Use of Excel Worksheets with User-Friendly Interface in the Production Scheduling in Batch Process (PSBP) to Minimize the Makespan

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Abstract

In the chemical industry, the necessity for scheduling is becoming more pronounced, especially in batch production mode. Nowadays, planning industrial activities is a necessity for survival. Intense competition requires diversified products and delivery in accordance with the requirements of consumers. These activities require quick decision making and the lowest possible cost, through an efficient Production Scheduling. So, this work addresses the Permutation Flow Shop scheduling problem, characterized as Production Scheduling in Batch Process (PSBP), with the objective of minimizing the total time to complete the schedule (Makespan). A method to approach the problem of production scheduling is to turn it into Mixed Integer Linear Programming- MILP, and to solve it using commercial mathematical programming packages. In this study an electronic spreadsheet with user-friendly interface (ESUFI) was developed in Microsoft Excel. The results showed that it is possible to use the ESUFI for small problems.

Keywords: Excel; Linear Program; Permutation Flow Shop.

1 Introduction

Permutation flow-shop scheduling problem (FSP) according to Wang et al. (2012) and J.N.D (2006), has been extensively studied because of its significance both in theory and industrial applications. The FSP system consisting to Zäpfel, Wasner and Braune (2012) of multiple lines where each line comprises buffer stations and workstations. Therefore, this work presents the development of a spreadsheet, created using Visual Basic (VB) with interface with the user, whose goal is to minimize the task completion time (Makespan) of a Permutation Flow Shop Scheduling environment.

This research is embedded in the area of Synthesis and Optimization of Processes of the Chemical Engineering Graduate Program at UEM – State University of Maringá, in partnership with GEPPGO - Group for Study and Research on Process and Operations Management from the Production Engineering Department of the State University of Paraná - Campus of Campo Mourão.

In the chemical industry, the necessity for scheduling is becoming more pronounced, especially in batch production mode. According to Raklaitis (1995), batch production can be described as income-oriented production, with equipment network connectivity and resource limitations. Mendez *et al.* (2006) classifies this type of operation: Single stage, which is subdivided into single or parallel resources, and multiple stages, which are subdivided into multipurpose (Job Shop) and multiproduct (Flow Shop).

The scheduling problem addressed in this work is of batch type - multiproduct - Permutation Flow Shop. According to Polon (2010), Batch-Multiproduct plants are in general employed for a set of products whose income structure is the same and production lines are also referred to as Flow Shop.

According to MacCarthy and Liu (1993) and Baker (1974), Flow Shop is a type of process where all tasks have a similar flow pattern, that is, they have the same processing schedule on all resources and the number of resources in each stage of production equals one.

The environment of the permutation Flow Shop production scheduling problem is described by MacCarthy and Liu (1993), Baker (1974), Taillard (1993), and Moccellin (1995) as a type of Flow Shop in which the processing order of tasks is the same in all resources. Severo (2007) states that many chemical process industries such as oil and paint, pharmaceutical and fine chemistry industries fit into this category.

The diversity and complexity of a batch production industry recommend, as stated by Severo (2007), the application of production planning techniques in order to meet consumer demands. Thus, scientific development in the area of Production Scheduling is increasing, especially concerning batch processes.

2 Methodology

For the creation of a user-friendly interface to solve a production scheduling model for the permutation Flow Shop system, it was necessary to divide it into five parts: Model development, model formulation, model resolution in Excel spreadsheets, creation of interface between user and worksheet in Visual Basic language (VB), and finally, evaluation of the consistency of the interface.

The problem proposed by EDGAR et al. (2002, Apud Polon et al. (2006)), of a multiproduct batch plant, characterized as a permutation Flow Shop environment, was analyzed for the model development. At this stage, the objective function was defined, considering the case of production scheduling as a mixed integer linear programming problem (MILP).

In this permutation Flow Shop programming environment, one research scenario were modelled, all of them with the aim of minimizing the total task completion time (Makespan).

