Implementation of fuzzy system using hierarchical Colored Petri Nets to model flexible manufacturing cell

To cite this article: S K Saren et al 2018 IOP Conf. Ser.: Mater. Sci. Eng. 400 042050

View the article online for updates and enhancements.
Implementation of fuzzy system using hierarchical Colored Petri Nets to model flexible manufacturing cell

S K Saren¹, F Blaga²,¹ and T Vesselenyi¹
¹University of Oradea-Romania, Mechatronics Department, Str. Universitii, Nr.1, 410087, Oradea, Bihor, Romania
²University of Oradea-Romania, Industrial Engineering Department, Str. Universitii, Nr.1, 410087, Oradea, Bihor, Romania

E-mail: sanjikbsaren@gmail.com

Abstract. In Flexible manufacturing field the Fuzzy application found in to solve conflict situation, production routing, and control in the system. In present days, to produce a product according to the Delivery dates is an important issue in Flexible Manufacturing industry. In order to focus on this issue, we try to solve this problem by implementing fuzzy rules according to due dates. The fuzzy rules are divided in three sections such as Early Due Dates (EDD), Exact Due Dates (EXACT), and Over Due Dates (OVER). In this flexible cell two other parameters are part processing time and the number of tools which are described in this fuzzy rules model. The part processing time and the number of tools are described with the small, medium and large linguistic variables. The fuzzy rule based model is constructed using Hierarchical Colored Petri Nets which is suitable to define each section as a sub model. The observed results provide the overall analysis and performance of cell. The constructed manufacturing cell model also provides the detailed behaviour of each resource where resource appears as Color token values. Also, we compare the simulation results from Hierarchical Fuzzy Colored Petri Nets and Matlab fuzzy rule based design for flexible cell.

1. Introduction
In present era of manufacturing industry focused on modernized the flexible manufacturing system using various types of techniques and algorithm. To obtain a better performance in flexible manufacturing needs more flexibility and better management. In present days, field of flexible manufacturing industry eyes on focusing higher productivity according to the customer demand. There are possibilities to fulfil the demand of customer according to demand of product. There are few factors are very important in flexible manufacturing but one of factor is such as due dates. Most of the industry focused on delivered the product according to due dates but it’s not possible to delivered in following due dates. To focus on this problem, we try to build fuzzy parameters in integrated flexible manufacturing system. The application of Petri Nets is one of powerful techniques to design flexible system to obtain better results. Petri Nets theory now extended with time, stochastic, colored and hierarchy to define the techniques more elaborately. It is found that FMS system modeling required conflict resolution free with decision making to obtain the better performance. The application of Colored Petri Nets found to modeling FMS to plan different production strategy including control of the system which is based on multi criteria fuzzy rules [1]. The application of multi criteria fuzzy rules used to solve conflicting process in manufacturing system using colored petri nets theory. The conflict
may be occurring in load station, buffers or system resources, to solve the issue fuzzy rules are most useful solution, such as lot size, due dates, priorities are useful rules to avoid conflict in the system [2].

Application of Colored Petri Nets found in modelling discrete event dynamic system in field of flexible manufacturing. The combination of Colored Petri Nets and fuzzy described as a fuzzy Colored Petri Nets which used for uncertain knowledge interface, to reduce graphic complexity in model and described dynamic behaviour [3]. The author in [4] explained hierarchical concept in Colored Petri Nets where large CP- nets CPN palette tool package for analysis. Hierarchical Colored Petri Nets application found in modeling error free flexible system also operation of each sub subsystem described by using single resource active cycle in [5]. In [6] Multi-criteria decision making (MCDM) method fuzzy application found in robot flexible assembly cell to determined best ranking solutions and decision making. Tool allocation in a system has priority to design in a proper way to perform operation in consideration that condition Chen in [7] proposed colored Petri nets theory used to model the FMS using object-oriented method to evaluate dynamic tool allocation and performance of the system. In [8] production line model analysis and simulation using hierarchical colored Petri Nets (HCPN) approach found and also the author explained prediction of production simulation of the model. Also HCPN is an object approach of Colored Petri Nets helps to re-use the model for better simulation.

This recent paper focused on modeling of flexible manufacturing cell design based on hierarchical Colored Petri Nets which is integrated with fuzzy rules system. The flexible cell design contains single CNC machine, two robots, conveyor and pallets. The design approach of fuzzy rules from Colored Petri Nets based on linguistic variables and the fuzzy rules from MATLAB based on real value to comparison the results after simulation. Implementing this fuzzy rules with integrated FMC system provide conflict free solutions, better dynamic production solutions and the system find the solution to process the part following due date based on fuzzy integrated system.

