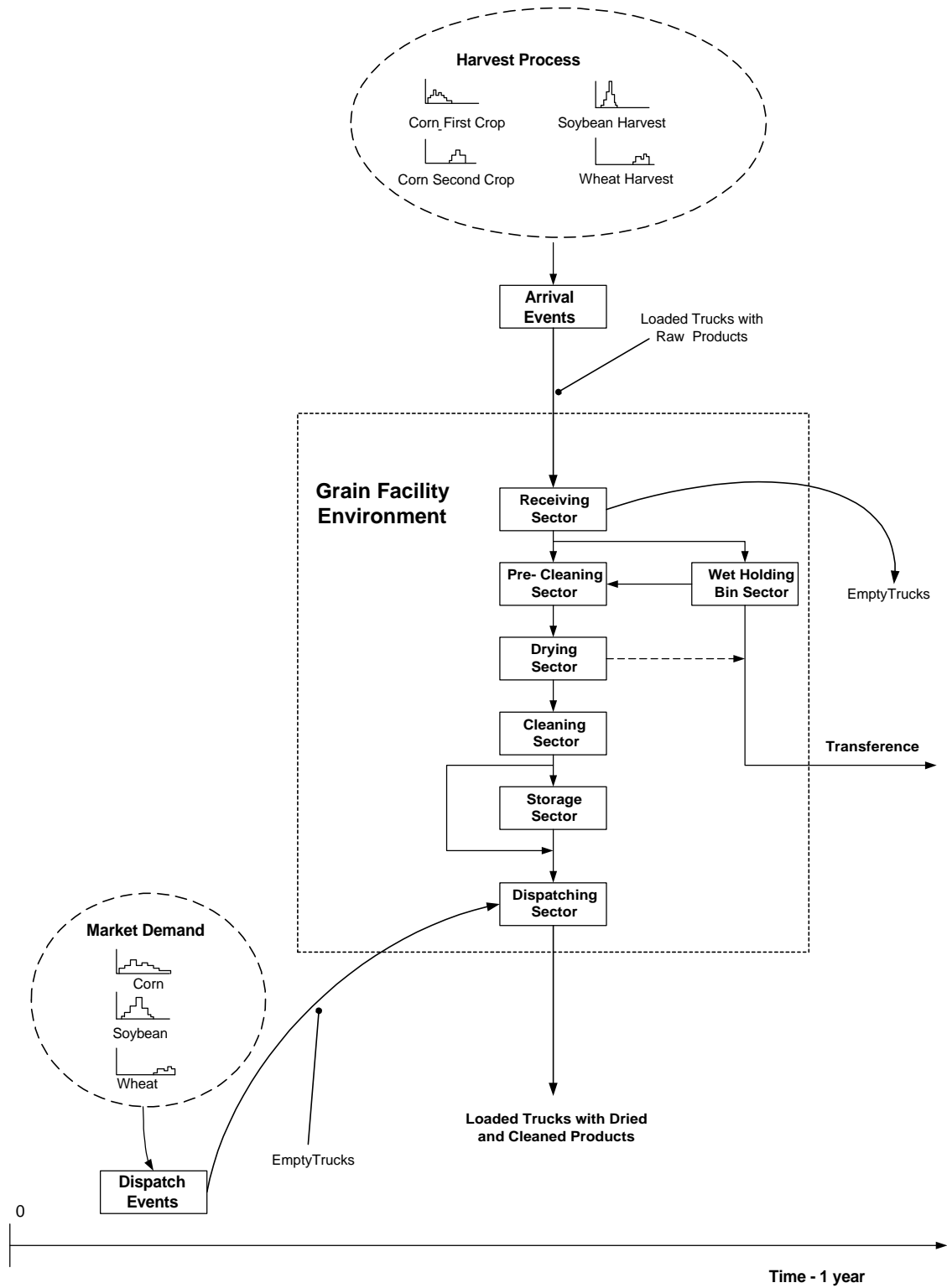


Figure 1 – Representation of the conceptualized model.

The *Grain Facility* library was developed to allow the user: (i) to input information that regulates system operations, (ii) to simulate unit operations that normally occur at a grain storage facility, (iii) to collect and display information during the simulation process, and (iv) to generate reports and graphics. To achieve these goals, a set of blocks was developed. The blocks were classified according to type of operation, as shown in Figure 2.

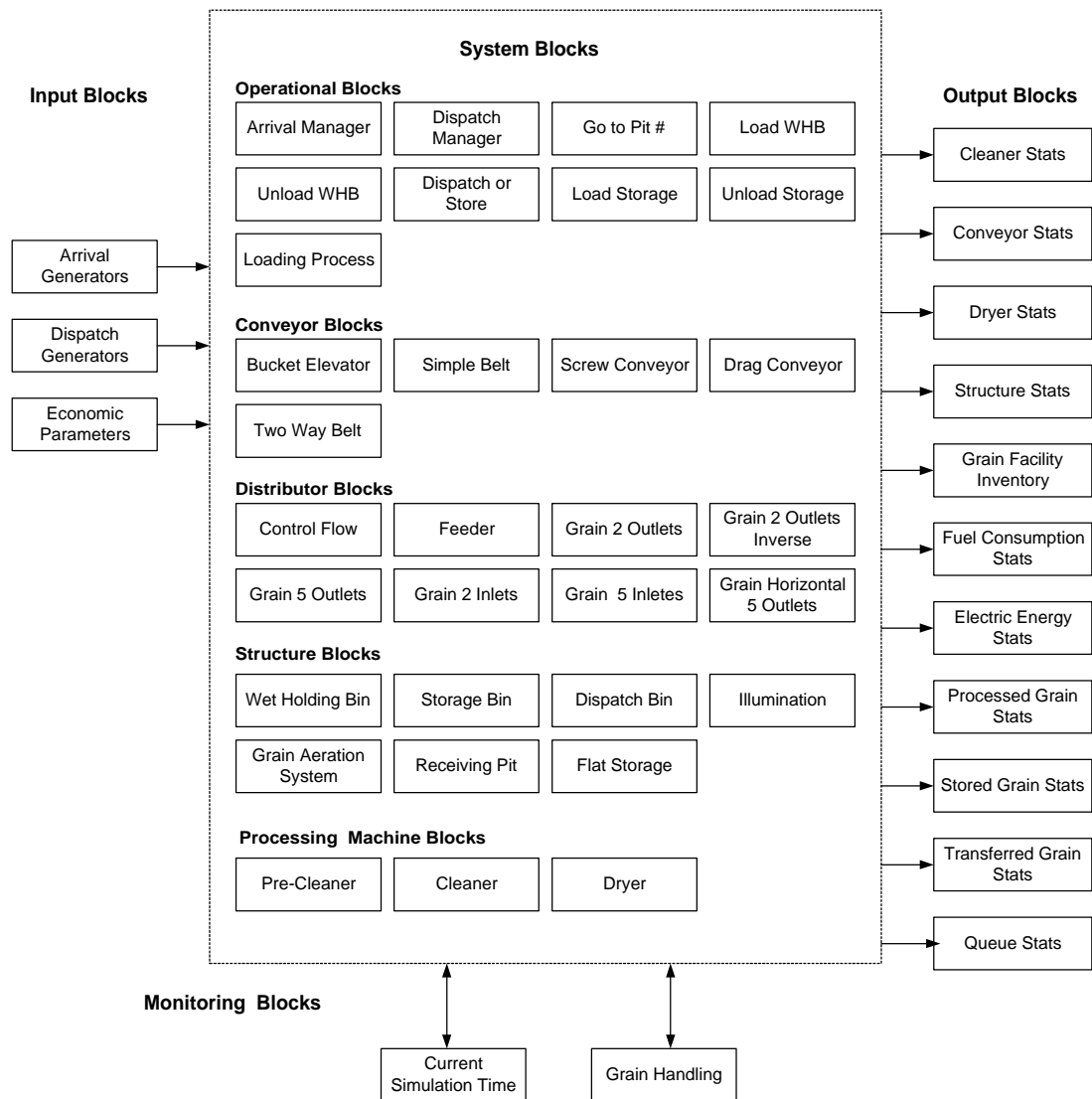


Figure 2 – Grain Facility library organization.

Input Blocks

This category contains the *Arrival Generators*, the *Dispatch Generators*, and the *Economic Parameters* blocks. They define the system operation conditions.

The *Arrival Generators*, a hierarchical block, was developed to generate arrival events. The main dialog window of this block is shown in Figure 3. The events were generated by four sets of blocks. Each set refers to one of the harvesting seasons. In the southern region of Brazil the grain storage facilities generally receive corn grown in two seasons; soybeans and wheat are grown during only one season.

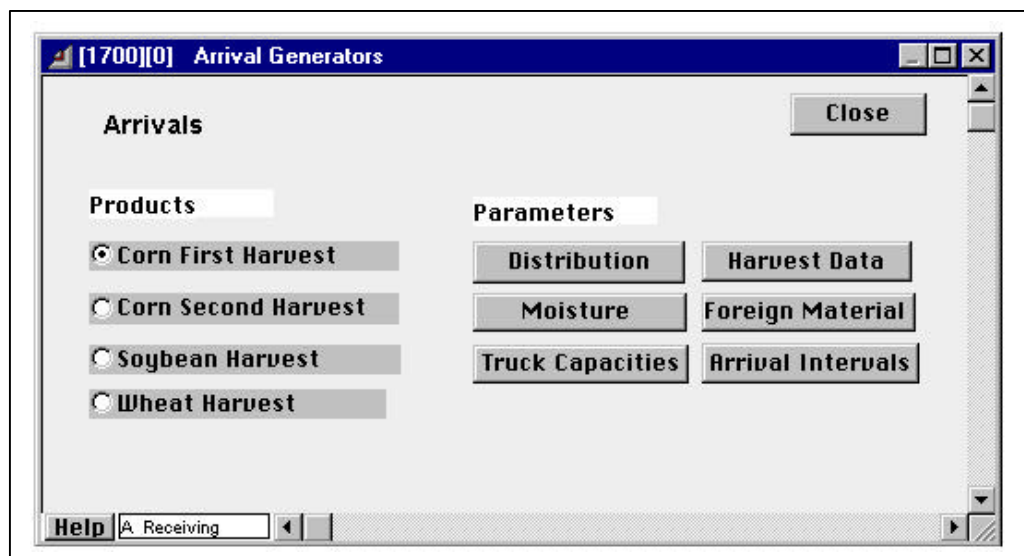


Figure 3 – *Arrival Generators* Block main dialog.

Each set of blocks holds an Extend™ block *Generator*, which was selected to generate items. Each item represents one tonne of raw product. A block called *Arrival Prob* was developed to calculate the number of items to be generated. It was programmed to predict the daily amount of product to be received by the grain storage facility. The prediction was made in accord with user supplied information entered into the model through the dialog window

shown in Figure 3. The information refers to distribution and harvest data parameters.

The distribution parameter relates to a fitted or empirical distribution, which describes the variable “*daily harvest success index – DHSI*”. This variable defines how many percentage points the day’s amount of product received is above or below the average daily value of product received. The average is calculated based on the number of harvest days and the total amount of product to be harvested. This information is introduced in the model through the dialog window shown in Figure 4.

The screenshot shows a software dialog window titled "[467][8] Arrival Prob". It has two tabs: "Main" and "Show Data & Graphic". The "Main" tab is active, displaying the title "Corn - First Harvest Season" and a "Calculate" button. Below the title, it says "User needs to characterize harvest season:". There are two rows of input fields: "Start" with "Month" (1) and "Day" (26), and "Finish" with "Month" (3) and "Day" (6). A checkbox "No Values" is next to the "Day" field. Below this, "User Forecast - to be received, mt:" is set to "7376.00" with a checked "Freeze" checkbox. A note reads "Note: Do not forget to press 'Calculate' after inputting". A section titled "Calculated Model Values:" shows "Number of Days : 41", "Average Daily Quantity - tonnes: 179.90", "Model Forecast - Tonnes to be received: 7376", and "Current Quantity - tonnes/day: 0". At the bottom left is a "Help" button.

Figure 4 – Harvest data dialog window.

Using empirical or fitted distributions, the user also needs to define other parameters, as shown in Figure 3. These parameters are moisture, foreign material, truck capacity, and arrival intervals. Moisture and foreign material

define attributes that are associated to generated items. The truck capacity parameter defines a value that is used by the Extend™ block *Batch (Variable)*. This block allows a defined number of items to be united into a single item, according to a requested number. In this study, the single item obtained represents a loaded truck. The requested number of items to be united refers to the weight of the load, which is also transformed into one more attribute, “load,” for a generated item. The parameter arrival interval refers to the time between loaded truck arrivals at a grain storage facility. These empirical or fitted distributions are introduced in the model through the Extend™ block *Input Random Number*.

From each set of blocks responsible for generating arrival events, a group of items representing the traffic of loaded trucks is generated. Each item has five attributes: (i) “*type*” – concerns the type of product: 1 – corn from the first harvest, 2 – soybean, 3 – wheat, and 4 – corn from the second harvest, (ii) “*moisture*” – refers to grain moisture content at arrival, (iii) “*umiCalc*” – also concerns grain load moisture content and is used in the simulated drying process, (iv) “*dust*” – alludes to the load’s foreign material content, and (v) “*load*” – alludes to load weight.

The *Dispatch Generators*, a hierarchical block, generates events related to the arrival of empty trucks at the dispatch sector. The main dialog window of this block is shown in Figure 5. Events are generated by three sets of blocks, since it was assumed that three types of products could be dispatched: corn, soybeans, and wheat. Each set of blocks has the genuine Extend™ block *Generator*. The block *Dispatch Prob* was developed to calculate the number of items to be generated. At the beginning of the simulation, it is used to calculate the conditional probabilities (Kazmier, 1995) according to the parameters of the dispatch plan (Figure 5). This plan refers to the monthly percentage of stock that needs to be delivered, which entered into the model using the dialog window shown in Figure 6. Using conditional probabilities and the model’s predicted value for the amount of product to be received, the monthly amount of product that needs to be dispatched is calculated. The information predicted by the model predicted is passed to the *Dispatch Prob* from the *Arrival Prob*, by means of global variable *Global18*.

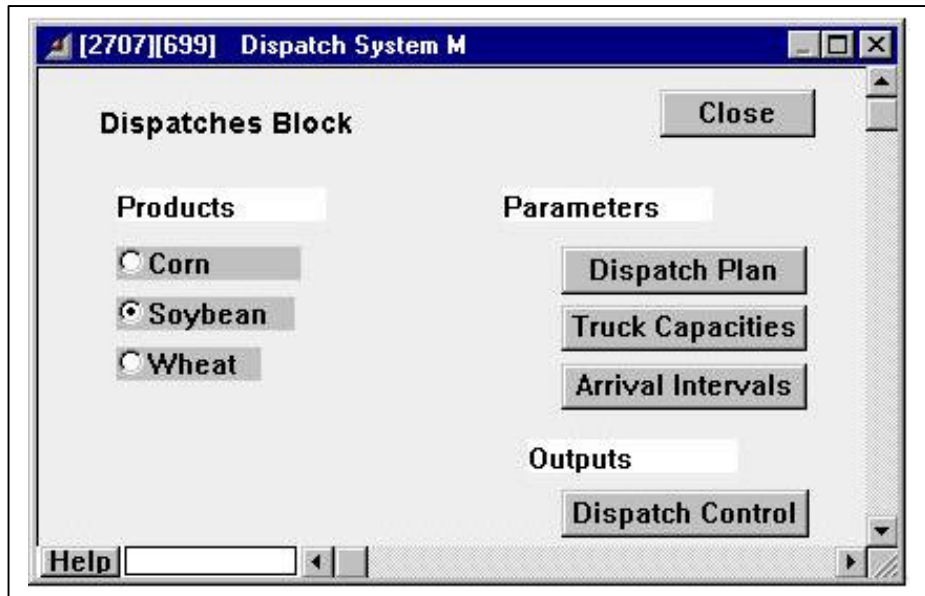


Figure 5 – Dispatch event main dialog window.

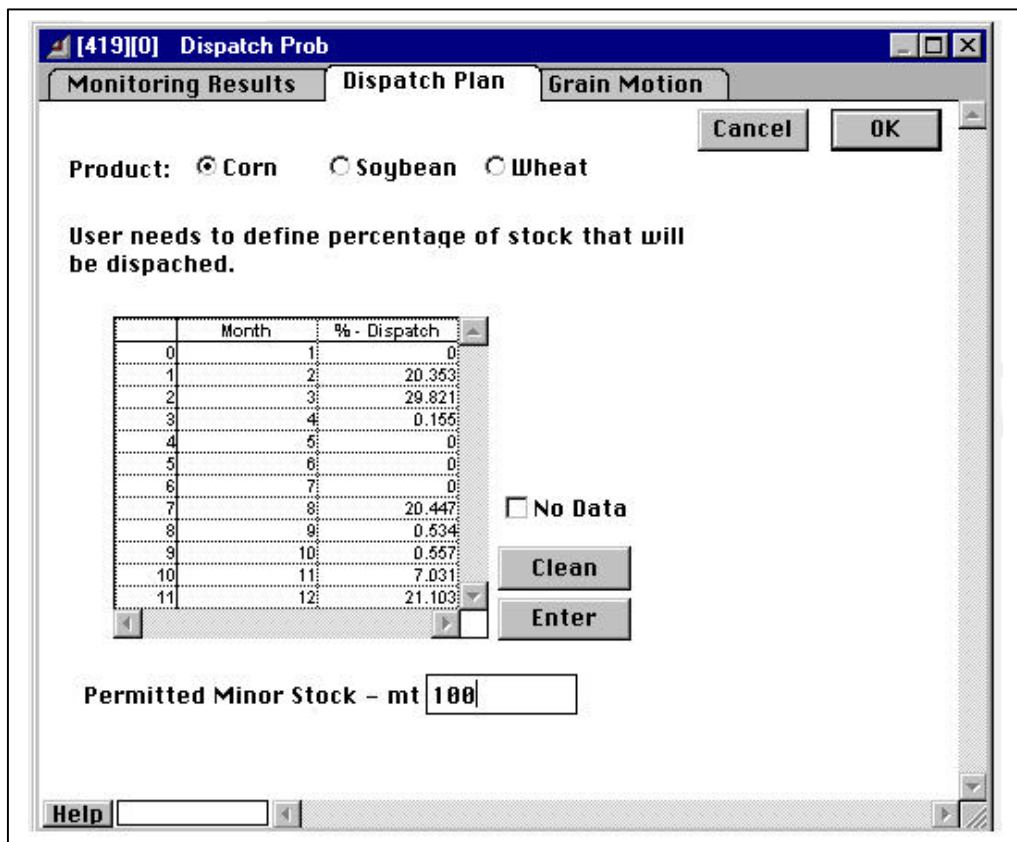


Figure 6 – Dispatch plan dialog window.

During the simulation, the *Dispatch Prob* block is also in charge of calculating the daily amount of product to be dispatched as determined by the monthly amount to be shipped. If current product stock can supply the calculated dispatch demand, this demand value is then passed to the *Generator* block. If supply falls short of demand, the dispatch value is adjusted to the current stock level.

Other parameters to be defined by the user in the *Dispatch Generators* block (Figure 5) are the fitted or empirical distributions related to truck capacity and arrival intervals. The truck capacity parameter defines a value that is used by the ExtendTM block *Batch (Variable)* for batching a number of items into a single item. This item represents an empty truck, and the number of clustered items is stored in the attribute called “*DemandedQty*.” Thus, each item generated by the *Dispatch Generators* block has two attributes: “*DemandedType*” and “*DemandedQty*,” which respectively refer to the type and amount of the required product.

The *Economic Parameters* block allows the user to specify data that are used in the model for calculating output variables. In this block, the user can access five dialog windows to input the following information: (i) monthly electrical energy prices and daily on-peak and off-peak periods, (ii) firewood or propane prices, (iii) fixed manpower team composition, (iv) monthly temporary manpower contracted, and (v) management tax, such as installation costs, machine insurance, and central administration tax. “*Global9*,” an ExtendTM global variable, passes this information to other blocks.

System Blocks

This category is made up of the blocks used to simulate elements and decision-making processes occurring within the grain storage facility environment (Figure 2). They are grouped in five subcategories: (i) operational blocks, (ii) conveyors, (iii) distributors, (iv) structure, and (v) processing machines.

Operational Blocks

This category has blocks that were developed to simulate management decision-making in grain storage facilities and to specify the constraints that establish the system logic. Figure 7 shows the adopted operational flowchart employed for modeling operational activities. Ten types of decisions were considered.

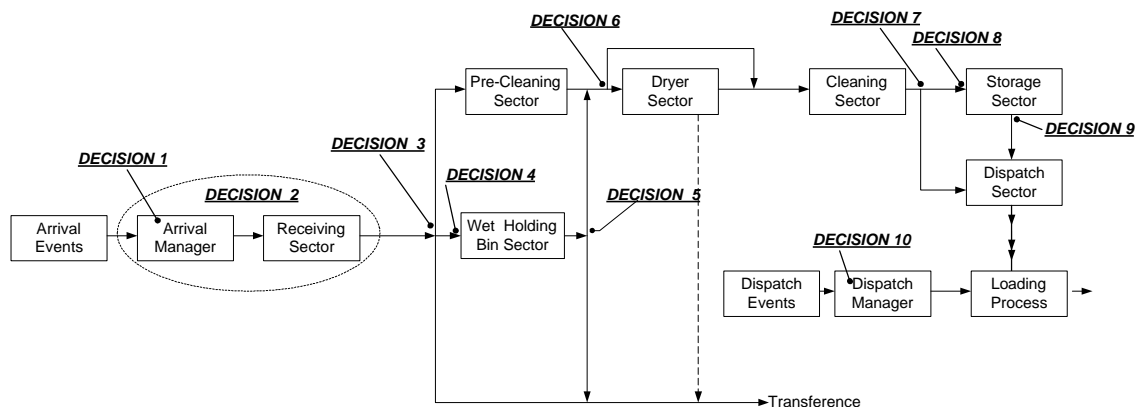


Figure 7 – Schematic operational flowchart decisions

- Decision 1 – the trucks are separated in queues according to product type. This decision was modeled using the hierarchical block called *Arrival Manager*.
- Decision 2 – defines to which receiving pit the loaded truck should go. The *Go to Pit#* block inside the *Arrival Manager* block defines this decision.
- Decision 3 – defines to which sector of the system the product from the receiving pit should go. The options are to the pre-cleaning sector, the wet holding bin sectors, or to be transferred to another grain storage facility. Transference to another grain storage facility occurs when the raw product is held at the receiving pit more than a specified period of time as defined by the user. The product is sent to pre-cleaning when the dryer can receive it. If

pre-cleaning cannot receive the product, it is transferred to the wet holding bin sector. Decision 3 is modeled by the block *Unload Pit*.