The model constraints are: a) the storage of intermediate products should not be available between the processing resources, that is, if a product is processed at resource j and resource j+1 is not available at the time of completion, the finished product should be kept at resource j, until resource j+1 is ready; b) after finishing the processing of a product at the last resource (equipment), this product is immediately sent to the stock of finished products; c) all resources are initially empty at time zero and the manufacture of any product may be delayed an arbitrary amount of time to keep it in the previous resource; d) the ordering of tasks on each resource is the same.

After finishing the modelling, the mathematical equations of all one scenario were manually transcribed into Excel spreadsheets, and solved by the add-in Solver.

The VB language was used to create an interface between the user and the Excel spreadsheet. This way, all the mathematical equations that had been modelled in the one scenario, along with the add-in Solver, were developed in order to create a generalized programming model for this environment and with the restrictions imposed by the proposed model.

The evaluation of the consistency of the spreadsheet interface with the user was done by comparing the results that were manually obtained with Excel spreadsheets with those obtained using the VBA language.

3 User-Friendly Interface for the Resolution of a Model of Production Scheduling in a Permutation Flow Shop System with Makespan Reduction

3.1 Model Development

To develop the research was analyzed a research scenario, referring to the programming environment of three tasks (t1, t2, t3) and five resources, with the respective processing times shown in Table 1.

Table 1: Processing time (h)

Resources	Tasks		
	t1	**t2**	**t3**
1	Pt 11	Pt 21	Pt 31
2	Pt 12	Pt 22	Pt 32
3	Pt 13	Pt 23	Pt 33
4	Pt 14	Pt 24	Pt 34
5	Pt 15	Pt 25	Pt 35

3.2 Model Formulation

The three scenarios were modelled. However, as all of them are part of the same programming environment (permutation Flow Shop) and meet the same constraints, only the modelling of scenario 1 will be presented. In the mathematical modelling of this scenario, Equation 1 represents the main goal of the problem to be solved.

$$Minimize\ C_{NM} \quad (1)$$

Variable *C* in Equation 1 represents the Makespan, while *N* and *M* represent the number of tasks and the number of resources, respectively. Thus, the objective function expressed by Equation 1, is about finding, among the various combinations of tasks and resources, the *NM* sequence that provides the lowest Makespan. For the scenario 1, *N* = 4 and *M* = 3 in the objective function. This objective function is subject to a number of constraints, as described below. The first constraints, shown in Equations 2 and 3, are binary.

$$\sum_i X_{ik} = 1 \quad \forall k \quad (2)$$

$$\sum_k X_{ik} = 1 \quad \forall k \quad (3)$$

Variable *i* represents the task to be processed at the resource and *k* represents the position of this task in the order of sequencing. Equations 2 and 3 thus represent a discrete optimization problem involving the decision between two alternatives, that is, if a task is processed at a given resource, the other tasks cannot be processed concurrently at the same resource. Therefore, X_{ik} is a binary variable defined as: X_{ik} = 1 if task *i* is in position *k*, and X_{ik} = 0, otherwise.

Each task is sequentially processed by resources (1), (2), and (3), respecting the permutation Flow Shop programming environment.

Equation 4 represents another problem constraint, which also involves Makespan. In this Equation, $C_{k,j}$ is the time of end of processing, by resource *j*, of the task occupying position *k* in the sequence; *N* is the number of tasks; $X_{s,k}$ is the binary variable, and $TP_{s,j}$ is the time for processing task *i* at resource *j*.

$$C_{k,j} \geq C_{k-1,j} + \sum_{s=1}^{N} X_{s,k} TP_{sj} \quad \forall j; k = 2, \dots, N \quad (4)$$

Generally, the resolution of the various alternatives of Equation 4 shows that for a scheduled task to be processed in resource *j*, from the second order of sequencing, it must present a Makespan greater than or equal to the Makespan of a task placed earlier on the same resource *j*, plus the processing time of the same task on resource *j*.

