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Object-Oriented Petri Nets Virtual Organization Structure

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Abstract

Managing a mega organization has become an extremely complex task, especially if the organization is virtual. The operating structure of such a multi-faceted organization is very difficult to construct, and traditional organization structure models seem to fall short in coping with the demands imposed by such huge and complex entities. The object-oriented (organic) structure has many attributes that are suitable for solving the complexity of such organization structure and seems successful in catering for the needs of big organizations. However, the organic structure is by nature a static model that does not allow for predicting dynamic operation problems before they occur. The goal of this paper is therefore to design a generic model, using a Petri net-based framework, to simulate the workflow of virtual organizations that follow the organic structure in essential tasks like scheduling, monitoring and supervising. This model is useful in predicting problems before they occur and is therefore quite a useful tool for resource allocation, business planning and overall monitoring. Because of its capability in predicting problems like deadlock, priority inversion and starvation, a Petri net may become an essential tool for organization management.

Keywords:

Organic Structure; Petri Nets; Object Oriented; Virtual Organization.

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Introduction

In traditional organizations there occurs an alliance between manufacturing and administrative services to provide specific business needs. While manufactured goods differ between organizations, much of the services are common, like for example finance, IT, sales, marketing, operations, distribution and many more. Traditionally all these services come under one roof, yet now many organizations are turning to virtual organizations, unlimited by physical space.

Where virtual organizations are concerned, structure designers differentiate between the virtual office and the virtual organization. The virtual office is basically an office where the space is virtual. In that description, the virtual office consists of many organizational and technological elements that operate as an office without a physical location. It makes use of IT tools (such as notebooks, email, the Internet, or Skype, etc…) for telecommuting. The concept of the virtual office suggests that employees are no longer bound by the managerial or the physical constraints of a conventional office space (Badr-El-Din, 2013).

In the virtual organization it is the value chain that is virtual and not the organization space as is the case with the virtual office. In a virtual organization the value chain comprises many departments and services that virtually combine to provide specific business needs.

According to Quinn (Quinn, 1992) the most successful virtual organizations are considered "Intelligent Enterprises" that convert intellectual resources into a chain of service outputs and integrating these into a form most useful for certain customers. Klein (Klein, 1994)described the virtual organization as one organization that consists of several independent organizations but functions as a single entity.

One can thus state that a virtual organization or "Intelligent Enterprise" is a company that designs its value chain by focusing on its core competences in-house and outsourcing all other services in the value chain. The core competency of some companies may only be managing the value chain. In this case the company outsources all other services. In that case the difficulty of management is compounded because of the added virtual aspect.

Organizational structure designers tackled the management complexity from an organizational structure point-of-view, yet not from the operational complexity point-of-view. A study by the Corporate Leadership Council (Board, 2013) compares between the five basic organization structures (functional, product, market, geographical and process) where a description, advantages, disadvantages, and characteristics supported by each structure are explored. Because of the multitude of dimensions that operate within multi-national enterprises, structure organization designers introduced the concept of the matrix organization and double reporting, which involves combining two organizational structures together.

However, this structuring approach can be quite elaborated, complex and sometimes even inefficient. For example, Badr-El-Din (Badr-El-Din, 2013)introduces a 3D matrix virtual organization representing the services, operations, and management of the ICT sector of the Egyptian Ministry for Transport (Figure 1: 3D Matrix Virtual Organization. As can be seen from the figure, the Ministry's ICT sector manages three core tracks. The first is for the transport industry, which is the core business and is presented by three managers (roads and bridges manager, railways and metro managers and maritime and river manager). One needs to note here that the Ministry is considered a virtual organization because its subdivisions (roads and bridges, railways and metro, and maritime and river) can be viewed as independent entities outsourced by the Ministry of Transport. The second track is for the technology and is presented by four managers (telecommunication manager, ICT infrastructure manager, ICT resources manager, and IT services manager). The third track presents the quality of service priority levels (safety, quality, and luxurious). As is evident from the figure, the employees in the ICT sector need to triple report to the managers.