- Decision 4 – defines in which holding bin the product should be stored. This decision is based on the type of conveyed product and type of product stored in the wet holding bins. The *Load WHB* block simulates this decision.
- Decision 5 – defines to which sector the product leaving the wet holding bin should go. The options are to go to pre-cleaning/drying sectors or to be transferred to another grain storage facility. Transference to another grain storage facility occurs when the raw product is held at the wet holding bin sector more than a specified period of time. The *Unload WHB* block simulates this decision.
- Decision 6 – defines if the product needs to be passed through the dryer sector. If the product has moisture content below 14.9% w.b., it is conveyed to the cleaning sector.
- Decision 7 – defines the direction of grain flow leaving the cleaning sector. The product can go to the storage sector or to the dispatch sector. If the type of product leaving the cleaning sector is required by the dispatch sector, the product goes to this sector. This decision is made by *Dispatch or Store* block.
- Decision 8 – defines to which bin or flat storage cell the product should go. This decision is based on the type of the conveyed product and the product that is in storage. The *Load Storage* block simulates this decision.
- Decision 9 – defines from which bin or flat storage cell the product should be unloaded. This decision is based on the product required by the dispatch sector and the amount of product stored in each bin or flat storage cell. The one that has the least product is unloaded first. The block used to model this decision is the *Unload Storage* block.
- Decision 10 – defines to which queue the empty truck should go. This decision is determined by the type of product to be loaded in the truck. If

there is no product available, the truck returns empty. Otherwise, the truck loading operation is performed. The block used to model decision 10 is *Dispatch Manager*.

The *Loading Process* block simulates the truck loading operation. It receives items that come from two sources: *Dispatch Generators* and processing or storage sectors blocks. Items from *Dispatch Generator* block represent empty trucks and have two attributes: “*DemandedType*” and “*DemandedQty*”. Each item held in processing or storage sectors blocks represents one tonne of product. The Extend™ block called *Batch* was used in the *Loading Process* block to allow items from the processing and storage sectors to be grouped with items from *Dispatch Generator*. Thus, a single item is formed, which represents a loaded truck.

All needed information to support the simulation of decision-making by grain storage facility management is passed among blocks by means of value connectors, global arrays, or global variables. In the modeling, fourteen Extend™ global variables were employed and one global array called “*GrainMonitor*” was created.

Distributors

Seven blocks are included in this category: *Control Flow*, *Feeder*, *Grain 2 Outlets*, *Grain 2 Outlets – Inverse*, *Grain 2 Inlets*, *Grain 5 Inlets*, and *Grain Horizontal 5 Outlets*. *Control Flow* is the only hierarchical block and was developed to govern the amount of items that need to be conveyed to the *Dispatch Bin* block. This amount is defined according to the value of the attribute “*DemandedQty*.” The six other blocks in this category were developed using Extend™ *routing* blocks from the Discreet Event and Manufacturing libraries and have had their icon appearances modified, as shown in Figure 8, to ease their identification in the grain storage facility models.

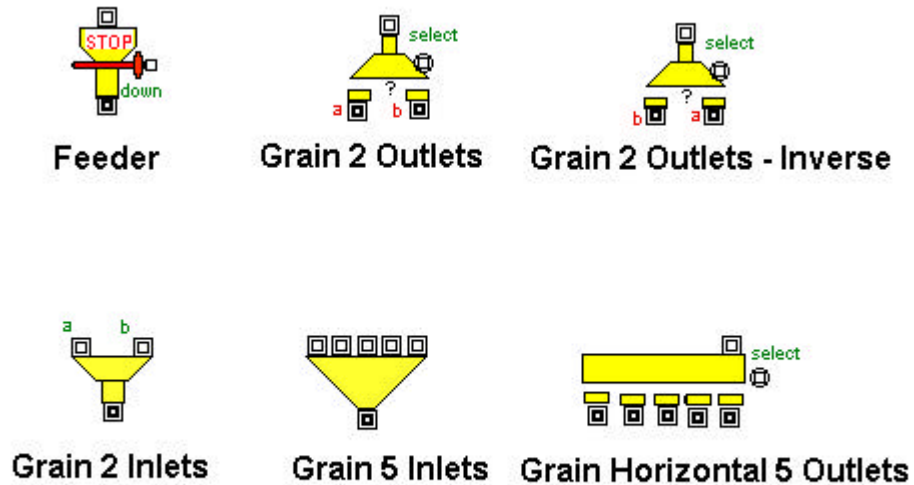


Figure 8 – Distributor blocks.

Conveyors

In this category, the following blocks were created: *Bucket Elevator*, *Simple Belt*, *Screw Conveyor*, *Drag Conveyor*, and *Two Way Belt*. The first three are code blocks that only differ in icon appearance. They were developed using the Extend™ block called *Machine* contained in the Manufacturing Library. The following modifications were applied: (i) the block icon appearance was changed to better represent bucket elevators, screw conveyors, and belt conveyors, (ii) the variable *processing time* was defined to be calculated according to the hourly capacity of conveyors (t/h), (iii) the variable *processing time* was defined to be updated during the simulation according to the attribute “*realvalue*”. This attribute was defined to express the update mass of each tonne of product that arrived in the grain storage facility and (iv) computational routines were introduced to calculate electrical energy use.

Electrical energy use is calculated according to the electrical power requirement of the equipment and utilization time. The results obtained refer to consumption and demand, expressed in kilowatt-hours (kWh) and kilowatts (kW) respectively. These results are calculated for on-peak and off-peak hours. The user provides this information for simulation through the *Economic Parameters* block.

Drag Conveyor and *Two Way Belt* are hierarchical blocks, which have the *Simple Belt* as the main block. *Drag Conveyor* uses two blocks: *Simple Belt* and *Grain Horizontal 5 Outlets*. The *Drag Conveyor* block simulates the conveyor operation, and the second, the flow distribution in accordance with the number of linked exits. The *Two Way Belt* block has two *Simple Belt* blocks, one of which simulates the forward direction of the product conveyed; the other simulates the backward direction.

Structure Blocks

This category is made up of the following blocks: *Wet Holding Bin*, *Storage Bin*, *Dispatch Bin*, *Illumination*, *Grain Aeration System*, *Receiving Pit*, and *Flat Storage*. The first three simulate specific types of bins and have the same codes, only differing in icon appearance. They were developed using the Extend™ block called *Buffers*, contained in the Manufacturing Library. The following modifications were implemented: (i) the icon block appearance was changed for a better representation of the wet holding bin, the storage bin, and the dispatch bin. Three routines were developed; the first routine calculates the amount of product stored according to the values of the attributes “*type*” and “*realValue*”. The second routine reports information about the type and amount of product, and global variable “*GrainMonitor*” passes this information to other blocks. The third routine calculates the bin unloading system’s electrical energy consumption.

Figures 8 and 9 show the major structure blocks dialog windows. The dialog window in Figure 8 is used for characterizing the facility’s structure, while the dialog window shown in Figure 9 is used to access the simulation results. When working with the *Wet Holding Bin*, *Storage Bin*, and *Dispatch Bin* blocks, the user must provide the unloaded system’s electrical power rating and the amount of product already stored in the bins when the unloading equipment starts to work.

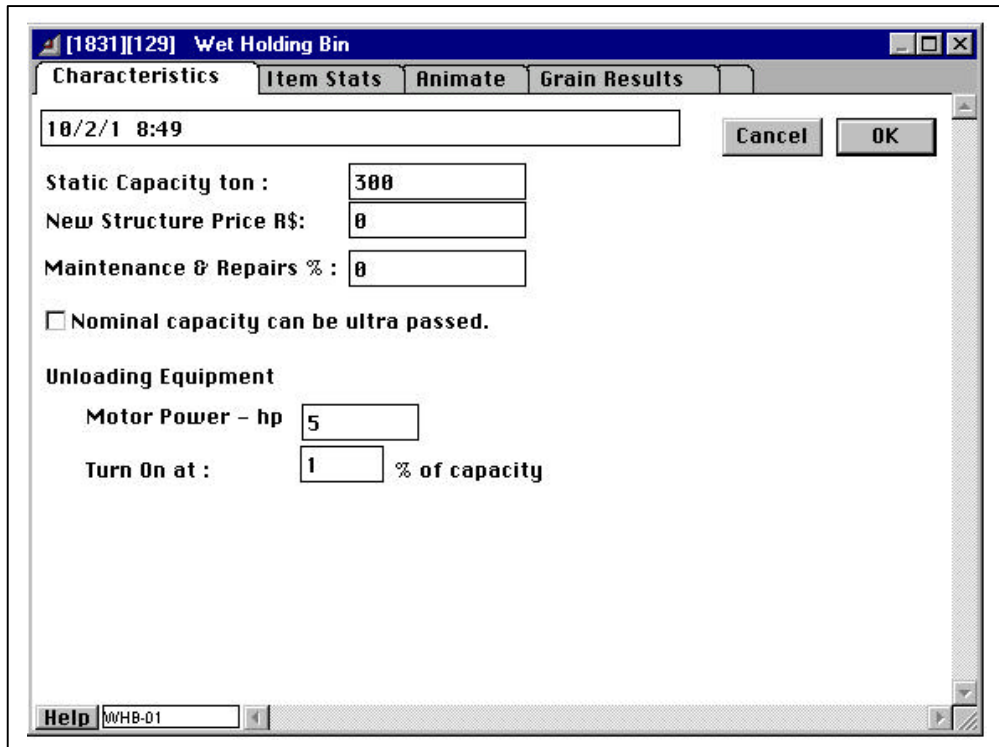


Figure 8 – Main dialog window of structure blocks.

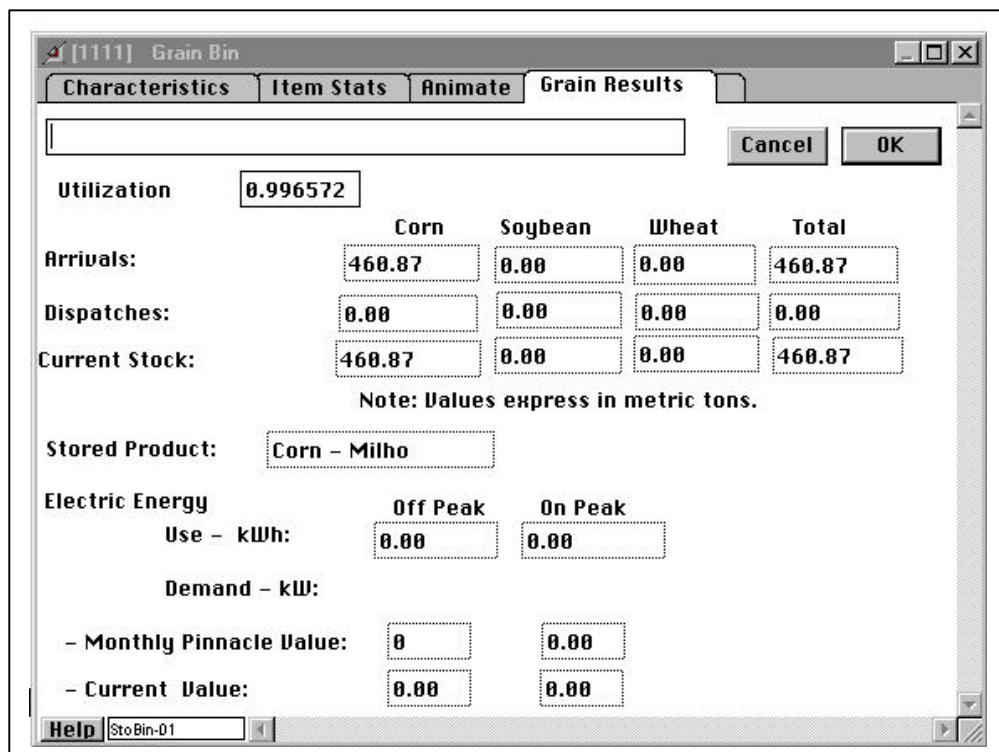


Figure 9 – Results dialog window of the structure blocks.

The *Illumination* and *Grain Aeration System* blocks were developed to simulate the electrical energy use of the offices and for external illumination and for the storage aeration system's the fan operations. For both blocks, the user needs to define the electrical power rating of the equipment and the equipment's run cycle times. Thus, electrical energy use is calculated during the simulation.

The hierarchical block *Receiving Pit* was developed to simulate two processes: the truck unloading operation and the storage of raw products. In the modeling, the *Simple Belt* block was employed for simulating the first process, and the *Storage Bin* block for the second. The user needs to specify a fitted or empirical distribution that describes the time spent unloading and the storage capacity of the receiving pit. Also, if the receiving pit is equipped with a mechanical truck unloading system, the user needs to input the electrical power used by the motor that makes this system work. The developed block *Motor* simulates this electric energy consumption.

The *OperationPit* block nested in the *Receiving Pit* block generates a protocol that describes the simulated operational condition of a receiving pit. The protocol has six digits "TUVWXY" that refer to: (i) "T" – the number associated with the receiving pit for identification purposes, for example 1, 2, 3, or 4; (ii) "U" – type of product in the receiving pit: 1: corn, 2: soybean, and 3: wheat; (iii) "V" – moisture content of the product: 0 if it is up to 18% w.b. and 1, if it is above 18% w.b.; (iv) "W" – 1 if the pit bay is busy, 0 if not; (v) "X" – 1 if pit is full, 0 if not; and (vi) "Y" – 1 if the item is held in the last *Buffer* block of the *Receiving Pit*, 0 if otherwise 0. The *Buffer* is an Extend™ block. Thus, each of the model's *Receiving Pit* blocks generates a protocol. The analyses of these protocols support decisions 2, 3, and 4 (Figure 7).

As it was previously mentioned in the *Arrival Generators* block description, the generated items are grouped into a single item, which represents a loaded truck. The requested number of items to be grouped is stored in the attribute "load." This grouped item is separated in the *Receiving Pit* block.

The *Receiving Pit* block uses the Extend™ block called *Unbatch (Variable)*. The *Unbatch (Variable)* block allows a single item to be turned into a number of identical items. This way, the *Unbatch (Variable)* is used to separate

the items that were grouped in the *Arrival Generators* blocks. The number of items resulting from this separation is defined according to the value of the attribute “*load*.” After the unbatching process, each item represents one tonne of product and receives three more attributes: (i) “*realvalue*” – used for updating the mass of one item according to simulation of unit operations. The first value of this attribute is 1, as it refers to one tonne of raw product, (ii) “*intermittent*” – used in the *Dryer* block for defining the need for the product to re-circulate through the dryer, (iii) “*empty*” – used in the *Dryer* block for defining in which situation this block can be emptied.

In Brazil, flat storage structures are divided in cells that allow storing products of different types. To consider each internal cell working as a single storage unit, the hierarchical block *Flat Storage* was developed. Since flat storage structures generally contain a maximum of three cells, *Flat Storage* was modeled using three *Storage Bin* blocks.

Processing Machines

This category includes the *Pre-Cleaner*, *Cleaner*, and *Dryer* blocks. The first two blocks have the same code and differ only in icon appearance. They were developed using the *Machine* block from the Extend™ Manufacturing Library. The modifications applied were the same as those adopted for modeling conveyors with the addition of one more routine for simulating the cleaning operation. This routine: (i) adjusts the value of the attribute “*realValue*” according to initial and final foreign material content, (ii) updates the value of the attribute “*dust*,” and (iii) calculates the amount of the foreign material removed.

The initial foreign material content refers to the value of the attribute “*dust*” when the item arrives at the *Pre-Cleaner* or *Cleaner* blocks. The user needs to define machine efficiency according to: (i) moisture content of product, and (ii) the possible reduction of foreign material content. The first definition affects the hourly capacity of the equipment while the second defines the amount of foreign material to be removed. In the modeling process, data presented by Weber (2001) was used.

The *Dryer* block, classified as hierarchical, was designed to simulate the drying process in mixed flow dryers (Brooker et al., 1992) by employing the

discrete simulation modeling concept. Thus, a dryer was conceptualized as a workstation that applies drying treatment to a defined number of items, which is determined by the dryer's static capacity.

Figure 10 shows a schematic representation of the *Dryer* block. The rectangular and diamond boxes refer to procedures and decisions respectively. Procedures and decisions were modeled using specific sets of blocks.

The Initial Stats procedure, Figure 10, was modeled to compute the input flow of wet product. When the item attribute "*intermittent*" has the value -1 , the item has been inputted only once at the *Dryer* block. This way, a block called *Flow* is in charge of computing this input, according to the item attributes "*type*" and "*realValue*." The attribute "*intermittent*" can also have its value of -1 changed to 1. This happens if the cooling section of the dryer tower is full. The *Dryer Tower* block, described below, reports this information.

The Tower procedure (Figure 10) relates to the physical structure of the dryer that holds the product during the drying process. The *Dryer Tower* block is in charge of simulating this structure. This block simulates a first-in-first-out queue and was developed from the ExtendTM block *Buffer*. The allowed maximum length of the queue represents the dryer's static capacity (t).

In the dialog window of the *Dryer* block, the user needs either to input the dryer's static capacity or accept the model suggestion. This suggestion is indicated according to values cited by Weber (2001). One third of a dryer's static capacity corresponds to the cooling section's static capacity. Also, the user has to input the minimum amount of product needed to begin the dryer's operation. This information defines the minimum number of items that need to be in the *Dryer Tower* block to simulate the dryer's operation. The model also offers a suggestion of this value.

During simulation, *Dryer Tower* block reports the number of held items as well as the averages of their attributes "*umiCalc*" and "*moisture*." Attributes "*umiCalc*" and "*moisture*" refer to the current and the initial product moisture content respectively.

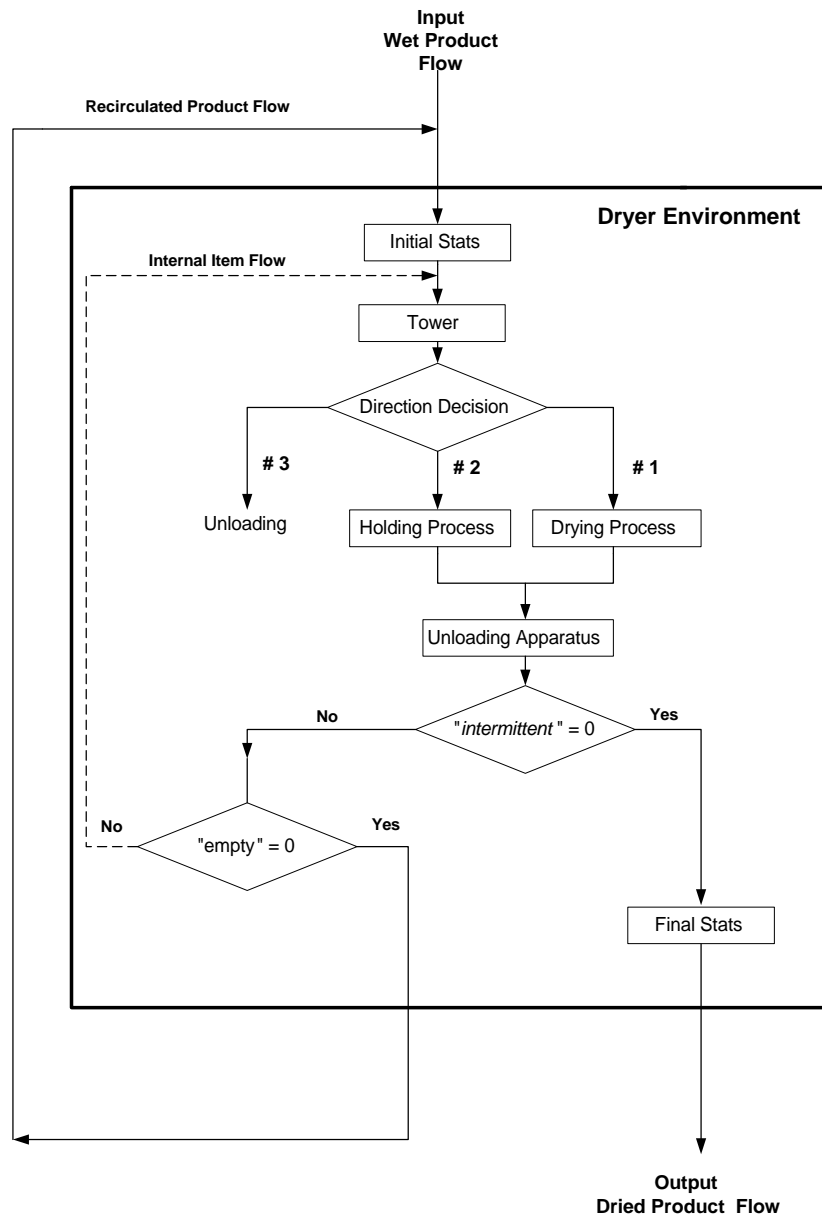


Figure 10 – The diagram representation of *Dryer* block.