Another important constraint is Equation 5, which also has to do with the Makespan of the tasks in the resources. Equation 5 shows that the Makespan of the task of order *k* on resource *j* is greater than or

equal to the Makespan of the same task on resource j-1 plus the sum of the products of the binary variable $X_{s,k}$ and the processing times $TP_{s,j}$, starting with resource (2) and finishing with resource (3).

$$C_{k,j} \geq C_{k,j-1} + \sum_{s=1}^{N} X_{s,k} TP_{s,j} \quad \forall j; j = 2, \dots, M \quad (5)$$

The Makespan of the task placed in the sequence 1 of the production scheduling, at resource j, is expressed in Equation 6. This Equation presents the constraint that the Makespan of such task is greater than or equal to the Makespan of the task placed in the sequence 1 of the production scheduling, at resource j-1, plus the sum of the products of the binary variable $X_{s,1}$ and the processing times $TP_{s,j}$. In this Equation, resource j must start with resource 2 and finish with resource 3, according to the model initially proposed.

$$C_{1,j} \geq C_{1,j-1} + \sum_{s=1}^{N} X_{s,1} TP_{s,j} \qquad j = 2, \dots, M \quad (6)$$

Another important constraint is the Makespan of the task sequenced with order 1 on resource 1, which is represented by Equation 7. This Equation shows that the Makespan of this task must be greater than or equal to the sum of the products of the binary variable ($X_{1,1}$, $X_{2,1}$, $X_{3,1}$, $X_{4,1}$) and the processing times ($TP_{1,1}$, $TP_{2,1}$, $TP_{3,1}$, $TP_{4,1}$).

$$C_{1,1} \geq \sum_{s=1}^{N} X_{s,1} TP_{s,j} \quad (7)$$

The constraint presented in Equation 8 shows that the Makespan sequenced in the order k on resource j must be greater than or equal to the Makespan sequenced in the order k-1 on resource j +1, starting from the order of sequence 1 on resource 1.

$$C_{k,j} \geq C_{k-1,j+1} \qquad k = 1, \dots, N \qquad j = 1, \dots, M-1 \quad (8)$$

Finally, the last constraint of the problem concerns the question of non-negativity of the model, which is represented by the general Equation 9.

$$C_{k,j} \geq 0 \quad \forall k, \forall j \quad (9)$$

3.3 Model Resolution in Excel Spreadsheets

Equations (1) through (9) of the three tasks and five resources model were inserted in the worksheet, in different cells. After that, the add-in Solver, available within the Microsoft Excel electronic spreadsheet, was used to optimize the scheduling of the tasks on the resources.

In general, for the development of the manual resolution of the processing orders scheduling model proposed in this study, all available data was first organized in an Excel spreadsheet, separating the cells representing the decision variables and the objective function. For each constraint of the problem, a formula was created in a separate cell of the spreadsheet, corresponding to the left-hand side (LHS) and the right-hand side (RHS) of the restriction.

LHS and RHS correspond to the transformation of the set of constraints into a set of equivalent equations, by introducing variables that will represent the gap between the left (LHS) and right (RHS) sides of the inequalities.

After inserting all the equations of the PSBP model, representing the objective function, decision variables and restrictions, in the Microsoft Excel electronic spreadsheet shown, the add-in Solver, available in the tool bar of this spreadsheet, was used to find the optimal solution for the problem.

3.4 Creation of the Friendly Interface between the User and the Excel Spreadsheet in the Language *Visual Basic for Applications* (VBA)

For the creation of the user-friendly interface with the Excel spreadsheet (ESUFI) used to solve the model, in order to reduce the Maskespan following the constraints set forth in the methodology, it was necessary

to first define a standard spreadsheet. The standard spreadsheet refers to a Microsoft Excel spreadsheet, composed of all the equations described in the study, organized in a standard model, which means to put each of the equations in an array of rows and columns, available to perform the generalization of the model. The generalization of this model was performed using the VBA programming language.

