Throughput Rate Calculation by Cycle Time Modeling for Multi Aisles AS/RS Using Timed Petri Nets

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Abstract

We present here a research approach for the calculation of the throughput rate for a physical configuration of automated storage and retrieval systems (AS/RS) called Multiple Aisles AS/RS (MA-AS/RS). In such configuration of discrete events system (DES) only one Storage/Retrieval machine (crane) is used for storage and retrieval operations, which has the advantage of decreasing the initial system costs (space and money) but at the same time has the disadvantage of reducing the system throughput. This important performances assessment parameter has significant repercussions on the whole system performances particularly in terms of efficiency and productivity.

We consider that the crane works under random policies i.e. bins are randomly situated for each operation and various functioning modes i.e. single command, double command and multiple command cycle. Thus, our approach is based on the calculation of the system throughput for each functioning mode using a strong and formal discrete modeling tool i.e. Timed Petri Nets (TPN).

Keywords
Multiple-Aisles AS/RS, performances assessment, throughput rate, Timed Petri Nets.

1.Introduction

Manufacturing and distribution systems are devoted to producing quality products and their delivery to customers in the best manner i.e. most economical and timely way. One of the most important goals is to optimize all the system's costs i.e. initial investments and functioning costs. For both, there are some activities, like storage, that could, uselessly, increase these costs. Indeed, the storage of raw materials, tools, work in process and finished product costs time, money and space without adding any value to stored items.

The Material Handling Institute (MHI) defines five characteristics of an automated factory or distribution center: data automation, networking controls for connected equipment, production automation, flexibility and automated material handling. An automated storage and retrieval system (AS/RS) can be categorized into both production automation, and of course, automated material handling.

Investing in AS/RS has significant costs. Therefore, their conception needs to consider many physical design (dimensions, components, ...) and control (configuration, times, …) issues in order to use them in an optimal way and to fully benefit of their advantages (details on designing decisions can be found in (Roodbergen and Iris, 2009). AS/RS are rather expensive and inflexible in future changes (Lerher et al, 2006). The choice of S/R machines number is closely depending on the throughput capacity. For a high capacity a single machine into the single picking aisle is recommended. For low capacity, double deep AS/RS can be used (Lerher et al, 2006).

Several configurations of AS/RS were developed and used years ago. They are widely used by companies to manage items. Till now, they evolve in consideration of different parameters: permanent need of space for storage, variety in size and kind of stored products, major need of optimizing storage costs (time, space, money, scheduling), cost-effective utilization of equipment. These AS/RS are a combination of equipment and controls which automatically handle, store and retrieve materials (components, tools, raw material and subassemblies) with great speed and accuracy (R.Manzini et al 2006). They are organized depending on the system configuration (Racks, S/R machines, Aisles, Pick-up/Deposit station, Control system) (Ghomri et al, 2009) and have lot of advantages like reducing labor costs, lowering workforce requirements and increasing safety. The conception of an AS/RS need to consider some influencing parameters according to their use such as dimensions and number of bins, number of S/R machines, duration of cycle time (single, double, multiple), throughput rate (Material Handling Institute Inc., 1977) & (Bozer and White, 1980).

The S/R machine only represents 40% or more of the initial costs of the whole system (Lerher et al, 2006). The throughput rate and cycle time are one if not the most important parameters in designing AS/RS and mostly in performances assessment and optimization for such systems. There are lot of achieved and under study works for their calculation and modeling for several configurations and under various conditions.

For cycle time modeling, AS/RS have been the subject of many studies years ago. A detailed survey on AS/RSs design, classification and functioning policies is given in [6]. Authors presented an extensive collection of research papers on AS/RS systems showing that very few papers deal with MAAS/RS and operational issues (Oser and Drobir, 2012). Modeling of the average cycle time has been developed in numerous studies since 1976.

Authors in [13] said that class-based storage proves to be a very effective way of both reducing the picking cycle time and maximizing the throughput of the system.

In this work, the MA-AS/RS system is considered as a Discrete Events Systems (DES). These Systems can be defined as systems in which state variables change under the occurrence of events. They are usually not described, like the classical continuous systems, by differential equations due to the nature of the phenomenon involved. These systems are often represented by state-transition models. Using the Timed Petri Nets (TPN), graphs are used to model possible cases (scenarios) that could be faced while the machine moves in the system to do storage/retrieval tasks. For a scenario we calculate the formula of the cycle time then we calculate the general formula of the average cycle time for a functioning mode for all bins in the system. Thus, we can easily deduce the throughput rate formula for this mode by applying TPNs theory.