2. Fuzzy Colored Petri Nets

The production rules of a fuzzy rule based system using Petri nets allow representation of knowledge was described by Chen [9]. In production rules based model where places are associated with propositions and transitions, with their respective input and output places. In [10] Colored Petri Nets suitable to design dynamic and concurrent systems but dealing with uncertainty and reasoning fuzzy reasoning, logics and production rules have been combined with Petri Nets representation which called Fuzzy Petri Nets (FPN). FPN used to modeling decision making, programming, control of manufacturing system and even to solve conflict situation in flexible manufacturing system. FPN represent the fuzzy production rules to describe the relation between two propositions for rule-base system. In [11] The FPN based on two approaches (a) Knowledge representation of model, where the transitions are associated with production rules which described fuzzy expert system or fuzzy control system, (b) in the second approach, possibility distributions where, transitions denote possible state changes and uncertain or imprecise temporal information.

A general definition of non- hierarchical Fuzzy colored petri nets (FCPN) as 12 tuples in [3]:

FCPN: \(\Sigma, P, T, D, A, N, C, G, E, \beta, f, I\), where

1. \(\Sigma = \{\sigma_1, \sigma_2, ..., \sigma_n\}\), a finite set of non-empty types, called colour sets, \(1 \geq 0\),
2. \(P = \{PC, PF\}\) a finite set of places,
3. \(P_c = \{pc_1, pc_2, ..., pc_m\}\), a finite set of places that model the dynamic control behaviour of system, called control places, \(m \geq 0\),
4. \(P_f = \{pf_1, pf_2, ..., pf_n\}\), a finite set of places that model the fuzzy production rules, called fuzzy places, \(n \geq 0\), \(P_c \cap P_f = \emptyset\),
5. \(T = \{TC, TR\}\), a finite set of transitions,
6. \(TC = \{tc_1, tc_2, ..., tc_c\}\), a finite set of transitions that are connected to and from control places, called control transition, \(c \geq 0\),
7. \(TR = \{tf_1, tf_2, ..., tf_f\}\), a finite set of transitions that are connected to or from fuzzy places, called fuzzy transition, \(f \geq 0\), \(TC \cap TR = \emptyset\).
4. \( D = \{ d_1, d_2, \ldots, d_k \} \), a finite set of propositions, \(|P_F| = |D|\),
5. \( A = \{ a_1, a_2, \ldots, a_k \} \), a finite set of arcs, \( k \geq 0 \), \( P \cap T = P \cap A = T \cap A = \emptyset \),
6. \( N: A \rightarrow P \cup T \times P \) is a node function, it maps each arc into a pair where the first element is the source node and the second is the destination node, the two nodes have to be of different kind,

In: an input function that maps each node, \( x \), to the set of nodes that are connected to \( x \) by an input arc of \( x \); out: an output function that maps each node, \( x \), to the set of its nodes that are connected to \( x \) by an output arc of \( x \),
7. \( C: (P \cup T) \rightarrow \Sigma_s \) is a colour function, i.e. it maps each place and transition to a super-set of colour set,
8. \( G: T \rightarrow \Sigma_c \), a guard function, \( \forall t \in T: [Type(G(t)) = Boolean \land Type(Var(G(t))) \subseteq \Sigma ] \), where Type(\( Vars \)) to denote the set of types \( \{ Type(v) \mid v \in Vars \} \), \( Vars \) is a set of variables, \( Var(G(t)) \) denotes the variables used in \( G(t) \),
9. \( E: A \rightarrow \text{Arc expression function} \), \( \forall a \in A: [Type(E(a)) = C(p(a))MSType(Var(E(a))) \subseteq \Sigma ] \) where \( p(a) \) is the place of \( N(a) \), MS stands for multi-set,
10. \( \beta: P_F \rightarrow \Sigma_c \) is a bijection function mapping from fuzzy places to proposition,
11. \( f: T \rightarrow [0,1] \), an association function, assigns a certainty value to each colour used in each fuzzy transition,
12. \( I: \) an initialization double \( (\delta, \alpha) \),
\( \delta: P \rightarrow \) an initialization function, \( \forall p \in P: [Type(\delta(p)) = C(p)MS] \),
\( \alpha: \) an association function, assigns a certainty value in the range \([0, 1]\) to each token in the fuzzy places.

**Firing Rules**: For a Fuzzy Colored Petri Nets, we need to pay special attention on the firing rules since there are integration between dynamics control part and fuzzy part of Petri nets.

Firing rules for a control transition are as follows: (a) a transition fires if and only if the colour token in the input places of that transition are members of the colour set associated with the transition. (b) The colour tokens are removed from the input places when a transition fires. A set of colour tokens will be created in the output places as defined by the expression of the output arc. (c) Colours associated with tokens are allowed to change across transitions.

In [12], a FCPN is proposed to solve conflict situation and production planning in manufacturing system. Fuzzy logic and colored Petri Nets are combined together provide useful information. A fuzzy is associated with mention transitions in the manufacturing model represent the fuzzy rules to give priority to the jobs. The authors in [13] explained the application of FCPN in printed circuit board production system. The paper also provides new weighted fuzzy production rules in the system.