From the Direction Decision (Figure 10), items can be sent in directions #1, #2 or # 3. Direction #1 is defined if *Dryer Tower* block reports: (i) an “*umiCalc*” average that is above the desired final moisture content, and (ii) the number of held items is above the minimum number of needed items for simulating the dryer’s operation. In this case, the procedure Drying Process is executed. This procedure simulates: (i) the dryer fans’ electrical energy consumption, (ii) the decrease in the product’s moisture content, (iii) fuel consumption, and (iv) the need for the product (item) to be re-circulated.

- The electrical power rating of the dryer's fans is determined using the "Simple Belt" block, which calculates consumption according to that rating and the fan's time in use. According to the behavior of the "Simple Belt" block, the user needs to input the dryer capacity (t/h) and electrical power rating (kW) of the fans.
- The simulation of the decrease in product moisture content involves a set of blocks that deal with two item attributes: "umiCalc", and "intermittent". The attribute "umiCalc" has a value equal to the initial moisture content when the item enters the *Dryer* block for the first time. After that, each time that an item is submitted to the Drying Process procedures (Figure 10), the value of its attribute "umiCalc" can be decreased. The decreased value is defined according to an empirical distribution shown in Figure 11. This distribution correlates the value of initial moisture content with percentage points the moisture content is reduced. During simulation, the *Dryer Tower* block reports the average of the held item's "moisture" attributes. This value defines the reduction that needs to be applied to the attribute "umiCalc". The value of "umiCalc" is only reduced if "intermittent" is equal to 1. The empirical distribution shown in Figure 11 was defined according to: (i) the mixed flow dryer efficiency presented in Figure 12 (Weber, 2001), (ii) the initial moisture content of product, and (iii) the dryer's hourly capacity (t/h). With this information, it is possible to calculate the number of times that the product load needs to be re-circulated within the dryer to achieve the desired final moisture content.
- Fuel consumption is calculated considering: (i) the number of items that pass through Direction #1 (Figure 10) and had their attribute "umiCalc" decreased, (ii) the dryer capacity (t/h), and (iii) the hourly fuel consumption of the heating system. The user needs to define this hourly fuel consumption or adopt the model's suggestion. This suggestion is formulated considering dryer capacity (t/h) and the dryer specific heat energy consumption, expressed in kJ per kg of evaporated water. This last information is suggested by the *Dryer* block in accord with filed data, manufactures' catalogues, and data from by Weber (2001).

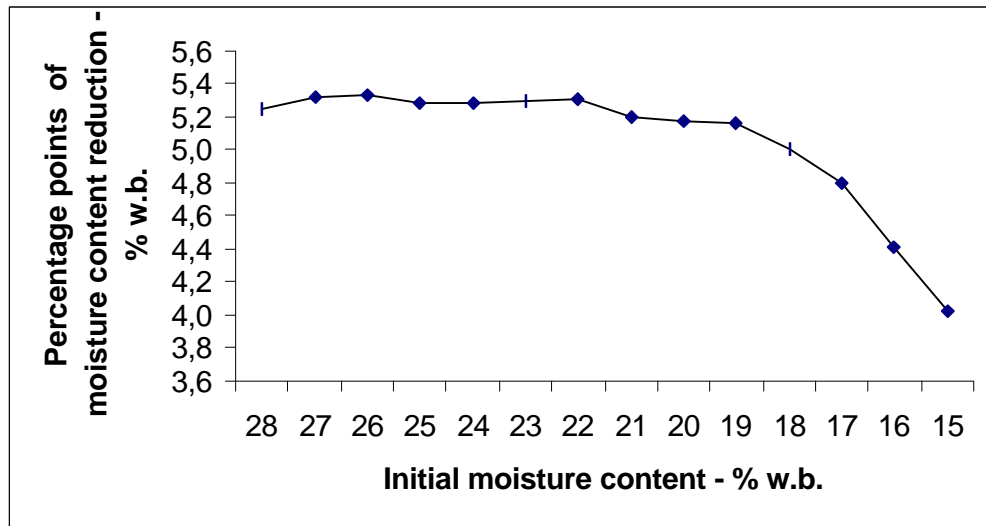


Figure 11 – Empirical distribution for moisture content drop in function of initial moisture content.

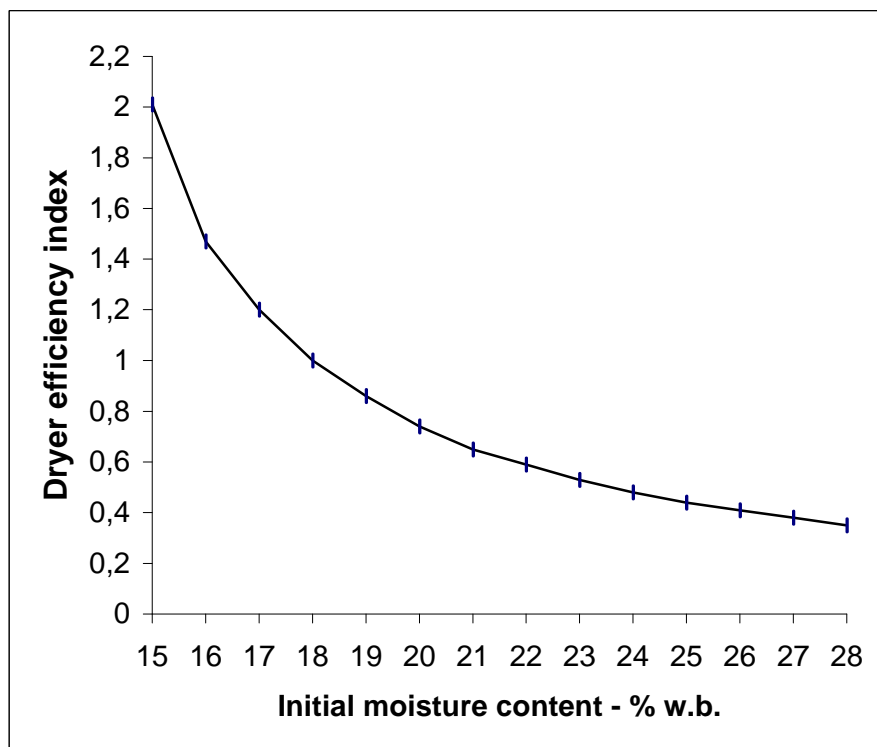


Figure 12 – Mixed flow dryer efficiency index as a function of initial moisture content considering a final moisture content of 13.0% w. b. (Weber 2001).

- The need for product (item) to be re-circulated through the *Dryer* block is defined according to the values of “*intermittent*” and “*empty*.” In the Drying Process procedure (Figure 10), the attribute “*intermittent*” receives the value 1 if item needs to be re-circulated through *Dryer* block. This happens if the *Dryer Tower* block reports that the held item’s average “*umiCalc*” attribute is: (i) higher than 18.3, or (ii) lower than 14.2, assuming that there is the minimum amount of product (item) needed for dryer operation to occur. The attribute “*empty*” was adopted to guarantee the complete drying simulation of the last product load in the dryer. “*Empty*” receives the value 1 if the *Dryer Tower* block reports that the held item’s average “*umiCalc*” attribute is below 14.66; otherwise it receives the value 0.

Direction # 2 (Figure 10) is defined if the *Dryer Tower* block reports the of held item’s average “*umiCalc*” attributes is lower than or equal to the desired final moisture content, and the amount of held item is equal or lower than the number of items needed for the simulation of dryer operation. If the user had defined that dried product can be held for a given time waiting for a new load of wet product, the Holding Procedure will shutdown the flow of items. The flow will be reestablished if the waiting period is exceeded or a new product load (items) arrives at the *Dryer* block.

Direction #3 (Figure 10) is proposed when the average “*umiCalc*” attribute for the item held in the *Dryer Tower* signals that the it has a higher than desired final moisture content, but the number of held items does not allow simulating the dryer operation. When this situation occurs, the *Dryer* block should be emptied.

Items that go to directions #1 and #2 necessarily are submitted to the *Unloading Apparatus* procedure. This procedure is in charge of simulating the electrical energy use of the dryer unloading system. The “*Simple Belt*” block was employed for simulating this energy consumption. The user needs to input the dryer’s handling capacity (t/h) and electrical power rating of the dryer unloading system.

After *Unloading Apparatus* procedure, items are submitted a decision test involving the value of the attribute “*intermittent*” (Figure 10). If the attribute value is 0, the item goes to the *Final Stats* procedure; otherwise, the item is submitted to a new decision involving the attribute “*empty*.” If the value of “*empty*” is 0, the item goes through the *Dryer* block again. In this case, the item is externally conveyed to the *Dryer* block’s input area using one of the conveyor blocks. If the value of “*empty*” is 1, the item is internally conveyed to the *Dryer Tower*. This was a modeling artifice used to guarantee the drying simulation of the last load of wet product. As it was earlier explained, the *Dryer* block needs a defined minimum number of held items in the *Dryer Tower* block to simulate the drying process.

The goals of the *Final Stats* procedure (Figure 10) are to: (i) to calculate the amount of water removed during the drying process for each item. This calculated value is then stored in the attribute “*waterRemoved*”; (ii) to update the value of the attribute “*realValue*” for each item according to the amount of water removed; and (iii) to register the total quantities of dried product and water removed as a result of the simulated drying.

The *Dryer* block generates a protocol that is used by decisions 3 and 4 (Figure 7). The generated protocol has seven digits, “*KLMNOPQ*.” These digits refer to: (i) “*K*” – the number associated to the dryer identification, for example 1, 2, 3, or 4; (ii) “*L*” – type of product in the dryer: 1: corn, 2: soybean and 3: wheat; (iii) “*M*” – if the dryer is full 1, otherwise 0; (iv) “*NOP*” – static dryer capacity; and (v) “*Q*” – if the dried product is held waiting for a new load of wet product 1, otherwise 0.

Monitoring Blocks

The blocks included in this category were developed for calculating, collecting, and passing the information needed during simulation. The *Current Simulation Time* block, for example, was developed for calculating the time variables year, month, day, hour, minute and weekday, and passing these values to the others blocks in the model. The values of these variables are defined according to the value of the ExtendTM system variable “*CurrentTime*.”

The *Grain Handling* block was developed to collect information about the *Dryer* block and all blocks categorized as structure blocks. These types of blocks access the created global array called “*GrainMonitor*” to report information related to: (i) system element behavior, such as type and static capacity, and (ii) held items, such as the number and type of held items and the sum of these held items “*realValue*” attributes, which refers to the amount of the product being held. The information stored in the components of “*GrainMonitor*” is processed in the *Grain Handling* block and passed to the Operational Decision Blocks. This information is passed through the Extend™ global variables.

Output Blocks

The blocks of this category (Figure 2) were developed using “*Activity Stats*”, an Extend™ block of the Stats library, and are intended to: (i) get information from specific blocks according to a frequency defined by the user, (ii) process this information, and (iii) elaborate reports in table or graphic format.

The *Electric Energy Stats* output block, which simulates electrical energy metering equipment, is in charge of collecting the output data from blocks that simulate electrical energy use. These data refer to the consumption (kWh) and demand (kW), according to on and off-peak hours. In this way, it is possible to obtain information for calculating monthly electricity bills from the *Electric Energy Stats* block's records.

APPLICATION OF THE GRAIN FACILITY LIBRARY

The grain storage facility library was used to model a grain storage facility belonging to COAMO, an agricultural cooperative of grain producers headquartered in Campo Mourão, Paraná, Brazil. Details about the equipment and structures used at this grain facility are presented in Table 1.

Table 1 – Some technical information of the modeled grain storage facility

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
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

The following information was collected to build the model: (i) data about structures, processing machines, and conveyors, such as type, static capacity (t), handling capacity (t/h), and electrical power rating (kW); (ii) the grain storage facility operational flowchart, (iii) data from the 1999 harvest season (Table 2); and (iv) data regarding the facility's dispatch plan (Table 3).

MODEL OUTPUTS AND DISCUSSION

Since the developed model is stochastic, each run refers to different sets of inputs and outputs. To illustrate types of model information output, results from one replication in which the simulation time was 8640 hours (12 months) are presented. Figure 13 graphically shows the monthly amount of products received, processed, stored, and dispatched; and Table 4 presents the summarized model output. The amount received information was collected at the *Arrival Manager* block, and represents the amount of product that was unloaded at the receiving sector. These data were generated according to the information shown in Table 2. The model simulated a combined input of 73,473.00 t of corn, soybeans, and wheat. However 4,516.33 t were transferred to other grain storage facilities. April was the month with maximum number of trucks arrivals 1,539 trucks, corresponding to 22,904.00 t of product unloaded.

Table 3 – Dispatch plans for corn, soybean and wheat

Month	Stock portions to be dispatched (%)		
	Corn	Soybean	Wheat
1	0	0	0
2	20.35	0	0
3	29.82	47.18	0
4	0.15	14.52	0
5	0	20.58	0
6	0	0.67	0
7	0	6.52	0
8	20.45	7.81	0
9	0.55	0.54	69.96
10	0.55	0	0
11	7.03	1.32	0
12	21.10	0.86	30.04

The processed quantities of product are the values in tonnes obtained after product pre-cleaning, drying, and cleaning operations. It was verified that 3,703.43 t of water, and 1,239.56 t of foreign materials were removed. Thus 12,205.02, 47,451.81, and 4,356.88 tonnes of dried and cleaned corn, soybean and wheat were obtained respectively (Table 4).

Stored quantities refer to the amount held in the storage sector at the end of the month. According to the simulated scenario, it can be verified that 52,868.81 tonnes were stored over the year, distributed in the following manner: Cell-01 18,107.17 t; Cell-02 9,167.31 t, and Cell-03 25,594.33 t. Cell-01, Cell-02, and Cell-03 also presented rotation indices equivalent to 3.62, 1.15, and 5.11 respectively, and time in use of 10.60, 1.16, and 7.97 months respectively. According to Figure 13, the greatest amount of product stored occurred in April, when all Flat Storage cells were filled with soybean and the final stock for this month was 14,409.20 t. As shown above, in some months two types of products are simultaneously stored.

Table 4 – Data related to the electric energy use and product flows among the grain storage facility's sectors

Sector (Installed Power)	Electric energy consumption (MWh)	Amount of handled products (tonnes)				
		Movement	Corn	Soybean	Wheat	Total
Receiving (50 kW)	19.9	Input	15,176.00	53,179.00	5,118.00	73,473.00
		Transferred	335.00	2,288.00	0	2,623.00
		Output	14,841.00	50,891.00	5,118.00	70,850.00
Pre- Cleaning (20.9 kW)	12.9	Input	14,841.00	50,891.00	5,118.00	70,850.00
		Output	14,638.18	50,165.55	5,054.75	69,858.45
Drying (87.3 kW)	111.5	Input	14,226.92	23,031.28	5,042.81	42,301.00
		Recirculation	37,419.16	31,329.80	8,899.01	77,647.97
		Transferred	551.77	1,087.32	254.23	1,893.32
		Output	11,840.14	20,503.79	4,360.34	36,704.26
Cleaning (33.6 kW)	36.1	Input	12,251.38	47,638.06	4,372.28	64,261.72
		Output	12,205.02	47,451.81	4,356.88	64,013.71
Storage (52.2 kW)	28.9	Input	11,813.51	36,994.62	4,060.69	52,868.81
		Output	11,813.51	36,994.62	4,060.69	52,868.81
Dispatch (22.4 kW)	10.9	Input	12,205.02	47,451.81	4,356.88	64,013.71
		Output	12,205.02	47,451.81	4,356.88	64,013.71
General Use (1.5 kW)	6.3	–	–	–	–	–
Total	226.6					

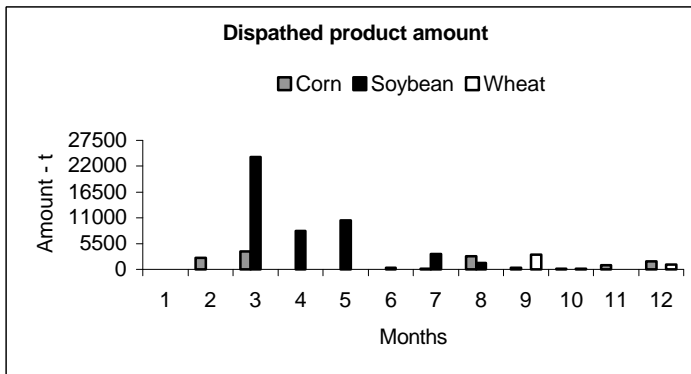
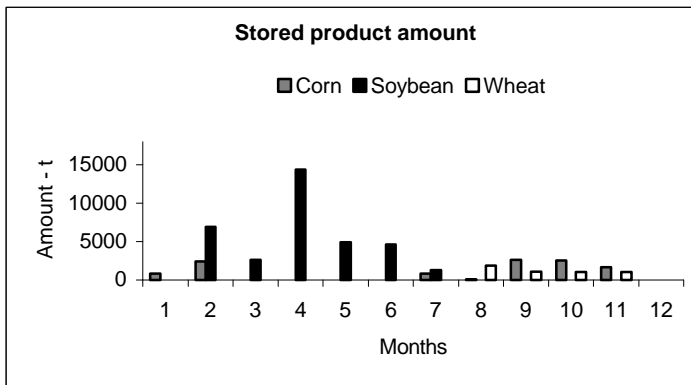
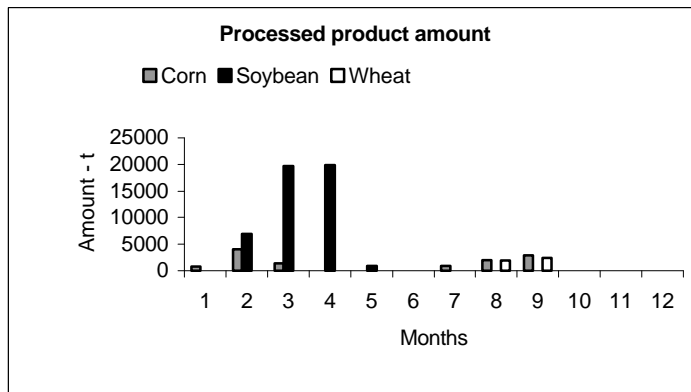
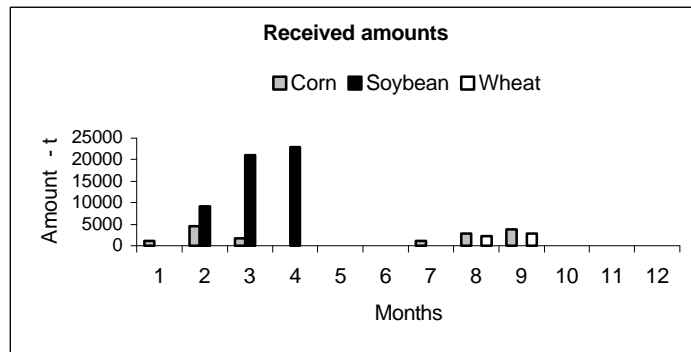


Figure 13 – Monthly quantities of corn, soybeans, and wheat that were received, processed, stored, and dispatched.

The dispatched product quantities were delivered according to the dispatch plans shown in Table 3. The greatest monthly quantity dispatched was in March, 27,809.43 t, which corresponded to 1,219 delivered loads with an average weight of 22.81 t.

Table 5 shows the simulated firewood and electrical energy use information. Over the simulated year, firewood consumption was 766.02 tonnes, while specific uses were 27.0, 13.0, and 16.0 kg per tonne of dried corn, soybeans, and wheat respectively. According to simulated output data, 1,835.02, 1,440.17, and 428.23 tonnes of water were removed from the received quantities of corn, soybean, and wheat respectively.

Table 5 – Firewood and electric energy use data

Month	Firewood consumption (t)			Electric energy use			
				Consumption (kWh)		Demand (kW)	
	Corn	Soybean	Wheat	Off peak	On peak	Off peak	On peak
1	26.34	0.00	0.00	3012.60	558.97	185.81	178.73
2	128.82	38.02	0.00	25961.86	3608.49	264.86	182.27
3	49.06	127.96	0.00	44081.03	9372.16	266.06	233.08
4	0.00	124.89	0.00	40008.93	4538.77	266.06	215.36
5	0.00	5.96	0.00	5661.40	196.26	201.19	27.23
6	0.00	0.00	0.00	374.60	45.00	22.76	0.30
7	26.49	0.00	0.00	3792.25	332.30	208.27	178.73
8	62.50	0.00	34.09	14317.73	1356.06	236.62	207.07
9	93.13	0.00	48.75	20452.89	2384.47	266.06	185.81
10	0.00	0.00	0.00	408.60	45.00	22.76	0.30
11	0.00	0.00	0.00	530.40	45.00	22.76	0.30
12	0.00	0.00	0.00	845.40	45.00	219.54	163.13
Total	386.34	296.83	82.84	159447.69	22527.48	–	–

The annual electric energy consumption during off peak hours was 159.45 MWh and 22.53 MWh during peak hours, totaling 181.98 MWh. The highest demand value was 266.06 kW, which occurred in March and April. In these months, the simulation showed that operations such as receiving,

cleaning, drying, and dispatching occurred simultaneously. Through the present study, it was verified that 34.78 % of the electric energy was consumed in the drying sector (Table 4). This occurred because product with moisture content above 18% w.b. needs to pass through the dryer at least twice if a mixed flow dryer is used. As shown in Table 2, almost 90% of the corn and 45% of the wheat had more than 18% w.b. This high percentage of wet product is the reason more electric energy was consumed in the drying operation than in any other operation.

According to the simulation (Table 4), the drying sector had to handle 37,419.16 t of corn, 31,329.80 t of soybeans, and 8,899.01 t of wheat to dry 14,226.92 t of corn, 23,031.28 t of soybeans, and 5,042.81 t of wheat, due to product re-circulation. The drying process presented specific electrical energy consumption of 2.138, 1.109, and 1.438 kWh per tonne of corn, soybean, and wheat respectively.