This paper is organized as following. After this general introduction with a succinct state of art of existing works on AS/RS, cycle time modeling and throughput estimation, we give, in section 2, a description of considered systems in this paper i.e. MA-AS/RS and details on operating modes of the crane, basic moves and related cycles times. Section 3 is dedicated to the presentation of the followed methodology to achieve the throughput rate calculation for MA-AS/RS and used tool for that i.e. TPN. Finally, we conclude the paper and present perspectives of our work.

2. Multi-Aisle Automated Storage and Retrieval Systems (MA-AS/RS)

In basic configurations, the S/R machine have a unit load capacity and could do only single command cycles or double command cycles, but in more sophisticated configurations, the S/R machine could have a multi-load capacity and could do multiple command cycles. Such AS/RS is capable of handling items without the interference of an operator, simply using a set of automated components. The common basic components of AS/RS are racks, bins, S/R machines, Pickup/Deposit stations (P/D stations), and conveyors.

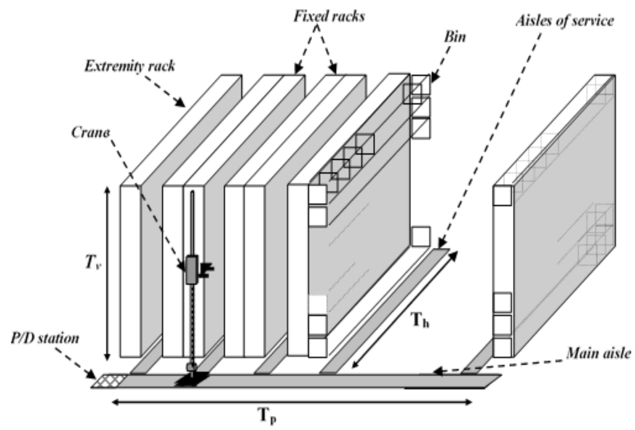


Figure 1. Multi-Aisle AS/RS

The system has following characteristics:
– The AS/RS contains several parallel aisles and each aisle has a storing rack on both sides and each rack contains several bins.
– P/D station is located at point 0 at the start point of the main aisle and the bottom of the first extremity rack.
– The crane start point for each cycle is P/D station and moves to any random bin throw main aisle and aisles of service. End point for each cycle is P/D station.
– A travel of the machine from a position to another in the system (from P/D station to a bin or from a bin to another bin or from a bin to P/D station) is a combination of a horizontal move and a vertical move. The horizontal move is composed of two basic horizontal moves: on the main aisle during a time, denoted *Tp*, and on the aisle of service during a time, denoted *Th*. So, the horizontal move time, denoted *TH*, is given by *Tp*+*Th*. The vertical move is the move to reach a bin on the sense of height during a time, denoted *TV*. Also, *Tv*, *Tp* and *Th* are durations of time starting at the beginning of each travel of the crane, from a starting position to an arriving position (P/D station to bin, bin to bin, bin to P/D station).
– The S/R machine has a Chebyshev move i.e. it moves simultaneously in the horizontal and vertical directions. Thus, any travel of the machine from a point to another in the system costs the duration of time equal to the maximum between the horizontal move duration of time *TH* and the vertical move duration of time *TV*.
– In single command and double command functioning modes, the machine has a capacity of handling equal to one item. In multiple command mode, the machine is equipped with a buffer with a capacity of handling equal to N item.

2.1. Storage/Retrieval machine (Crane)

The Crane is used to store and retrieve items in and from random bins situated in racks. It is an automated machine commanded by three computer-controlled motors allowing it to move in horizontal and vertical directions to reach any bin in the system.
• On main aisle: the crane moves horizontally along the main aisle to reach an aisle of service starting from P/D station or to move from an aisle to another. The time taken for moving on main aisle is the horizontal travel time (*Tp*).
• On aisle of service: the crane moves horizontally on the length of an aisle of service to reach targeted bins situated in racks. The crane always runs on the main aisle before running on an aisle of service in both cases: going from P/D station to an aisle of service or moving from an aisle of service to another.
Along rack height: the crane moves vertically to reach a targeted bin simultaneously to its horizontal moving at the beginning of any travel i.e. from P/D station to targeted bin or from a bin to another when changing aisle of service.

