OPTIMIZATION OF FLEXIBLE MANUFACTURING SYSTEMS: COMPARISON BETWEEN STOCHASTIC AND DETERMINISTIC TIMING AASOCIATED TO TASKS

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ABSTRACT
Modeling of Flexible Manufacturing Systems has been one of the main research topics dealt with by researchers in the last years. The modeling paradigm chosen can be in many cases a key decision that can improve or give an added value to the example modeling task. Here, two different modeling manners are presented both based in the Petri Net paradigm, Stochastic and Colored Petri Net models. These two models will be compared in terms of the performance measures that could be interesting for the production systems. The production indicators used here are related with the productivity of the systems. These productivity measures could be included in a later stage into an optimization process by changing a certain number of parameters into the model. A comparison between the performance measures and also other computational effort measures will be depicted to check whether one model is more appropriate or the other.

Keywords: Petri nets, flexible manufacturing, deterministic timing, stochastic timing, simulation, optimization

1. INTRODUCTION

The process of optimizing a Production System can be divided clearly into three tasks that will be the modeling, analysis and optimization. The first part applied to the different production systems examples will be the modeling issue. The modeling paradigm used in our case are Petri Nets but other different modeling paradigms can be used to model the FMS. The second part is dedicated to the obtaining of Performance Measures for these models. These results can be exact or approximated depending or even bounds (upper or lower) of the performance measures needed to compute the final cost function. Here, we will consider for the models two possibilities, one where the time associated to the tasks performed can be considered deterministic or a second one where the time is considered stochastic. This timing constraint difference will allow us to consider later on some comparisons int the optimization process at different levels. Finally, the optimization in the design of the Manufacturing System is considered.

The rest of the paper is as follows, in section 2 the FMS that will be used along this paper will be explained and all the elements that will be interesting to be represented in our models will be enumerated. Later on, in sections3 the two Petri net models will be depicted. Section 4 is devoted to the presentation of the optimization problem that will be considered in this paper. Finally, the results we are interested in are represented associated to the models in section 5 where a comparison of the simulation results is shown. Finally some conclusions are presented in section 6.

2. DESCRIPTION OF THE FMS

The example that will be used in the development of this thesis will be a Flexible Manufacturing Cell of the Flexlink. The layout of the cell corresponds with Figure 1.

The Flexible Manufacturing Cell under study is formed by two different lifters (left and right one) that perform the operation of raising/descending of the pallets that are being produced.. The left lifter will perform the operation of taking the pallets from the lower level central line (that has 6 possible positions) to the higher one, while the right lifter is in charge of the opposite operation. The next element that appears in the FMC is the starting GWS, This is in charge of moving the material to the three possible positions (upper layer, middle layer, low layer). This decision will be taken from the moment that a pallet arrives to initial position of the station (middle layer) coming from the left lifter (GWS lifter).The decision whether to go one way or the other two will be taken randomly with equal probabilities for the three options (immediate transitions will be used for this decision). The higher line and the lower one are exactly equal while the intermediate line is a by-pass to the second part of the cell. When the pallets are arriving to the upper/lower line they are process in the GWS main station.

The SpecOpen Line is divided in six parts, each part is controlled by one Controller and the layout is shown in Figure 1.
The shaded part is used to show the part below the line, where the pallet go from left to right, from JOT_Lifter to GWS_Lifter. The conveyors below are controlled by the same PTC as the upper parts.

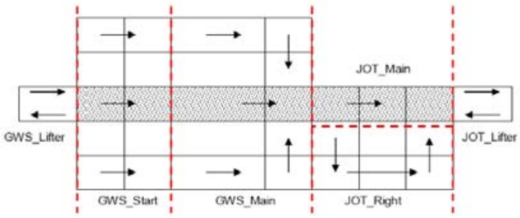

Figure 1: FMS Layout

The following times show how long does a pallet takes to go from one part of the line to the next.