CONCLUSION

A simulation toolset called *Grain Facility* was developed. It provides a suite of blocks that allow: (i) modeling a wide variety of grain storage facility layouts, and (ii) simulating dynamic behavior considering the stochastic factors that affect system performance.

To demonstrate an application of the *Grain Facility* library, a grain storage facility was modeled. It received 15,176.00 t, 5,3179.00 t, and 5,118 t of corn, soybean and wheat respectively. Simulated results show that: (i) after processing unit operations, 12,205.02 t, 47,451.81 t, and 4,356.88 t corn, soybeans and wheat were obtained respectively, (ii) the maximum amount of product stored occurred in April when the final monthly balance showed 14,409.20 t of soybean, (iii) the amount of firewood burnt in the drying operation totaled 766.02 tonnes with 27.0, 13.0, and 16.0 kg of firewood being consumed to dry each tonne of corn, soybeans, and wheat respectively, and (iv) the total facility's annual electrical energy consumption was 181.98 MWh, 34.78% of which was used in the drying sector.

By using the *Grain Facility* toolset, structured models become a more useful simulation mechanism because the toolset addresses a wide range of outputs and has significant problem-solving potential. It can be used to: (i) conduct grain storage facility feasibility analysis, (ii) define the ideal type of structures, process machines, and conveyors, (iii) detect bottlenecks, (iv) plan maintenance services, (v) optimize consumption of electricity and heat energy, (vi) test the impact of different operating conditions on the grain facility storage sector, and (vi) conduct simulation experiments, such as sensitivity analysis, scenario analysis, optimization, and Monte Carlo simulation.

REFERENCES

- Benock, G., O. J. Loewer, T. C. Bridges, and D. H. Loewer. 1981. Grain flow restrictions in harvesting–delivery-drying systems. *Trans ASAE* 24(5): 1151-1161.
- Bridges, T. C., G. M. White, I. J. Ross, and O. J. Loewer, Jr. 1982. A computer aid for management of on-farm layer drying systems. *Trans. ASAE* 25(3): 811-815.
- Bridges, T. C., D. G. Colliver, G. M. White, and O. J. Loewer. 1984. A computer aid for evaluation of on-farm stir drying systems. *Trans. ASAE* 27(5): 1549-1555.
- Bridges, T. C., O. J. Loewer, Jr., J. N. Walker, and D. G. Overhults. 1979. A computer model for evaluating corn harvesting, handling, drying and storage systems. *Trans. ASAE* 22(3): 618-629.
- Brooker, D. B., F. W. Bakker-Arkema, and C. W. Hall. 1992. *Drying and storage of grains and oilseeds*, Chapter 10:287-291, New York: Van Nostrand Reinhold.
- Imagine That, Inc. 1997. *Extend [Extend User's Manual – Version 4]*. San Jose, CA, USA
- Kazmier, L. J. 1995. *Business statistics*. 3rd Edition, Schaum's Outline Series. New York: McGraw-Hill.
- Krahl, A. 2000. The extend simulation environment. *Proceedings of the 2000 Winter Simulation Conference*. Eds. J. A. Joines, R. R. Barton, K. Kang, and, P. A. Fishwick, pp 280-289. IEEE, Piscataway, NJ.

- Law, A. M., and W. D. Kelton. 1991. *Simulation modeling and analysis*. 2nd Edition. New York: McGraw Hill.
- Loewer, O. J., T. C. Bridges, and R. A. Bucklin. 1994. *On-farm drying and storage systems*. ASAE Publication 9, American Society of Agricultural Engineers.
- Loewer, O. J., M. K. Kocher, and J. Solamianian. 1990. An expert system for determining bottlenecks in on-farm grain processing. *Applied Engineering in Agriculture* 6(11): 69-72.
- Loewer, O. J., Jr., T. C. Bridges, and D. G. Overhults. 1976. Computer layout and design of grain storage facilities. *Trans. ASAE* 19(6): 1130-1137.
- Maria, A. 1997. Introduction to modeling and simulation. *Proceedings of the 1997 Winter Simulation Conference Proceedings*. Eds. S. Andatóttir, K. J. Healy, D. H. Withers, and B. L. Nelson, pp 7-13. IEEE, Piscataway, NJ.
- Palisade Corporation. 2000. *@Risk: Advanced risk analysis for spreadsheets*. Newfield, NY. USA.
- Rivera, J. 1997. Modeling with Extend™. Proceedings of the 1997 Winter Simulation Conference, eds. S. Andradóttir, K. J. Healy, D. H. Healy, D. H. Withers, and B. L. Nelson, pp 674-679. IEEE, Piscataway, NJ.
- Roberts, C. A. and Y. J. Dessouky. 1998. An overview of object-oriented simulation. *Simulation* 70(6): 359-368. 1998 Simulation Councils, Inc.
- Thompson, T. L., R. M. Peart, and G. H. Foster. 1968. Mathematical simulation of corn drying – A new model. *Trans. ASAE* 11(4): 582-586.
- Weber, E. A. 2001. *Armazenagem agrícola [Farm Storing]*. Guaíba, RS. Brasil: Livraria e Editora Agropecuária

CHAPTER III

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™ 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™*

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.

Considering this system and using the software Extend™, 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 ExtendTM, version 4.1.3C (Krahl, 2000). The simulation toolset is a developed ExtendTM 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.

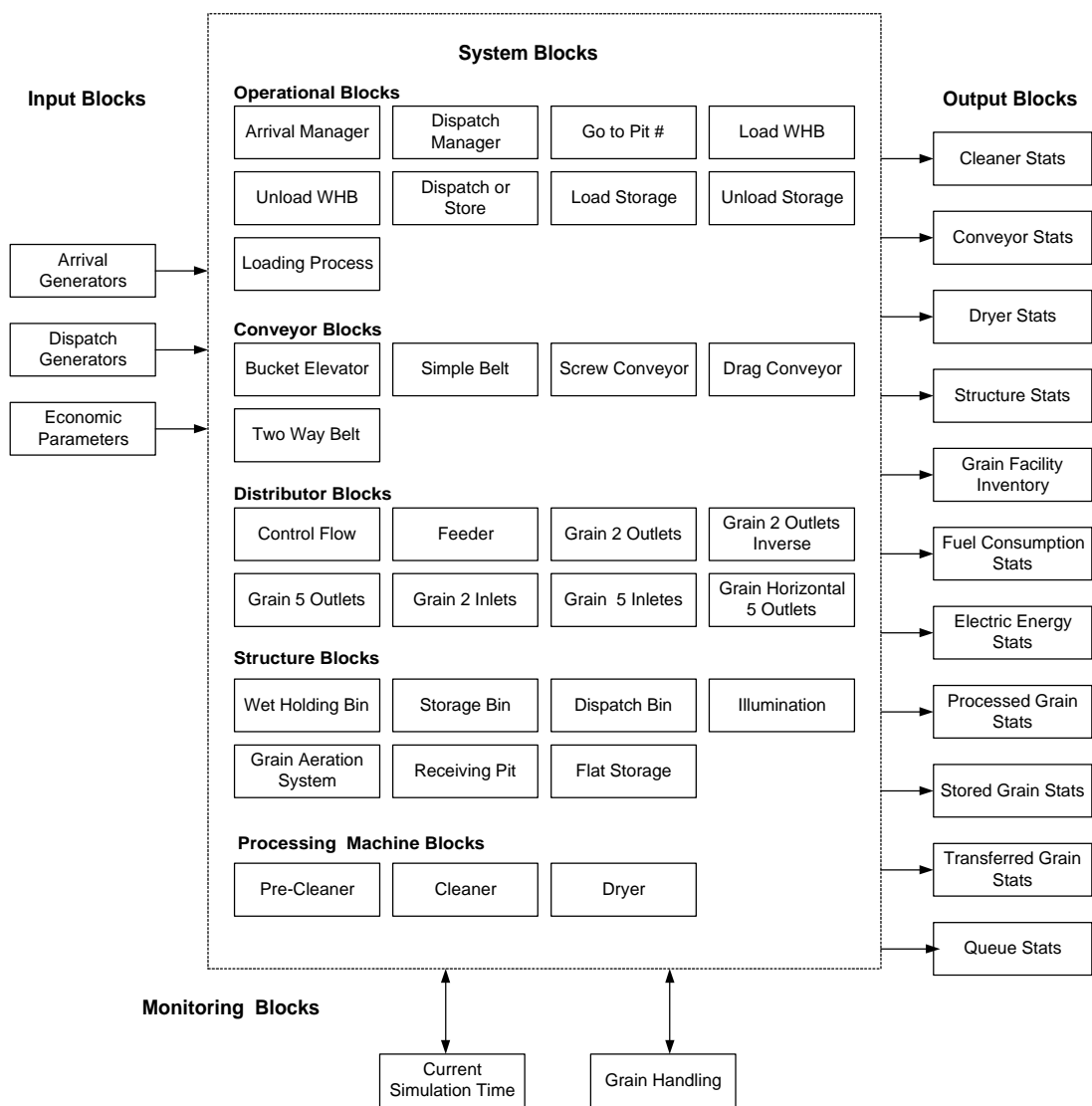


Figure 1 – Grain Facility Library schematic representation.

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

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 (1 st Crop)	Beta Distribution $\infty_1 = 0.2287$ $\infty_2 = 0.5360$ Minimum = 0 Maximum = 317.18	7,376	01/26/99	lower than 14.2	1.42	1.1 to 2.0	93.87
			to	14.3 to 18.2	4.22	2.1 to 3	6.13
			03/06/99	18.3 to 24.0	57.60		
				higher than 24.0	36.75		
Corn (2 nd Crop)	Exponential Distribution $\beta = 101.355$ Shift = -1.3697	7,804	07/17/99	lower than 14.2	1.64	lower than 1.0	3.37
			to	14.3 to 18.2	10.27	1.1 to 2.0	96.63
			09/30/99	18.3 to 24.0	55.12		
				higher than 24.0	33.96		
Soybean	Beta Distribution $\infty_1 = 0.3665$ $\infty_2 = 1.7942$ Minimum = 0 Maximum = 686.70	53,179	02/26/99	lower than 14.2	55.02	1.1 to 2.0	92.54
			to	14.3 to 18.2	39.03	2.1 to 3.0	6.88
			04/30/99	18.3 to 24.0	5.85	3.1 to 6.0	0.56
Wheat	Exponential Distribution $\beta = 100.001$ Shift = -2.2728	5,118t	08/16/99	14.3 to 18.2	54.60	lower than 1.0	29.22
			to	18.3 to 24.0	45.40	1.1 to 2.0	54.55
			09/29/99			2.1 to 3.0	16.24

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 (1 st Crop)	Beta	5,830	02/05/99	18.3 to 24.0	2.52	1.0 to 2.0	87.39
	$\infty_1 = 0.1919$ $\infty_2 = 0.4865$		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
Corn (2 nd Crop)	Normal	1,387	07/20/99	18.3 to 24.0	24.50	1.0 to 2.0	57.84
	$\mu = 101.003$ $\sigma = 83.67$		to	higher than 24.0	75.50	2.1 to 3.0	24.50
			08/25/99				3.1 to 4.0
Soybean	Beta	28,604	03/01/99	up to 14.2	0.05	Up to 1.0	1.48
	$\infty_1 = 0.2049$ $\infty_2 = 0.7287$		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
	$\infty_1 = 0.3265$ $\infty_2 = 1.576$		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 (1 st Crop)	Beta	6,682	02/20/99	14.3 to 18.2	10.83	Lower than 1.0	8.17
	$\infty_1 = 0.2044$		to	18.3 to 24.0	89.67	1.3 to 2.0	90.79
	$\infty_2 = 0.9165$		06/10/99			2.1 to 3.0	1.04
	Minimum = 0 Maximum = 686.5						
Corn (2 nd Crop)	Exponential	3,002	08/24/99	18.3 to 24.0	15.00	2.1 to 3.0	67.50
	$\beta = 100.00$		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

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.

VERIFICATION ANALYSIS

Figure 2 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 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.

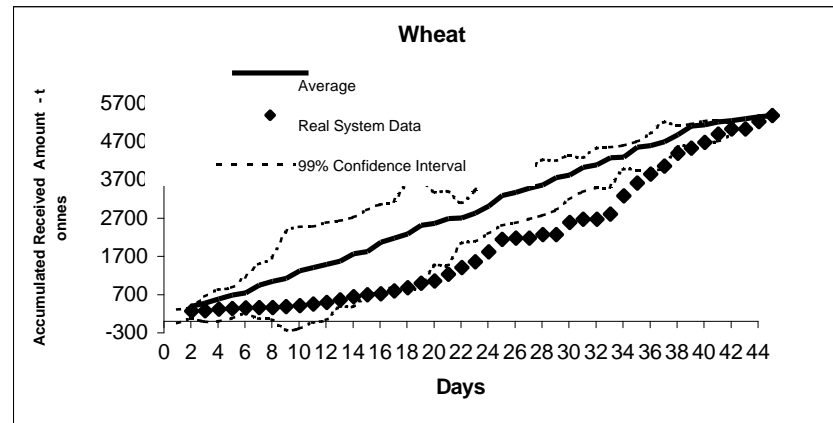
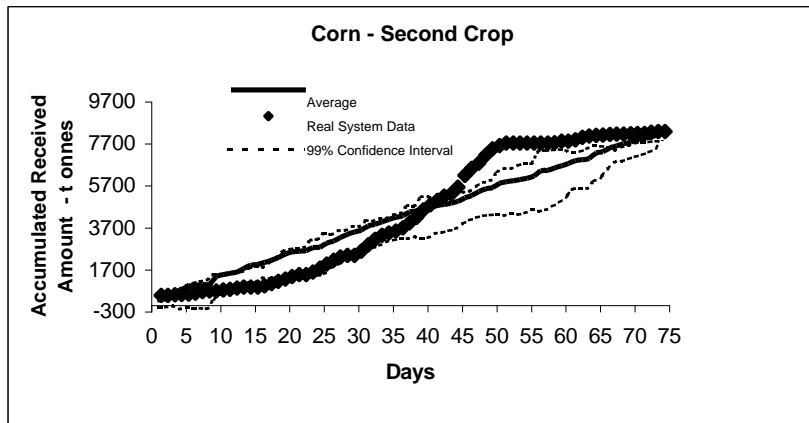
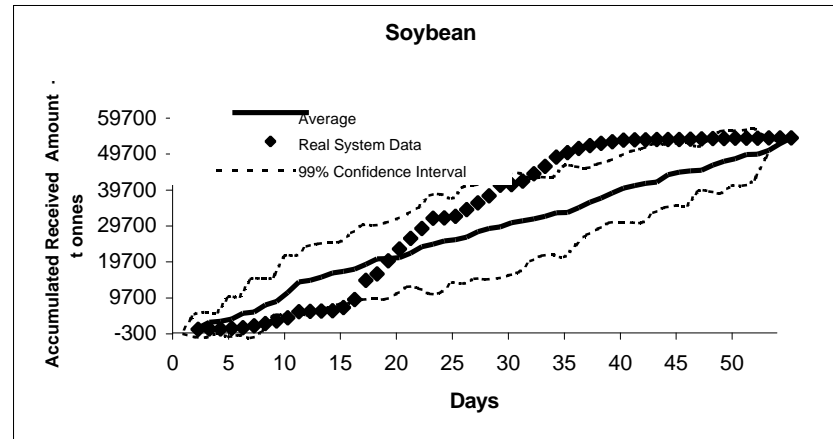
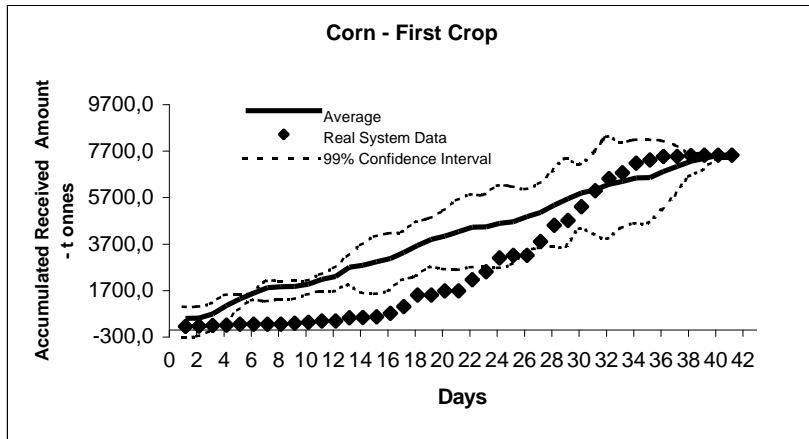


Figure 2 – The cumulative curves for received amount of raw products (Grain Storage Facility – “A”).

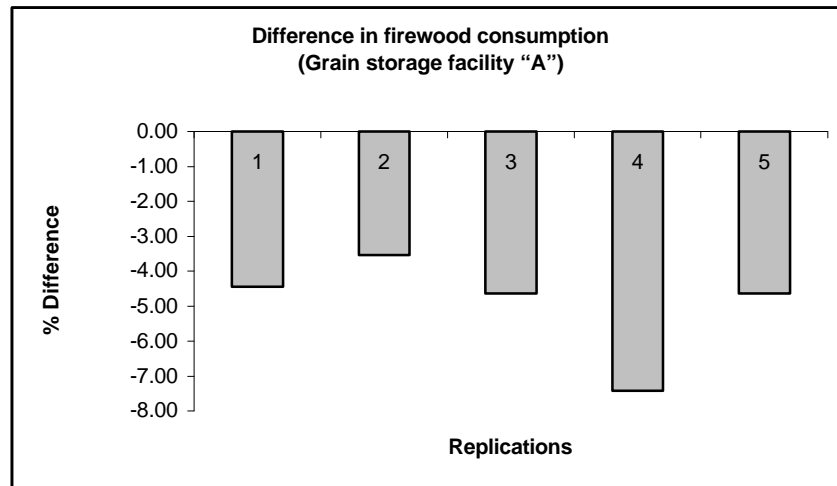


Figure 3 – Comparison between real system and model output for annual firewood consumption (Five replications, Facility “A”).

VALIDATION ANALYSIS

Figures 4 and 5 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.

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.

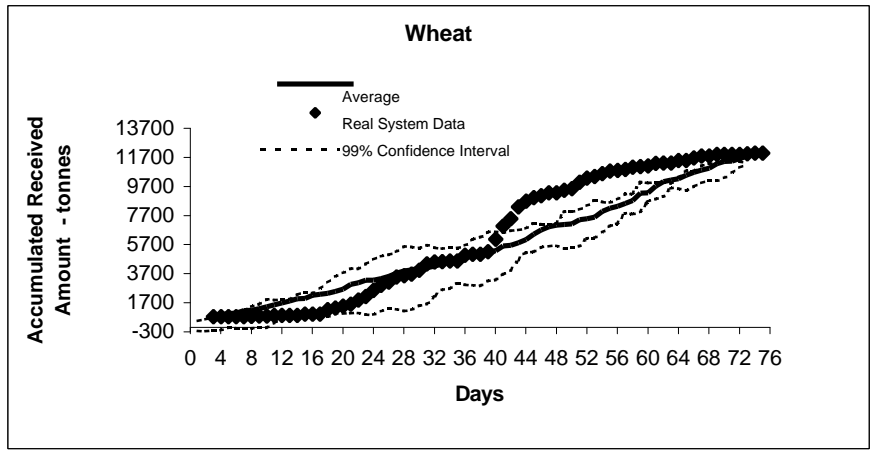
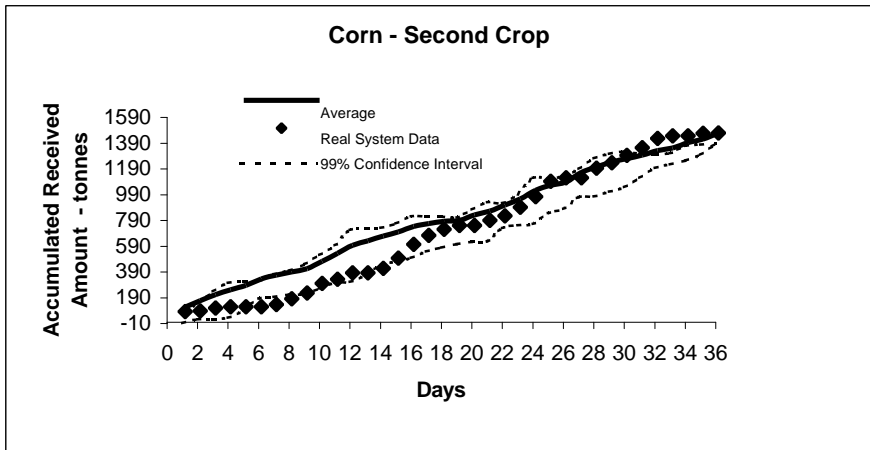
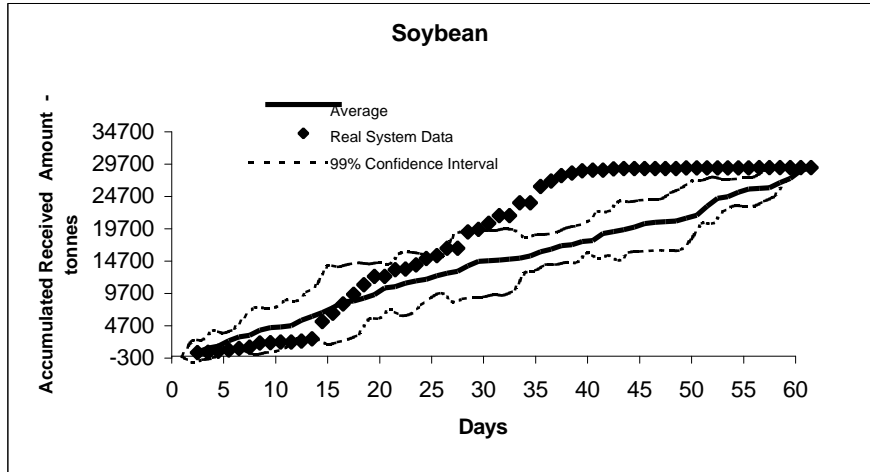
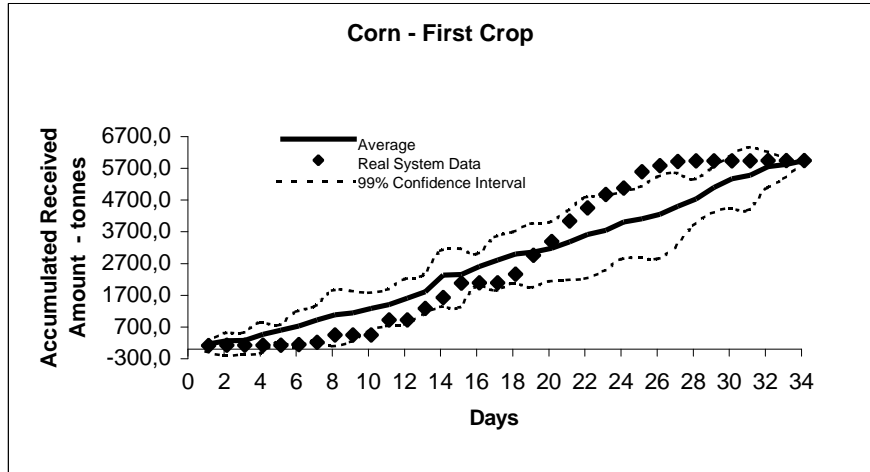


Figure 4 – Cumulative curves for received amount of raw products (Grain Storage Facility – “B”).