3. What to do and how

3.1 Throughput rate deduction from average cycle time modeling

Here we aim to estimate the throughput rate for this system which is an important performances assessment parameter. To achieve that, we need first to make a modeling of another equally important and very relative performances indicator i.e. the average Cycle Time of the crane. This time is defined as the time taken by the crane to go from the P/D station and come back to P/D station. During a cycle the machine could:

- Achieve only one job i.e. store in a bin or retrieve from a bin (Single command during a Single command cycle time) and this is the basic work of the crane.
- Achieve two consecutive jobs i.e. store in a bin then retrieve from another bin (Double command during a Double command cycle time). This mode is useful to eliminate “hand free” returns of the crane to the P/D station.
- Achieve several consecutive jobs i.e. store and retrieve several times in various random bins (Multiple command during a Multiple command cycle time). This mode is useful to minimize go/return travels from/to the P/D station and optimize the use of the crane.

So, the first part of our work here consists on the modeling of the average cycle time for each one of the three precited functioning modes of the crane. For this machine there are different scenarios. A scenario is defined as the course of the crane in the system to achieve a cycle depending on the requested job (storage/retrieval/both/several), on the location of the item(s) in the system and on other moving parameters of the machine that we’ll detail in following. We’ll summarize the possible scenarios for every mode and show how we calculate the cycle time for one, then determine the average cycle time for each mode.

The second part consists on the deduction of the throughput rate of the system for each functioning mode from its own average cycle time formula. All this using the formal and strong modeling tool TPNs.

3.2. Used tool: Timed Petri Nets

In this part, we present the used modelling tool to evaluation the average cycle time in the different cases which will be presented in the next.

- **Basic Notations and Definitions**

Let us briefly introduce the definitions and some basic properties of Timed Petri Nets. See (David and Alla, 2004) for a more exhaustive description.
A Timed Petri Net is a graph given by a 4-tuple (P, T, m, τ):
- P is the finite set of places.
- T is the finite set of transitions.
- $m \in NP$: mp assigns an initial number of tokens to place p.
- $\tau \in NP$: τp gives the minimal time a token must spend in place p before it can contribute to the enabling of its downstream transitions.

In the next, we interest a subclass of Timed Petri Net, know under the name of Timed Event Graphs (TEG’s), it well adapted to model synchronization and saturation phenomena.

Example TEG depicted in Figure 2, models a workshop consisting of a machine, modeled by the place P2, and a stock represented by place P1, powered by the input U. When a command arrives, and the machine is available, the product is processed during two units of time. Once the processing is completed, the processed part is sent to the downstream stock, modeled by the place P4. The availability of the machine is modeled by the presence of a token in the place P3.

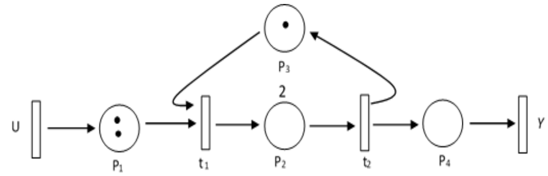


Figure 2 . Model TEG of a production machine

To evaluate the performance of these graphs, we interest to two indicators performance: Cycle time and production rate equivalent to the firing frequency of each transition. In (David and Alla, 2004) the firing frequency of transitions of an elementary circuit cj (i.e., path such as its last transition is also its first transition) of an ordinary TEG is given by:

$$f\left(c_j\right) = \frac{\sum_{i=1}^{n} m_i}{\sum_{i=1}^{n} \tau_i} \qquad (1)$$

where mi, represents the number of tokens in the i-th place in the circuit cj and n the total number of places in this circuit.
All transitions of a have the same firing frequency, i.e. f1 = f2 = … = l. This firing frequency l is given by the following equation where m represents the total number of circuits in the graph:

$$\lambda = \operatorname*{Min}_{j=1}^{m}\left(f(c_j)\right) \qquad (2)$$

The Cycle time, denoted by TC, is equal to:

$$TC = \operatorname*{Max}_{c_j \in C}\left(\frac{\sum_{i=1}^{n} \tau_i}{\sum_{i=1}^{n} m_i}\right) \qquad (3)$$

In this equation, C is the set of elementary circuits of the ordinary TEG.

Example, in the TEG depicted in figure 5, only the circuit described by t1, P2, t2, P3, t1 is considered to evaluate the performance of this graph. The relations presented previously, allow to find l = 2 firing/units of time and *TC* = ½ unit of time. In practice this means that this machine produces 2 pieces every time unit or one piece every 2 units of time.

