Contribution to the modelling and analysis of logistics system performance by Petri nets and simulation models: Application in a supply chain

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Abstract. In this paper, the focus is on studying the performance of complex systems in a supply chain context by developing a structured modelling approach based on the methodology ASDI (Analysis, Specification, Design and Implementation) by combining the modelling by Petri nets and simulation using ARENA. The linear approach typically followed in conducting of this kind of problems has to cope with a difficulty of modelling due to the complexity and the number of parameters of concern. Therefore, the approach used in this work is able to structure modelling a way to cover all aspects of the performance study. The modelling structured approach is first introduced before being applied to the case of an industrial system in the field of phosphate. Results of the performance indicators obtained from the models developed, permitted to test the behaviour and fluctuations of this system and to develop improved models of the current situation. In addition, in this paper, it was shown how Arena software can be adopted to simulate complex systems effectively. The method in this research can be applied to investigate various improvements scenarios and their consequences before implementing them in reality.

1. Introduction
The mastering of supply chains is often attached to identify the intrinsic constraints and to optimize the various parameters relating to the functioning of this chain. To achieve these objectives, it is important to acquire a better understanding of the complexity of the chain and to predict their behaviours, which requires a pertinent modelling that will provide the required information.

In this context, the work presented in this paper contribute to purpose a formal methods for modelling the logistics systems in order to diagnose and understand its functioning then to evaluate its performance. The approach adopted to develop our models is based on the methodology ASDI (Analysis, Specification, Design and Implementation) [1], which consist to construct a knowledge model and an action model in order to properly model and to analyse all parameters and constraints related to our system. For that reason, we used two powerful modelling tools to achieve a finer and a precise modelling, these tools are the Petri nets to develop the knowledge model and the simulator ARENA [2] to transform the knowledge model in the action model.

To accomplish this work, firstly we examine the existing literature in order to review what has already been said on modelling of logistics systems, also we define the approaches adopted to model this kind of problems. Secondly, we start to model a logistics system adopting the methodology ASDI by taking on a companies in phosphate industry as a case study in the aim of analysing this system and extracting results from different experiments.
2. Literature Review

In the literature, there is a variety of taxonomies of approaches and methods used to model supply chains [3-7]. These approaches can be grouped into three major classes, namely organizational models, analytical models and simulation models.

Many research are based on modelling and simulation to address performance evaluation of supply chains problems. We present below a few researches:

- Belkadi [8] and Moussa [9] modelled and simulated a hospital logistics system, adopting the ASDI methodology by using the ARIS and Simula tools.
- Labadi et al. [10] presented a modelling and analysing the performance of logistics systems, based on a new model of stochastic Petri nets.
- Samata et al. [11] proposed a model for supply chain using a hybrid Petri nets. They transposed the concepts developed on the traffic transportation in the supply chain.
- El Kadiri et al. [12] proposed a simulation models by using performance indicators to evaluate the impact of a set of factors on the supply chain performance.
- Abo Hamad et al. [13] Fu [14] and Boesel [15] presented the approaches and methods to improve and evaluate the performance and complexity of supply chains. These approaches are based on the coupling between the simulation and optimization.

In this context, a lot of research is presented in literature reviews of Til [16] and Mourtzis [17]. As a results, this literature reviews we show that modelling of logistics systems are very interest the scientific research. Therefore, we found that modelling logistics systems based on ASDI methodology combining Petri nets models and simulation models is a little used.

3. The modelling approach adopted

The ASDI methodology was first proposed by Gourgand and Kellert [1], it is based on the construction of two classes of models: knowledge model and action model.

- The knowledge model describes the structure and the operation of the system in a natural or graphic language; it is built using the three subsystems (logical, physical and decisional). For an existing system, the knowledge model contains the knowledge acquired by the system observation. For a system to be designed, the knowledge model contains the specifications of the future system [18].

- The action model is a translation of the knowledge model in a mathematical formalism or a programming language, for example a simulation language, allowing the evaluation of the selected performance criteria. Several action models can be built starting from the same knowledge model [18].

In our case, we used two tools, Petri nets to construct our knowledge model and software simulation ARENA to transform our knowledge model in action model. The figure 1 illustrates the process of this approach.

