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Workflow balancing in a manufacturing unit using Petri Nets

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Abstract

High productivity in a shop floor can be achieved if there is sufficient solution for its inherent management task. This task comprises very demanding decisions, in particular, the dynamic complexity of the layout and its short response time. Hence an adequate Petri net support in this decision process is indispensable.

Workflows involve the coordinated execution of multiple tasks performed by different processing entities. Balancing the work flow requires the optimal allocation of resources, of all kind, to perform the multiple tasks effectively. Optimization is achieved by introducing a balance between centralization and decentralization of resources (equipment and staff) while preserving the soundness property.

Keywords: *TAKT time, Things Gone Wrong (TGW), State Chart, Resource Oriented Petri nets.*

1. Introduction

Today's information system no longer suffices to focus on just the tasks but control, monitor and support the logistical aspects of a business process. In other words, the information system has to manage the flow of work through the organization. Many organizations with complex business processes have identified the need for concepts, techniques, and tools to support the management of workflows. Based on these needs the term workflow balancing was born

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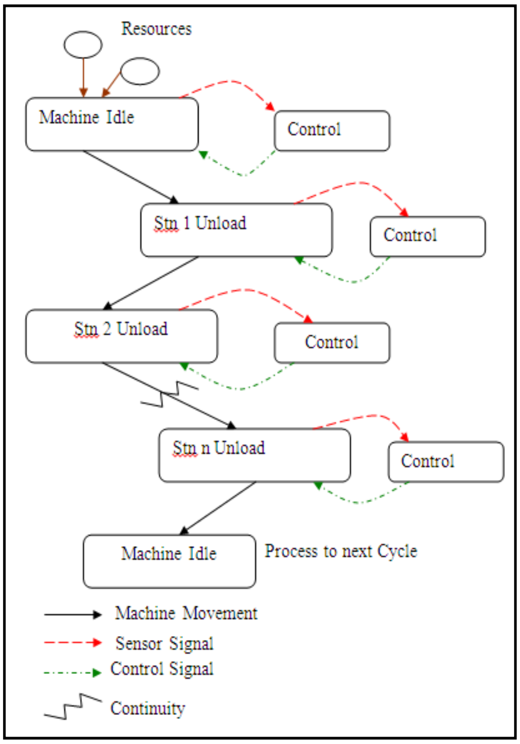

Figure1: Illustrative example – State Chart

Considering the inventory and resources as the key parameters we have set a control sequence for loading /unloading. This is demonstrated using a state chart as it helps in proper scheduling of the part processing station. State chart involves modeling the behaviour of reactive/dynamic objects (machine). State chart shows the flow of controls from state to state (Machine to Machine). An illustration of a state chart is shown in the figure 1.

2. Resource Oriented Petri Nets

A technique of modeling a Resource Oriented Petri Net (ROPN) was carried out as resources are the backbone of a workflow.

We have taken macro transition for our modeling in order to have an ease of design. A macro transition is a time delayed transition in which many operation can be clustered in to a single transition. Thus we use a macro transition in firing as it corresponds to a subset for a machine to deliver a part from a node to another node. This macro transition X contains two transitions ‘a’ and ‘b’ and place ‘p’ for convenience, lets denote X = {a, q, b}, Xi = {ai, qi, bi} and Q = {qi}. Firing transition ‘a’ represents the use of a machine in ‘q’ and firing ‘b’ releases the part as output. A token in q represents a delivering a part transition X can be treated just as an ordinary transition in a net. A token in place ‘r’ represents an available machine. The macro transition can be pictured as a rectangle as shown in Figure2

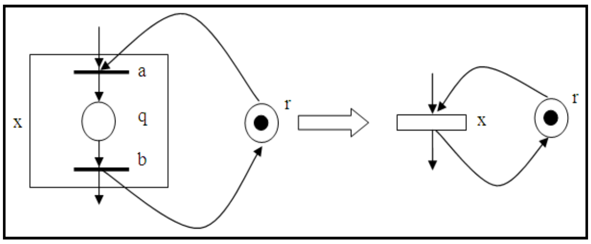

Figure2: Depicts the modeling of a macro transition

Deadlock avoidance is very vital for the production flow and maintaining proper balance to the system. There are different techniques developed to resolve workflow conflicts.

3. System modeling with ROPN

ROPN’s has been developed to model the machine and part processing process and then integrating in a hierarchical way. The hierarchy is maintained by following the Production Part Approval Process (PPAP) for individual components manufactured.