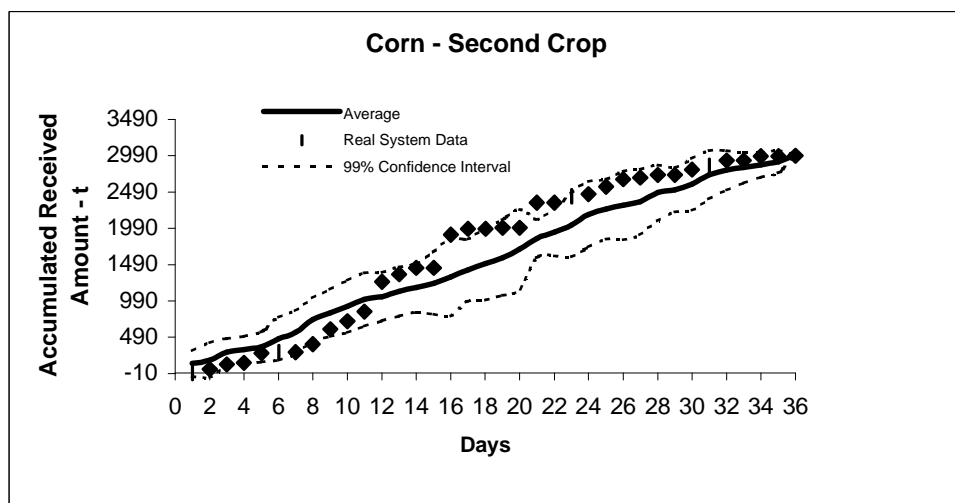
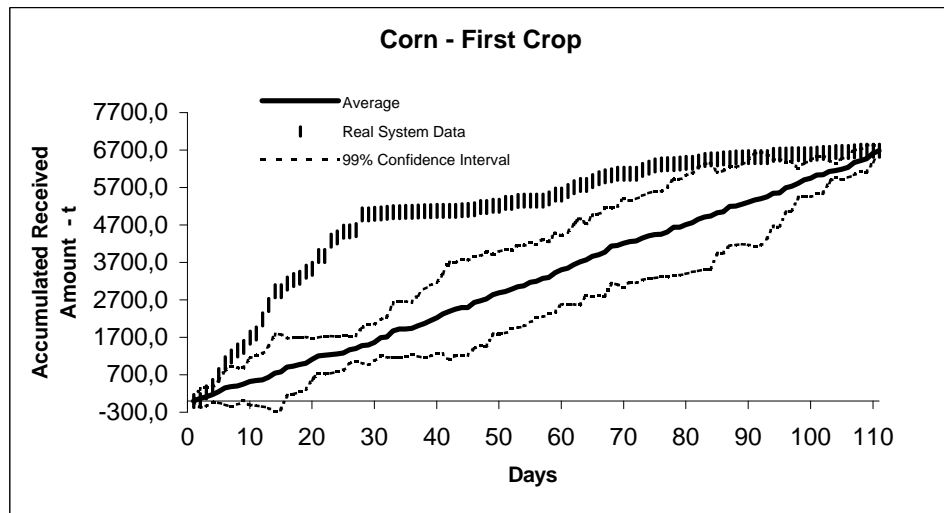


Figure 5 – Cumulative curves for received amount of raw products (Grain Storage Facility “C”)

For facility C, the first crop of corn had the lowest correlation coefficient (Figure 5). 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 6 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.

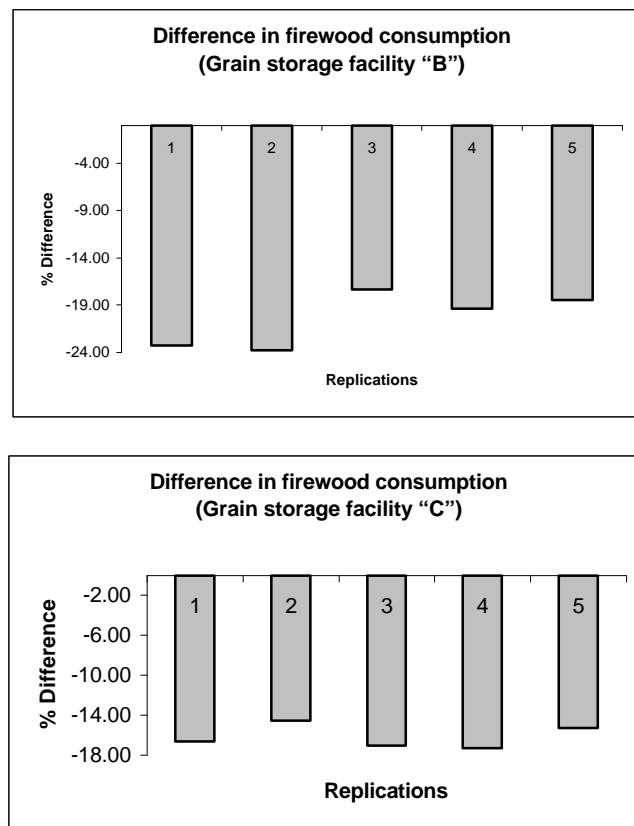


Figure 6 – Comparison among system and model outputs for annual firewood consumption.

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 7 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 7, the cumulative curves for electrical energy consumption were determined. These curves are presented in Figure 8. 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 7 and 8 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.

According to Figures 7 and 8, 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 5). 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.

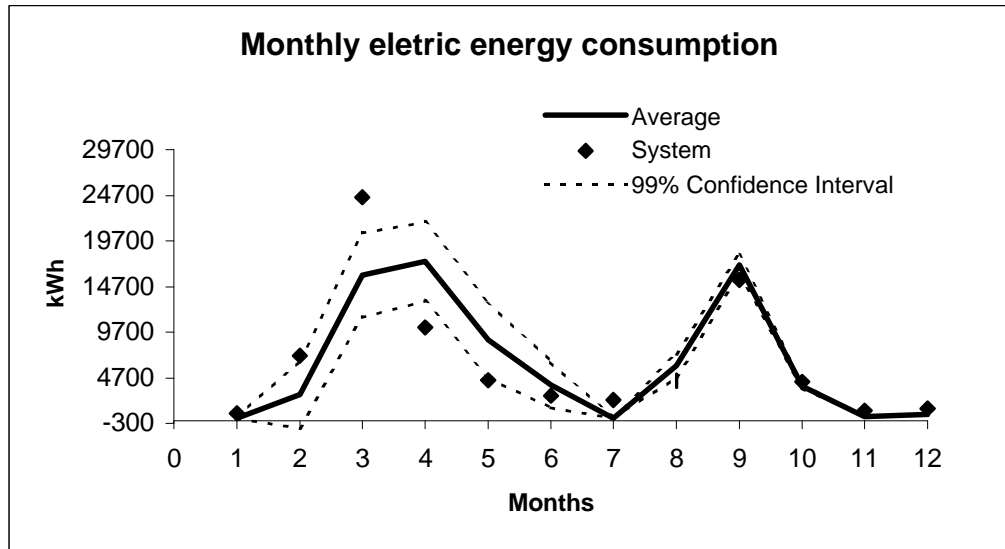


Figure 7 – Comparison among system and model outputs for monthly electrical energy consumption – (Grain Storage Facility – “C”)

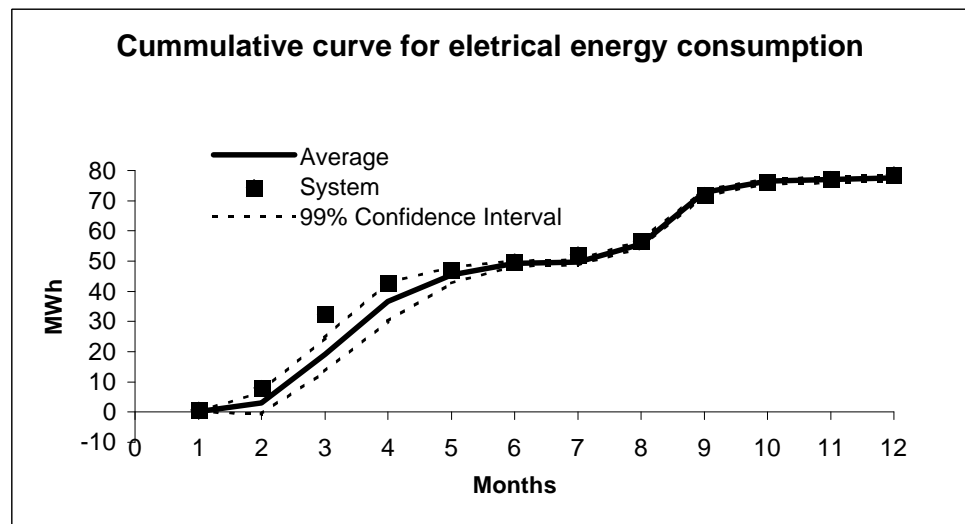


Figure 8 – Cummulative electrical energy consumption curves (Grain Storage Facility – “C”).

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.

REFERENCES

- Balci, O. 1997. Principles of simulation model validation, verification, and testing. *Trans. of the Society for Computer Simulation International*. 14(1): 03-12
- Flores, R. A. 1988. Quality is chief priority in grain storage units. *Agribusiness Worldwide* 11 (10): 9-16.
- Krahl, A. 2000. The Extend simulation environment. *Proceedings of the 2000 Winter Simulation Conference*. Eds. J. A. Joines, R. R. Barton, K. Kang, and, P. A. Fishwick, pp 280-289. IEEE, Piscataway, NJ.
- Law, A. M. and W. D. Kelton. 1991. *Simulation modeling and analysis*. 2nd Edition. New York: McGraw Hill, Inc.
- Loewer O. J., Bridges, T. C., and Bucklin R. A. 1994. *On-farm drying and storage systems*. ASAE Publication 9, American Society of Agricultural Engineers.
- Maria, A. 1997. Introduction to modeling and simulation. *Proceedings of the 1997 Winter Simulation Conference Proceedings*. Eds. S. Andatóttir, K. J. Healy, D. H. Withers, and B. L. Nelson, pp 7-13. IEEE, Piscataway, NJ.
- Menner, W. A. 1995. Introduction to modeling and simulation. *Johns Hopkins APL Technical Digest* 16(1): 6:17.

- Sargent, R. G. 1999. Validation and verification of simulation models. *Proceedings of the 1999 Winter Simulation Conference Proceedings*. Eds. P. A. Farrington, H. B. Nembhard, D. T. Sturrock, and G. W. Evans, pp 39-48. IEEE, Piscataway, NJ.
- Winston, W. L. 1994. *Operations Research: applications and algorithms*. 3rd edition Belmont, California: Wadsworth Publishing Company. 1353p.
- Weber, E. A. 2001. *Armazenagem agrícola.[Farm storing]*. Livraria e Editora Agropecuária, Guaíba: RS, Brazil

CHAPTER IV

SENSITIVITY ANALYSIS USING A GRAIN STORAGE FACILITY MODEL

Abstract *A sensitivity analysis study was carried out using a grain storage facility model, which was implemented using ExtendTM software and the developed simulation toolset “Grain Facility.” The toolset holds a set of blocks that allows simulating: (i) grain processing unit operations, (ii) operational decisions, and (iii) electric energy and fuel consumption. The model refers to one grain storage facility that annually receives approximately 9,500 t of corn, has four receiving pits with a holding capacity of 60 t each, one dryer with a drying capacity of 40 t/h, and four storage bins with a total storage capacity of 6,600 tonnes. The sensitivity analysis experiment was carried with the objective of verifying the impact on firewood and electrical energy consumption of a 10% increase or decrease in the quantity of raw product received and of a 2 percentage point increase or decrease in this raw product’s initial moisture content. The 2% reduction in raw product initial moisture content resulted in the highest magnitude impacts, causing firewood consumption, specific firewood consumption, electrical energy consumption, and specific electrical energy consumption at drying sector to decrease an average of 14.90%, 15.10%, 7.90%, and 15.15 % respectively.*

Keywords. *grain storage facility, sensitivity analysis, ExtendTM*

INTRODUCTION

The performance of a grain storage facility’s system is highly tied to stochastic phenomena, such as the harvest process and product market demand. Because of this, dependence on the use of static methodology to generate feasibility analyses and shape grain storage facility decision making is not recommended, as this can lead to erroneous assumptions. Stochastic simulation has been shown as the most appropriated tool for these uses. According to Song et al. (1990), the great advantage of stochastic models is that they allow the prediction of not only the average of the outputs but also their variances.

In addition, with developed simulation models, users are able to carry out sensitivity analysis, scenario analysis, optimization, and Monte Carlo simulation.

These types of experiments support the decision making process and do not require intervention in the actual system, which can be costly and disruptive.

It is known that the performance of grain storage facilities can be affected by external factors, such as the received amount and the moisture content of raw products. These parameters, for example, can directly impact the performance of the facility's drying sector. Increases in these parameters will require more use of grain dryers, impacting electric and heat energy consumption.

The present article deals with a sensitivity analysis study to verify the magnitude of the impact on grain storage facility performance when the received quantity of raw products is increased and decreased 10% and when the initial moisture content of received raw products is increased and decreased 2 percentage points.

BACKGROUND

According to the operations research concept, a system may be defined as "*any sorted group of objects that perform together or inter-work in order to reach one logical goal*" (Schmidt and Taylor, 1970). This definition is strongly related to the purposes of this study, which are to learn, analyze, design, change, preserve, and, if possible, control system performance (Neelamkavil, 1987). In order to achieve these purposes satisfactorily, it is necessary to select all the involved system elements and then establish their interrelationships (Law and Kelton, 1991). This can be done by means of the simulation technique, which has been demonstrated to be a valuable tool for: (i) guiding the decision process, (ii) proceeding the evaluations and feasibility analyses, (iii) defining solutions for optimizing system performance, and (iv) carrying out experiments that do not affect the real system's routine (Monsef, 1997; Neelamkavil, 1987; Maria, 1997).

In the engineering field, simulation has been successfully employed for: (i) forecasting results before execution of a specific action, (ii) minimizing risks in making decisions, (iii) identifying problems before their occurrence, (iv) eliminating procedures that do not add value, (v) cutting costs related to manpower, energy, water, and physical structure, and (vi) revealing a project's integrity and viability according to economic and technical feasibility analyses

(Law and Kelton, 1991). However, many authors, including Law and Kelton (1991) and Palisade (2000), state that simulation by itself does not provide exact answers nor optimize system performance. Nevertheless, a well-built model captures significant data and reports this data, which then may be used in conducting simulation experiments, such as: (a) *sensitivity analysis* to check the impact on a system when the values of one or more parameters are modified, (b) *scenario analysis* to allow comparisons between different scenarios when the system's configuration is changed, (c) *optimization* to define the optimum combination of inputs to produce a desired output, and (d) *Monte Carlo simulation* to enable, with a certain level of confidence, the determination of expected system performance according to variation (Krahl, 2000; Imagine That, Inc., 1997).

EXPERIMENT ORGANIZATION

This sensitivity analysis experiment was carried out to verify the magnitude of impacts on grain storage facility performance when the received quantity of raw product is increased or decreased 10%, and when the initial moisture content of received raw product is increased or decreased by two percentage points.

The experiment was carried out using a dynamic, stochastic and discrete model that was developed for one of the grain storage facilities belonging to COAMO, an agricultural cooperative headquartered in Campo Mourão, Paraná, Brazil. Technical information about the modeled facility is given in Table 1.

The model was built using the simulation language Extend™, version 4.1.3C and a developed simulation toolset called “*Grain Facility*.” “*Grain Facility*” is an Extend™ library, which has a set of blocks that represent structure and equipment used in grain storage facilities. In Figure 1, the main blocks of this library are presented. The model constructed allows simulation of the grain storage facility's dynamic behavior.

Table 2 presents input information for the *Arrival Generators* block. Table 3 presents the dispatch plans for corn. Information listed in Tables 2 and 3 refers to the 1991 crop year.

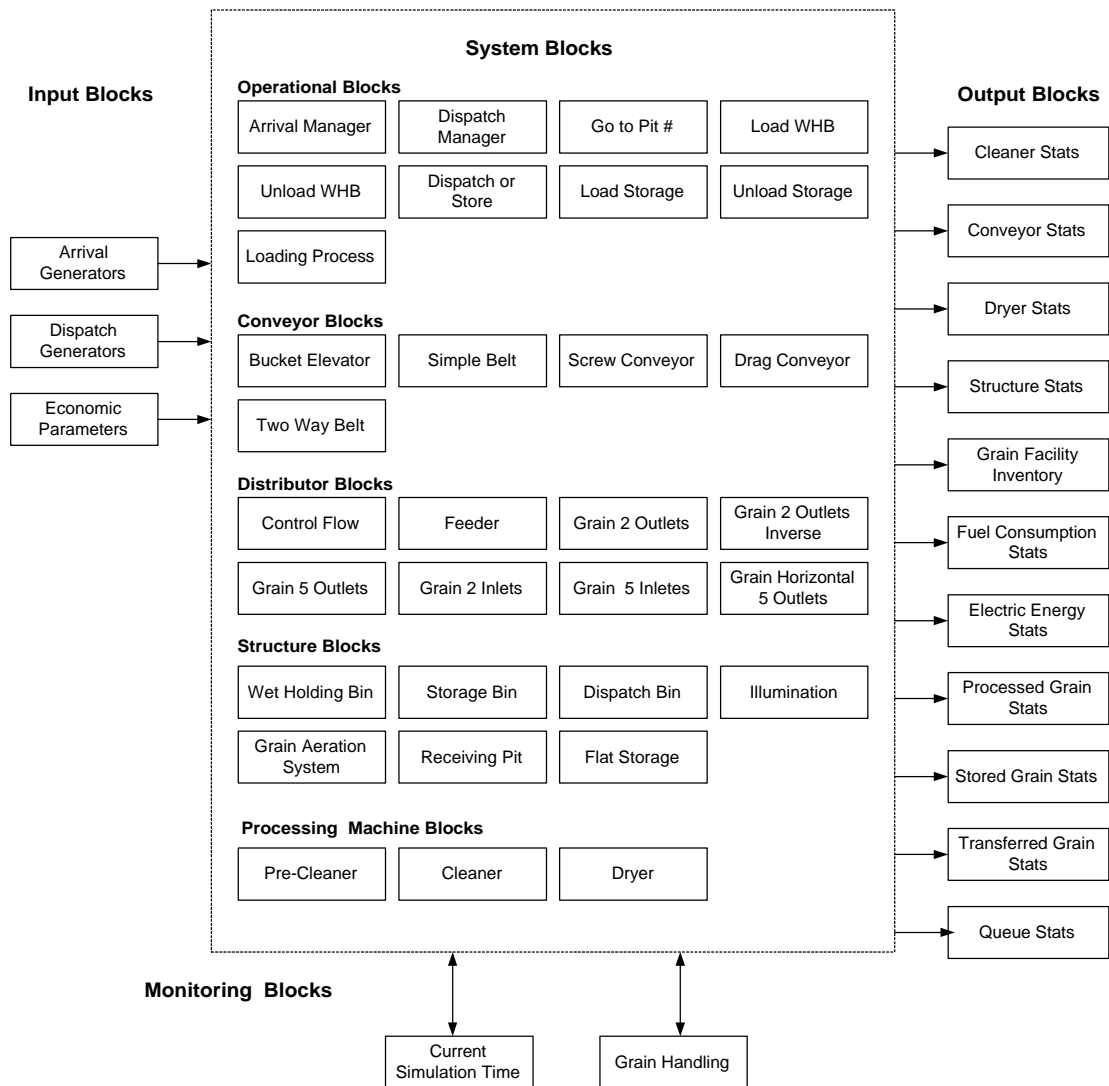


Figure 1- *Grain Facility* Library schematic representation.