3.3. Cycle Time and Throughput rate

For more simplicity we'll use the following notation:
Tp: Travel time necessary to run along the main aisle.
Th: Travel time necessary to run along an aisle of service to reach targeted bin.
TV: Travel time necessary to run vertically throw the height to reach a bin.
TH: Horizontal travel time necessary to run horizontally along the main aisle plus along an aisle of service and simultaneously to **TV** to reach targeted bin.
i: index of current job i.e. current bin
j: index of next job i.e. next bin with j=i+1
k: index of case (scenario)
N: capacity of the buffer of the crane
M: total number of bins in the system
E(SC)k: Expected single command cycle time for scenario k
E(SCA)k: Expected going single command cycle time for scenario k
E(SCR)k: Expected return single command cycle time for scenario k
$\overline{\mathbf{E(SC)}}$: Expected average single command cycle time
E(DC)k: Expected double command cycle time for scenario k
E(DCA)k: Expected going double command cycle time for scenario k
E(DB)k: Expected time between (time necessary to travel between 2 random bins) in double command cycle time for scenario k.

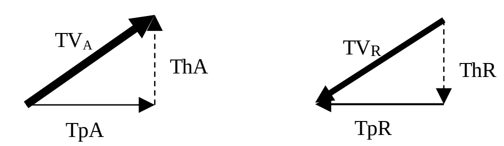
E(DCR)k: Expected return double command cycle time for scenario k
$\overline{\mathbf{E(DC)}}$: Expected average double command cycle time
E(MC)k: Expected multiple command cycle time for scenario k
E(MCA)k: Expected going multiple command cycle time for scenario k
t: index of the time between in the 2N-1 times between composing the whole time between in multiple command cycle time for scenario k
E(MCB)k: Expected time between in the 2N-1 travel times between for scenario k
E(MCB)k: Expected time between in multiple command cycle time for scenario k.
E(MCR)k: Expected return multiple command cycle time for scenario k
$\overline{\mathbf{E(MC)}}$**:** Expected average multiple command cycle time

3.3.1. Single command Cycle Time

In this cycle the machine starts from P/D station, do only one task (storage or retrieval of an item) then returns to P/D station. $E(SCA)_k$ is the going travel time and it is equal to the maximum between the horizontal time ThA and the vertical time TvA. $E(SCR)_k$ is the return travel time which is also equal to the maximum between the horizontal time ThR and the vertical time TvR.
In this mode the cycle is equal to one go from P/D station to targeted bin plus one come back to P/D station. So:
$E(SC)_k = E(SCA)_k + E(SCR)_k$
The same distance is travelled on going and on coming back so:
$E(SCA)_k = E(SCR)_k = \text{Max}(TV, TH)$ where TH= Tp+Th
Max (TV, TH) = TV ≤ Tp+Th (case A_1) $\vee$ TV >Tp+Th ………… (case A_2)

- **Case A_1**

TpA=TpR, ThA=ThR, $TV_A=TV_R$



E(SCA) =TH=TpA+ThA   E(SCR) =TH=TpR+ThR

In this case TV is less or equal to TH. So, the machine reaches the targeted bin when going in a duration of time $E(SCA)_k$ equal to Tp+Th and when coming back to P/D station in a duration of time $E(SCR)_k$ equal to Tp+Th. So, we obtain following graph which models the scenario moving of the machine allowing calculating $E(SC)_k$:

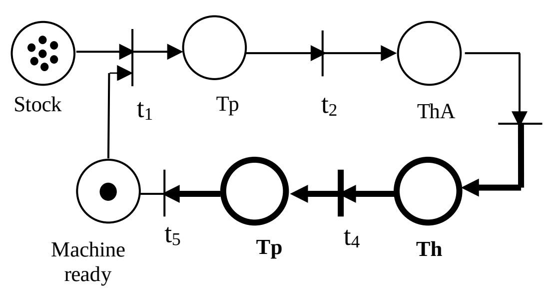


Figure 3. TEG which models scenario of the Case A_1

——— : Going $E(SCA)_k$
▬▬▬ : Coming back $E(SCR)_k$

Applying the Petri nets theory and relation (3), we calculate $E(SC)_k$ as following:

The Cycle time $E(SC)_k = TC = \underset{c_j \in C}{Max}\left(\frac{\sum_{i=1}^{n}\tau_i}{\sum_{i=1}^{n}m_i}\right)$ in case of several circuits (c_j).