Definition:

A transition t∈T in a finite-capacity PN at marking M is said to be enabled if

$$M(p) \geq I(p, t), \forall\, p \in P \quad \rightarrow (1)$$

and $K(p) > M(p) - I(p, t) + O(p, t) \rightarrow (2)$

Explanation:

It means ‘t’ is enabled and can fire if all the places in t have enough tokens and all the places in t have enough free spaces. When condition (1) is satisfied, t is process-enabled. When condition (2) is satisfied, t is resource-enabled. Thus, t is enabled only if it is both process and resource-enabled. Firing an enabled transition t∈T at M changes M into M’ according to

$$M'(p) = M(P) - I(p, t) + O(p, t), \forall\, p \in P$$

A sequence of transition firing yields a sequence of markings. A marking M is said to reachable from M0 if there is a sequence of transition firings that transform M0 to M. The set of all possible markings reachable from M0 is denoted by R (M0), where R implies reachable marking.

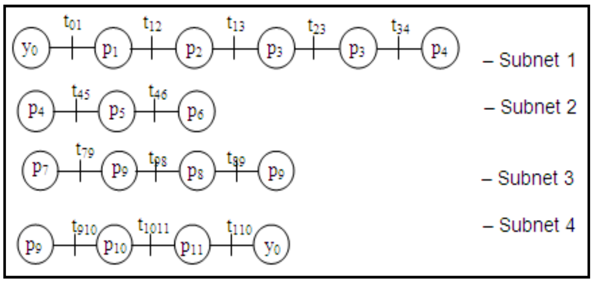

Figure3: System modeling sequence

Figure 3 represents one machine accomplishing the tasks in the state system. We call such model a subnet that models an individual part traveling from one node to another. Each subnet begins and ends with places.

From the individual subnet we can obtain the model for the parts by the union of subnets. The obtained Petri net is structurally a state machine. A state machine happens when each transition has exactly one input and one output, thus making the complexity of the workflow structurally simple.

4. ROPN design and findings

For part processing, there are many types of inventory in a production unit, such as machines (work stations or processing devices), pallets, tools and fixtures. In general, it is assumed that before a part is moved to a machine for processing, the tools needed to process the part are already in the magazine of that machine. Therefore, tools do not have any contribution to deadlocks and hence the workflows. Similarly, taking conditions that pallets and fixtures are not subjected to any bottle-necks. Also, assume that there is infinite supply of raw materials.

Machines and raw materials are the main entities in the production process. This part processing takes only machines and raw materials into consideration. There are buffers (input/output buffers, or both) associated with some machines, or there are multiple machines for some types of machines. Nevertheless, in the sense of workflow balancing, the multiplicity of a type of machines or a machine with buffers just implies that it can hold multiple parts and it is not necessary to distinguish the individual machines or the machine and its buffers, thus we can just model a machine as a type of resource. In the part processing, the route of each part type in a production unit is often known in advance and may admit routing flexibility.

Routing flexibility allows an operation to be processed by more than one machine. To model the part processing by ROPN, one only needs to connect the resource requested by transitions according to operation sequence for each part type.

From the conventional system, we have modeled the key machines, where dead lock frequently occurs and it is of prior importance for control measures. So taking these into account we have catapulted 7 machines for a single type of product to be processed. Those 7 machines are: (i) Bed Milling, (ii) Seam Welding, (iii) Boring, (iV) brake flange Welding and Dome Welding, (V) Drilling, (Vi) inspection, (Vii) Painting.

Based on the study carried out in a conventional layout a PN model was designed. On further investigation of the baseline parameters we came to know that this design layout can further be optimized. So we designed a layout where the workflow is slightly modified to increase efficiency. Deadlocks that prevailed in an existing model are from figure 4