Table 1 – Major 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

Table 2 – Information used at the *Arrival Generators* block - grain facility C

Product	Distribution Types for Predicting The “ <i>daily harvest success index</i> ” - DHSI	Received Amount of Products (t)	Harvest Period	Moisture Content		Foreign Material Content		
				% w.b.	% of loads	%	% of loads	
Corn (1 st Crop)	Beta Distribution	6,682	02/20/99	14.3 to 18.2	10.83	lower than 1.0	8.17	
	$\infty_1 = 0.2044$		to	18.3 to 24.0	89.67	1.1 to 2.0	90.79	
	$\infty_2 = 0.9165$		06/10/99				2.1 to 3.0	1.04
	Minimum = 0 Maximum = 686.5							
Corn (2 nd Crop)	Exponential Distribution	3,002	08/24/99	18.3 to 24.0	15.00	2.1 to 3.0	67.50	
	$\beta = 100.00$		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 3 – Dispatch plans for corn

Month	Stock portions to be dispatched (%)
1	0
2	0.80
3	2.00
4	6.58
5	8.70
6	10.85
7	2.89
8	2.45
9	12.25
10	10.89
11	11.40
12	31.19

For each studied situation, five simulation model replications (runs) were made. Averages and 99% confidence intervals, using t-distribution, were determined for the performance parameters related to firewood and electrical energy consumption. Firewood is used as the heat energy source in the drying operation. The length of each simulation refers to one operational year (8,640 hours).

RESULTS AND DISCUSSIONS

Table 4 shows the predicted 99% confidence interval for firewood consumption, specific firewood consumption, and electrical energy consumption, and specific electrical energy consumption for the five contrasted suited situations. “Normal situation” figures are the output from an unadjusted simulation of the actual storage facility.

In Table 4 and Figure 2, it can be observed that average firewood consumption increases 11.5% with the simulated increase in raw product quantity and increases 2.65% with the increase in product’s initial moisture content. When the quantity of raw product quantity is decreased, average firewood consumption decreases 12.30%, and when the product’s initial

moisture content is decreased, firewood consumption decreases 14.90%. It is observed that more significant differences occur when the initial moisture content is decreased. A similar occurrence was not detected when the initial moisture content was increased. This could be because the model was constrained by a maximum moisture content of 30% w.b.

Table 4 – Results of sensitivity analysis

Parameter	Normal Situation	Received Quantity Increased 10%	Received Quantity Decreased 10%	Initial Moisture Content Increased 2 points	Initial Moisture Content Decreased 2 points
Firewood consumption (t)	343.80 ±4.23	383.40 ±5.40	301.40 ±8.34	352.92 ±2.54	292.60 ±3.44
Specific firewood consumption (kg of firewood / t of product inputted at dryer)	36.32 ±0.41	36.72 ±0.50	35.57 ±0.99	37.27 ±0.37	30.83 ±0.37
Electrical energy consumption (MWh)	77.60 ±0.40	83.03 ±0.52	71.65 ±1.13	78.45 ±0.39	71.74 ±0.47
Specific electrical energy consumption capacity (kWh / t of product inputted at the dryer)	3.63 ±0.04	3.66 ±0.06	3.55 ±0.10	3.71 ±0.03	3.08±0.04

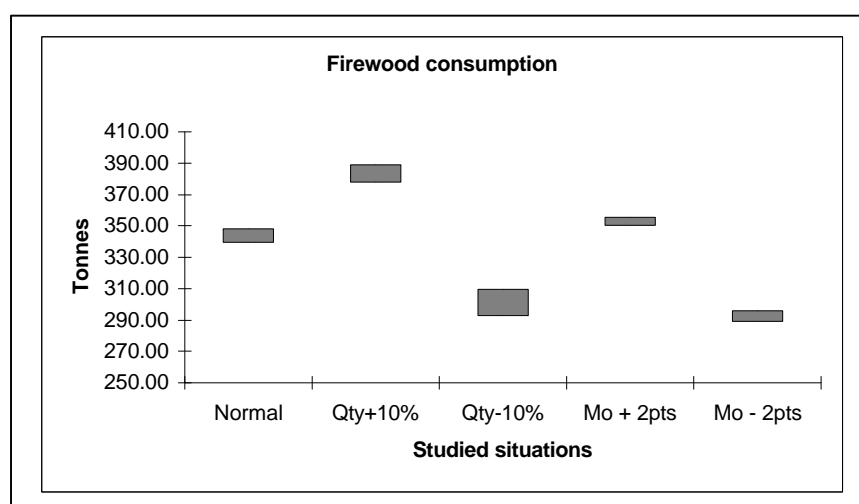


Figure 2 – Schematic representation of 99 % confidence interval boundaries for firewood consumption.

For specific firewood consumption, according to the information shown in Table 4 and Figure 3, it was noticed that the magnitude of impacts were more accentuated for modifications of initial moisture content, since the predicted 99% confidence interval for the normal situation and for quantity of received raw product alternatives are similar. The greatest difference occurred when the initial moisture content was decreased two percentage points. In this instance, the specific firewood consumption average dropped 15.11 %.

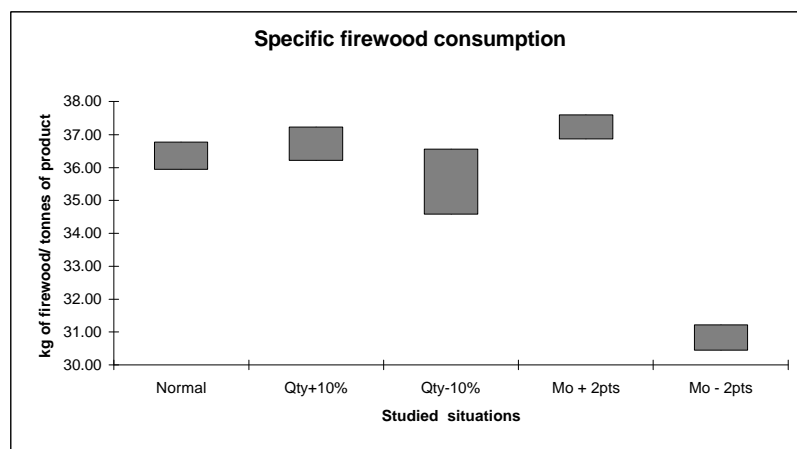


Figure 3 – Schematic representation of 99 % confidence interval boundaries for specific firewood consumption.

Table 4 and Figure 4 schematically represent electric energy consumption data. It was verified that the average electric energy consumption increases 6.99% when the quantity of received raw product increases 10% and decreases 7.66% when that quantity decreases 10%. It was also found that a 2 percentage point increase in raw material initial moisture content caused average electric energy consumption to increase 1.1%, while a 2 percentage point decrease in initial moisture content caused that consumption to decrease 7.90%. This large percentage decrease in the consumption of electricity with the decrease in product moisture content is most explained by reduced dryer use, as dryers consume the most electrical energy at grain storage facilities.

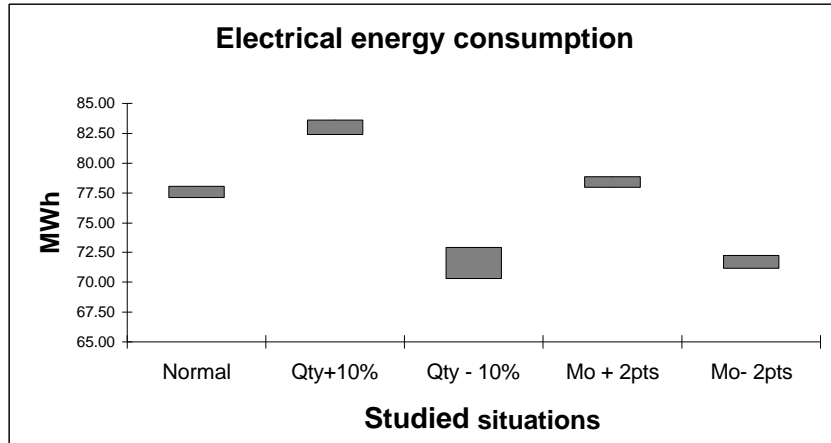


Figure 4 – Schematic representation of the 99 % confidence interval boundaries for annual electrical energy consumption.

For specific electric energy consumption in the drying sector, according to the information presented in Table 4 and Figure 5, the greatest difference occurred when initial moisture content is changed. The increase and the decrease for the initial moisture content of the raw material caused average specific electric energy consumption to increase 2.20% and decrease 15.15%, respectively. This could be because raw product with lower moisture content needs less recirculation in the mixed flow dryer.

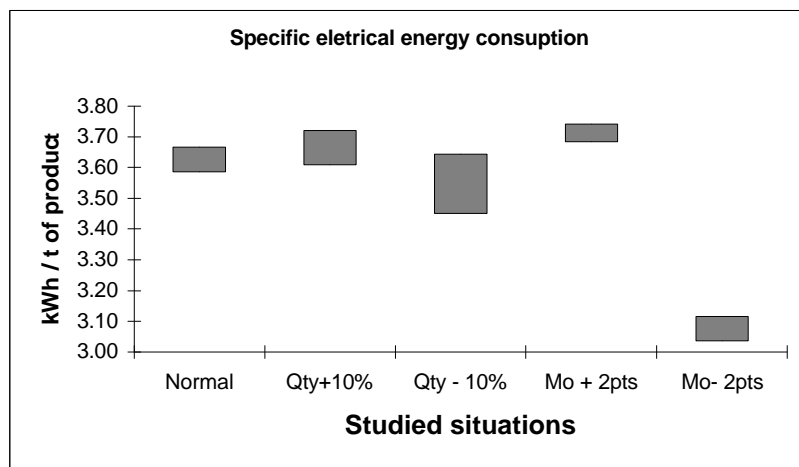


Figure 5 – Schematic representation of the 99 % confidence interval boundaries for specific electrical energy used capacity in drying sector.

CONCLUSION

This paper presents a sensitivity analysis experiment, carried out to verify the magnitude of impacts on grain storage facility firewood and electrical energy consumption when the received quantity of raw products is increased and decreased 10% and when the initial moisture content of received raw products is increased and decreased by two percentage points.

The results demonstrate that the highest magnitude impacts occurred when initial moisture content of received raw products is decreased two percentage points. Contrasting outcomes from the normal system simulation with the simulation in which initial moisture content is decreased 2 percentage points, it was verified that in the adjusted simulation: (i) average firewood consumption decreases 14.90%, with consumption values decreasing from 343.80t \pm 4.23 t to 292.60t \pm 3.44 t, (ii) average specific firewood consumption decreases 15.11%, with consumption values decreasing from 36.32 \pm 0.41 to 30.83kg \pm 0.37 kg per tonne of corn input at the drying sector, (iii) average electrical energy consumption drops 7.90%, with consumption values decreasing from 77.60 \pm 0.40 to 71.74 \pm 0.47 MWh, and (iv) average specific electrical energy consumption decreases 15.15%, with consumption values decreasing from 3.63 \pm 0.04 to 3.08 \pm 0.04 MWh per tonne of corn input at the drying sector.

REFERENCES

- Imagine That, Inc. 1997. *Extend + Manufacturing [Extend +Manufacturing User's Manual – Version 4]*. San Jose, CA.
- Krahl, A. 2000. The Extend simulation environment. *Proceedings of the 2000 Winter Simulation Conference*. Eds. J. A. Joines, R. R. Barton, K. Kang, and, P. A. Fishwick, pp 280-289. IEEE, Piscataway, NJ.
- Law, A. M. and W. D. Kelton. 1991. *Simulation modeling and analysis*. 2nd Edition. New York: McGraw-Hill, Inc.

- Maria, A. 1997. Introduction to modeling and simulation. *Proceedings of the 1997 Winter Simulation Conference Proceedings*. Eds. S. Andatóttir, K. J. Healy, D. H. Withers, and B. L. Nelson, pp 7-13. IEEE, Piscataway, NJ.
- Monsef, Y. 1997. *Modeling and simulation of complex systems*. Hungary: European Publishing House.
- Neelamkavil, F. 1987. *Computer simulation and modeling*. Great Britain: John Wiley & Sons Ltd.
- Palisade Corporation, 2000. *@Risk: Advanced risk analysis for spreadsheets*. Newfield: NY
- Song, A., D. S. Chung, and R. Nassar. 1990. A stochastic compartmental model simulating a grain cleaning process. *Trans. ASAE* 33(3): 877-884.
- Schmidt, J. W., R. E. Taylor. 1970. *Simulation and Analysis of Industrial Systems*. Georgetown, Canada: Richard Irwin Inc.

CHAPTER V

SCENARIO ANALYSIS RELATED TO DRYING SECTOR CONFIGURATION

Abstract. *This work deals with a scenario analysis of a drying sector's configuration. To support this study, a simulation model was built by using Extend™ software and the software library "Grain Facility." Three scenarios were contrasted. Scenario #2 refers to a facility modeled with has one 80 t/h mixed flow dryer, three 40 t/h pre-cleaners, and four 30 t/h four cleaners. Scenario #1 was defined by decreasing dryer capacity to 60 t/h and the number of pre-cleaners and cleaners to two and three respectively. Scenario #3 was defined by increasing dryer capacity to 100 t/h and the number of pre-cleaners and cleaners to four and five respectively. Results showed no significant differences in the operational parameters related to the amounts of received, processed, transferred, and stored products (corn, soybean and wheat). The lowest firewood consumption value was found in scenario #1 (719.28t). This value was 4.95% and 10.12% lower than average values found in scenarios #2, and #3 respectively. Scenario #1 also had the lowest electrical energy consumption values. The predicted average (143.53 MWh) was 9.08% and 17.49% lower than similar values from scenarios #2, and #3 respectively.*

Keywords. *grain storage facility, drying capacity, Extend™*

INTRODUCTION

Operationally, grain storage facilities may be divided into sectors, such as receiving, cleaning, drying, storage, and dispatch, which need to be equipped, structured, linked upon a logical flowchart, and managed efficiently. This division and organization is warranted to conserve product qualities and facility profits (Flores, 1988).

Drying sector is one of the key elements in a grain storage facility, due to the large investment needed, the dryer's possible operational effect upon final product quality, and the amount of fuel and electrical energy the dryer consumes. This paper deals with a study intended to demonstrate how changes in dryer capacity influence the grain storage facility's system performance. The

experiment was carried out using a dynamic, stochastic, and discrete model that allows simulation of the dynamic of grain storage facility systems.

BACKGROUND

According to the grain storage facility concept presented herein, the facility's system may be operationally divided into sectors. The receiving sector is in charge of accepting or rejecting a product load that needs to be cleaned, dried, and stored. Structurally, this center may include an office, a grain quality control laboratory, a scale, receiving pits, and wet holding bins.

The cleaning sector contains machines that are used to remove undesired materials, such as broken kernels, and foreign materials from grain or legume mixtures. Products are normally run through pre-cleaner machines before drying and cleaner machines after drying (Vaughan et al., 1968; Weber, 2001; Song, 1990).

The drying sector is the key element for maintaining the product quality. In Brazil, the great majority of grain storage facilities use mixed-flow dryers, also called cascade or rack type dryers (Brooker et al., 1992) with dryer capacities ranging from 15 to 120 tonnes per hour. Firewood is the traditional fuel used to heat the drying air; however, some facilities have been using propane and fuel-oil (Weber, 2001).

The storage sector is responsible for quality maintenance. Thus, it needs to have the types of structures that allow grain or legumes to be held in perfect conditions. These structures may be metal or concrete bins or a type of flat storage, which may have one or more sections. The bottom of flat storage can have flat, W, or V formats. The W and V formats being the most commonly employed in Brazil because they can be emptied using gravity (Weber, 2001). For monitoring and preserving product quality, storage structures can be equipped with thermometry and/or aeration systems. The thermometry system allows monitoring of the grain mass's temperature, a key parameter used for evidencing problems during the storage period. The aeration system is mainly employed for homogenizing and maintaining the product mass's temperature at proper levels.

The dispatching sector is in charge of delivering the stored products by means of truck or railcar. Structurally, this center is comprised of a holding structure built to allow trucks or railcars to be parked beneath it. Thus, the loading process is carried out by gravity force. The holding structures themselves are normally bins or boxes built of metal or concrete.

EXPERIMENT ORGANIZATION

The experiment was carried out by contrasting three scenarios, which basically involved the adoption of three different capacity dryers and different numbers of pre-cleaning and cleaning machines. In scenario #1, dryer capacities are 60t/hr; in scenario #2, dryer capacities are 80t/hr; and in scenario #3, dryer capacities are 100t/hr. To support this scenario analysis, a dynamic, stochastic and discrete model was developed using the simulation language Extend™, version 4.1.3C (Krahl, 2000), together with the *Grain Facility* library. This library has a set of blocks that allows the simulation of structures and equipment used in grain storage facilities. Figure 1 shows the main blocks of this library.

The implemented model was developed according to the technical characteristics of a grain storage facility that belongs to COAMO, an agricultural cooperative headquartered in Campo Mourão, Paraná State, Brazil. The main technical information about the modeled facility is presented in Table 1. Table 2 shows the input information for the *Arrival Generators* block, and Table 3 shows the dispatch plans for corn, soybeans, and wheat. The model constructed is defined by scenario # 2, in which the dryers have a capacity of 80 t/h and there are three pre-cleaning and four cleaning machines.

Scenarios #1 and #3 were established by modifying the scenario #2 model. For scenario #1, the modifications were a decrease in dryer capacity to 60 t/h and a decrease in the number of pre-cleaners and cleaners to two and three respectively (Table 1). For scenario #3, the modifications were an increase of dryer capacity to 100 t/h and an increase in the number of pre-cleaners and cleaners to four and five respectively. In addition, the nominal capacity of the conveyors that input and output the products at the drying sector was adjusted.

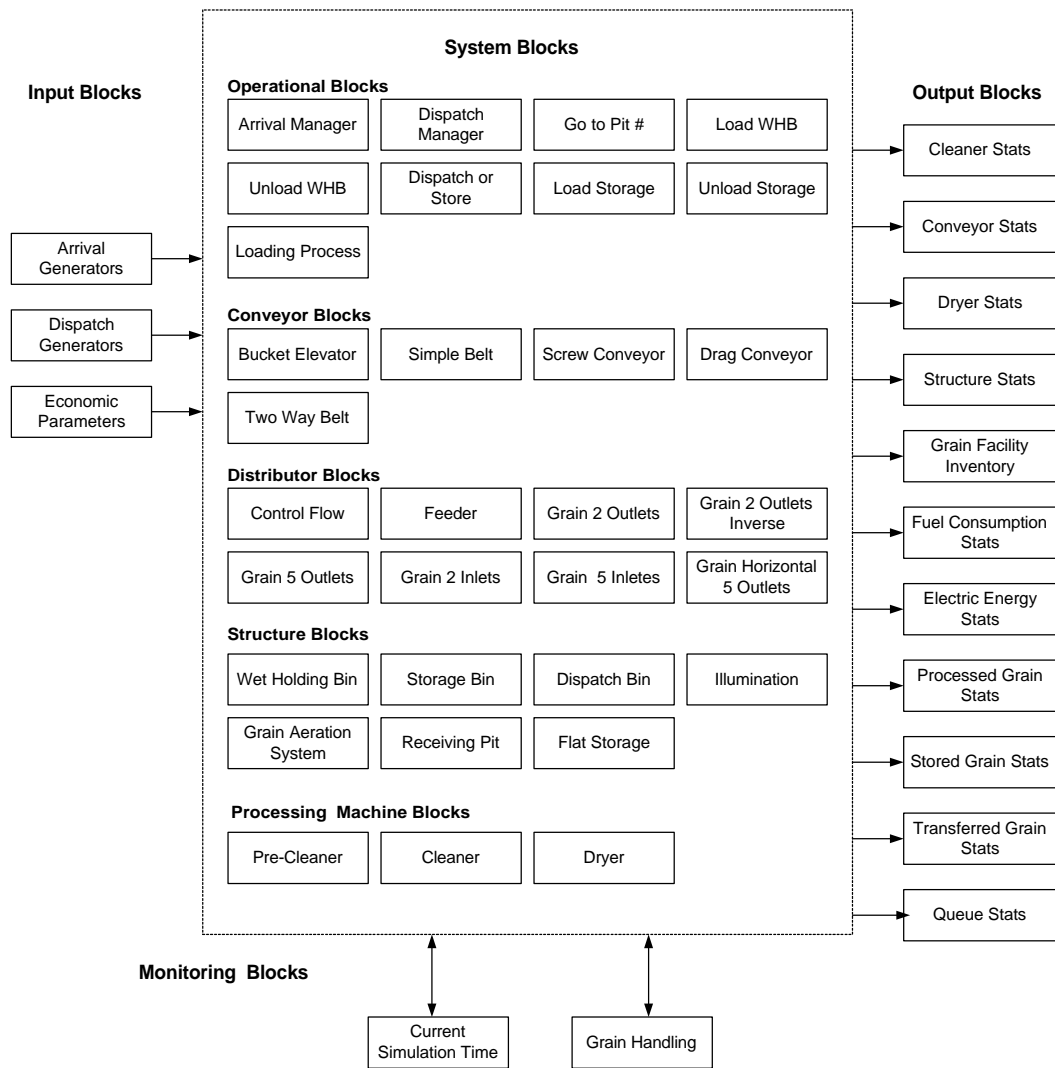


Figure 2 – Grain Facility library schematic representation

Table 1 – Some technical information of the modeled grain storage facility (Scenario #2)

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
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 – Information used at the *Arrival Generators* block

Product	Distribution Types for Predicting The “ <i>daily harvest success index</i> ” - DHSI	Received Amount of Products (t)	Harvest Period	Moisture Content		Foreign Material Content	
				% w.b.	% of loads	%	% of loads
Corn (1 st Crop)	Beta $\alpha_1 = 0.2287$ $\alpha_2 = 0.5360$ Minimum = 0 Maximum = 317.18	7,376	01/26/99	lower than 14.2	1.42	1.1 to 2.0	93.87
			to	14.3 to 18.2	4.22	2.1 to 3	6.13
			03/06/99	18.3 to 24.0	57.60		
				higher than 24.0	36.75		
Corn (2 nd Crop)	Exponential $\beta = 101.355$ Shift = -1.3697	7,804	07/17/99	lower than 14.2	1.64	lower than 1.0	3.37
			to	14.3 to 18.2	10.27	1.1 to 2.0	96.63
			09/30/99	18.3 to 24.0	55.12		
				higher than 24.0	33.96		
Soybean	Beta $\alpha_1 = 0.3665$ $\alpha_2 = 1.7942$ Minimum = 0 Maximum = 686.70	53,179	02/26/99	lower than 14.2	55.02	1.1 to 2.0	92.54
			to	14.3 to 18.2	39.03	2.1 to 3.0	6.88
			04/30/99	18.3 to 24.0	5.85	3.1 to 6.0	0.56
Wheat	Exponential $\beta = 100.001$ Shift = -2.2728	5,118t	08/16/99	14.3 to 18.2	54.60	lower than 1.0	29.22
			to	18.3 to 24.0	45.40	1.1 to 2.0	54.55
			09/29/99			2.1 to 3.0	16.24

Table 3 – Dispatch plans for corn, soybeans, and wheat

Month	Stock portions to be dispatched (%)		
	Corn	Soybean	Wheat
1	0	0	0
2	20.35	0	0
3	29.82	47.18	0
4	0.15	14.52	0
5	0	20.58	0
6	0	0.67	0
7	0	6.52	0
8	20.45	7.81	0
9	0.55	0.54	69.96
10	0.55	0	0
11	7.03	1.32	0
12	21.10	0.86	30.04

Table 4 lists the installed electrical energy demands for the grain storage facility sectors, according to defined scenarios.

