PERFORMANCE COMPARISON BETWEEN COLORED AND STOCHASTIC PETRI NET MODELS: APPLICATION TO A FLEXIBLE MANUFACTURING SYSTEM

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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 in order to check whether one model is more appropriate or the other.

Keywords: Colored Petri Nets, stochastic Petri nets, flexible manufacturing, modeling and simulation, performance measures

1. INTRODUCTION

Flexible Manufacturing Systems and their representation in an adequate model that expresses their behavior the more accurately possible is a typical topic treated by many researchers. Here, a comparison between two models based on the same modeling paradigm is presented, namely colored Petri nets and stochastic Petri nets.

Petri nets have shown their capacity to represent the behaviors that Flexible Manufacturing Systems presents, and specially concurrency and resources representation that are typical features of Manufacturing Systems.

Stochastic Petri nets have been used largely to represent systems where a stochastic behavior is associated to tasks. This modeling method has some lacks when dealing with complex models where the state space is clearly untreatable and even simulation can be a great time consuming task.

Table 1: Productive processes involved in the different production systems, and Operators

Task	**Description**	**Performed By**
Task1	Selection of materials	Operator 1
Task2	cutting of the PVC profiles	Operator 1
Task3	Introduction of the reinforcements	Operator 1
Task4	Numerical Control Machine 6 Operations	NCM
Task5	Reinforcements material selection	Operator 11
Task6	Reinforcements Cutting	Operator 11
Task7	Reinforcement distribution	Operator 11
Task8	Screwing of reinforcements	Operator 1 and Machining Center
Task9	Leaf cutting	Operator 2
Task10	Inverse Leafs distribution	Operator 2
Task11	Wagon distribution	Operator 2
Task12	Retest the strip/post	Operator 2
Task13	Crossbar distribution	Operator 4
Task14	Soldering and cleaning	Operator 3
Task15	Frame distribution	Operator 6
Task16	Crossbar Mounting	Operator 5
Task17	Locks and hinges fixing	Operator 7
Task18	Window hanging	Operator 7
Task19	Inverse leaf mounting	Operator 6
Task20	Box assembly (with all options)	Operator 9
Task21	Glazing	Operator 10
Task22	Insert the reeds	Operator 10
Task23	Glass selection and distribution	Operator 13
Task24	Reeds cut and distribution	Operator 14
Task25	Disassemble leaf/frame	Operator 12
Task26	Pack finished window	Operator 12