Despite its evident complexity, many of the world's mega organizations are still using the matrix structure for management and monitoring. Yet because of its complexity, the matrix structure was the reason why structure designers were forced to develop alternative models that were more flexible and less elaborate. The desired model needed to be adapted, changed, simulated and tested to predict, monitor and visualize the changes introduced at different layers in the virtual organization environment. It should also allow for easy modifications and enhancements to the operational layer of the virtual organization, which in turn would allow for constant improvements.

Badr-El-Din, (Badr-El-Din, 2013) addressed such demand by introducing the object-oriented (organic) model for a virtual organization (Figure 2: Virtual Organization Organic Structure). In his paper, Badr-El-Din discusses the intricate details of the organic structure and why it is suitable for mega virtual corporations. In addition to the benefits of the organic approach as discussed in (Badr-El-Din, 2013), the object-oriented approach affords other advantages like abstraction, encapsulation and inheritance. Abstraction is the principle of concentrating only on relevant aspects of the problem and ignoring all other irrelevant aspects. Encapsulation states that each component should hide a single design decision, and the interface of the component should reflect as little as possible about component's internal design. Inheritance is the principle of expressing similarity and making use of already existing components to reflect the essence of the new components.

Yet in any approach used for organization management, the core problems remains the same: how to organize, coordinate and monitor different tasks (competing for limited resources), with timing constrains to achieve the organization's goals. Yet again these core issues become more difficult when employees and resources are managed remotely.

Even the evaluation of human resource utilization has changed with the advent of the virtual organization. Abdul Kareem et al. (Abdulkareem et al., 2011) examined the relationship between human resources utilization and internal efficiency in Nigerian state universities. According to Abdul Kareem et al., human resources are the people who constitute the workforce of an organization. People, their knowledge, skills (technical, personal, educational etc.) and attitudes constitute human resources. University as an educational institution has a teaching staff, non-teaching personnel and students. Their knowledge, abilities and skills are all human resources of the university. Although it is quite complex to design an organizational structure for such a human resource based entity, the object-oriented model can be easily adapted to this task. Simply put, any human resource is an object with attributes such as technical, mechanical, managerial skills, etc. While Abdul Kareem et al. evaluated human resources utilization by survey the object-oriented approach does not have the capability to do so. However, a Petri net can be used to evaluate this utilization of human resources.

Since management needs to address coordination and resolve any problems pertaining to it, the following section will discuss some of these problems in detail and provide specific examples.

Coordination Problems

The need to coordinate the use of company resources is on top of the priority list for any organization. Many of the organization's resources can only be used by just one job at a time. In addition, a job may need access to several different resources, whether exclusively or in conjunction, at any one point. In any organization, the resources, whether tangible (such as computers, printers, or office space etc.) or non-tangible (such as managers' time slots) are limited and a problem may arise when requests for resources outnumber the resources themselves. This, in turn, makes the challenging management task even more challenging because it imposes on the management the allocation of resources to tasks in such a way that ensures maximum utilization of resources. This happens in any type of organization, whether virtual or traditional, and several problems may arise when the management fails to coordinate the use of resources. In the following section we will explore two problems that can arise from mismanaged resource allocation in a virtual organization.

1. Tasks Deadlock

- In a virtual organization environment, many jobs can't be allowed to progress just because one job in a group has to wait for a resource that can only be released by another job in the group, which is dependent on another resource captured or occupied by the first job (see Figure 3: Deadlock Situation).
- Assume the following scenario:
  - At time T_0: Job_1 starts execution.
  - At time T_1: Job_1 requests an available resource A.
  - At time T_2: Job_1 is granted the available resource A.
  - At time T_3: Job_3 starts execution, and requests resource B.
  - At time T_4: Job_3 is granted the available resource B.
  - At time T_5: Job_3 requests the busy resource A. So it waits for it.
  - At time T_6: If Job_1 requests the busy resource B, then it is a deadlock between Job_1 and Job_3.