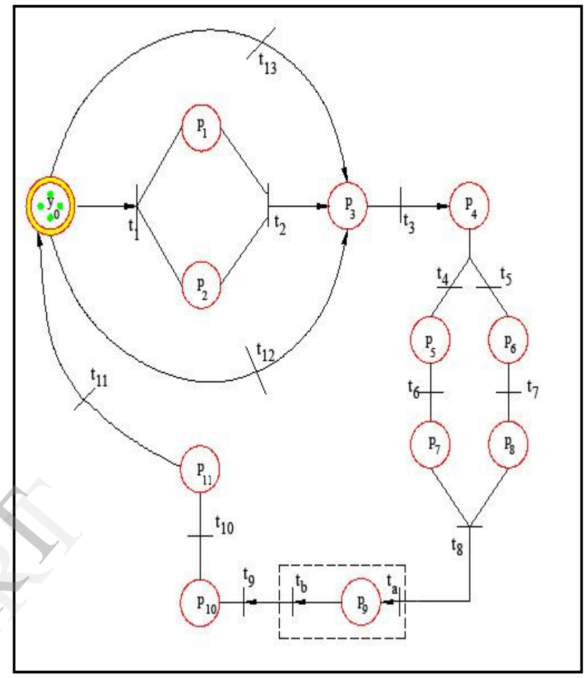

Figure4: Conventional Petri net model of a manufacturing unit

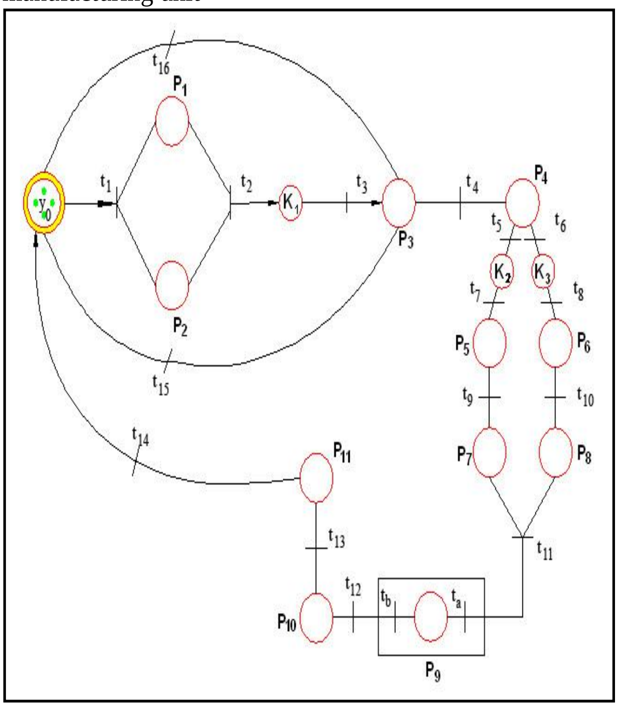

Figure5: Proposed Petri net model of a manufacturing unit

In a conventional model two separate conveyors are employed in commuting the resources from p1 and p2 to p3 respectively, in this condition when p1 is in the process of unloading and at the same time p2 also comes in line with p3 for unloading, then there occurs an idle time for conveyor 2 until conveyor 1 completes its unloading operation, Thus a bottle-neck is visualized.

Similarly the conveyors 3 & 4 are involved for loading/unloading from stations p5 to p9. There arises a conflict between conveyors 3 & 4, in transferring resources from places 7 & 8 to macro transition p9. This is where another clog is noticed also there are possibilities that one of the conveyors 3 or 4 will encounter an idle time when the others are in macro transition, all the above factors are treated to the best of the possibilities in an optimized model, which is shown in figure5.

ROPN for a system is modeled to optimize the layout to attain best output. So taking this into account we have taken seven machines for a single type of product to be processed. The conventional layout (shown in figure4) for these machines is modeled using Petri nets. By this, we had a pictorial representation of the workflows.

Based on the conventional layout we came up with an optimized layout using Petri net as a tool (shown in figure5). The workflow is streamlined using a Kanban system of production control.

A P-Kanban authorizes the conveyor to upstream station and produces a batch of parts. Production of more than this quantity is restricted in the Kanban system.

A T-Kanban authorizes the transport of part to the downstream station.

5. Calculated results

Data obtained using Model Study:

Availability of machine (A)	– 90%
Traffic Factor (Tf) (Bottle-neck)	– 85%
Worker Efficiency (E) (Automatic)	– 1.0
Delivery Schedule (Rf)	– 90 del/shift
Time to Load (TL)	– 0.75 min
Time to Unload (TU)	– 0.5 min
Distance to Load & Unload (Ld & Le)	– 478 mts
Velocity of Conveyor (V)	- 50 mts/min

Cycle Time / Machine / Delivery (Tc)

$Tc = TL + (Ld/V) + TU + (Le/V)$
$= 0.75 + 478/50 + 0.5 + 478/50$
$= 20.37$ min

Total Work Load (WL)

$WL = Rf * Tc$
$Rf = 90/8 = 11.25$ del / hr.
$WL = 11.25 * 20.37$
$= 229$ min / hr (all machines)

Available Time / Machine (AT)

$AT = 60 * A * Tf * E$
$= 60 * 0.9 * 0.85 * 1$
$= 45.9$ min / hr/machine

No. of machines used (nc)

$nc = WL/AT$
$= 229/45.9$
$= 4.98 = 5$ machines

6. Conclusion and future works

We get better visibility on the available resources and their utilization as this modeling is graphical in nature. The issues which were persisting with the conventional layout were analysed. A petri net model is proposed based on the conventional workflow which produced some constructive results.

Based on the design and analysis a permissive control model was obtained as it offers maximal flexibility. This concept can also be used to improve other production operations in a manufacturing unit. The proposed model may also be helpful in system design when the automated material handling system is implemented by robots. Future studies can include analysis of a robotic system as it provides more flexibility in terms of automation. Stochastic (time-dependent) petri nets can be included between the process model to analyse time lag and perform research on cycle-time reduction. A simulated model can be created using yEd graphical editor which can be used to analyse different layout configurations in a shop floor.

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