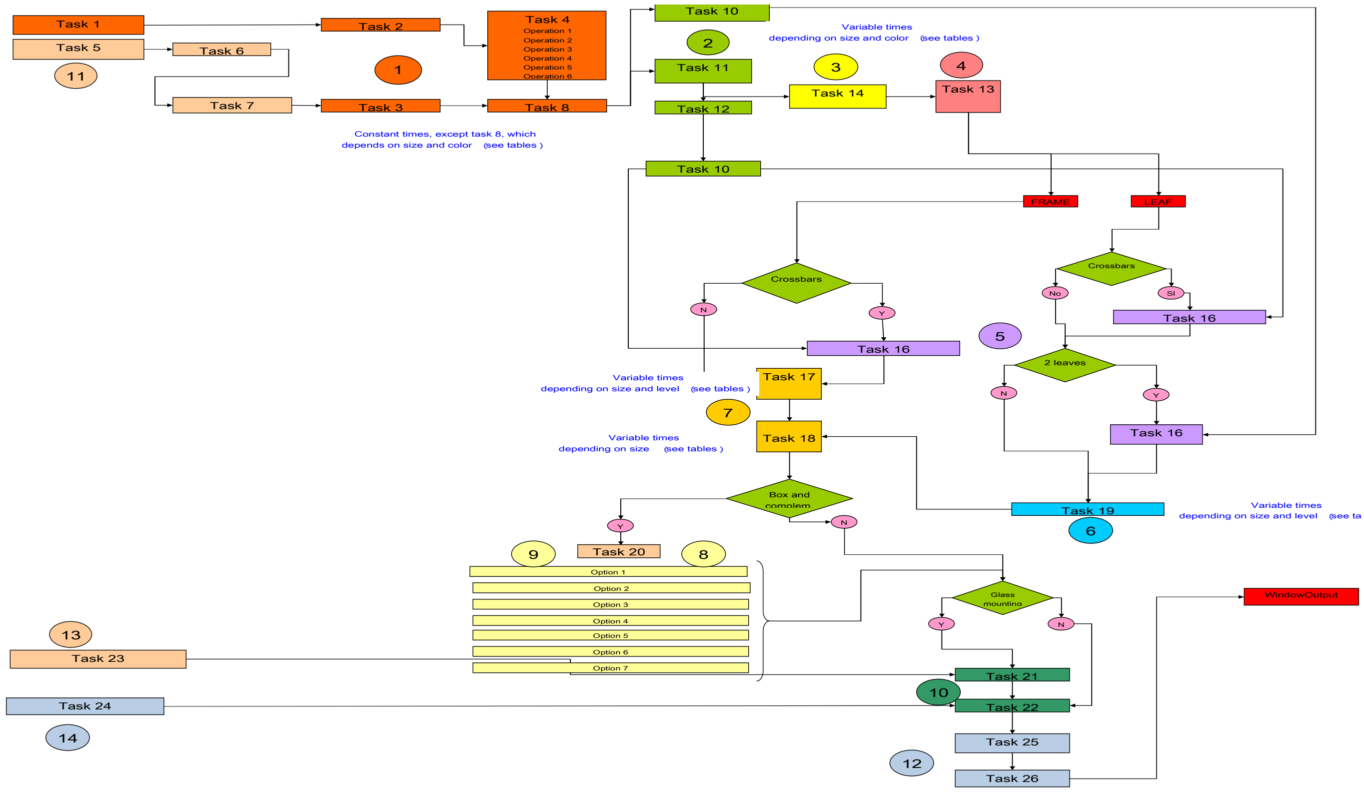

Figure 1. FMS Layout. Productive processes (Tasks, in squares) involved in the different production systems, and Operators (in circles).

To cope with the previous problems that appear when considering complex models mainly related with multi-product manufacturing systems, colored Petri nets have shown their capacity to solve these problems. Here, a colored model that will represent the initial FMS will be depicted, but, in order to be completely sure of the quality of the colored approach, by comparing with the previous stochastic PN model.

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 sections 3 and 4 the two Petri net models will be depicted. 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 Manufacturing system initially considered is able to perform window frames with the following different features:

Feature 1

The first feature to be considered when modeling the system is the type of window where the frame will be included:

- Accessible window,
- tilt and turn window,
- Slide window
- Frames without any other element.

Feature 2

This feature is related with the presence of a crosspiece that goes horizontally from one extreme to the other of the window frame.

- With crosspiece
- Without crosspiece

Feature 3

The number of leafs that compose the window is the next differentiation element.

- One leaf
- Two leafs

It was considered a third leaf in the initial modeling constraints but finally it was decided that the third leaf could be added as a future improvement of the manufacturing system.

Feature 4

The last feature is related with the size of the window that will change the treatment or steps that must be followed in case of considering one size or the other.