The implementation of the VBA code in the spreadsheet made possible the generalization of the model of three tasks and five resources for the configuration of (n) tasks and (m) resources. With this implementation, a friendly interface was created between the user and the Microsoft Excel spreadsheet. At this friendly interface the user should only report the number of tasks (n) and resources (m), and the processing time of each task at the respective resource, and then click on the button "Optimize Scheduling Order" to obtain the best production sequence that minimizes the Makespan. Figure 1 exemplifies the model of the Microsoft Excel spreadsheet with user-friendly interface.

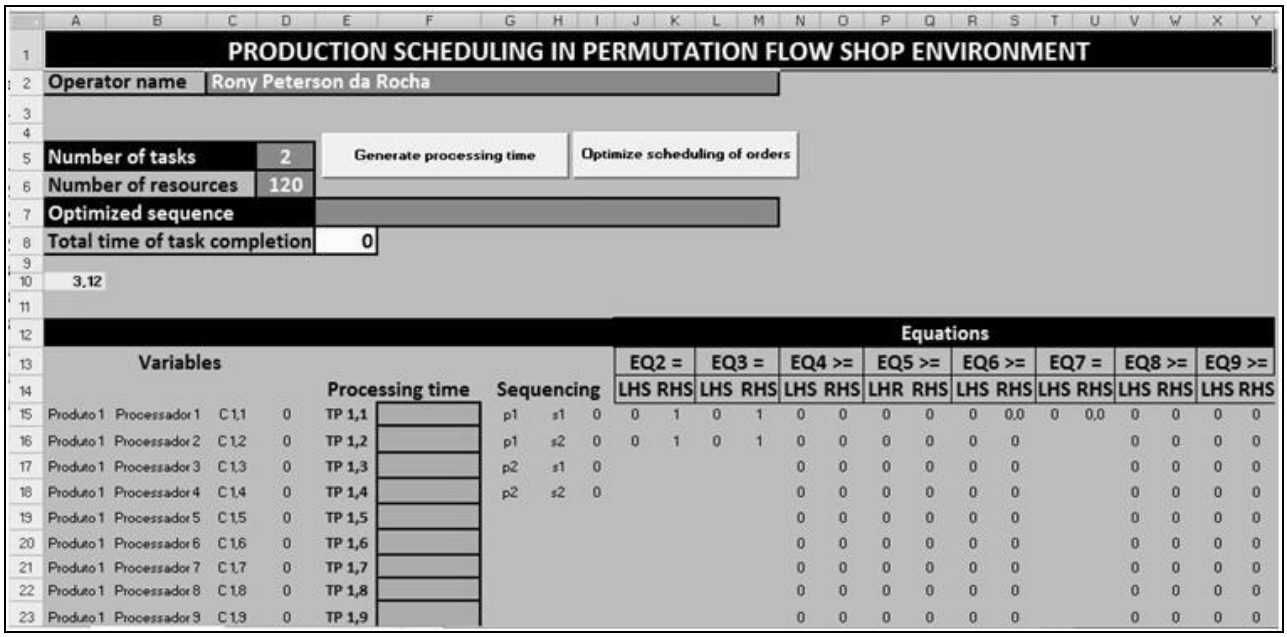

Figure 1: Microsoft Excel spreadsheet model with user-friendly interface

To build the user-friendly interface created for the ESUFI presented in Figure 2, it was necessary to carry out some validation tests for each of the model equations. These tests serve to validate the model, that is, to show the veracity of each of the equations from the expansion of the model of three tasks and five resources for different situations of (N) tasks and (M) resources. The tests also served to find a number of combinations of (N) and (M) possible to be applied with the help of the Solver tool.