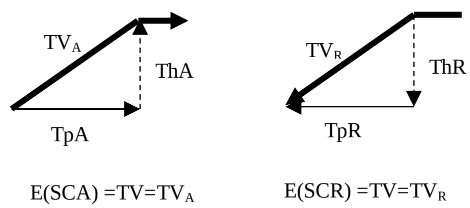
Here, we have only one circuit (t_1 t_2 t_3 t_4 t_5), so:

$$E(SC)_k = \left(\frac{\sum_{i=1}^{n}\tau_i}{\sum_{i=1}^{n}m_i}\right) = \frac{2(Tp+Th)}{1}$$

$E(SC)_k = 2(Tp+Th)$

- **Case A_2**

  $TpA=TpR$, $ThA=ThR$, $TV_A=TV_R$



In this case TV is higher than Th. So, the machine reaches the targeted bin when going in a duration of time $E(SCA)_k$ equal to TV and when coming back to P/D station in a duration of time $E(SCR)_k$ equal to TV. So, we obtain following graph of this scenario $E(SC)_k$:

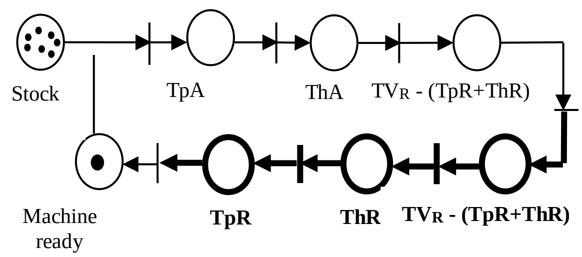


Figure 4. TEG of scenario for Case A_2

——— : Going $E(SCA)_k$
▬▬ : Coming back $E(SCR)_k$

Applying the Petri nets theory, we calculate $E(SC)_k$ as following:

$$E(SC)_k = \left(\frac{\sum_{i=1}^{n}\tau_i}{\sum_{i=1}^{n}m_i}\right) = \frac{2(TV)}{1}$$

$E(SC)_k = 2(TV)$

There is only these two cases and the Single Command cycle time for any bin in the system is equal to one of these two possible cases. Now we can easily estimate the average Single Command cycle time for all bins in the system. We obtain following formula:

$$\overline{\mathbf{E(SC)}} = \frac{\sum_{k=1}^{M} \mathbf{E(SC)k}}{\mathbf{M}}$$

Now for the second part of work in this mode we can easily deduce the system throughput noted λ simply by applying the TPNs theory as following:

$$\boldsymbol{\lambda} = \frac{\mathbf{1}}{\overline{\mathbf{E(SC)}}}$$

3.3.2. Double Command cycle time

From a system throughput standpoint, it will be clearly more productive to always execute DC cycles (S.Hackman - ISyE 6202 - 2003). This cycle is the duration of time taken by the machine to do two consecutive tasks (storage in bin **i** then retrieval from bin **j**). It is equal to one go from P/D station to first bin **i** noted $E(DCA)_k$ plus the time between necessary to move between bin **i** and second bin **j** noted $E(DCB)_k$ plus one return from bin **j** to P/D station noted $E(DCR)_k$. So :

$E(DC)_k = E(DCA)_k + E(DCB)_k + E(DCR)_k$.
$E(DCA)_k = Max(TV_A, TH_A)$
$TV_A = Tv_i$
$TH_A = Tp_A + Th_A = Tp_i + Th_i$
$E(DCA)_k = A1 \vee A2$
$E(DCB)_k = Max(TV_B, TH_B)$
$TV_B = Tv_j$
$TH_B = Th_A + Tp_B + Th_B \quad \vee \quad Th_B \quad = Th_i + Tp_j + Th_j \quad \vee \quad Th_j$
$E(DCB)_k = B1 \vee B2 \vee B3 \vee B4$
$E(DCR)_k = Max(TV_R, TH_R)$
$TV_R = TV_j$
$TH_R = Th_R + Tp_B \pm Tp_R \quad \vee \quad Th_B \pm Th_R \quad = Th_j + Tp_i \pm Tp_j \quad \vee \quad Th_i \pm Th_j$
$E(DCR)_k = R1 \vee R2 \vee R3 \vee R4 \vee R5 \vee R6 \vee R7 \vee R8$