- Big size
- Little size

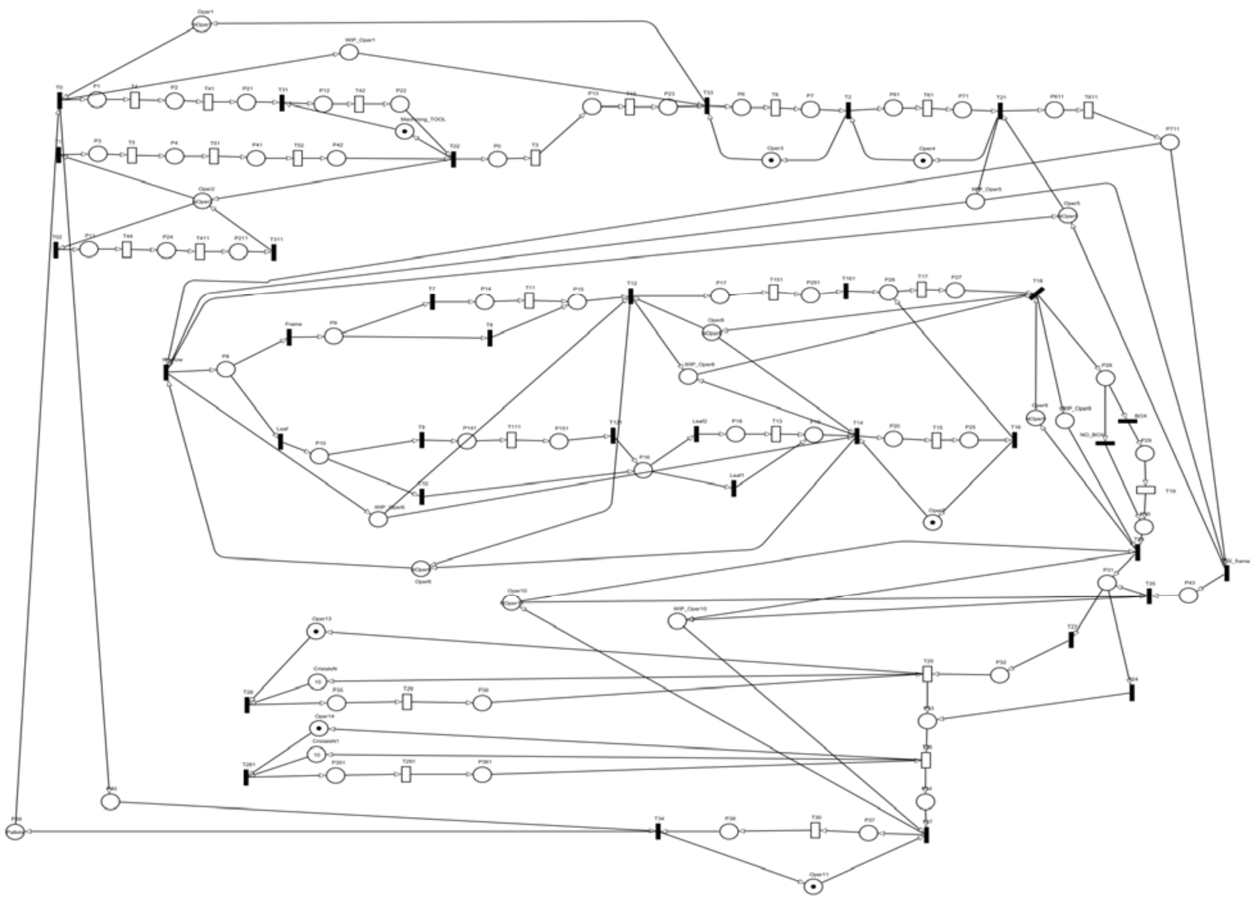

Figure 2. Petri Net model of the FMS defined in Table 1 and Figure 1

Considering all the features depicted here, there are finally 32 different types of products that our manufacturing cell will be able to produce.

Apart from these types of windows, a set of accessories can be added to the different products. These accessories are:

- Box and Guide to include into this device the blind that can be integrated into the window.
- Drip edge to get all the water that can slide through the window

Once considered all the parts that can be produced in our factory, we will concentrate now in the productive processes that have to be fulfilled during the whole production (Table 1). Figure 1 represents the different ways that any window can follow, and which of these productive processes will receive, depending on the type of window.

3. STOCHASTIC PETRI NET MODEL

In this section the Petri net that has been modeled using stochastic PN is presented. The complete model is represented in Figure 2.

This complete Petri net model shown before will be more clearly presented in the next figures where it will be divided in substructures that will help understanding the modeling issues.

Figure 3 presents the operations where operators 1, 2 and the numerical control machine are involved. Places Oper1 and Oper2 represent the availability of the operators when marked. Transitions T45, T412, T32 and T431 represent the 4 operations that can be performed or supervised by Operator 1,while T53, T511, T521, T441 and T4111 represent the five operations that the second operator can perform. Finally, the machining tool availability is represented by place Machining_TOOL1 and the operation is shown under transition T421.