3.5 Evaluation of the Consistency of the Interface

The assessment of the consistency of the generalized equations in the Excel spreadsheet with user-friendly interface was done by comparing the results that were manually obtained with Excel spreadsheets with those obtained with the user-friendly interface, using the VBA language.

To validate the automated spreadsheet regarding the accuracy of the equations generated by the expansion of the model, two scenarios were tested in each one of the classes N $\in$ {2,3,4,5,6,7,8,9,10,11,12,13} and M $\in$ {2,3,4,5,6,7,8,9,10,15,20,25,30,40,60}, with time intervals of [1,99], totalling 360 problems tested (2 scenarios x 12 classes of tasks x 15 classes of resources).

The classes of problems n $\in$ {2,3,4,5,6,7} and m $\in$ {2,3,4,5,6,7,8,9,10,15,20,25}, according to the classification of BOIKO (2008), represent the small sized production scheduling problems. However, for the same author, classes N $\in$ {8,9,10,11,12,13} and M $\in$ {30,40,60} correspond to medium-sized production scheduling problems.

In assessing the consistency of generalized equations in the Excel worksheet with user-friendly interface, tests were performed in cases of production scheduling in small and medium businesses. Besides verifying the veracity of equations (1) through (9), expanded on the Excel worksheet with user-friendly interface, the tests sought to find the limits of adjustable cells on the spreadsheet. Adjustable cells mean the largest number of tasks (N) and resources (M) of the subclasses that have the possibility of solving the objective function (minimizing the Makespan) in the Excel worksheet with user-friendly interface, regardless of the final solution.

The correlation coefficient (r) given by Equation 10 (MOREIRA, 2000, p 327) was used to assess the relationship between the number of tasks (N) and resources (M) of the limiting subclasses of the Excel spreadsheet model with user-friendly interface.

$$r = \frac{n.(\sum X.Y) - (\sum X).(\sum Y)}{\sqrt{n.(\sum X^2) - (\sum X)^2}.\sqrt{n.(\sum Y^2) - (\sum Y)^2}} \quad (10)$$

Where: r = correlation coefficient; n = number of limiting subclasses; X = value of the number of the task subclass (n); Y = value of the number of the resource subclass (m).

4 Results and Discussion

It was verified in the tests of each problem of subclasses {2,2}, {2,3}, {2,4}, {2,5}, {2,6}, {2,7}, {2,8}, {2,9}, {2,10}, {2,15}, {2,20}, {2,25}, {2,30}, {2,40}, and {2,60} that all equations were consistent with the generic model equations. However, one realized that there was still scope to increase the number of resources, since the expansion of the equations was not at the limit allowed in the Excel spreadsheet. Therefore, a new set of problems with N $\in$ {2} and M > 60 was tested, and the limit of {2,98} was found.

The same behavior was observed with the subclasses {3,2}, {3,3}, {3,4}, {3,5}, {3,6}, {3,7}, {3,8}, {3,9}, {3,10}, {3,15}, {3,20}, {3,25}, {3,30}, {3,40}, and {3,60}. This way, a new set of problems with N $\in$ {3} and M > 60 was tested, and the limit of {3,62} was found.

All equations of the problems of subclasses {4,2}, {4,3}, {4,4}, {4,5}, {4,6}, {4,7}, {4,8}, {4,9}, {4,10}, {4,15}, {4,20}, {4,25}, {4,30}, {4,40}, and {4,60} were consistent with the generic model. However, subclass {4,60} could not be verified, since it went beyond the limit of Solver adjustable cells present in the ESUFI. Thus, after conducting further tests, the limit of {4,46} was found.

The same behavior was observed for the subclasses {5,2}, {5,3}, {5,4}, {5,5}, {5,6}, {5,7}, {5,8}, {5,9}, {5,10}, {5,15}, {5,20}, {5,25}, {5,30}, {5,40}, and {5,60}, and it was found that subclasses {5,40} and {5,60} went beyond the limit. New tests led to the determination of the limit {5,35}.