In [14] presents a fuzzy expert system for scheduling part in an FMS. A simulation model of FMS constructed and a fuzzy logic is proposed to take decision of the system to obtain better system performance. In [15] the author proposed the application of fuzzy logic to select the next possible step for possible alternatives routing sequence for the processing of a product.

### 3. Flexible manufacturing cell configuration

The flexible manufacturing cell (FMC) configuration based on from University of Oradea laboratory. The Flexible Manufacturing Cell is consisting of one CNC machining centres TMA 55 OP has computer control to run the program which is FANUC system, two ABB IRB 1600 robots equipped with pneumatic gripping devices for loading and unloading purpose, conveyor used as a transfer system and separate storage area for specific raw material and finished parts. Five different parts are processing on the simulation model where the parts are processed in Colored Petri Nets model follow linguistic variables and for MATLAB simulation we implement real part processing from the experiments. The parts processing times are respectively, \( P_1 = 336 \) sec; \( P_2 = 458 \) sec; \( P_3 = 1158 \) sec; \( P_4 = 2160 \) sec and \( P_5 = 2460 \) sec. Below in figure 1, the flexible cell from the University of Oradea laboratory and figure 2, the observation of processing time from the machine.
4. Hierarchical Fuzzy ruled based structure of FMC

The theory of Hierarchical Color Petri Net was first explained by Huber in a paper that highlighted the relation of a set of sub-models in a single model [4]. The advanced design of flexible manufacturing cell used to design by implementing hierarchical approach. Colored Petri Nets theory are very useful to design and simulation for flexible cell, when the complex system difficult to explain in simple manner need to explain using various sub models in main model means hierarchical approach. Below in figure 3, we illustrated the view of the main model structure design of the flexible manufacturing cell.

Figure 1. The modelled flexible manufacturing cell operates at the laboratories of the Faculty of Managerial and Technological Engineering, University of Oradea.

Figure 2. Part is processing on CNC machine to observed processing time.

Figure 3. The hierarchical structure of flexible manufacturing cell based on Faculty of Managerial and Technological Engineering, University of Oradea.
Hierarchical Coloured Petri Nets able to combine properties of Petri Nets and object oriented approach which allows the analysis of concurrent systems and the description, and the Hierarchical Coloured Petri Nets the reuse, inheritance and specialization of the models [8]. The model is designed using CPNTools software which is capable of feature likes time, token color and hierarchical modeling. In this flexible cell manufacturing model, we employed CPN Tools software to design with hierarchical technique. The base model contains 17 places and four transitions which represent the overall system view. The double square block represents the hierarchical section, such as (a) Fuzzy rules for system, (b) Part follow due dates, (c) Prat processing, (d) Part near storage. The places are respectively, represented by circle with color token value. In each places the resources present the color set, token value, place name and unit name for color. The system follows the fuzzy rules following from place P19, the system following places such as raw part, pallet_1, pallet_2, robot_1, robot_2, machine, T1, T2, T3, T4, T5, T6, T7, part near machine and part complete. Below in table 1 we show the characteristic of important places for the flexible cell using Colored Petri Nets theory.

| Places        | Characteristics                        | Initial Token | Initial Marking                     | Variables |
|---------------|----------------------------------------|---------------|-------------------------------------|-----------|
| Raw part      | Storage area for raw part              | 9             | P1 ∈ {p1}                           |           |
| P19           | Fuzzy rules                            | 3             | 1'PT1+1'PT2+1'PT3+1'PT4+1'PT5       | X ∈ {x}   |
| Robot_1       | Robot_1 for loading and unloading parts| 1             | 1'R1                               | R1 ∈ {r1} |
| Pallet_1      | Pallet used for transport part          | 3             | 3'PL1                              | PL ∈ {pl1}|
| Part near mc  | The part should be near mc              | 0             | -                                   | -         |
| Robot_2       | Robot_2 for loading and unloading parts| 1             | 1'R2                               | R2 ∈ {r2} |
| Machine       | CNC machine                            | 1             | 1'M1                               | M1 ∈ {mc} |
| T1            | Tool_1                                 | 1             | 1'NT1                              | T1 ∈ {t1} |
| T2            | Tool_2                                 | 1             | 1'NT2                              | T2 ∈ {t2} |
| T3            | Tool_3                                 | 1             | 1'NT3                              | T3 ∈ {t3} |
| T4            | Tool_4                                 | 1             | 1'NT4                              | T4 ∈ {t4} |
| T5            | Tool_5                                 | 1             | 1'NT29                             | T5 ∈ {t5} |
| T6            | Tool_6                                 | 1             | 1'NT30                             | T6 ∈ {t6} |
| T7            | Tool_7                                 | 1             | 1'N39                               | T7 ∈ {t7} |
| Pallet_2      | Pallet used for transport part          | 2             | 2'PL2                              | PL ∈ {pl2}|
| Part in R2    | Final part in robot_2 gripper          | -             | -                                   | -         |
| Part complete | Final Storage area for complete part    | -             | -                                   | -         |