Possible values for A1, A2, B1, B2, B3, B4, R1, R2, R3, R4, R5, R6, R7, R8 are listed in table 1.
There are cases where the machine retrieves item **j** from the same aisle of service of item **i** called non-aisle changing cases and others where the crane retrieves from a different aisle called aisle-changing cases. Since $E(DC)_k = E(DCA)_k + E(DCB)_k + E(DCR)_k$ we'll have 32 possible combinations to estimate $E(DC)_k$, 16 for aisle changing and 16 for non-aisle changing.
A1, A2 in $E(DCA)_k$ is the same for all but B1, B2 in $E(DCB)_k$ works only with R1, R2, R3, R4 in $E(DCR)_k$ and B3, B4 works only with R5, R6, R7, R8.

Table1. Possible cases and values

$E(DCA)_k$		
$TV_A \le TH_A \rightarrow TV_i \le Tp_i + Th_i$		A1
$TV_A > TH_A \rightarrow TV_i > Tp_i + Th_i$		A2
$E(DCB)_k$		
Aisle changing	$TV_B \le TH_B \rightarrow TV_j \le Th_i + Tp_j + Th_j$	B1
	$TV_B > TH_B \rightarrow TV_j > Th_i + Tp_j + Th_j$	B2
Non-aisle changing	$TV_B \le TH_B \rightarrow TV_j \le Th_j$	B3
	$TV_B > TH_B \rightarrow TV_j > Th_j$	B4
$E(DCR)_k$		
Aisle changing	$TV_R \le TH_R \rightarrow TV_j \le Th_j + Tp_i + Tp_j$	R1
	$TV_R > TH_R \rightarrow TV_j > Th_j + Tp_i + Tp_j$	R2
	$TV_R \le TH_R \rightarrow TV_j \le Th_j + Tp_i - Tp_j$	R3

	$TV_R > TH_R \rightarrow TV_j > Th_j + Tp_i - Tp_j$	R4
Non-aisle changing	$TV_R \leq TH_R \rightarrow TV_j \leq Tp_i + Th_i + Th_j$	R5
	$TV_R > TH_R \rightarrow TV_j > Tp_i + Th_i + Th_j$	R6
	$TV_R \leq TH_R \rightarrow TV_j \leq Tp_i + Th_i - Th_j$	R7
	$TV_R > TH_R \rightarrow TV_j > Tp_i + Th_i - Th_j$	R8

Due to pages restriction, we present in next only some scenarios just to show how we proceed to calculate the cycle time.

——— Going to 1st targeted bin

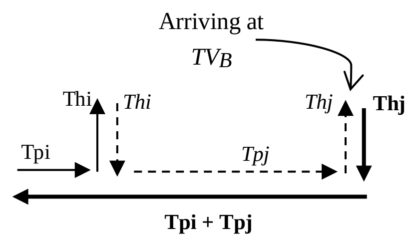
------- Moving between 1st bin and 2nd bin

▬▬ Return from 2nd bin to P/D station

a. Aisle changing case

- **Scenario A1+B2+R1**

Here $E(DC)_k = TH_A + TV_B + TH_R$
$TH_A = Tp_A + Th_A = Tp_i + Th_i$
$TV_B = Th_B + Tp_B + TV_B - (Th_B + Tp_B)$ where $Th_B = Th_i + Th_j$ and $Tp_B = Tp_j$
$TH_R = Th_R + Tp_R$ where $Tp_R = Tp_i + Tp_j$ and $Th_R = Th_j$



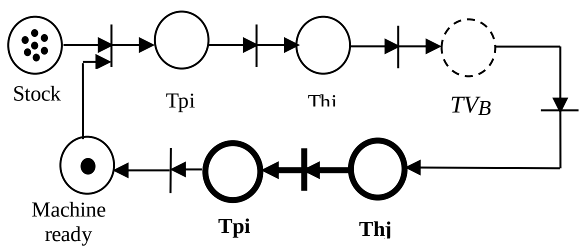


Figure 5. TEG for scenario A1+B2+R1

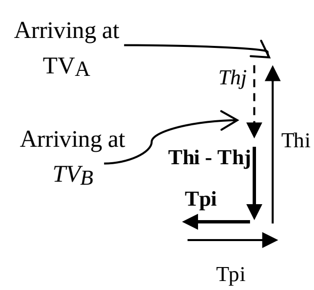
$$E(DC)_{A1+B2+R1} = \left(\frac{\sum_{i=1}^{n} \tau_i}{\sum_{i=1}^{n} m_i}\right) = \frac{Tpi+Thi+TVB+Thj+Tpi+Tpj}{1}$$