2. Tasks Priority Inversion

- A job with a lower priority can block or displace a higher priority job and start execution (see Figure 4: Priority Inversion).
- Assume the following scenario:
  - Assume Job_1, Job_2, and Job_3 are three jobs with three priorities.
  - Assume Job_3 is the highest priority and Job_1 is the lowest.
  - At time T_1: Job_1 requests the resource A, and is granted the resource.
  - A higher priority job (Job_3) interrupts the lower priority job (Job_1) and requests another free resource B.
  - If Job_3 requested the resource A, it will have to wait until Job_1 releases it.
  - Assume Job_2 displaces Job_1 because it has a higher priority.
  - In this case a lower priority job will continue while a higher priority is waiting.
  - At time T_0: Job_1 starts execution
  - At time T_1: Job_1 requests an available resource A.
  - At time T_2: $Job_1$is granted the available resource A.
  - At time T_3: Job_3 starts execution, and requests resource B.
  - At time T_4: $Job_3$is granted the available resource B.
  - At time T_5: Job_3 requests the busy resource A. So it waits for it, and Job_1 starts execution.
  - At time T_6: If a higher priority job like Job_2 interrupts a lower priority job like Job_1, then Job_2 will start execution indefinitely while Job_3 is waiting.

This may happen even within a sophisticated structural approach such as the object-oriented (organic) approach. To make things more complicated, the organic approach cannot on its own predict such workflow problems as discussed above because in and of itself, it is a static model rather than a dynamic one. Predicting problems before they occur can be simulated via a Petri net, as this paper aims to discuss. A Petri net is a well suited generic model for virtual organizations that can be used to monitor, supervise, and manage virtual organization tasks or activities, thus providing a means for predicting problems (deadlock, priority inversion,.. etc.) before they occur.

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Business Process Management for Organic Organization Using Petri Nets

In his paper, Aalst (Van der Aalst, 2002)argues that “more and more work processes are being conducted under the supervision of information systems that are driven by process models” and that information technology has changed the business processes within enterprises, as well as between them. While he claims that it is hard to imagine information systems that are unaware of processes taking place, Aalst addresses some of the scientific challenges in business process management using information technology Petri nets and proves that it is vital to have techniques to assert the correctness of workflow designs.

Aalst (Van der Aalst, 1996)also proposes that a Petri net-based framework could serve as a conceptual standard for the modeling and analysis of business process management. He discusses three valid reasons that could motivate the organization to use Petri nets for workflow management. Within its folds, a Petri net encompasses many analysis techniques. These techniques, as described by Aalst, can be used to prove properties (safety, invariance, deadlock, etc.), to calculate performance measures (response times, waiting times, occupation rates, etc.), and to check for the validity of certain properties by constructing occurrence graphs (for example, the occurrence graph can be used to detect deadlocks and undesirable states).

Aalst (Van der Aalst, 1996) also argues that the formal and graphical language used by Petri nets could quite efficiently represent business logic. Aalst has shown how the six workflow primitives identified by Workflow Management Coalition (WFMC) (AND-JOIN, AND-SPLIT, OR-JOIN, OR-SPLIT, ITERATION, CASUALITY) can be mapped onto Petri nets, as seen in Figure 5: Petri Net Work Flow Basic Functions.

Towards the same end, Kounnev et a. (Kounev & Buchmann, 2003) demonstrate how queuing Petri net models can be used to analyze the performance of distributed e-business systems. In their study, Kounnevet al. reviewed a real world application and demonstrated the benefits, in terms of modeling power and expressiveness that Queue Petri Net (QPN) models provide over conventional modeling paradigms. The object-oriented model presented in Badr-El-Din (Badr-El-Din, 2013) depends on job queues waiting for resources, andFigure 6: Petri-Net Queue Model presents the Petri net simulation of one sample queue.

Yet using both the object-oriented approach and Petri nets at the same time appears to be contradictory. With all the benefits encompassed by the organic design (abstraction, encapsulation and inheritance) as discussed above, it remains a static model that cannot be used to represent the business processes management itself, or even to predict a deadlock situation. On the other hand, Petri nets in their basic form lack abstraction, encapsulation and inheritance, thus they are not per se appropriate for modeling large systems (i.e. virtual organization). However, Petri nets are useful for building smaller, simpler blocks or components of the system itself, and in that form they can be efficiently used to identify flows or problems that occur within .For example, Petri nets can be used to model a deadlock situation between two jobs competing for two resources (Figure 7: Petri Net Deadlock).