Further tests with the subclasses {6,2}, {6,3}, {6,4}, {6,5}, {6,6}, {6,7}, {6,8}, {6,9}, {6,10}, {6,15}, {6,20}, {6,25}, {6,30}, {6,40}, and {6,60}, pointed to the limit of {6,27}, after it was found that subclasses {6,30}, {6,40}, and {6,60} went beyond the limit of Solver adjustable cells present in the ESUFI.

Similarly, in the problems of subclasses {7,2}, {7,3}, {7,4}, {7,5}, {7,6}, {7,7}, {7,8}, {7,9}, {7,10}, {7,15}, {7,20}, {7,25}, {7,30}, {7,40}, and {7,60}, all equations were consistent with the generic model, although subclasses {7,25}, {7,30}, {7,40}, and {7,60} exceeded the limit of adjustable cells in the ESUFI. Thus, after performing new tests, the limit of {7,21} was determined.

For the same reason, subclasses {8,20}, {8,25}, {8,30}, {8,40}, and {8,60} could not be verified, when analyzing the subclasses {8,2}, {8,3}, {8,4}, {8,5}, {8,6}, {8,7}, {8,8}, {8,9}, {8,10}, {8,15}, {8,20}, {8,25}, {8,30}, {8,40}, and {8,60}, but all equations were consistent with the model up to the limit of {8,17}.

During the tests with the problems of subclasses {9,2}, {9,3}, {9,4}, {9,5}, {9,6}, {9,7}, {9,8}, {9,9}, {9,10}, {9,15}, {9,20}, {9,25}, {9,30}, {9,40}, and {9,60}, all equations were consistent with the generic model, but the last six

subclasses could not be verified, as they went beyond the limit of Solver adjustable cells present in the ESUFI. New tests were performed and the limit of {9,13} was found.

Analogously, the last six subclasses of the set {10,2}, {10,3}, {10,4}, {10,5}, {10,6}, {10,7}, {10,8}, {10,9}, {10,10}, {10,15}, {10,20}, {10,25}, {10,30}, {10,40}, and {10,60} were not verified, and the limit of {10,10} was found after performing new tests.

Following the same pattern, the limit observed for the subclasses {11,2}, {11,3}, {11,4}, {11,5}, {11,6}, {11,7}, {11,8}, {11,9}, {11,10}, {11,15}, {11,20}, {11,25}, {11,30}, {11,40}, and {11,60} was {11,7}, while for the subclasses {12,2}, {12,3}, {12,4}, {12,5}, {12,6}, {12,7}, {12,8}, {12,9}, {12,10}, {12,15}, {12,20}, {12,25}, {12,30}, {12,40}, and {12,60} the limit was {12,4}.

As for the results of the tests with the problems of subclasses {13,2}, {13,3}, {13,4}, {13,5}, {13,6}, {13,7}, {13,8}, {13,9}, {13,10}, {13,15}, {13,20}, {13,25}, {13,30}, {13,40}, and {13,60}, all equations were found to be consistent with the generic model, but only the subclass {13,2} could be generated on the spreadsheet, as the others went beyond the limit of Solver adjustable cells present in the ESUFI.

Therefore, after performing all the tests in the classes of problems N $\in$ {2,3,4,5,6,7,8,9,10,11,12,13} and M $\in$ {2,3,4,5,6,7,8,9,10,15,20,25,30,40,60}, with time intervals of [1,99], for the validation of the automated spreadsheet regarding the accuracy of the equations generated by the model expansion, and establishment of the limits of classes NxM of the PSBP model in the ESUFI, it was possible to conclude that equations (1) through (9) were correctly expanded in all 360 analyzed problems, thus ensuring the accuracy of the results obtained with the ESUFI.