Table 4 – Installed demand (kW) per grain facility sector

Grain Facility Sector	Installed Demand (kW)		
	Scenario #1	Scenario #2	Scenario #3
Receiving	64.40	64.40	64.40
Pre- Cleaning	14.72	20.60	26.50
Drying	45.63	71.39	86.11
Cleaning	38.27	47.84	57.40
Storage	55.20	55.20	55.20
Dispatch	22.08	22.08	22.08
General Use	1.50	1.50	1.50
Total	241.80	283.01	313.91

Scenario analysis was performed considering the following parameters: processed, transferred, stored, and dispatched amounts of product (corn, soybeans, and wheat) and firewood and electrical energy uses.

For each studied scenario, five model runs were performed and averages and 99 % confidence intervals determined. The simulation time was programmed for one year (8,640 hours).

RESULTS AND DISCUSSION

Table 5 presents the predicted 99% confidence interval for received, processed, transferred, and stored amount of products in the three studied scenarios. Figure 3 presents a schematic of the confidence interval bands for processed and transferred amounts. This last parameter corresponds to the quantity of product that had to be transferred to another grain facility for processing due facility limitations.

Table 5 – Predicted 99% confidence interval bands for received, processed, transferred, and stored amounts of products

Scenario	Amount of products – (t)			
	Received	Processed	Transferred	Stored
#1	73,474.00	62,689.18 ± 2,416.06	5,945.57 ± 2,618.26	51,477.72 ± 3,834.02
#2	73,474.00	64,031.42 ± 1,462.57	4,533.57 ± 1,590.92	53,642.34 ± 3791.62
#3	73,474.00	63,593.19 ± 897.10	4,968.29 ± 1,015.19	52,698.57 ± 2,247.81

According to the information in Table 5 and Figure 3, it can be noted that values obtained for the three scenarios are very similar. The highest average amount of product processed is found in scenario # 2. This value is 2.09% and 0.68% above the values obtained from for scenarios #1 and #3 respectively. This means that, from an operational perspective, any one of the scenarios could be chosen if one is opting to maximize processed amounts.

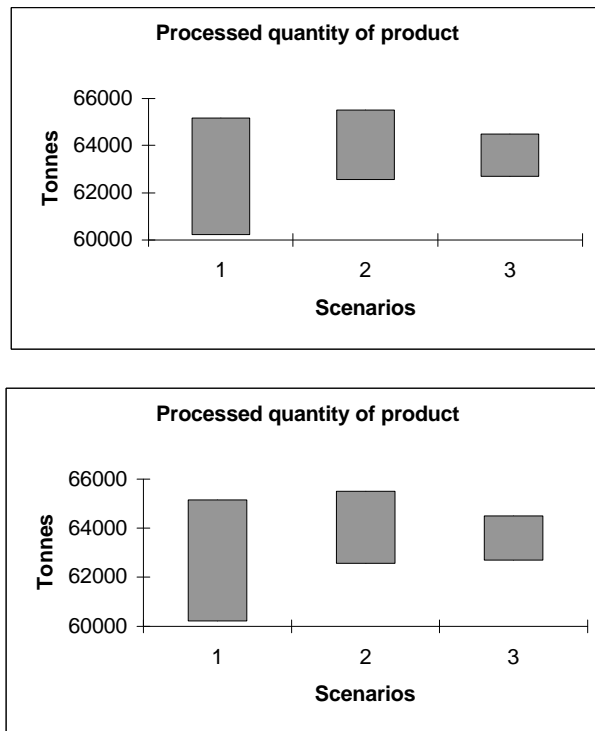


Figure 3 – Boundaries representation of 99% confidence intervals for processed and transferred quantities of product.

Considering firewood consumption, the 99% confidence intervals determined for model outputs were: $719.28t \pm 24.77t$, $754.91t \pm 23.94t$, $792.08t \pm 22.61t$ for the scenarios #1, # 2, and #3 respectively. Comparing the average values, the greatest firewood consumption was found in scenario #3 (792.08 t). This value is 10.12% and 4.92% higher than the firewood consumption values from scenarios #1 and #2 respectively. Table 6 shows the values of simulated firewood specific consumption for the studied scenarios. The highest values were from scenario #3. It can be verified that firewood specific consumption values for processing corn, soybean, and wheat were 9.65%, 1.53% and 9.20% lower respectively in scenario #1 than in scenario #3. Therefore, considering the firewood consumption, the better option is scenario #1's dryer arrangement.

Table 6 – Specific firewood consumption in kg of firewood per tonne of product

Scenarios	Corn	Soybean	Wheat
#1	26.20 ± 1.72	12.80 ± 0.92	15.80 ± 0.92
#2	26.80 ± 0.92	12.60 ± 1.13	16.40 ± 1.13
#3	29.00 ± 1.46	13.00 ± 0.00	17.40 ± 1.84

The 99% confidence intervals for annual electrical energy consumption in scenarios #1, # 2 and # 3 were 143.53 ± 8.10 , 156.57 ± 9.98 , and 168.64 ± 13.92 MWh respectively. The highest average value was found in scenario #3, which was 14.88% and 7.15% higher than the electrical energy consumption values from scenarios #1 and #2 respectively.

The 99% confidence intervals for the highest annual electrical energy demand from scenarios #1, # 2 and # 3 were 232.05 ± 15.98 , 258.06 ± 6.83 , and 288.01 ± 32.72 kW respectively. The highest average value was found in scenario #3 (288.01 kW), which was 19.42% and 10.40% higher than the values from scenarios #1 and #2 respectively.

Table 7 shows the values predicted for annual electrical energy consumption in the studied scenarios' grain storage sectors. Consumption was predicted according to installed demand values listed in Table 4.

According to Table 4, the total installed demand for scenarios #1, #2 and #3 was 241.80, 283.01, and 313.91 kW respectively. The major differences arose from the pre-cleaning, drying, and cleaning sectors. The most pronounced difference was found between drying sectors in which installed demand values were 45.63, 71.39, and 86.11 kW for scenarios #1, # 2 and # 3 respectively.

In Figure 5, predicted average annual electrical consumption was plotted for different grain facility sectors. The greatest differences were found between the drying sectors, in which average electricity consumption was 47.37, 60.46, and 68.76M Wh for scenarios #1, #2, and #3 respectively. The electricity consumption value for scenario #3 was 31.10% and 12.07% higher than in scenarios #1, and #2 respectively.

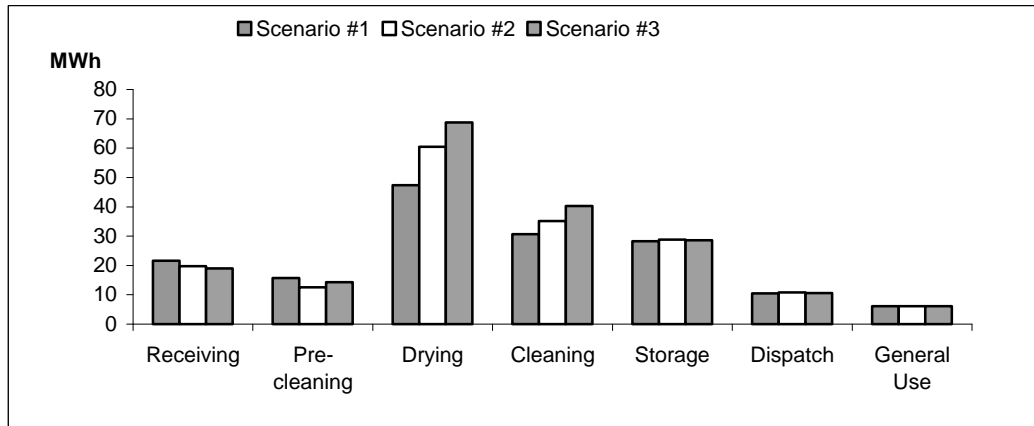


Figure 5 – The predicted average annual electric energy consumption, according to grain storage facility sectors in the studied scenarios.

Table 7 – Specific electric energy consumption for products at the drying sector

Product	Specific electric energy consumption (kW/ kg of product)		
	Scenario #1	Scenario #2	Scenario #3
Corn	1.687 ±0.023	2.133 ±0.341	2.368 ±0.264
	0.836 ±0.031	1.093 ±0.112	1.183 ±0.073
Soybean			
Wheat	1.089 ±0.066	1.445±0.288	1.580 ±0.242

In Table 6, the specific electric energy consumption for the drying sector is presented. As can be noted, scenario #1 had the lowest consumption value. The presented values are strongly linked with the installed demand in the drying sector (Table 4) and the product's initial moisture content (Table 2).

Therefore, scenario #1 was the best scenario if one is trying to reduce consumption of electric energy.

CONCLUSION

Considering the parameters amount of product received, processed, transferred, and stored, it was found that the values generated in each scenario were very similar. Specifically, the model's predicted average values for the amount of product processed in scenarios #1, #2 and #3 were 62,698.18t, 64,031.42t, and 63,593.19t respectively. The highest value for amount processed was found in scenario # 2; 2.09% and 0.68% above the values obtained from scenarios #1 and #3 respectively. Thus, from operational point of view, the amount processed is essentially the same in all scenarios.

Firewood consumption was found to be the least in scenario #1, with a predicted annual average value of 719.28 tonnes. This value was 4.95% and 10.12 % below the average values observed in scenarios #2 and #3.

Electrical energy consumption was also found to be the least in scenario #1. The 99% confidence intervals for annual electric energy consumption for scenarios #1, # 2 and # 3 were 143.53 ± 8.10 , 156.57 ± 9.98 , and 168.64 ± 13.92 MWh respectively. The average consumption value predicted for scenario #1 was 9.08% and 17.49% lower than the consumption values from scenarios #2 and #3 respectively.

In summary, for studied conditions, it can be concluded that the grain storage facility's actual configuration, scenario #2, appeared well designed because operationally very similar results were obtained from the three scenarios. However, the best results in terms of electric energy and firewood consumption were came from scenario #1. Realizing that scenario #2 refers to an existing grain storage facility, a change in dryer sector configuration might not be economically justified. But, if it one were designing a new facility, the scenario #1 represents the best design. It had the lowest investment and operational cost of all modeled scenarios.

REFERENCES

- Brooker, D. B., F. W. Bakker-Arkema, and C. W. Hall. 1992. *Drying and storage of grains and oilseeds*. New York: Van Nostrand Reinhold.
- Flores, R. A. 1988. Quality is chief priority in grain storage units. *Agribusiness Worldwide*. 11 (10): 9-16.
- Krahl, A. 2000. The Extend simulation environment. *Proceedings of the 2000 Winter Simulation Conference*. Eds. J. A. Joines, R. R. Barton, K. Kang, and, P. A. Fishwick, pp 280-289. IEEE, Piscataway, NJ.
- Song, A., D. S. Chung, and R. Nassar. 1990. A stochastic compartmental model simulating a grain cleaning process. *Trans. ASAE* 33(3): 877-884.
- Vaughan, C. E., G. R. Bill, and J. C. Delouche. 1968. *Seed processing and handling*. Section K: 235-250. Handbook No. 1, Seed Technology Laboratory. Mississippi State University. Mississippi: Mississippi State.
- Weber, E. A. 2001. *Armazenagem agrícola.[Farm storing]*. Guaíba, RS, Brazil: Livraria e Editora Agropecuária,

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

This study focused on the modeling of grain storage facilities, taking into consideration the randomness of factors that might affect their performance. A simulation toolset for the construction of models that replicate the dynamic behavior of grain storage facilities was introduced to address these factors and to support facility evaluation and feasibility analyses.

The simulation toolset was developed from a conceptualized model in which the grain storage facility environment was separated into sectors (receiving, pre-cleaning, drying, cleaning, storage, and dispatching), equipped, structured, and logically linked by conveyors. The harvest process and market demand were considered the most relevant external stochastic factors. They were modeled to generate events related to the arrival of trucks at the receiving and dispatch sectors.

To develop the simulation toolset, called "*Grain Facility*," Extend™ software, version 4.1.3C, was employed. The toolset works as an Extend™ library and contains a set of blocks. These blocks were programmed for the simulation of the grain facility's: (i) receiving and dispatch activities, (ii) grain processing unit operations, (iii) operational decisions, (iv) system constraints, (v) electric energy consumption, and (vi) fuel consumption in the drying process. The structured models built by using "*Grain Facility*" are classified as dynamic, stochastic, and discrete.

Three models were introduced. They were used in the system performance, verification, and validation studies. The data for their elaboration were obtained from the Brazilian "*Cooperativa Agropecuária Mourãoense Ltda.*" (COAMO), an agricultural cooperative headquartered in Campo Mourão, Paraná State, Brazil. The verification and validation analyses, considering the models' domains, lead to the conclusion that model outcomes and system outcomes were in good agreement, which indicates the *Grain Facility*' toolset's

significant problem solving potential. The introduced models were demonstrated to be valuable tools.

Grain storage facility models developed using the “*Grain Facility*” toolset can be used to: (i) conduct grain storage facility feasibility analyses, (ii) as a teaching tool to clarify cases under study, (iii) estimate electrical energy and fuel uses, and (iv) analyze existing and planned systems and assist in facility expansion, remodeling, and technological updating. In addition, according to characteristics of the simulation language ExtendTM, the developed models can support decision makers working in the grain handling area by supplying them with pre-assembled simulation models of systems under their management. This will minimize risks when defining strategies to reduce operational costs. The simulation tool also allows engineers and designers to model existing or proposed systems, contributing to facility evaluations and feasibility analyses.

Models developed using ExtendTM in conjunction with the “*Grain Facility*” library offer a great variety of output information, which, according to the user’s background and study purpose, can be selected for numerous applications.

Analysis of the implemented models suggests the following possibilities for future investigation in this area:

1 – Time spent in simulation needs to be decreased

It was observed that the time spent running a simulation is strongly linked with the amount of quantities of raw product received at the facility. For example, using a PentiumTM 500 Mhz microcomputer to simulate the handling of 75,000 t of raw product, approximately 3.5 hours is spent in simulation. Possibly, the defined relationship of one tonne of raw product corresponding to one item should be improved. However, this relationship is now needed to ensure the model’s accuracy.

2 – A method to improve characterization of raw products should be investigated

Moisture and foreign material content information needs to be obtained more rigorously and described by means of an adequate distribution, considering the harvest time period progress. This is especially important for moisture content since it directly affects dryer operations and, thereby, the consumption of electric energy and fuels.

3 – Simulation time could be extended beyond 12 months

The time routine controls needs to be updated in order to allow a simulation covering more than 12 months of operational activities.

4 – Hierarchical blocks could be modeled as code blocks

Blocks that simulate receiving pits, dryers, and arrival and dispatch generators are hierarchical blocks; they should be transformed into code blocks. This could reduce the time for simulation and make model use more flexible.

5 – Other products and operations should be considered

The developed models only consider the possibility of grain storage facility systems that handle corn, soybeans, and wheat. More product options are needed. In addition, the modeling procedures are exclusively focused on grain handling unit operations, ignoring the impact of other storage facility operations, such as foreign material handling, storage, and dispatch; therefore, precluding the study of processes that affect electric energy consumption.

6 – Economic variables should be added

In order to meet the needs of decision makers more effectively, new item attributes should be introduced into the simulation to allow the determination of all costs related to unit operations. In addition, other variables should be added to support the elaboration of economic feasibility analyses.

APPENDICES

Appendix A

1A – Grain Storage Facility A – Technical Characteristics

Table 1A – Receiving Center

Description	Identification	Capacity – t	Note
Receiving Pit	PIT-01	300	
Receiving Pit	PIT-02	300	Has a mechanical unloading system.
Receiving Pit	PIT-03	300	Has a mechanical unloading system.
Receiving Pit	PIT-04	300	
Wet Holding Pit	WHP-01	300	
Wet Holding Pit	WHP-02	300	

Table 2A – Bucket Elevators

Description	Identification	Hourly Capacity (t/h)	Power (hp)	Main Function
Bucket Elevator	BK-01	120	20	Unloads – Receiving Pit
Bucket Elevator	BK-02	120	20	Unloads – Receiving Pit
Bucket Elevator	BK-03	120	20	Unloads – Receiving Pit
Bucket Elevator	BK-04	120	20	Loads – dryer
Bucket Elevator	BK-05	120	20	Unloads – dryer
Bucket Elevator	BK-06	120	20	Loads – flat storage
Bucket Elevator	BK-07	120	20	Loads – dispatching box
Bucket Elevator	BK-08	120	20	Loads – foreign material bin

Table 3A – Drag Conveyors

Description	Identification	Hourly Capacity (t/h)	Power (hp)	Main Function
Drag Conveyors	DC-01	120	4	Loads: pre-cleaners
Drag Conveyors	DC-02	120	3	Loads – cleaners

Table 4A – Belt Conveyors

Description	Identification	Hourly Capacity (t/h)	Power (hp)	Main Function
Simple Belt	SB-01	120	7,5	Unloads: Receiving pits
Double Belt	DB-02	120	10	Direction 1 – Unloads: Receiving pits Direction 2 – Allows direct transference
Double Belt	DB-03	120	10	Direction 1 – Unloads – cleaners Direction 2 – reprocessing
Simple Belt	SB-04	120	10	Loads – flat storage
Simple Belt	SB-05	120	10	Unloads – flat storage

Table 5A – Pre-cleaners

Description	Identification	Hourly Capacity (t/h)	Power (hp)	Note
Pre-cleaner	PC-01	40	8	-
Pre-cleaner	PC-02	40	8	-
Pre-cleaner	PC-02	40	8	-

Table 6A – Cleaners

Description	Identification	Hourly Capacity (t/h)	Power (hp)	Note
Cleaner	CL-01	30	8	-
Cleaner	CL-02	30	8	-
Cleaner	CL-03	30	8	-
Cleaner	CL-04	30	8	-

Table 7A – Dryers

Description	Identification	Hourly Capacity (t/h)	Fan Power (hp)	Note
Dryer	DR-01	80	3x25	Fans located at top

Table 8A – Storage Center – Flat Storage

Description	Identification	Capacity (t)	Note
Cell	FSCL-01	5,000	-
Cell	FSCL-02	8,000	-
Cell	FSCL-03	5,000	-

Table 9A – Dispatch Center

Description	Identification	Capacity (t)	Note
Metal Box	DP-01	80	-

Table 10A – Foreign Storage Bin

Description	Identification	Capacity (t)	Note
Foreign Material Storage Bin	FMB-01	600	-

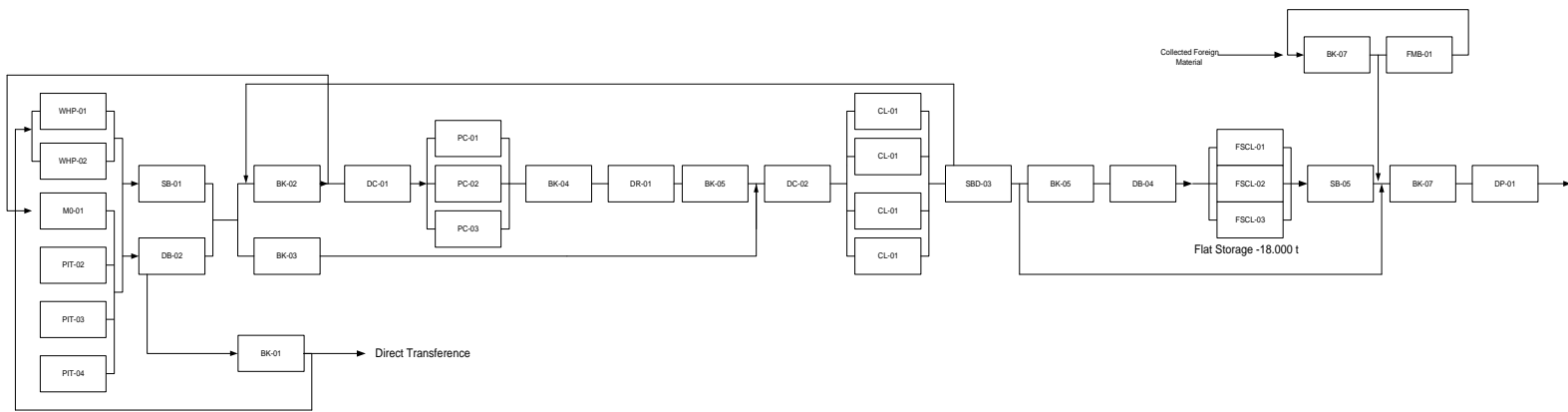


Figure 1A – Operational flowchart – Grain Storage Facility A.