**Figure 1.** The global Approach of modelling.

3.1. Petri Nets and Simulation tools ARENA

As already announced, to formalize and conceive our models we opted the Petri Nets for the knowledge model that provides a description of different processes in order to formalize all key processes contribute
to the perfect realization of our model to represent its generic functioning and its flows. This passage is an essential step to proceed to the action model (simulation model Siman-Arena) in order to evaluate and analyse our system also to exploit the different experiments made to extract results from the proposed indicators.

However, the Petri nets has a simple language to describe objectively the real system, but the difficult is in how to evaluate and analyse the performances of a complex system. Consequently, a simulation language was necessary. SIMAN/ARENA proved to be the right option, it allows the most of the specific description of the conceptual model and its blocks are analogous to places and transitions in the Petri nets [19]. The choice of ARENA is based on the work of Dias [20], Yuri [21] and Tewoldeberhan [22] which show its performance over the other simulation tools.

4. Case study

4.1. Description

The system studied is a logistics platform designed to export goods (phosphoric acid and fertilizers) and to import raw materials (sulphur) to and from various world places. This platform is implemented in a port at 13 km from the production sites.

It composed of two zones (see figure 2), the first area has the role of reception, storage and unloading of products coming from the production sites, while the second area has the role of reception, storage and loading raw materials coming from suppliers. The production site (see figure 2) is designed of two zones, the first one is for loading products and the second for receiving and unloading raw materials coming from the port.

The routing of products in this chain is made by three reams, the first one is located in the product loading station, the second is in the unloading station and the last one is in circulation.

These reams are towed by two locomotives, the first one provides traction of the mixed ream (sulphur and phosphoric acid) and the second tows the fertilizers ream.

![Figure 2. The supply chain studied.](image)

We can describe the cycle of dessert products as follows, both machines (the mixed and the fertilizers reams), mark their departures from the train station, then each one transport at the same time and respectively a ream to the factory and to the port, after that they return to the train station, where one waits to cross the other one, then each of both machines arrives respectively at the port and the factory, after they return to the station to restart this cycle.

The purpose of this study is to model and simulate this supply chain, to diagnose and evaluate its performance in order to improve its functioning by optimizing the routing process of products, which limits the capacity of the supply chain to transport the planned daily quantities.

4.2. Models development
4.2.1. The Assumptions
Before developing our models, several assumptions of modelling are to be taken in consideration:

- The durations of each processes in this supply chain (transportation, crossing, loading, unloading of products...) are estimated by a uniform distribution;
- The number of spare transportation equipment (wagons, tanks and locomotives) is supposed infinite, consequently the equipment which breaks down is immediately replaced, because the transportation service provider has a large park of spare vehicle;
- The effect of the equipment breakdowns and maintenance, was not included in the model because these operations are supposed to be made except durations of functioning.

4.2.2. Developing the knowledge model: Petri Nets
To achieve our knowledge model, we develop a macro model which gathers many sub models i.e. a sub model of fertilizers loading in the factories, sub model of fertilizers unloading in the port, sub model of sulphur loading and phosphoric acid unloading in the port and sub model of sulphur unloading and phosphoric acid loading in the factories.