Conclusion

Multi-dimensional virtual organizations can be extremely hard to manage by using the traditional organization structures (Functional, Divisional, Product, Geographical, etc.). Even newer structuring models, likethe matrix organization structure, can prove redundant and inefficient for this task. In this paper we solve the complexity of multi-dimensional virtual organization by introducing a new design: the organic organization structure. This model is based on the object-oriented approach, and the nature of organically creating objects for jobs, resources, and employees. The object-oriented approach has many benefits but specifically it utilizes concepts like abstraction, encapsulation, and inheritance which are all principles for managing complexity. However, it is a static system which cannot simulate different states and is therefore not capable of predicting problems or results. On the other hand, Petri nets can be very useful for prediction and are frequently used to simulate workflow or business processes, yet they miss the concepts of managing complexity like abstraction, encapsulation, or inheritance. This paper argues that both the organic approach and Petri nets can be combined together in smaller parts where Petri nets are used to simulate just one part of the bigger organic structure at a time.

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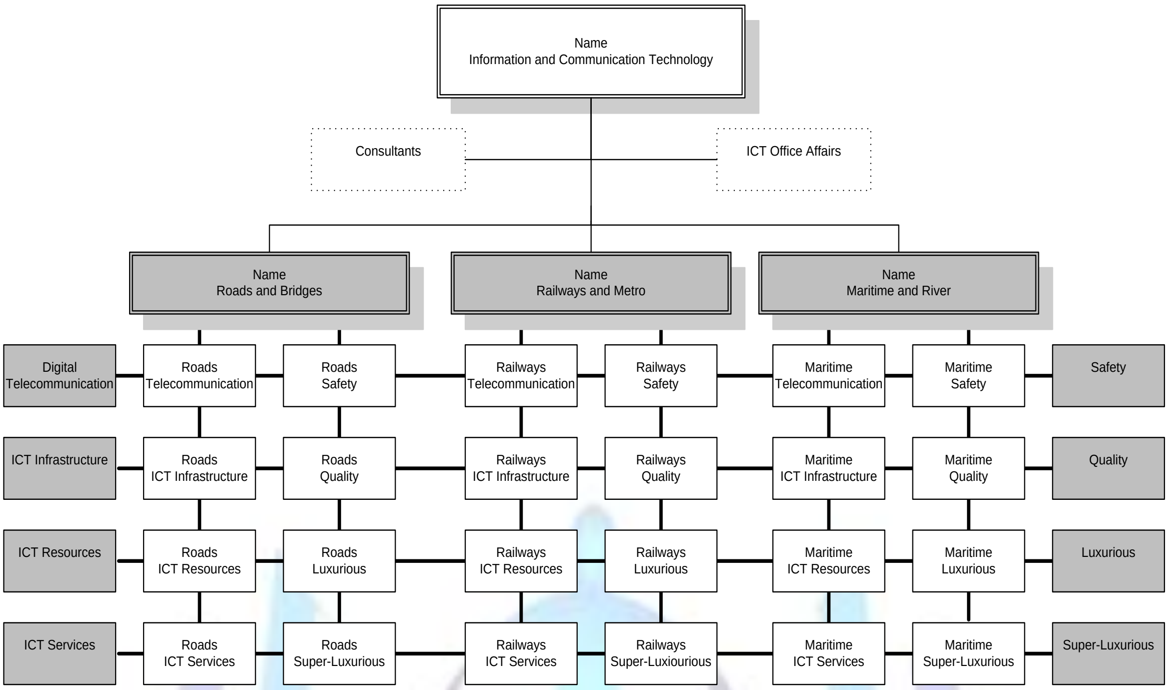