4.1. Fuzzy system design for flexible cell
The design of flexible manufacturing cell integrated with fuzzy ruled based system. The author in [15] proposed concept of CPNs and FPNs combined together call Fuzzy Coloured Petri Nets (FCPNs) for modeling production inference of Flexible Manufacturing Systems and dynamic behaviour. To construct the system, we have to use hierarchical technique to understand the behavior of each sub model such as fuzzy system is one sub model in this design. The system will follow the rules as we described in the sub model. The rules are based on two linguistic input variables and one linguistic output variable, such as linguistic input variables is (a) Processing Time (PT), (b) Number of Tools (NT) and linguistic output variable Due Dates (DD). During design the fuzzy rules in Petri Nets the
definition of places and transitions are play significant role to provide the output results. Three input places are PT, NT and DD are connected through transition to com places to provide output results for phase. The respective places from P1 to P9 are connected through transitions T10 to T18 defined the rules individually, such rules like, (if pt=PT then 1`SM else empty) or (if dd=DD then 1`OVER else empty). The connection from transitions T10 - T18 to places P10-P18 define the combination of all rules. In this design we mention three important transitions (a) OVER (b) EXACT, (c) EDD which represents the output results appear on place P19. The color token value plays major role to provide output results and also during the design each arc contain the rule for decision. As in final three transitions the decisions are (a) if pt= PT then 3`OVER else empty, (b) if pt= PT then 3`EXACT else empty (c) if pt= PT then 3`EDD else empty. In fuzzy based modeling, the transitions T0, T10, T11, T12, T13, T14, T15, T16, T17, T18, OVER, EXACT and OVER define the significant action to send information from input places to output places. To design the fuzzy system integrated with flexible cell we employed colored Petri Nets theory. In this model, the rules are implemented in each are to create a connection from places to transition as an input and as output from transition to place. The rules are following criteria based on Processing time (PT) and Number of Tools (NT) as an input linguistic variable with three different parameters such as SM, MED and LRG where Due Date (DD) is the output linguistic variable in the hierarchical model. The resource places for fuzzy rules are presented below in table 2 also the fuzzy based model presented in figure 4.

| Places | Characteristics | Initial Marking |
|--------|-----------------|-----------------|
| PT     | Processing time | 1`PT            |
| NT     | Number of tools | 1`NT            |
| DD     | Due Dates       | 1`DD            |
| com    | Complex color set | 1`PT++1`NT+1`DD |

Table 2. Definition and characteristics of places for fuzzy rules model.

Figure 4. Fuzzy rules used in flexible manufacturing cell to obtain the due dates.
The simulation of fuzzy sub model in the flexible cell provides the output linguistic variable as a Due Date in the place P19 with color token value. The output shows that nine color token values will appear after simulation and will provide the Due Date as EDD, EXACT and OVER which represent by the color token value separately. In Place P19, 3’EDD++3’EXACT++3’OVER define the number of token with output color. Below in figure 5, the linguistic variables for Due Dates appear as an output color value after simulation.

Figure 5. Fuzzy rules appear after simulation as due dates in flexible manufacturing cell.

4.2. Part arrival sub model as fuzzy rules
Raw parts are following the outcome results from fuzzy, the resource place contain due date as an outcome results. The flexible manufacturing cell is integrated with fuzzy rules based system. During design the places for raw parts and robot_1 connected through the transition to follow the rules. Robot_1 will load the part in the system as following due dates which are outcome from place P19. During design in raw part carry color set 1’PT1++2’PT1+2’PT3+2’PT4+2’PT5 for parts. In this sub model, robot_1 take the part from resource places and unload in the pallet_1 to move forward towards robot_2, then robot_2 ready to unload the part in machine. In sub model double circle means that resource place work as an input and output function for another sub model. In this sub model the variables such as x, r1, r2, pl1, (x, r1, pt1), (x, pl1, pt1) are important parameters to create a connection between places and transitions. Below in the figure the sub model for part arrival section as following fuzzy rules are presented. Also in the figure 6, the significant color token values of each place, action of the transitions and related variables for the resource places mention in the arc with part arrival sub model section are mention below.
Figure 6. Part arrived in flexible manufacturing cell according to the due dates.

Also in the table the significant meaning and characteristic of each place, transitions and their action are mention below in the table 3 and table 4.