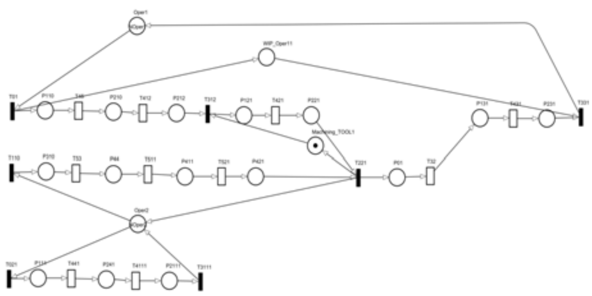

Figure 3. Petri Net model Operator 1, Operator 2, and NCM of the system.

Figure 4, represents the operators 3 and 4, and due to their simplicity, because they are only performing an operation, we have considered that a simple operator can cover each one of the tasks associated. There is no competition for the operators tasks.

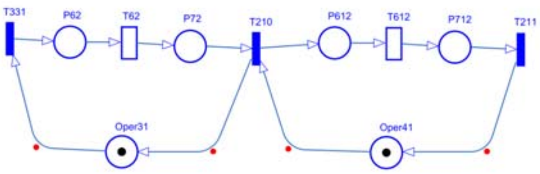

Figure 4. Petri Net model Operator 3 and 4 from example

Figure 5 represents the tasks where operators from 5 to 9 are involved. This Petri net model represents most of the decisions that must be taken (depending on the type of final product that the FMS is generating).After operator 5 performs its task (transition T611) then the raw parts will take one way or another depending on the type of final product (window or frame). If window, it will continue through transition window and then a second decision should be taken depending on what has to be built is a leaf of this window or a frame of it (transitions Leaf or Frame). All these operations will be supervised by operator 6. Then operators 7 and 8 will perform their tasks associated to them (transitions T15, T151 and T17). Finally, operator 9 will perform its operation represented by transition T19, but before that a decision should be taken regarding the presence of a BOX in the window structure represented by immediate transitions BOX and NO_BOX.

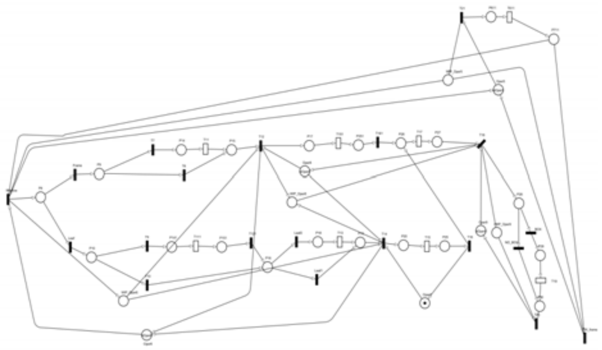

Figure 5. Petri Net model Operators 5 to 9 from example.

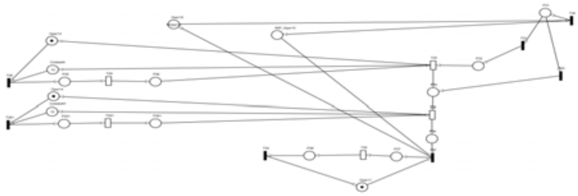

Figure 6.Petri Net model Operators 11 to14 from example

The last Petri net submodel is represented in Figure 6, where operators from 10 to 14 are modeled. These operators generally are performing simpler operations than the previous ones and their model representation is simpler also.

4. COLORED PETRI NET MODEL

The colored Petri Net of the previous model can be simulated and analysed by using the TimeNET software.

The main properties we are interested in with respect to the models are: check that all the places included in the model are at least included in a P-invariant (set of places that conserve a constant number of tokens during the Petri net token evolution). The P-invariants can be computed solving a linear programming problem and the TimeNET package has implemented this algorithm so that it can be computed in a reasonable time. The application calculate that the net contains 87 P-invariants, and that all the places are covered by p-invariants. Also the decisions that should be taken referring to the features of the windows to be produced compose the conflicting situations that the application calculates (Window/FIX_frame, Frame/Leaf, BOX/NO_BOX, and Leaf2/Leaf1).