Figure 1: 3D Matrix Virtual Organization

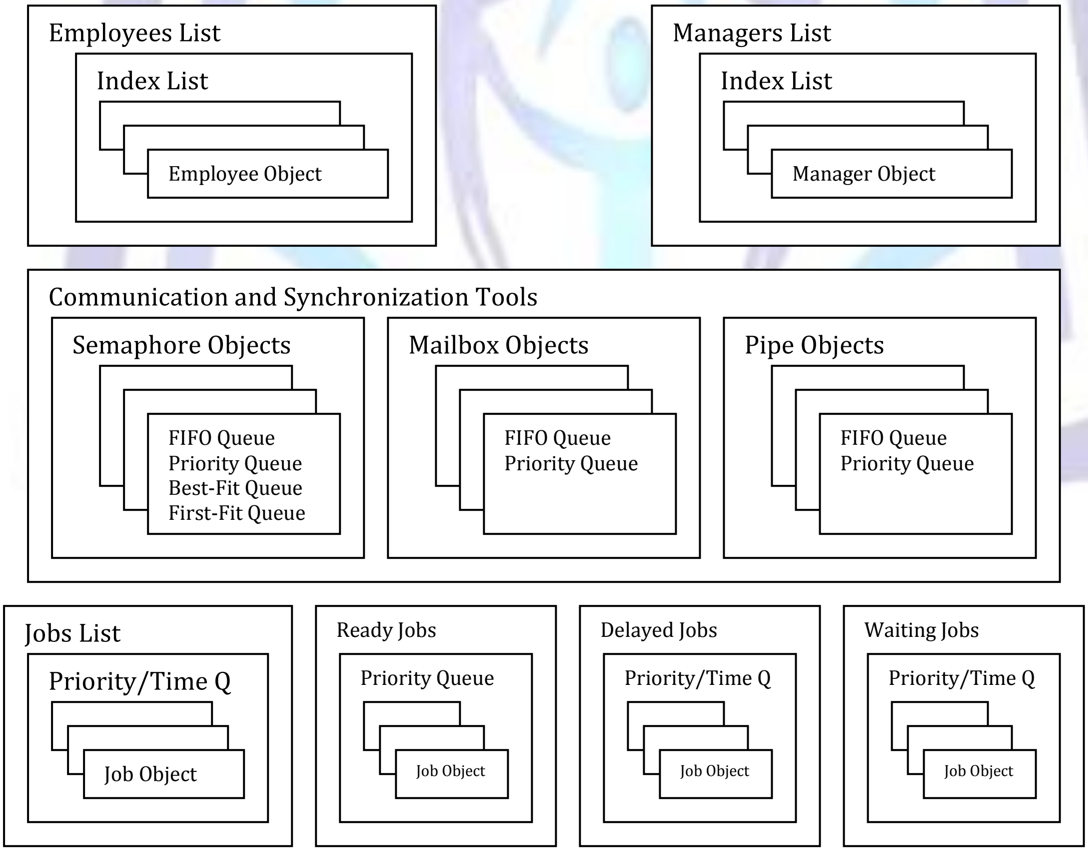

Figure 2: Virtual Organization Organic Structure

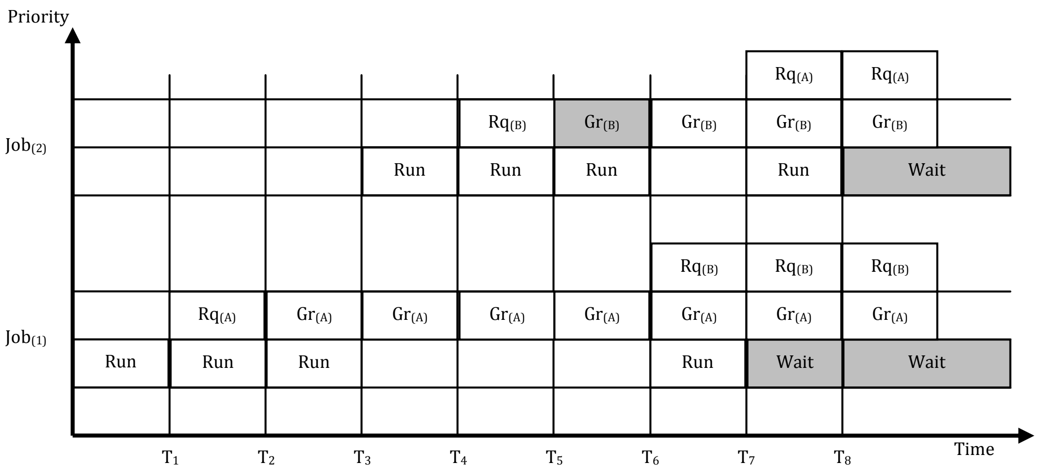