Table 3. Transitions for part arrival sub model.

| Transitions                                | Actions                          |
|--------------------------------------------|----------------------------------|
| Robot_1 take part as a rules               | Part is in Robot_1 gripper       |
| Connection between pallet_1 and robot_1    | Robot_1 unload the part in pallet_1|
| Robot_2 take part                         | Part is in Robot_2 gripper       |

Table 4. Definition and characteristics for part arrival sub model.

| Places         | Characteristics                  | Initial Token | Initial Marking | Variables |
|----------------|----------------------------------|----------------|-----------------|-----------|
| Raw part       | Storage area for raw piece       | 9              | 1`PT1+2 PT1+    | P1 ∈ {pt1}|
| P19            | Fuzzy rules                      | 3              | 1`PT++1’NT+1’DD | X ∈ {x}   |
| Robot_1        | Robot_1 for loading and          | 1              | 1’R1            | R1 ∈ {r1} |
|                | unloading pieces                 |                |                 |           |
| Pallet_1       | Pallet used for transport piece  | -              | 3’PL1           | PL ∈ {p1} |
| Part near mc   | The part should be near mc       | -              | -               |           |
| Robot_2        | Robot_2 for loading and          | 1              | 1’R2            | R2 ∈ {r2} |
|                | unloading pieces                 |                |                 |           |
| P3             | Part is in robot_1 gripper       | -              | -               |           |
| P0             | Part is in Pallet_1 gripper      | -              | -               |           |

4.3. Part processing sub model

In this sub model, the parts are processing following appropriate tools for machining. To design this section each tool, contain resource places with color token value such as 1’NT1, 1’NT2, 1’NT5, 1’NT6, 1’NT29, 1’NT30 and 1’NT39 for different tools in the system. In each resource places we consider token value 1 means in resource place contain only one tool and all the tools perform different operations. As mention before double circle mention places works as an input and output function in the system. During the design we describe the guard function in each transition to perform exact sequence to machining the part. Such as in transition TA, guard function [p=P1] is activated when information is transfer by arc from place to transitions. So, in this sub model each transition is able to identify the part for processing according to sequence in machine using appropriate tools. Also, in this section we establish a connection between place and transitions through the arc to perform exact operation. Such as in transition TA is used to processing part type 1 using variables (x, t3, mc,
pt1) where, $x =$ fuzzy, $t3 =$ tool, $mc =$ machine and $pt1 =$ part 1 respectively. The part processing sub model with machine and tool configuration showed in the figure 7 below illustrated.

**Figure 7.** Parts are processing in flexible manufacturing cell according to the due dates.

We describe each place and transitions and their meaningful function below in the table 5 and table 6.

**Table 5.** Definition and characteristics for part processing sub model.

| Places                  | Characteristics                        | Initial Token | Initial Marking | Variables                        |
|-------------------------|----------------------------------------|---------------|----------------|----------------------------------|
| Part processing 1       | Part 1 is processing following the due dates | -             | -              | $(x,t3,mc,pt1)$                  |
| Part processing 2       | Part 2 is processing following the due dates | -             | -              | $(x,t3,mc,pt1)$                  |
| Part processing 3       | Part 3 is processing following the due dates | -             | -              | $(x,t6,t1,mc,pt1)$               |
| Part processing 4       | Part 4 is processing following the due dates | -             | -              | $(x,t6,t7,mc,pt1)$               |
| Part processing 5       | Part 5 is processing following the due dates | -             | -              | $(x,t6,t5,mc,pt1)$               |
| Part processing complete| Part processing complete               | -             | -              | $(x,pt1)$                        |
### Table 6. Transitions for part processing sub model.

| Transitions | Actions |
|-------------|---------|
| TA          | Part1 is processing on machine using Tool_3. |
| TB          | Part2 is processing on machine using Tool_3. |
| TC          | Part3 is processing on machine using Tool_6, Tool_1, Tool_3, and Tool_4. |
| TD          | Part4 is processing on machine using Tool_6, Tool_7. |
| TE          | Part5 is processing on machine using Tool_6, Tool_5, and Tool_2. |
| Proc TA     | Part1 processing complete. |
| Proc TB     | Part2 processing complete. |
| Proc TC     | Part3 processing complete. |
| Proc TD     | Part4 processing complete. |
| Proc TE     | Part5 processing complete. |
| PART & R2   | Finished part in robot_2 gripper. |

### 4.4. Part complete sub model

The sub model designed with robot_1, robot_2 and pallet_2 and storage area for final finished part. This model describes the finishing part moved by robot_2 to pallet_2 then robot_1 unload the part from alle_2 and storage the part in storage place. Due to conflict situation we used two pallets in here which define in 2`PL2 where 2` is color token for pallet_2. In the part complete place, the due date and part will appear after the end of simulation of all different part for the flexible cell. In figure 8, the sub model for final section presented below.

![Figure 8](image_url)

**Figure 8.** Finished parts are store in storage in flexible manufacturing cell according to the due dates.

Below in the table 7 and table 8 places and transitions characteristics & actions illustrate properly.