Table 1. Processing times

START	END	TIME (ms)
GWS_Start (Down)	GWS_Lifter(Down)	1800
GWS_Lifter (Out, Down)	GWS_Lifter(In, Down)	2150
GWS_Lifter(In, Down)	GWS_Lifter(In, Up)	1950
GWS_Lifter(In, Up)	GWS_Lifter(In, Down)	1290
GWS_Lifter(In, Up)	GWS_Lifter(Out, Up)	1800
GWS_Lifter(Out, Up)	GWS_Start(Center Cross)	2200
GWS_Start(Center Cross)	GWS_Start(Right Cross)	3820
GWS_Start(Center Cross)	GWS_Start(Left Cross)	3820
GWS_Start(Center Cross)	GWS_Main(Middle Conveyor)	2500
GWS_Start(Left Cross)	GWS_Main(Left Conveyor)	3730
GWS_Start(Right Cross)	GWS_Main(Right Conveyor)	3730
GWS_Main(Middle Conveyor, 1st)	GWS_Main(Middle Conveyor, 2nd)	1640
GWS_Main(Left Conveyor, 1st)	GWS_Main(Left Conveyor, 2nd)	1580
GWS_Main(Right Conveyor, 1st)	GWS_Main(Right conveyor, 2nd)	1580
GWS_Main(Middle Conveyor, 2nd)	GWS_Main(Center Cross)	2300
GWS_Main(Left Conveyor, 2nd)	GWS_Main(Left Cross)	1450
GWS_Main(Right Conveyor, 2nd)	GWS_Main(Right Cross)	1450
GWS_Main(Left Cross)	GWS_Main(Center Cross)	4270
GWS_Main(Right Cross)	GWS_Main(Center Cross)	4270
GWS_Main(Center Cross)	JOT_Main(Start)	1850
JOT_Main(Start)	JOT_Main(Conveyor)	1500
JOT_Main(Conveyor)	JOT_Main(End)	1800
JOT_Main(Start)	JOT_Right(Start)	2100
JOT_Right(Start)	JOT_Right(Conveyor)	1450
JOT_Right(Conveyor)	JOT_Right(End)	1500
JOT_Right(End)	JOT_Main(End)	1900
JOT_Main(End)	JOT_Lifter(Up)	1200
JOT_Lifter(Up)	JOT_Lifter(Down)	7600
JOT_Lifter(Down)	JOT_Lifter(Up)	8500
JOT_Lifter(Down)	JOT_Main(Down, 1st)	1500
JOT_Main(Down, 1st)	JOT_Main(Down, 2nd)	1000
JOT_Main(Down, 2nd)	JOT_Main(Down, 3rd)	1480
JOT_Main(Down, 3rd)	GWS_Main(Down, 1st)	2000
GWS_Main(Down, 1st)	GWS_Main(Down, 2nd)	1900
GWS_Main(Down, 2nd)	GWS_Main(Down, 3rd)	1700
GWS_Main(Down, 3rd)	GWS_Start(Down)	2800

3. STOCHASTIC PETRI NET MODEL

Here we present the Petri net it has been modeled using stochastic PNs.

The complete model is represented in the following figure 2.

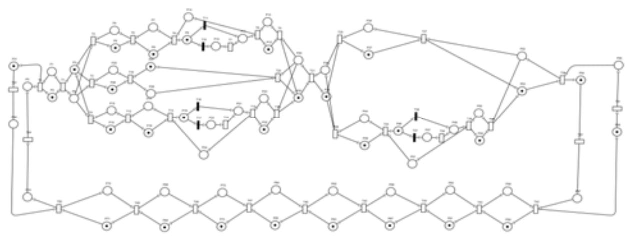

Figure 2: Sample Figure Caption

Now, the different parts/machines that compose this model will be depicted and explained individually and finally these models will be merged reaching finally the model of figure 3.4.

The left lifter model is represented in Figure 3.

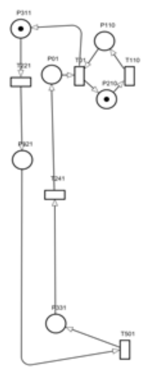

Figure 3: Left lifter Petri net model

Here places P311 and P331 when marked represent the state that the lifter is ready for receiving pallets, from the upper or from the lower level. Transitions T221 and T241 represent the time that takes to the lifter to ascend or descend with the pallet containing the material to be assembled. Transitions

T01 and T501 represent the time that takes to the pallet to get out/enter into the lifter to be ready to go to the corresponding level. Because this lifter is thought to transfer pallets from the lower level to the upper one, the transition T221 is automatically fired when the lifter is free of pallets.