The macro model developed (see figure 3) is an ordinary “Timed Petri Nets”. However, according to the initial marking, the transitions T0 and T9 are enabled, the upstream places represent arrivals of entities: the locomotive (place P0) with its fertilizer reams (place P1) and a second locomotive (place P24) with its mixed sulphur (place P13) and phosphoric acid (place P13) reams, then the tokens pass on places P2 and P15 to allocate respectively the railway station-factory for the fertilizer train and the railway station-port for sulphur and acid train, in this case we have a resource sharing between tokens (the railway station-factory represented by the place P6 and the railway station-port represented by the place P12). After that, trains make the travel between station-factory (represented by the timed place P3) for routing fertilizers (the duration is presented by a uniform distribution of parameters (20, 25) minutes) and between station-port (represented by the timed place P16) for routing sulphur and acid (the duration is presented by uniform distribution of parameters (15, 20) minutes). Consequently, the transitions T11 and T2 is respectively enabled, that activate respectively the loading process of fertilizer in the factory (place P4, see figure 4) and the process of loading sulphur and unloading phosphoric acid in the port (place P18, see figure 5). At the end of these processes, the train movement is initiated respectively by two places: P5 represent displacement between factory-station (the duration is represented by uniform distribution (20, 25)) and P17 represent displacement between port-station (the duration is represented by uniform distribution (15, 20)). As a consequence, the transition T3 and T12 are respectively enabled, that permits to trains to switch the railways (releasing the railways: presented by places P6 and P12, and at the same time allocating it: presented by places P7 and P19). After, the displacement of trains is started (represented by places P10 for fertilizers and P20 for sulphur and acid), which activates respectively, when the transitions T6 and T15 are enabled, the unloading process of the fertilizers in the port (place P9, see figure 6) and the process of unloading sulphur and loading phosphoric acid in the factory (place P19, see figure 7). Consequently, trains move to the station (represented by two timed places: P10 the duration is represented by uniform distribution (10, 15) and P22: the duration is represented by uniform distribution (20, 25)), finally the counters (P11, P23) of numbers of travels made is incremented and the cycle is initialised to remake.
Sub model fertilizer load process in factory
This sub model (see figure 4) regroups the operations made in the factory during fertilizers loading. When the transition T2 of the macro model are fired, a token (fertilizers trains) is created at the timed place P40, which represents the duration (represented by uniform (20, 30) distribution) to park the train in the fertilizer loading station, after that the locomotive and their reams are separated (represented by the places P41 and P42). Then this reams become segmented into two half-reams (Places P45 and P46) in order to be loaded into the two load lines (Places P48 and P47). After, the reams already loaded are waiting (in the initial marking, the reams in wait are represented by the place P43) to hang on to locomotive (place P49) in order to make a testing brakes (represented by the timed place P410 and the duration is an uniform distribution (13, 15)).

Sub model of process sulphur loading and acid unloading in the port
This sub model (see figure 5) regroups the operations made in the port to assure the load of sulphur and unload of phosphoric acid. When the transition T11 of the macro model are fired, a token (sulphur and acid train) is created at the timed place P180. Then, the same tasks as in the first process are made, but this time the mixed ream becomes segmented (place P182) in two other reams: the sulphur ream (represented by a token in the place P184) and the phosphoric acid ream (represented by a token in place P183).
Sub model of fertilizer unloading process in the port

This sub model (see figure 6) regroups the operations made in the port during unloading fertilizer process. When the transition T6 of the macro model are fired, a token (loaded fertilizers train) is created at the timed place P90. Then, the same tasks as in the loading process are made, but in this case, the initialization of fertilizers entities (place P99) is made after unload of fertilizer, because the locomotive is awaiting the empty ream.

Sub model of process of sulphur unloading and phosphoric acid loading in the factory

This sub model (see figure 7) regroups the operations made in the factory to ensure the discharge of sulphur and the load of phosphoric acid. When the transition T15 of the macro model are fired, a token (sulphur and acid train) is created at the timed place P210. Then, the same tasks described in sulphur loading and acid unloading process are made, but this time when the mixed ream divides in two reams (place P211), the sulphur ream divides in two semi reams (place P214) in order to be discharged in the two sulphur unloading lines (P2112 and P2114), in same time the phosphoric acid ream becomes segmented into two semi reams (place P213) in order to be loaded in phosphoric acid lines conferring to two modes: The normal mode, that is made when the transition T216 is fired conferring to a probability (m) and the special mode, that is made when the transition T217 is fired conferring to a probability (1-m).
4.2.3. Developing the action model: ARENA

The knowledge models presented in the previous sections are implemented in the ARENA simulation software to create the action models. In the following, more details about each model is provided.

- Global model
  We adopted, in the global simulation model (see figure 8), the same organization represented in the Petri nets models, except for initializing entities we regrouped them in another sub model called the initialization.

- Sub model of initialization
  This model (see figure 9) includes all blocks in charge to create the various entities (locomotives, wagons and tankers) of the system studied.