Observing the limits found for the classes of problems N $\in$ {2,3,4,5,6,7,8,9,10,11,12,13} and M $\in$ {2,3,4,5,6,7,8,9,10,15,20,25,30,40,60}, with time intervals of [1,99], there is a clear reduction in the number of resources (M), as the number of tasks (t) increases. This reduction in the number of resources, concerning the limitation of adjustable cells in the ESUFI for the use of the Solver tool to solve the objective function of the PSBP problem, can be assessed by the application of the correlation coefficient (r), given by Equation 10. The value of -0.89 shows a very high inverse correlation between the number of tasks (n) and the number of resources (m), that is, for the adjustable cells of the ESUFI, as the number of tasks is increased, the number of resources decreases, resulting in a reduction in the number of resources to be programmed in the ESUFI.

In analyzing the performance of the model PSBP ESUFI held for class 3, were tested percentage of success $(\%S_{\mathrm{ESUFI}})$ of earch of the subclasses listed in Table 2.

Table 2: class 3

CLASS	SUBCLASSES	INTERVAL OF TIME
		[1,8]
		[1,12]
3	{3,2};{3,3};{3,4};{3,5};{3,6};{3,7};{3,8};{3,9};{3,10};{3,15};{3,20};{3,25};{3,30};{3,40};{3,62};	[1,24]
		[1,45]
		[1,99]

In the time intervals [1,8] and [1.12], the subclasses {3,2}, {3,3}, {3.4}, {3,5}, {3,6}, {3 , 7}, {3.8}, {3,9}, {3.15}, {3.20}, {3.25}, {3.30}, {3.40} and {3.62 }, showed that 100% of the scenarios tested in the ESUFI (10 scenarios / subclasses) had the objective function of optimization.

In the time interval [1.24] subclasses {3,2}, {3,3}, {3.4}, {3,5}, {3,6}, {3,7}, {3 , 8}, {3,9}, {3.15} {3.20} {3.25} {3.30} {3.40} and showed that 100% of the scenarios tested in the ESUFI (10 scenarios / subclasses) had the objective function of optimization, since the subclass {3.10} presented 90%.

In the time interval [1.45] subclasses {3,2}, {3,3}, {3.4}, {3,5}, {3,6}, {3,7}, {3 , 8}, {3,9}, {3.15} {3.20} {3.25} {3.30} and {3.40}, showed that 100% of the scenarios tested in the ESUFI (10 scenarios / subclasses) had the objective function of optimization, since the subclasses {3.10} {3.62} showed 90%.

In the time interval [1.99] subclasses {3,2}, {3,3}, {3.4}, {3,5}, {3,6}, {3,7}, {3 , 8}, {3,9}, {3.15} {3.20} {3.25} {3.30} and {3.40}, showed that 100% of the scenarios tested in the ESUFI (10 scenarios / subclasses) had the objective function of optimization, since the subclasses {3.10} and {3.62} showed 80% and 90%, respectively.

In general, the results of tests $\%S_{\mathrm{ESUFI}}$ of Class 3, show that 93.33% of the scenarios tested in the ESUFI showed 100% response (optimization of the objective function), 5.33% had 90% response and 1.33 % showed 80% of responses.

5 Final Considerations

With the completion of this study, focused on the development of the Microsoft Excel spreadsheet with friendly interface, it was observed that this spreadsheet could be used to minimize the Makespan in the environment of production scheduling in batch processes.

During the research, a primary study was conducted on the production scheduling, where it became clear the vast amount of information involved in this area. Thus, for the specific case of using the ESUFI in the sequencing of production orders for minimization of the Makespan, which is an activity involved in the production scheduling, the ESUFI played a very important role in the production scheduling, since spreadsheets are known by most computer users and are available in almost all Office packages.

The ease of manipulation of the ESUFI is quite evident, as with the use of VBA language a user-friendly interface could be created between the user and the spreadsheet itself. To generate the production scheduling that minimizes the total time of completion of tasks, the only information needed in the worksheet is the number of tasks and resources and the processing times of the tasks in their respective resources. However, the ESUFI had some limitations.