5. RESULTS AND COMPARISON

The results we are interested to compare between the two models previously shown are related with productivity measures. It will be considered the number of pieces produced per time unit (throughput) for each type of product (32 different types can be produced in the FMS), that is, the optimization that we can carry out based on each one of the models.

Another performance measure we will consider will be the utilization of the different operators that are present into the system.

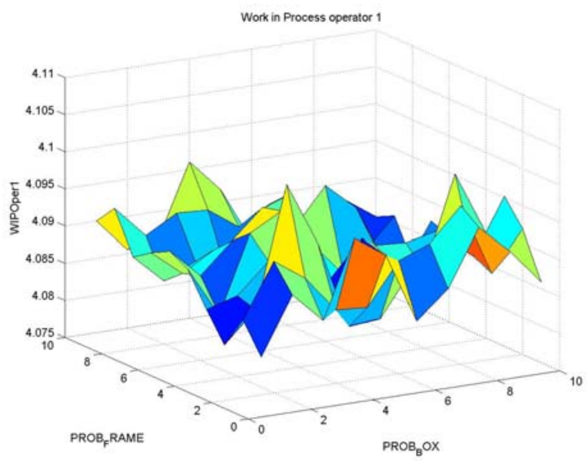

Figure 7. Work in progress of Operator 1 depending on the probability of frame and the probability of Box

Another important comparison measure will be how efficient is the convergence process for the two models and the accuracy they can reach.

Also the computational time that the computer will be calculating the measures will be another measure of how good the simulation process is with respect to the colored and the stochastic models.

The search space corresponding to the optimization problem is composed by the variables of Table 2.

6. CONCLUSIONS

Two different modeling formalism, both of them under the umbrella of Petri nets paradigm, Stochastic and Colored Petri Nets, have been used to model and optimize a real complex production factory. These two models have been compared in terms of the performance measures that could be interesting for the production system, using indicators related with the productivity of the system as well as with the computational effort.

The results shown that in complex production systems, in which an exhaustive analysis is not possible, the best solution is to deal with both formalisms in a combined way, since both of them presents advantages depending on the parameter (production, computational effort) and on the available time.

Table 2. Variables used to compose the search space of the optimization and their values (minimum, maximum, initial, delta, temp)

NOper i	integer variable that represents the number of operators that will perform the operations initially assigned to operator i. (1, 10, 1, 0.9, 1)
Mach_Delay	real variable that represents the time that in average takes to the Numerical Control Machine to perform the different tasks. (1, 140, 1, 0.1, 1)
PROB_BOX	real variable that represents the percentage of windows that has a box inside its structure. (0.05, 0.95, 0.5, 0.1, 1)
PROB_FRAME	real variable that represents the percentage of windows that will be a fixed frame window without any leaf (or with a unique one). (0.05, 0.95, 0.5, 0.1, 1)
PROB_WINDOW	real variable that represents the percentage of products that will have a window struc-ture instead of a frame one. (0.05, 0.95, 0.5, 0.1, 1)

The results of the comparison can be seen represented in Figures 7 to 9.