Figure 6. Sub model fertilizer unloading process in the port.

Figure 7. Sub model sulphur discharge and acid loading process in the factory.

Figure 8. Global simulation model.
With the regard to not clutter this paper by many figures, we will not present the others sub models and we settle only for the Petri nets models, which have the same construction principle.

4.2.4. Determining the permanent state

Before proceeding to the simulation of our model, we need to determine the transitional simulation phase to avoid influence of initial conditions on the final simulation results, so it is necessary to consider the results after the moment system reaches the steady state (this is called the initial data deletion). To do so, we executed a simulation test to identify the warm-up period, we observed graphically (plotted in Arena) the evolution of results (the product routing times) and we founded that after a 48 hours in simulation running time, the system becomes steady. Therefore, warm-up period was determined 48 h.

4.2.5. Verification and validation of the model

Verification is about constructing the model correctly. It draws a comparison of the conceptual model with the software representation that implements that conception. Having developed the model, its behaviour was checked visually, in order to be reasonably similar to real-world condition.

Validation is concerned with constructing the correct model. In this phase, usually a steady output of the model is considered to be compared with its real value obtained from data collection. To do so, the product routing time was selected to calculate confidence intervals (CI) (see equation 1) obtained from 10 replications of model simulation.

\[
\bar{X}(n) \mp t_{n-1,1-\alpha} \frac{S^2(n)}{\sqrt{n}}
\]  

Or \( n = 10 \) is the number of replications, \( \alpha = 5\% \) error risk of the CI in 100 \((1-\alpha)\% \). \( \bar{X}(n) \) and \( S^2(n) \) are respectively the mean and variance of the simulation results obtained for \( n \) replication.

The table 1 shows the results of this validation, we comprehend that the limits (lower and higher bound) of the confidence interval of simulation results are contained in the range of real time.

| Performance indicators (hours)      | Real results (Uniform distribution) | Simulation results (Validation test) |
|------------------------------------|--------------------------------------|-------------------------------------|
|                                    | Min        | Max         | Average \( \bar{X}(n) \) | CI à 95% [LB, HB] |
| Fertilizers routing time           | 3,18       | 4,16        | 3,747      | 3,72  | 3,77       |
| Sulphur and acid routing time      | 3,35       | 4,16        | 3,748      | 3,73  | 3,76       |

Table 1. Validation Result.
4.2.6. Simulation results

To analyse the performance of this chain, which is determined by the products routing process, we chose as performance indicators: the routing time, the number of routes made and the number of unloaded wagons that eventually reflect the performance of this chain.

Moreover, the software generates two kinds of indicators, the automatic performance indicators and performance indicators specified using the block “Statistics” and “Record”. Therefore, table 2 indicates the performance indicators selected in our model.

The model was simulated using the software Arena Version 14 for a 30 day.

| The product routing time (hours) | 3.76 |
|---------------------------------|------|
| Number of routes made           | 113  |
| Number of unloaded acid tanks   | 1746 |
| Number of wagon unloaded fertilizer | 1281 |
| Number of wagon unloaded sulphur | 1127 |

Noting that we have integrated the routing time of others products in a single indicator, because they converge to the same value. The calculated time in this model correspond to the average time.

According to the simulation results we notice that the routing time remains below objective as a consequence, it limits the ability of this chain to serve many customers, this effect is valid also for other indicators. Therefore, this indicators need to be improved to reduce the time routes and increase the number of routes and number of thanks served. However, these improvements will be the subject in another paper.

The models which we established are an exhaustive analysis of the current situation of the supply chain studied. Therefore, the followed methodology has contributed to understand and diagnose the functioning of this supply chain.

5. Conclusion

We presented in this paper the modelling approach ASDI and how to implement it in order to analyse and study the logistics systems. We developed a knowledge model with the Petri nets and an action model using ARENA simulation software. We tested the behaviour and fluctuations of this system, by using the results of performance indicators chosen in these models. In addition, the obtained results can help to size the necessary resources to comply with expected performance to conduct the activities in this supply chain.

In our future works, we plan to generalize this study to the other components of this supply chain and to develop an analytical models to validate this simulation model.

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