$$\mathbf{E(DC)_{A1+B2+R1} = 2Tpi+Tpj+Thi+Thj+TV_B}$$

b. Non-aisle changing case

- **Scenario A2+B4+R7**

Here $E(DC)_k = TV_A + TV_B + TH_R$
$TV_A = Tp_A + Th_A + TV_A - (Tp_A + Th_A)$ where $Tp_A = Tp_i$ and $Th_A = Th_i$
$TV_B = Th_B + TV_B - Th_B$ where $Th_B = Th_j$
$TH_R = Th_R + Tp_R$ where $Tp_R = Tp_i$ and $Th_R = Th_i - Th_j$



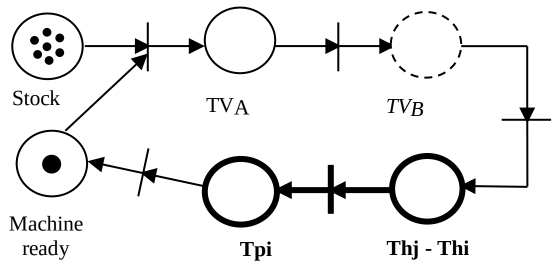


Figure 6. TEG models for the scenario A2+B4+R7

$$E(DC)_{A2+B4+R7} = \left(\frac{\sum_{i=1}^{n} \tau_i}{\sum_{i=1}^{n} m_i} \right) = \frac{TVA+TVB+Thi-Thj+Tpi}{1}$$

$$\mathbf{E(DC)_{A2+B4+R7} = TV_A+TV_B+Thi\text{-}Thj+Tpi}$$

Now we know how to calculate $E(DC)_k$ according to faced case, we can calculate the average Double Command cycle time for all bins of the system and we obtain this formula:

$$\overline{E(DC)} = \frac{\sum_{k=1}^{C_2^M} E(DC)_k}{C_2^M} \quad \text{where:} \quad C_2^M = \frac{M!}{2!(M-2)!}$$

M: total number of bins to visit

From this formula we can deduce the system throughput, denoted λ for this functioning mode with following:

$$\boldsymbol{\lambda = \frac{1}{\overline{E(DC)}}}$$

3.3.3. Multiple Command cycle time

In this configuration, the S/R machine can handle N items and is able to do 2N jobs each cycle.
One multiple command cycle is equal to one go from P/D station to first targeted bin plus 2N-1 time between (one for each 2 consecutive jobs) plus one return from last targeted bin to P/D station. Consequently, the total time taken by the machine to achieve such a cycle noted E(MC) is defined by:

$E(MC)_k=E(MCA)_k + E(MCB)_k + E(MCR)_k$, where:
$E(MCA)_k = Max(TV_A, TH_A)$ and $E(MCA)_k$
$= A1 \vee A2$
$E(MCB)_k= Max(TV_B, TH_B)$ and $E(MCB)_t$
$= B1 \vee B2 \vee B3 \vee B4$
$E(MCB) = \sum_{t=1}^{t=2N-1} E(MCB)t$ and $E(MCR)_k$
$= Max(TV_R, TH_R)$
$E(MCR)_k = R1 \vee R2 \vee R3 \vee R4 \vee R5 \vee R6 \vee R7 \vee R8$

Consequently, the average multiple command cycle time is defined by formula:

$$\overline{E(MC)} = \frac{\sum_{k=1}^{C_N^M} E(MC)_k}{C_N^M}$$

Using this formula, we can deduce the system throughput, for multiple command functioning mode by following:

$$\boldsymbol{\lambda = \frac{1}{\overline{E(MC)}}}$$

4.Conclusion

In this work we have made a performances assessment for a type of AS/RS called Multi-Aisle AS/RS. We used Timed Petri Nets as work tool to make a modeling of average cycle time for three functioning modes of the crane to deduce the aimed parameter of this performances evaluation i.e. the throughput rate. Under randomly situated bins condition, we presented possible scenarios of the crane moving in the system and showed how we procced for the deduction of this rate by the calculation of each scenario's cycle time according to its mode. We obtained very simple formulas thanks to the proven formalism and robustness of TPNs. Such evaluation could help a lot for the design of such systems.

5.References

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