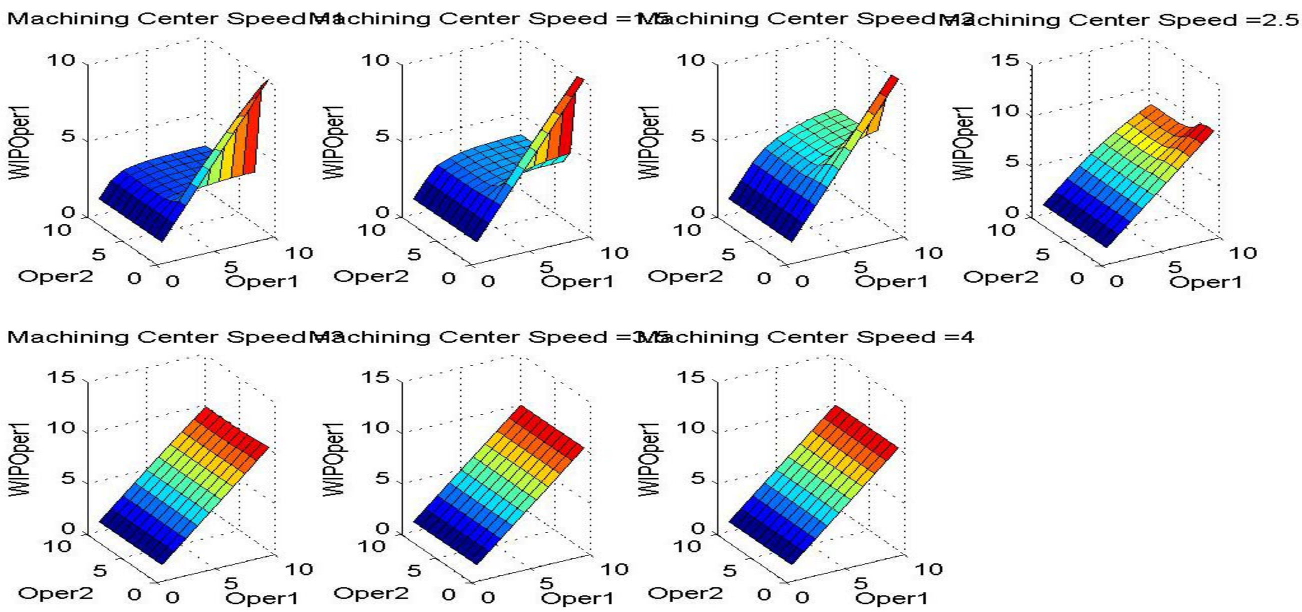

Figure 8. Work in progress of Operator 1 depending on Operator 1 and Operator 2 for different machining center speed (1, 1.5, 2, 2.5, 3, 3.5, and 4)

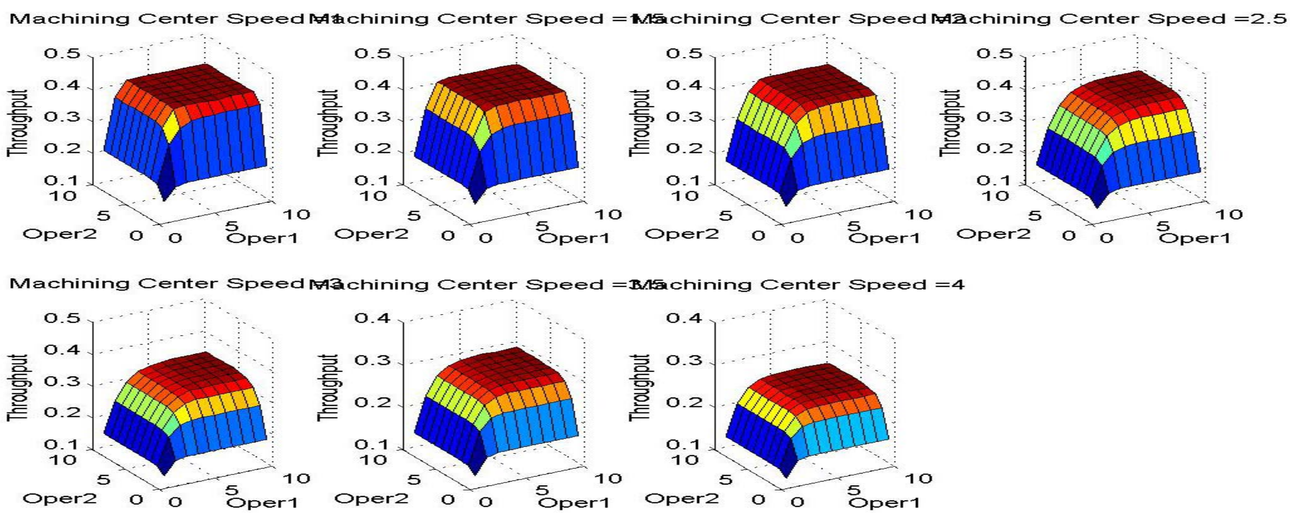

Figure 9. Throughput depending on Operator 1 and Operator 2 for different machining center speed (1, 1.5, 2, 2.5, 3, 3.5, and 4)

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