The second lifter is represented in Figure 4. The process is quite similar to the one explained for the first one with the only difference that the process is the opposite, this lifter will carry pallets from the upper level to the lower one. Here transitions T401 and T411 represent the operation times associated to the down and up movement of the lifter respectively.

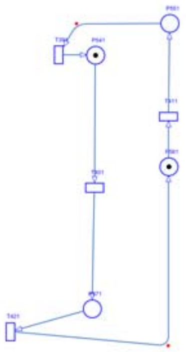

Figure 4: Right lifter Petri net model

The lower level pallet transfer system is represented in figure 5. and the 8 possible positions that the pallet can adopt are shown there.

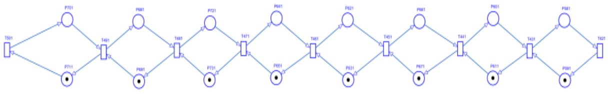

Figure 5: Lower level Petri net model

Finally, the upper level that contains the robot center the JOT Main and Right, the GWS center and all the by-pass parts is represented in figure 6.

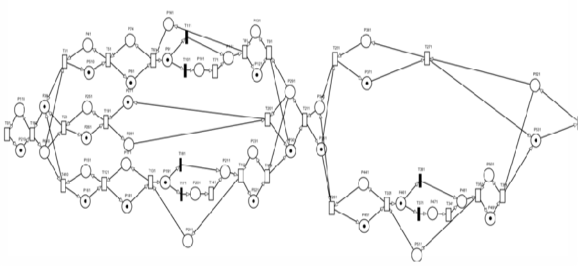

Figure 6: Upper level Petri net model

The deterministic Petri net considered here is represented by the following figure. It can be seen that this model is quite similar to the original stochastic one.

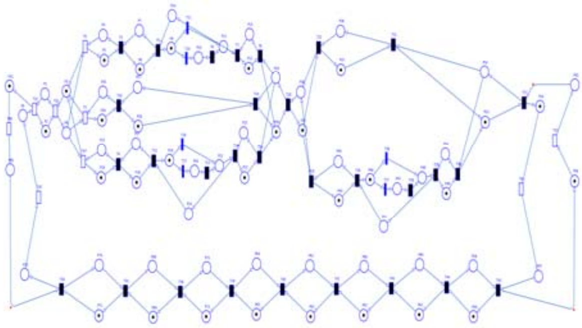

Figure 7: Deterministic FMS Petri net model

It has been considered a deterministic behavior only in the machining part and in the conveyors that compose the system. It has been conserved the stochastic behavior in the lifters due to their possible parameter change associated to their movements. For the transitions that have been changed to deterministic it has been considered the value of the mean associated to the corresponding exponential transition.

4. OPTIMIZATION OF THE FMS MODEL

The search space corresponding to the optimization problem that it is solved during this thesis is composed by the following variables:

Variable ➔ **LiftUP** that controls the time spent by the first lifter to go from the lower level to the upper one

Variable ➔ **Lift2UP** that controls the time spent by the second lifter to go from the lower level to the upper one

Variable ➔ **LiftDown** that controls the time spent by the first lifter to go from the upper level to the lower one

Variable ➔ **Lift2Down** that controls the time spent by the second lifter to go from the upper level to the lower one

Variable ➔ **Prob1** value corresponds to the percentage of situations where the GWS Main Left part is available to operate

Variable ➔ **Prob2** value corresponds to the percentage of situations where the GWS Main Right part is available to operate

Variable ➔ **Prob3** value corresponds to the percentage of situations where the JOT Right station is available to operate
The search space where the optimization process will look for the solution of the problem will be in this particular case the one depicted in the following.

Parameter definitions:

```
# name       type minimum maximum initial delta  temp
0 LiftUP     REAL 2.00    4.00    3.00    0.01   1.000000
1 Lift2Up    REAL 2.00    4.00    3.00    0.01   1.000000
2 LiftDown   REAL 1.00    3.00    2.00    0.01   1.000000
3 Lift2Down  REAL 1.00    3.00    3.00    0.01   1.000000
4 Prob1      REAL 5.00    95.00   50.00   0.10   1.000000
5 Prob2      REAL 1.00    100.00  50.00   0.10   1.000000
6 Prob3      REAL 1.00    100.00  50.00   0.10   1.000000
```