In carrying out the validation tests of the macros used to automate the use of the Microsoft Excel using Visual Basic Application (VBA), a limitation of the spreadsheet was found concerning the amount of adjustable cells, that is, as the number of tasks to be programmed in the spreadsheet increases, the number of resources decreases. Thus, production scheduling is limited to an amount of up to 13 tasks, and therefore this shows that within standard Excel, the present ESUFI can be used for small-scale problems.

As a suggestion, it is important to develop studies applied to real cases, as well to use a professional Excel version to increase the number of adjustable cells, which would extend the limit of variables in the production scheduling and therefore permit working with larger problems.

References

BAKER, K. R. *Introduction to Sequencing and Scheduling*. NEW York: John Wiley & Sons, Inc, 1974.

BOIKO, T. J. P. *Métodos heurísticos para a programação em flow shop permutacional com tempos de setup separados dos tempos de processamento e independentes da seqüência de tarefas.* 207 f. Dissertation (Master Degree in Production Engineering)- São Carlos Engineering School, São Paulo University - USP, São Carlos, 2008. Available at: http://www.dominiopublico.gov.br/download/texto/cp058596.pdf.

J.N.D. Gupta, E.F. Stafford. *Flowshop Scheduling Research After Five Decades*. European Journal of Operational Research, 169 (2006), pp. 699–711.

MACCARTHY, B. L.; LIU, J.Y. *Addressing the Gap in Scheduling Research: A Review of Optimization and Heuristic Methods in Production Scheduling*. International journal of Production Research, London, 31, 59-79, 1993.

MENDÉZ, C.A. et al. *State-of-the-art Review of Optimization Methods for Short-term Scheduling of Batch Processes*. Computers and Chemical Engineering, 30, 913-946, 2006.

MOCCELLIN, J. V. *A New Heuristic Method for the Permutation Flow Shop Scheduling Problem*. Journal of the Operational research Society. Oxford, 46, 883-886, 1995.

POLON, P. E.; ANDRADE, C. M. G.; PARAÍSO, P.R.; JORGE, L. M. de M. *Utilização de Planilha Eletrônica na Resolução de Problemas de Planejamento e Programação da Produção*. XXXIV COBENGE, Passo Fundo: Ed. Passo Fundo University, September, 2006. Available at: http://www.dee.ufma.br/~fsouza/anais/arquivos/1_207_804.pdf.

POLON, P. E. *Otimização da Produção da Indústria de Embutidos*, PEQ/UEM, Maringá- PR (Thesis), 115p. (Doctorate in Chemical Engineering) – Chemical Engineering Graduate Program, State University of Maringá, 2010.

REKLAITIS, G.V. *Scheduling Approaches for the Batch Process Industries*. ISA Transactions, 34, 349 – 358, 1995.

SEVERO, L. S. *Aplicação de Modelo de Programação da Produção na Indústria de Couros*, PEQ/UFRGS, Porto Alegre- RS (Dissertation), 96p. (Master Degree in Chemical Engineering) – Chemical Engineering Graduate Program, Federal University of Rio Grande do Sul, 2007.

TAILLARD, E. *Benchmarks for Basic Scheduling Problems*. European Journal of Operational Research, Amsterdam, 64, 278-285, 1993.

WANG, Cheng.; SONG, Shiji.; Jatinder.; GUPTA, N.D.; WU, Cheng. *A Three-phase Algorithm for Flowshop Scheduling With Blocking to Minimize Makespan*. Computers & Operations Research, Volume 39, Issue 11, November 2012, Pages 2880–2887.

ZÄPFEL Günther.; WASNER, Michael.; BRAUNE, Roland. Integration *Between Flow Scheduling and Personnel Allocation in a Parallel Line System in Automotive Industry*. Business and Economics, Volume 82, Number 4, 2012, 417-432.