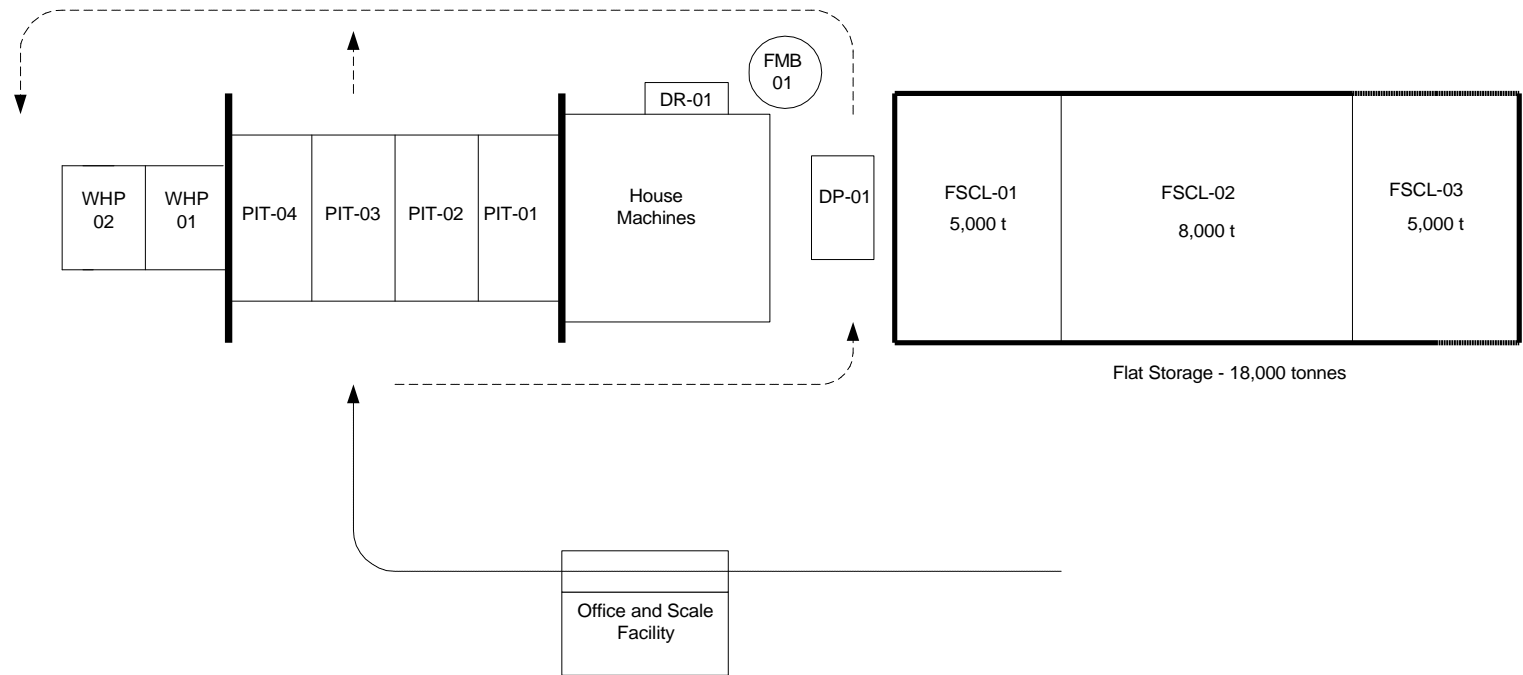


Figure 2A- Layout - Grain Storage Facility A.

Appendix B

1B – Grain Storage Facility B – Technical Characteristics

Table 1B – Receiving Center

Description	Identification	Capacity – t	Note
Receiving Pit	PIT-01	150	
Receiving Pit	PIT -02	150	Has its own mechanical unloading system.
Receiving Pit	PIT -03	150	Has its own mechanical unloading system.
Receiving Pit	PIT -04	150	–
Wet Holding Pit	WHP-01	150	–
Wet Holding Pit	WHP-02	150	–

Table 2B – Bucket Elevators

Description	Identification	Hourly Capacity (t/h)	Power (hp)	Main Function
Bucket Elevator	BK-01	120	20	Loads – wet holding pits
Bucket Elevator	BK-02	120	20	Unloads – receiving pits
Bucket Elevator	BK-03	120	25	Loads – receiving pits
Bucket Elevator	BK-04	60	12,5	Loads – dryer 01
Bucket Elevator	BK-05	60	7,5	Unloads – dryer 01
Bucket Elevator	BK-06	40	7,5	Loads – foreign material bin –02
Bucket Elevator	BK-07	40	7,5	Loads – foreign material bin –01
Bucket Elevator	BK-08	120	25	Loads – flat storage
Bucket Elevator	BK-09	120	20	Loads – flat storage
Bucket Elevator	BK-12	60	12,5	Loads – dryer 02
Bucket Elevator	BK-13	60	7,5	Unloads – dryer 02

Table 3B – Drag Conveyors

Description	Identification	Hourly Capacity (t/h)	Power (hp)	Main Function
Drag Conveyor	RD-01	120	4	Loads: pre-cleaners
Drag Conveyor	RD-02	120	4	Loads: pre-cleaners

Table 4B– Belt Conveyors

Description	Identification	Hourly Capacity (t/h)	Power (hp)	Main Function
Double Belt	DB-01	120	7,5	Direction 1 – Loads: wet holding pits; Direction 2 – Unloads: receiving pits
Simple Belt	SB-02	120	5	Unloads: receiving pits
Double Belt	DB-03	120	7,5	Direction 1 – unloads cleaners Direction 2 – to reprocessing
Simple Belt	SB-05	120	10	Loads – flat storage
Simple Belt	SB-07	120	10	Unloads – flat storage
Simple Belt	SB-21	120	10	Loads: flat storage
Double Belt	DB-22	120	7,5	Direction 1 – unloads pre-cleaners Direction 2 – to reprocessing

Table 5B – Pre-cleaners

Description	Identification	Hourly Capacity (t/h)	Power (hp)	Main Function
Pre-cleaner	PL-01	40	8	Manufacturer: Caliver
Pre-cleaner	PL-02	40	8	Manufacturer: Caliver
Pre-cleaner	PL-15	40	8	Manufacturer: Caliver
Pre-cleaner	PL-16	40	8	Manufacturer: Caliver

Table 6B – Cleaners

Description	Identification	Hourly Capacity (t/h)	Power (hp)	Note
Cleaner	CL-01	30	8	Manufacturer: Caliver
Cleaner	CL-02	30	8	Manufacturer: Caliver
Cleaner	CL-03	30	8	Manufacturer: Caliver
Cleaner	CL-17	30	10	Manufacturer: Armco
Cleaner	CL-18	30	8	Manufacturer: Caliver
Cleaner	CL-19	30	8	Manufacturer: Caliver

Table 7B – Dryers

Description	Identification	Hourly Capacity (t/h)	Power (hp)	Note
Dryer	DR-01	40	50	Manufacturer: Caliver
Dryer	DR-02	40	50	Manufacturer: Kepler Weber

Table 8B – Storage Center – Flat Storage

Description	Identification	Capacity (t)	Note
Cell	CL-01	5,400	-
Cell	CL-02	7,200	-
Cell	CL-03	5,400	-

Table 9B – Dispatch Center

Description	Identification	Capacity (t)	Note
Metal Box	DP-01	60	-

Table 10B – Foreign Storage Bin

Description	Identification	Capacity (t)	Note
Foreign Material Storage Bin	FMB-01	600	-
Foreign Material Storage Bin	FMB-02	600	-

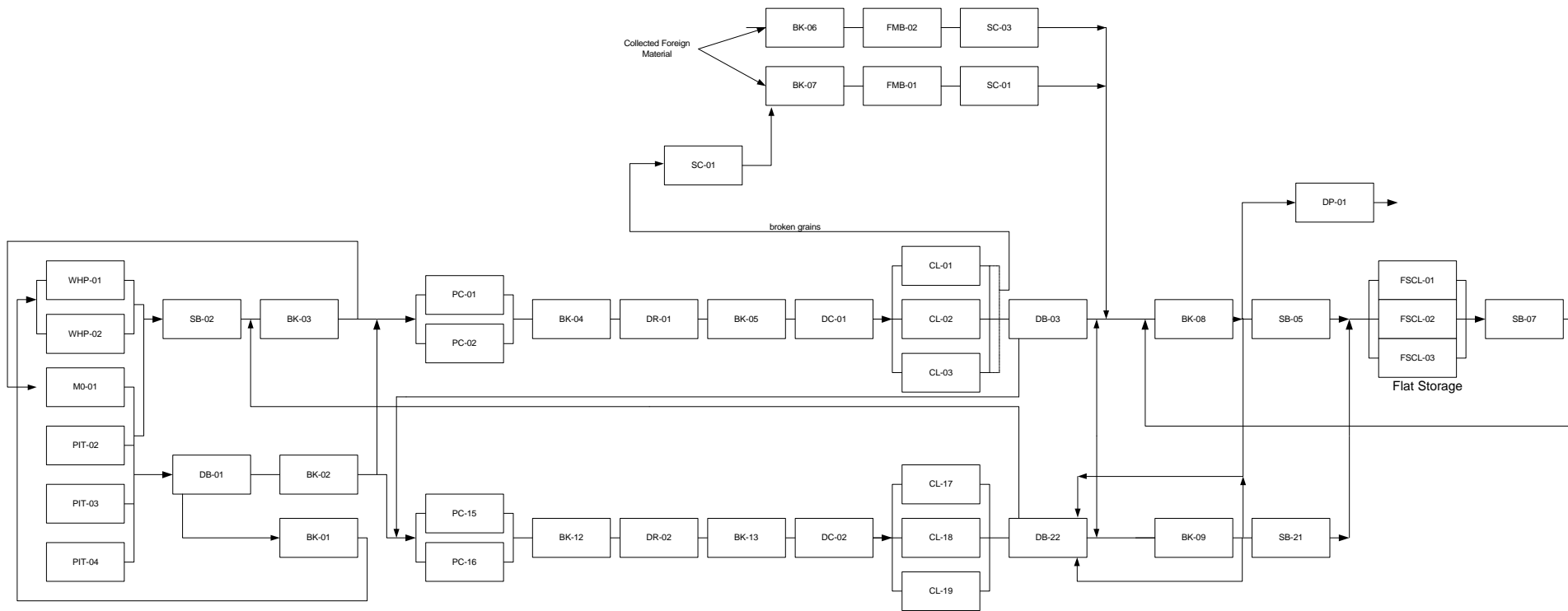


Figure 1B – Operational flowchart – Grain Storage Facility B.

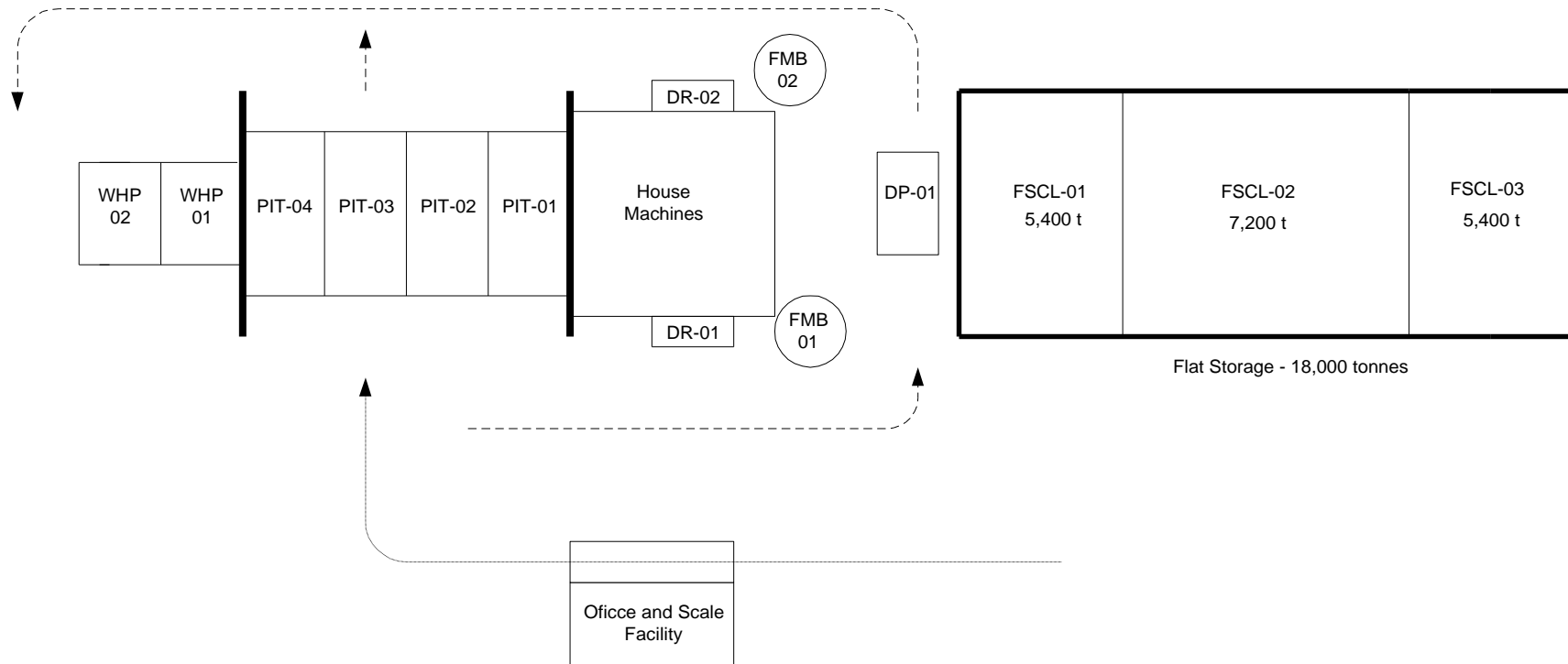


Figure 2B – Layout – Grain Storage Facility B.

Appendix C

1C – Grain Storage Facility C – Technical Characteristics

Table 1C – Receiving Center

Description	Identification	Capacity – t	Note
Receiving Pit	PIT-01	60	-
Receiving Pit	PIT-02	60	-
Receiving Pit	PIT-03	60	-
Receiving Pit	PIT-04	60	-

Table 2C – Bucket Elevators

Description	Identification	Hourly Capacity (t/h)	Power (hp)	Main Function
Bucket Elevator	BK-01	60	10	Unloads – receiving pits
Bucket Elevator	BK-02	60	10	Unloads – receiving pits
Bucket Elevator	BK-03	60	10	Loads – dryer
Bucket Elevator	BK-04	120	20	Unloads – dryer
Bucket Elevator	BK-05	60	10	Loads – storage bins
Bucket Elevator	BK-06	120	20	Loads – storage bins

Table 3C – Screw Conveyors

Description	Identification	Hourly Capacity (t/h)	Power (hp)	Main Function
Screw Conveyor	SC-01	60	5	Unloads – pre-cleaners
Screw Conveyor	SC-11	60	5	Unloads – storage bins
Screw Conveyor	SC-12	60	5	Unloads – storage bins
Screw Conveyor	SC-13	120	7.5	Unloads – storage bins
Screw Conveyor	SC-14	120	7.5	Unloads – storage bins

Table 4C – Belt Conveyors

Description	Identification	Hourly Capacity (t/h)	Power (hp)	Main Function
Simple Belt	CT-01	60	5	Load – dispatch bin
Simple Belt	CT-02	120	7.5	Loads – storage bins
Simple Belt	CT-03	120	7,5	Loads – storage bins

Table 5C – Pre-cleaners

Description	Identification	Hourly Capacity (t/h)	Power (hp)	Main Function
Pre-cleaner	PC-01	40	8	-
Pre-cleaner	PC-02	40	8	-

Table 6C– Cleaners

Description	Identification	Hourly Capacity (t/h)	Power (hp)	Main Function
Cleaner	CL-01	30	8	Model – KW LC 160SP
Cleaner	CL-02	30	8	Model – KW LC 160SP

Table 7C – Dryers

Description	Identification	Hourly Capacity (t/h)	Power (hp)	Main Function
Dryer	DR-01	40	30	Model – KW 215R

Table 8C – Storage Center – Metal Bins

Description	Identification	Capacity (t)	Note
Metal Bin	BIN-01	300	-
Metal Bin	BIN -02	300	-
Metal Bin	BIN -03	3,000	-
Metal Bin	BIN -04	3,000	-

Table 9C – Dispatch Center

Description	Identification	Capacity (t)	Note
Metal Bin	DP-01	42	-

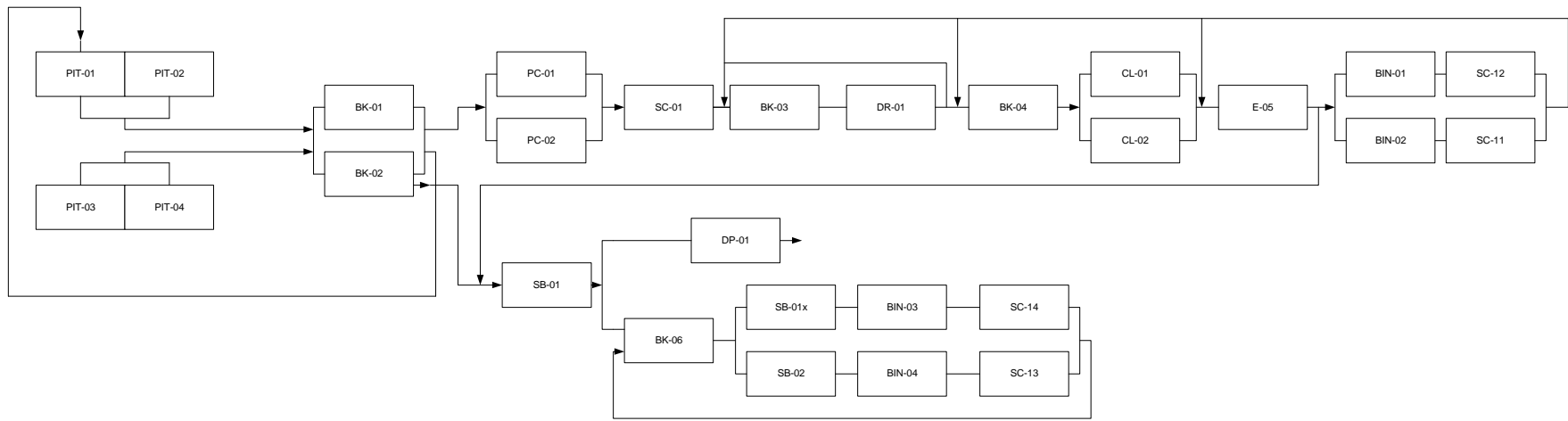


Figure 1C – Operational flowchart – Grain Storage Facility C.

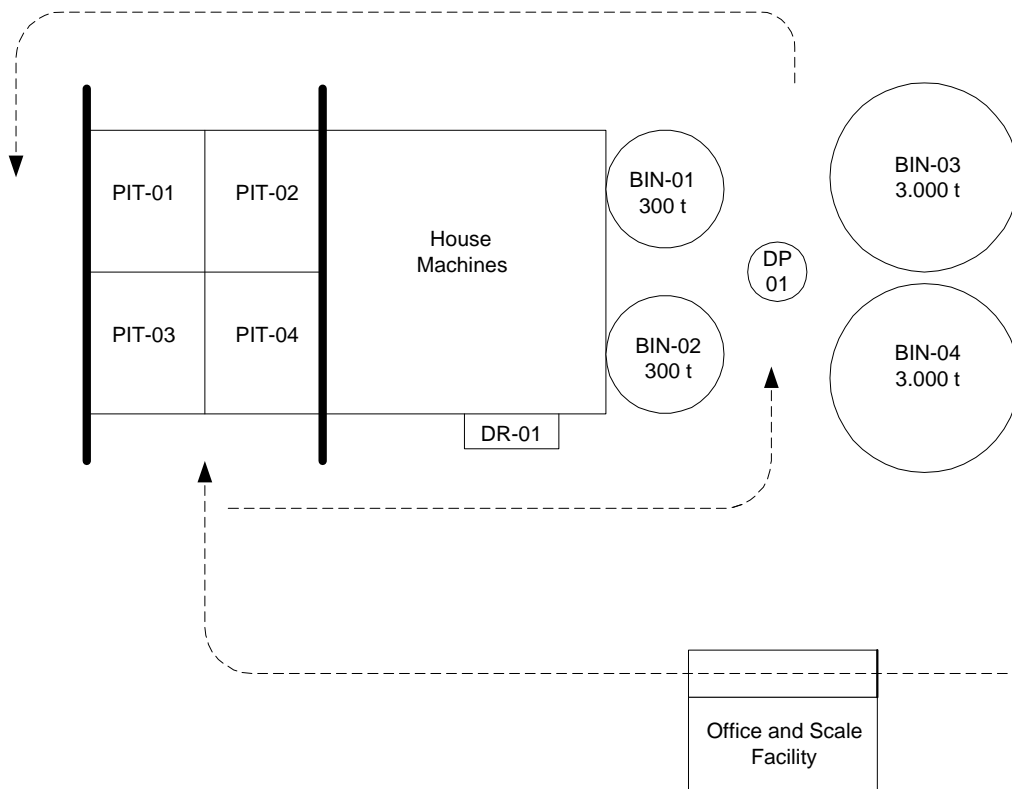


Figure 2C – Layout – Grain Storage Facility C.