The Profit function used in this example is a simple combination of the utilizations of the different stations/machines that are available in the FMS (Lifters, JOT, GWS). The objective is to maximize this amount, so that our system is used at the maximum level. This maximal utilization will revert in a maximal throughput of the system, taking into consideration that with the maximum utilization of the devices we are ensuring that the by-pass are used at their minimum value but using them as an option to avoid deadlock or material stopping situations.

```
Final result of optimization:
-----------------------------
LiftUP=3.330168,
Lift2Up=3.501725,
LiftDown=1.330764,
Lift2Down=2.107886,
Prob1=27.838387,
Prob2=76.333992,
Prob3=36.824970
Profit=1.128963

Queue information:
-----------------
Queue length:         10000
Queue entries:        1006
Cost function calls:  1140
Queue hit rate:       11% (this run only)
```

```
Final result of optimization:
-----------------------------
LiftUP=3.571091,
Lift2Up=3.948040,
LiftDown=2.404728,
Lift2Down=2.937917,
Prob1=28.740118,
Prob2=11.330377,
Prob3=70.051277
Profit=0.882584

Queue information:
-----------------
Queue length:         10000
Queue entries:        1010
Cost function calls:  1140
Queue hit rate:       11% (this run only)
```

For optimizing the problem here shown, it has been considered a Simulated Annealing algorithm based on the Adaptive Simulated Annealing package (Ingber 1996)

5. COMPARISON OF RESULTS

Here the results obtained for the optimization using the two representations are shown.

This first table shows the result obtained with the stochastic model while the second textbox shows the results obtained with the deterministic one.

Table 2 shows in a summarized manner the results obtained for the two experiments. It is clear that the profit obtained with the stochastic model is a bit greater than with the deterministic one and also the computational effort associated to the deterministic experiment is greater than the one obtained with the stochastic one.

Table 2: Experiments results

Example 1

Exp.	Time (Minutes)	Simul.	Profit
STOCH.	2,612.62	1006	1.128963
DET.	2,792.75	1010	0.882584

Once we have obtained these results, it will be interesting to characterize the evolution of the profit function according to the changes in the different variables and also compare the results obtained for the two models here depicted.

In order to check the real difference between the stochastic and the deterministic model we have evaluated a couple of search spaces varying some variables that are included into the original search space.

SEARCH SPACE1:

Parameter definitions:

```
# name       type minimum maximum
0 LiftUP     REAL 2.00    4.00
1 Lift2Up    REAL 2.00    4.00
2 LiftDown   REAL 1.00    3.00
3 Lift2Down  REAL 1.00    3.00
4 Prob1      REAL 5.00    FIXED
5 Prob2      REAL 5.00    FIXED
6 Prob3      REAL 5.00    FIXED
```

The following figure 8, represents the results obtained for this experiment. The upper level of the figure corresponds to the stochastic experiment while the lower one corresponds to the deterministic behavior. It can be observed that the variation in the stochastic version of the model is higher; a clear reasoning is associated to this behavior taking into consideration the stochastic nature of most of the variables included in the model. With respect to the deterministic model it is clear that the variation of certain speed variable has a direct relationship with the utilization of the different devices included, not observing some paradoxical situations that can be clearly identified in the stochastic model.