Figure 3: Deadlock Situation

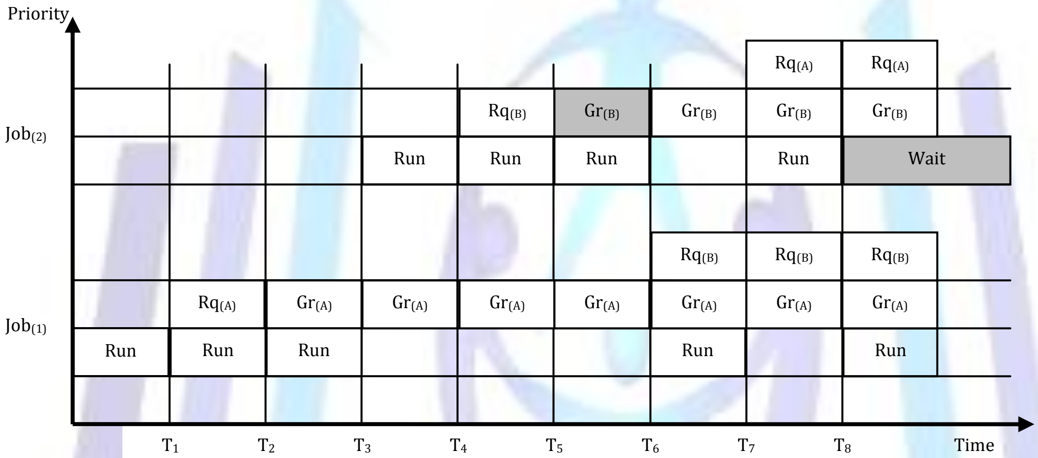

Figure 4: Priority Inversion

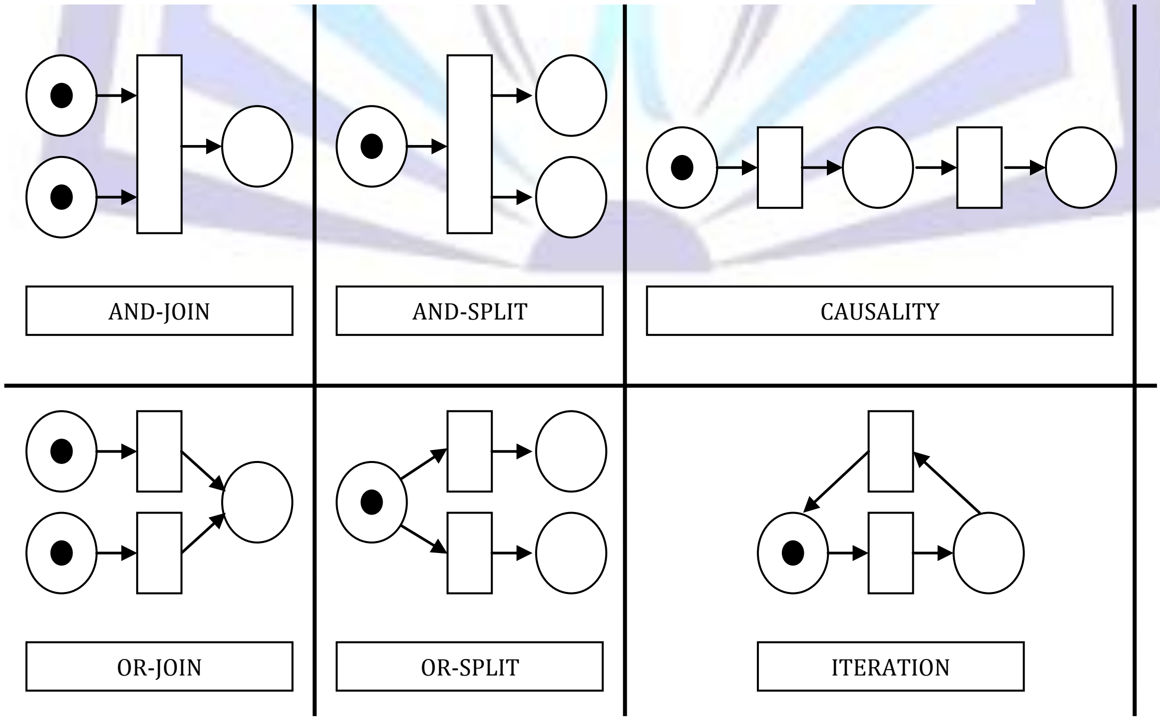

Figure 5: Petri Net Work Flow Basic Functions