### Table 7. Definition and characteristics for part processing sub model.

| Places         | Characteristics                          | Initial Token | Initial Marking | Variables |
|----------------|------------------------------------------|---------------|-----------------|-----------|
| Pl2& part      | Finished part in pallet_2                | -             | -               | -         |
| Part near r1   | Robot_1 ready to unload the part from pallet_2 | -             | -               | -         |
| Robot_1        | Robot_1 for loading and unloading pieces | 1             | 1`R1            | R1 ∈ {r1} |
| Pallet_2       | Pallet used for transport piece          | -             | 2`PL2           | PL ∈ {pl2}|
| Part in R2     | Final part in robot_2 gripper            | -             | -               | -         |
| Robot_2        | Robot_2 for loading and unloading pieces | 1             | 1`R2            | R2 ∈ {r2} |
Table 8. Transitions for part processing sub model.

| Transitions          | actions                                      |
|----------------------|----------------------------------------------|
| PI2 & part           | Robot_2 unload the part on pallet_2          |
| Part near r1         | Robot_1 unload the part in pallet_2          |
| Part near storage    | Robot_1 unload the part in storage           |

5. Simulation of flexible hierarchical fuzzy model

In this fuzzy based hierarchical flexible cell, the simulation approach performs on each sub model following the fuzzy rules. The base model contains all important resources as places and transition to identify the characteristics. In base model, fuzzy rules followed by the robot_1 to pick the appropriate part from the storage based on due dates. The output results from fuzzy appear on place P19 with color set fuzzy. Three different outputs will appear on place P19 respectively, EDD, EXACT and OVER.

In part arrival fuzzy model, robot_1 will pick up the raw part from storage according to the due date. When the transition is firing the token from robot_1, raw part and due date are moving from input places to output places to transfer the information and perform next operation. Here, 3PL1 define the number of pallet which is used to transfer part through the conveyor. Robot_1 unload the part in pallet_1 and moved forward robot_2. The used of three pallet defined here to avoid conflict situation in the cell. Most of the time found during simulation the raw parts are waiting in the queue because the parts are processing on one machine. Here, in part arrival section significantly depends on fuzzy rules.

In part processing model, part will follow the due date according to the fuzzy rules to perform processing. Different tools are allotted for processing five different parts. Seven different tools with color token value highlighted in resource places respectively, 1NT1, 1NT2,1NT5,1NT6,1NT29,1NT30,1NT39. Only one-part processing in a machine at a time, other part wait until the processing is finish. To design this section, five different transitions defined to perform the action. Such as, in transition TA, part 1 is processing following guard function [pt1=PT1]. When the color set from resource places are connected through the arcs using variables to the transition, there is possible to firing in transition and output will appears in connected resource places as a color token value. Such as, resource places part near mc, machine and tool_3 are connected in transition TA through variable (x, r2, pt1), mc, t1 and when the firing is occurred in transition TA the output value will appear using variables (x, t3, mc, pt1) in part processing place with color token value. So on, when each transition is active for other processing part the output value will appear as well. After the complete processing part, the resource places will return in their places with color token value means those places are now free and available for next operation. The complete part will move in next place and robot_2 ready for move the part from that place to the pallet_2. Here, in variable represent such as (x, t3, mc, pt1), x= fuzzy as a due date, t3= tools, mc= machine and pt1= part one. Here, in place PART with color set com4_3 used as an output of complete part according to due date using (x, pt1) variable and the output color value will appear in PART place.

In part complete model, when the part is complete robot_2 load the part in pallet_2 to move towards robot_1 to transfer the part in final storage. The final part will appear in resource place part complete1 with color token value. The color token values are 2(EDD, PT4), 1(EDD,PT5), 1(EXACT,PT1), 1(EXACT,PT3), 1(EXACT,PT5), 2(OVER,PT2), 1(OVER,PT3). The values are total number of parts used to process in the machine and also present the due dates with appropriate part. The system can define exact way to present the output color token value in final resource place. Also, it is observed that the final value appears in hierarchical base model with all token values. After complete the simulation for the flexible hierarchical model all resource places are now fill with color token value and ready for perform to processing next nine different part.

Below in figure 9 and figure 10 final results appears after simulation of the fuzzy based hierarchical model, the results shows suitable fuzzy combination of parts and Due Dates in final resource place.
6. Using Fuzzy tool box from MATLAB to design decision system

In MATLAB design we used mamdani fuzzy interface to build the fuzzy rules. Processing Time and Number of Tools used as an input value and Due Dates as an output value. After run the simulation in fuzzy rules we observed some useful results with data. The processing time and number of tools implement in fuzzy rules are taken from experiment in CNC machine. The processing time for different part implemented as a one input function and Number of Tools used for processing parts which is also one input function in the fuzzy. For fuzzy design, “if” and “then” rules implemented to define the rules. In fuzzy rules, the output results appear as a Due Date which contains the score value for Processing Time and Number of Tools. The Fuzzy rule based system able to estimate if-then rule using fuzzification, interference and composition procedures. To transformed fuzzy results into crisp value, defuzzification method implemented where fuzzified value converted into single crisp vale with respect to fuzzy set. Below in the figure 11, we mention the fuzzy decision based diagram and the defined rules are mention below in the table 9.
Figure 11. Decision based fuzzy system.