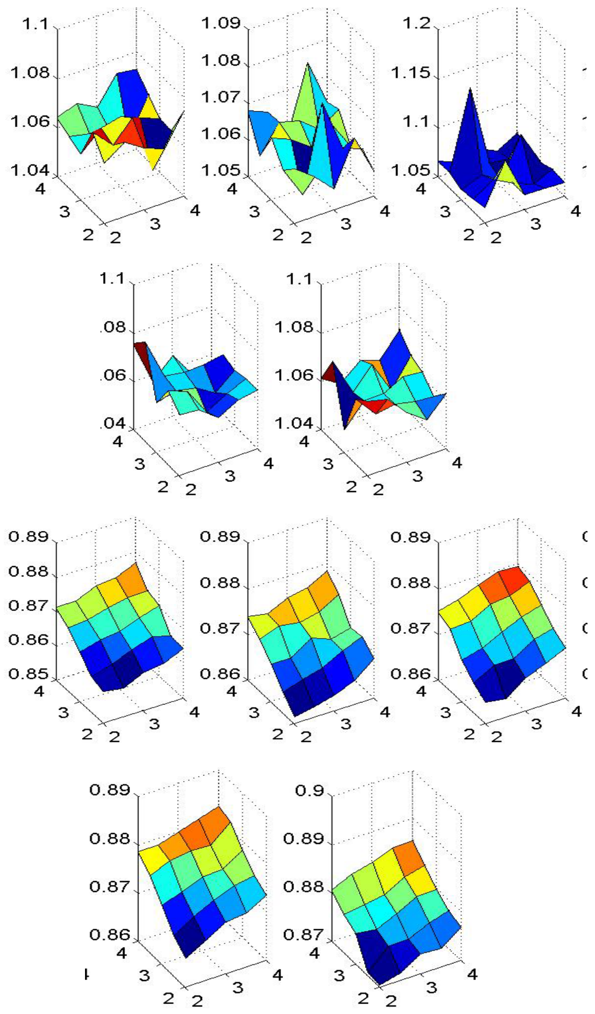

Figure 8: Stochastic vs. Deterministic behavior

Table 2: First Exhaustive Search Experiment results

	Mean	Max	Min	Nº Exps.
Comparison	82.01%	84.18%	73.11%	2500
Stochastic	1.06424	1.2043	1.0448	2500
Deterministic	0.87268	0.8874	0.8874	2500

The comparison between the two representations gives us the following results. The deterministic experiment is in mean an 82% less than the stochastic experiment for this first set of solutions where the machine/operations speeds are varied.

The second search space considered to compare the two approaches is shown below and the change in the parameters in this particular case is more concentrated on the probabilities of utilization of the different machining centers or workstations (variables Prob1 and Prob2).

SEARCH SPACE2:

Parameter definitions:

# name	type	minimum	maximum
0 LiftUP	REAL	3.00	FIXED
1 Lift2Up	REAL	3.00	FIXED
2 LiftDown	REAL	2.00	FIXED
3 Lift2Down	REAL	2.00	FIXED
4 Prob1	REAL	5.00	95.00
5 Prob2	REAL	5.00	95.00
6 Prob3	REAL	5.00	FIXED

Figure 9 shows the results obtained for these experiments. The left part of the figure corresponds to the deterministic model while the right part corresponds to the stochastic one. As mentioned before, the variation in the results is higher for the stochastic model due to the nature of the variables involved in the process.

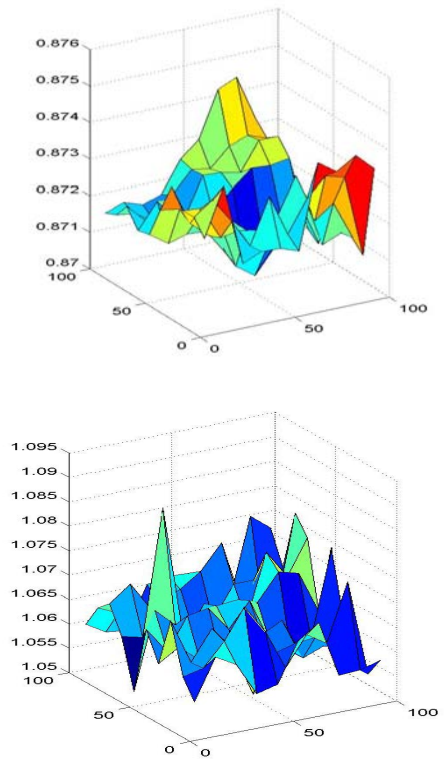

Figure 9: Stochastic vs. Deterministic behavior

Table 3: Second Exhaustive Search Experiment results

	Mean	Max	Min	Nº Exps.
Comparison	82.00%	82.86%	80.22%	100
Stochastic	1.06361	1.0866	1.0520	100
Deterministic	0.87214	0.8745	0.8745	100

Table 3 shows global results obtained for the second experiment comparing the behaviors of the two models (stochastic and deterministic). The results are quite similar to the ones shown in table 2 in terms of comparison of results, showing that there is a clear relationship between the results that can be measured around 82%, independently of the variables that we want to vary.

6. CONCLUSIONS

An approach to the optimization of Flexible Manufacturing Systems modeled using stochastic or deterministic timing associated to the operations is presented in this paper. The paper shows that there is a clear difference between the results obtained with the two approaches in terms of the utilization of the resources present in the system. It has also been shown that the stochastic model has more chaotic behavior with respect to changes in certain parameters.

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