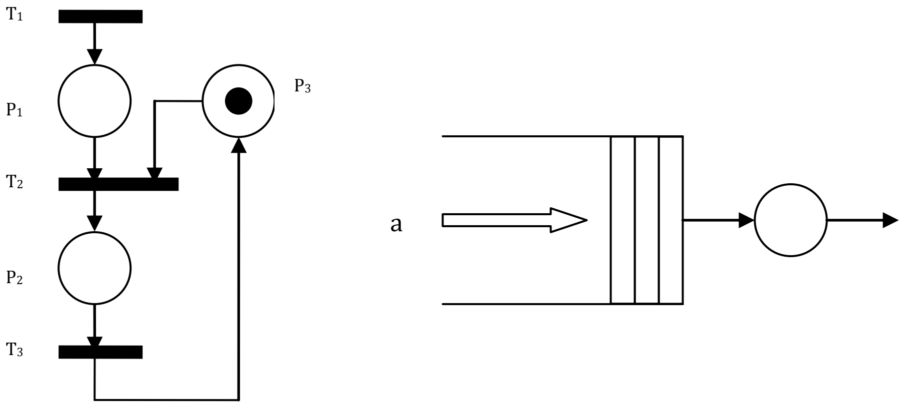

Figure 6: Petri-Net Queue Model

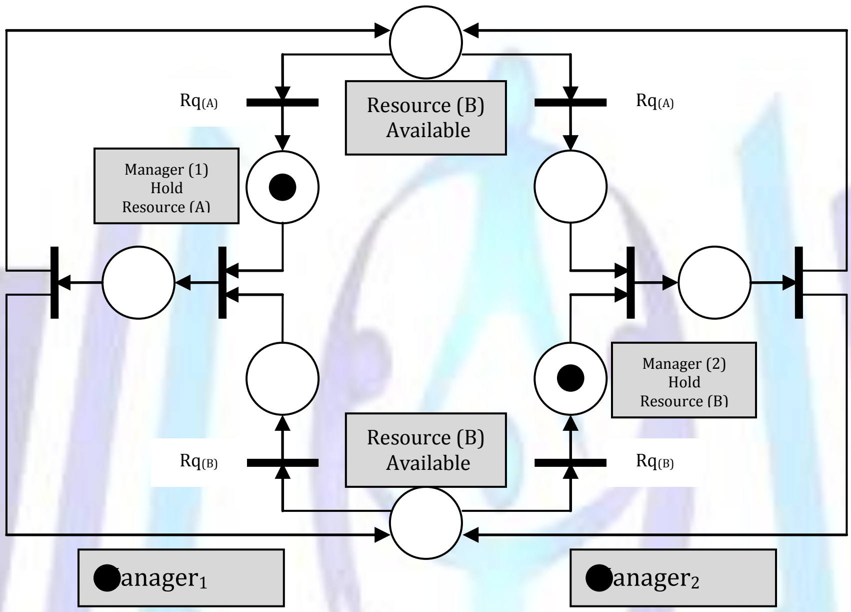

Figure 7: Petri Net Deadlock

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