Table 9. Fuzzy Rules implemented in MATLAB.

| PT is small and NT is small  | Then Due Date is OVER |
| PT is small and NT is medium | Then Due Date is OVER |
| PT is small and NT is large  | Then Due Date is EXACTLY |
| PT is medium and NT is small | Then Due Date is OVER |
| PT is medium and NT is medium| Then Due Date is EXACTLY |
| PT is medium and NT is large | Then Due Date is EARLY |
| PT is large and NT is small  | Then Due Date is EXACTLY |
| PT is large and NT is medium | Then Due Date is EARLY |
| PT is large and NT is large  | Then Due Date is EARLY |

In table 10, we described the possible application of Processing time and Number of tools to obtain the respected Due Dates. It’s found that the score of the Due Dates represent the part processing sequence in the system. The Due Date with low value processing first in the system which follow the due dates such as EDD, EXACT and OVER.

Table 10. Results from fuzzy MATLAB.

| Processing time (PT) | Number of tools (NT) | Due Dates (DD) |
|---------------------|----------------------|----------------|
| 336                 | 1 (x,t3,mc,pt1)      | 7.85 (OVER)    |
| 458                 | 1 (x,t3,mc,pt1)      | 6.67 (OVER)    |
| 1148                | 4 (x,t6,t1,t3,t4,mc,pt1)| 1.92 (EDD)    |
| 2160                | 2 (x,t6,t7,mc,pt1)   | 4.37 (EXACT)   |
| 2460                | 3 (x,t6,t5,t2,mc,pt1)| 3.36 (EDD)     |

The membership function in the fuzzy model contains input_1 with Processing time range [0, 3000] and number of membership functions define the range as a MF1='SM': 'trimf',[0 1800], MF2='MED': 'trimf',[1800 3000], MF3='LRG': 'trimf',[3000 4200] and the input_2 with Number of tools with range [0 8] where the membership functions are MF1='SM': 'trimf',[-1.6 0 1.6], MF2='MED': 'trimf',[0.4 2.3 3.6], MF3='LRG': 'trimf',[2.4 4.5 6.8] respectively. The output value for contain the range [0 10] where membership function are MF1='EDD': 'trimf',[-4 0 4], MF2='EXACT': 'trimf',[1 5 9], MF3='OVER': 'trimf',[6 10 14]. The output result shows the combination of all rules in a surface graph in figure 12.

The graph represent suitable due dates range for parts based on Processing time and Number of tools. Also the figure 13 described the relation between Processing time and due date where large processing time required low due date to process the part according to fuzzy rules. So, the parts are processing from large processing time to low processing time in the cell.
Figure 12. Due dates, processing time and number of tools results appears after run simulation in MATLAB fuzzy.

Figure 13. Due dates and processing time results appears after run simulation in MATLAB fuzzy.

7. Comparison between HFCPN and MATLAB fuzzy results
The design techniques of fuzzy rules in Colored Petri Nets and fuzzy model using Matlab Toolbox are different. The defined rules applications in both fuzzy models are similar, but the design procedure quite different. In Colored Petri Nets, the rules are defined in arcs from resource place to transition and transition to place. The input variables are defined in places with color token value. Such as, 1 PT ++ 1 NT ++ 1 DD which defined the processing time, number of tools and due dates. The output
value will appear in final resource place in P19 with fuzzy unit. After run the simulation the color token value found in P19 as a 3`EDD+3`EXACT++3`OVER mean three rules for early due date, three for exact due date and three for over due date. The fuzzy rule based model integrated with flexible manufacturing cell to follow the due dates to processing the defined parts from the storage unit. The simulation results provide due date and the part combination in part complete1 place after the simulation run. The color token value with due date and part shows the results as 2'(EDD, PT4), 1'(EDD,PT5), 1'(EXACT,PT1), 1'(EXACT,PT3), 1'(EXACT,PT5), 2'(OVER,PT2), 1'(OVER,PT3).

The observe value from Colored Petri Nets fuzzy based model implement in the rules and in processing time we insert the part and in number of tools the value of the tool to fit in the fuzzy rules. The value from color petri nets are 2'(EDD, PT4), 1'(EDD,PT5), 1'(EXACT,PT1), 1'(EXACT,PT3), 1'(EXACT,PT5), 2'(OVER,PT2), 1'(OVER,PT3). Below in the table 11 we presented the due date and processing time with number of tools for fuzzy hierarchical Colored Petri Nets.

| PT(2)       | NT(1)                             | Due Date          |
|-------------|-----------------------------------|-------------------|
| is small    | is small                           | is small          |
| and         | and                                | and               |
| PT(3)       | NT(4) is medium                    | Due Date is OVER  |
| is small    | is medium                          | Due Date is OVER  |
| PT(1)       | NT(1) is large                     | Due Date is EXACT |
| is small    | NT(4) is small                     | Due Date is OVER  |
| PT(3)       | NT(4) is medium                    | Due Date is EXACT |
| is medium   | and                                | and               |
| PT(4)       | NT(2) is large                     | Due Date is EDD   |
| is medium   | and                                | and               |
| PT(5)       | NT(3) is small                     | Due Date is EDD   |
| is large    | and                                | and               |
| PT(5)       | NT(3) is medium                    | Due Date is EDD   |
| is large    | and                                | and               |
| PT(4)       | NT(2) is large                     | Due Date is EDD   |

The difference found between hierarchical fuzzy Colored Petri Nets and fuzzy from Matlab Toolbox based on the design and the implement of real value. Where, Colored Petri Nets describe the rules in arcs in the system and in Matlab fuzzy provide the application of real value for processing time to justify the results.

8. Conclusions

In this recent work proposed the application of fuzzy rules implemented in colored petri nets with hierarchical extension. The design of fuzzy section quite difficult to integrate with flexible manufacturing cell but the combination of fuzzy rules and Colored Petri Nets provide powerful advantages. In this, flexible model variables used in fuzzy based arcs which provide connection between resource places and transitions. Here, all the found fuzzy rules appear in place P19 as a 3’OVER, 3’EXACT and 3’EDD which represent the types of due date and 3’ defined the number of rules as a color token value and total nine defined rules find after fuzzy simulation. The flexible manufacturing cell follow the fuzzy rules due date as an output results to processing the part. It’s found that the flexible cell follows the rules and the output results appear on the final resource places. The output results appear as a (dd,pt1) due date and part such as, 2'(EDD,PT4), 1'(EDD,PT5), 1'(EXACT,PT1), 1'(EXACT,PT3), 1'(EXACT,PT5), 2'(OVER,PT2), 1'(OVER,PT3).

The design of the fuzzy based flexible cell follows hierarchical techniques to define the behavior of the all resources. All the resources define by the color token values which describe how many resources we need to build the system. The advantage of the system, the defied fuzzy rules is integrated with flexible manufacturing cell where the parts are processing according to fuzzy rules.

We also compare the obtained results from fuzzy based colored petri nets and MATLAB based fuzzy rules for the flexible cell. For MATLAB based fuzzy we implanted the processing time of part and number of tools as an input data to justify the due date. It’s found that if the processing time medium and number of tools are large then due date is exact such as 1148 (PT) and 4 (x, t6, t1, t3, t4, mc, pt1) then 1.92 (EXACT). So from MATLAB fuzzy simulation we found the processing time following the due dates low value to high value to process in the cell. The results from MATLAB provide with numeric value where Hierarchical Colored Petri Nets fuzzy provide linguistic approach.
Both cases found results are correct according to design procedure. At last, the suggestion for further research the application of fuzzy rules using Petri Nets theory on flexible cell proper implementation of rules to improve the operation sequence, implement of time in fuzzy with integrated system.

Acknowledgments
The paper published has been sponsored under the Erasmus mundus partnership program agreement vide number 2014-0855/001-001 coordinated by and between University of Oradea and City University of London Under Action Plan 2 for the year 2015-2018.

9. References
[1] Felipe B R, Vinicius F C, Morandin O, Renan L C and Tuma C C M 2013 Industrial Electronics Society IECON 39th Annual Conf. of the IEEE 3216-3221
[2] Kato E R R, Morandin Jr O and Sgavioli M 2010 SMC IEEE Int. Conf. 3983-3988
[3] Yeung D S, Liu J N K, Shiu S C K and Fung G S K 1996 Proc. Joint Conf. on Int. Systems/ISAI/IFIS IEEE 100-107
[4] Huber P, Jensen K and Shapiro R M 1990 Hierarchies in coloured petri nets Advances in Petri Nets 313-341
[5] Valavanis K P 1990 IEEE SMC 20 94–110
[6] Abd K, Abhary K and Marian R 2014 IEEE Int. Conf. on Ind. Eng. and Eng. Magt. 374 – 378
[7] Chen J and Chen F F 2003 Int.J.of Adv. Manuf. Tech. IJAMT 21 98–109
[8] Eloundou J, Sahnoun M H, Baudry D, Bensrhair A and Louis A 2015 Int.Conf.on Integ. Des. and Prod., CPI
[9] Chen S M, Ke J S and Chang J F 1990 IEEE Transactions On Knowledge and Data Engineering 2 311-319
[10] Cardoso C and Mzalviel B P 1997 In Workshop on Manufacturing and Petri nets (Toulouse, France) pp 17-34
[11] Qiao F, Wu Q, Li L, Wang Z and Cao Z 2008 Proceedings of the 17th World Congress the International Federation of Automatic Control
[12] Fengler W, Wendt A, Bogoljubow J and Dane B 1996 International Conference on Application and Theorie of Petri Nets: Workshop for Manufacturing and Petri Nets (Osaka) pp 24-28
[13] Yeung D S, Shiu S C K and Tsang E C C 1999 Journal of Intelligent & Fuzzy Systems Applications in Engineering and Technology 7 137-149
[14] Chan F T S, Chan H K and Kazerooni A 2003 Journal of intelligent Manufacturing 14 341-350
[15] Bilge I, Firat M and Albey E 2008 Computers and Industrial Engineering 55 15-33