

SIMULATING THE LAST PLANNER WITH SYSTEMS DYNAMIC

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ABSTRACT

The Last Planner System is one of the most remarkable practices in lean construction and usually a starting point for lean implementation in construction companies. Different aspects of its application have been discussed along a number of articles since the first IGLC conferences. However, despite the many studies on this subject, the reasons for some recurrent patterns in the outcome data of the system and how they influence each other still remain to be explained. One of them is the cyclic nature of the PPC indicator that appears in most of the implementation examples presented in those articles. This article aims to help understanding such behaviour by developing a system dynamics model to investigate the influence of the variability, delays and project performance over the whole system. The model offers an explanation about how PPC fluctuations in the present may be explained by events in the past and, particularly, how to avoid undesirable outcomes in the future behaviour of the indicator.

KEY WORDS

System dynamics, Last Planner System

INTRODUCTION

Planning and scheduling practices are usually inadequate to deal with uncertainties that affect the production system (Alarcón 1999) the success of construction projects being highly dependent on the coordination of a fairly large number of stakeholders. To achieve better results, production systems should create appropriate conditions for controlling and improvement (Ballard et al. 2001).

In IGLC annual conferences, many papers have reported the use of Last Planner System (Ballard 2000) in construction projects, indicating that this system has been successfully implemented in a large number of projects in several countries, such as USA, Brazil, Chile, England, Finland, Denmark, among others (IGLC 2007).

This system is able to increase the reliability of short term planning by shielding planned work from upstream variation, and by seeking conscious and reliable commitment of labour resources by leaders of the work teams involved (Ballard and Howell 1997). At a medium term level, constraints are identified and removed, ensuring that the necessary materials, information and equipment are available (Ballard 1997).

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To control the system, one of the main indicators of the Last Planner System is the percentile of packages concluded (PPC), which is a rate to help manage the production (Ballard 2000). The PPC consists of the quotient between the number of executed tasks and the total number of planned tasks, expressed in percentage.

Although the Last Planner System is well described in the literature (Ballard and Howell 1997; Ballard 1997; Ballard 2000), much needs to be discussed on the core ideas within this system. Moreover, there is a continuing effort to further improving it, developing software tools which support its implementation.

So, the main aim of this article is to establish a relationship among the indicators associated to the Last Planner. The idea is to develop a tool based on dynamic systems capable to capture the influence of the variation and/or modification of the indicators in the whole system.

There are two hypotheses discussed in this paper: (1) that the PPC fluctuations may be explained by events previously occurred and (2) that the production commitment rate can be influenced by the delay of the construction site production.

However, as the model is a simplified representation of the reality, it can only present a simplified vision of the one proposed by the Last Planner, taking into consideration known variables and situations. Thus the model can not be considered as a faithful model of reality in all of its aspect but the ones that are explicitly considered in its construction.

PPC CYCLES / PATTERNS

The study started by trying to identify similarities between previous studies from different regions and different types, by analysing the PPC behaviour during a certain amount of time.

Ballard et al. (2009) cited the case of a Last Planner implementation in a design process. The Boulder Associates Architects worked for four years on Lean construction projects, before beginning an internal Lean transformation. The first 13 weeks of the implementation of Last Planner presented a high variability between the weekly PPC, the average was 80% but the individual measurement went across all the scale (from 0 to 100%). The second round of 13 weeks of implementation had a decrease of the variability. The goal of the group was to achieve 85% of completion. In spite of the positive results of a dramatic reduction in overtime and off-hours work after the implementation of Last Planner, the PPC still presents a variation between 50 to 100% in the second 13-weeks.

Kalsaas, Skaar and Thorstensen (2009) made a study inside utility buildings of a Havlimyra housing estate, in Norway, comprising the execution of concrete and woodworks using the LPS. The results indicated that they had a very low score the first weeks but on week 4, when it achieved an 85% score. After the beginning of the concrete works, in the 5th week, the PPC score dropped down again and was under 25% in the 7th week, then the planning reliability recovered and scored the period's average of 65% in the next week. After that, the ongoing weeks have not scored under the average.

In the Alsehaimi et al. (2009) study, the authors used an action research strategy to describe the process for implementing LPS aiming to improve construction planning within two construction projects in Saudi Arabia. The case study took approximately

18 weeks long in the two sites. In both projects, the PPC of the first weeks were lower and had a great variability and after 8 weeks it stabilised around the average of 86%.

Olano et al. (2009) produced a study carried out in two construction projects that show the relationship of the PPC with the SPI (Schedule Performance Index), it was collected data about 41 and 44 weeks in the projects. The PPC results pointed out a great variability around the indicator average rate. In one of the projects the PPC oscillation was between 10 and 90% in the first 20 weeks, and in the last half of the period it was between 30 and 80%. However, in both cases, the data showed that a stabilisation of the PPC could not achieved, but just a little reduction of its variability. The use of office controller, field engineer, kanban, and LPS were reported as the means that helped to increase the PPC and to make it more constant, reducing variability (Jang, 2007).

Also, the PPC rate can be related to other processes. Jang (2008) suggests the existence of a positive relationship between a performance of the make-ready process and PPC.

In most cases it was observed that the weekly plans took some time to stabilise production at an adequate level. Thus, this paper is an attempt to understand the fluctuation of the PPC rate until it gets stabilised, what can influence on that variability, and when this influence occurs.

SYSTEM DYNAMICS

System dynamics is a method to enhance learning in complex systems (Sterman 2001). According to the author, the complexity of a system is not due to the number of its components, or in the number of possibilities to be taken into consideration in making a decision. Rather it is about the complexity in finding the best solution out of an astronomical number of possibilities. For Kelly (1994), complex and dynamics systems are regulated through the independent action of distributed decision maker.

Sterman (2001) argued about the importance of systems thinking when there are needs to intervene in the system, avoiding policies resistance due to the unforeseen reactions of the decisions made. A systemic perspective would enable consistent decision makings for the system as a whole.

A system dynamics enables the decision makers to analyze the consequences of an intervention when changing the system coordinates (Katok; Hasselblatt 1995). Therefore, it is necessary to focus on the understanding and on the qualitative prediction of the system behaviour to detect the gaps between the new action goals and the organization strategic goals (Größler; Stotz; Schieritz 2003).

According to Sterman (2001), in a dynamic, evolving and interconnected world the most problematic elements are: feedbacks, time delays, stocks and flows accumulations, and non-linearity.

1. **Feedback** – The results of past actions alters the assessment of the problem and the decisions of tomorrow (Figure a). The understanding of the feedback processes avoids the common view that the world is unpredictable and uncontrollable.
2. **Time Delays** – Time delays between taking a decision and its effects on the state of the system can lead to wrong interpretations about the system, since delays reduce the decision maker ability to gather experience, test hypotheses and learning.

3. **Stocks and flows** – The accumulation and dispersal of resources are central to the dynamics of complex systems. Since the 90s the strategic management community has begun to consider the role of stocks and flows explicitly. Koskela's Report 72 (1992) was the first to apply the flow awareness into the production system in the construction. The resource-based view was expanded to include less obvious but more important stocks underlying firm capabilities, such as employee skills, customer loyalty, and other forms of intangible human, social, and political capital.
4. **Non-linearity** – The belief that experience and market forces enable good managers to learn quickly about the feedbacks and side effects of their decisions, is shown as erroneous by Sterman (2001). Actually, the heuristics used to judge causal relationships systematically lead to cognitive maps that ignore feedbacks, non-linearity, time delays, and other elements of dynamic complexity.

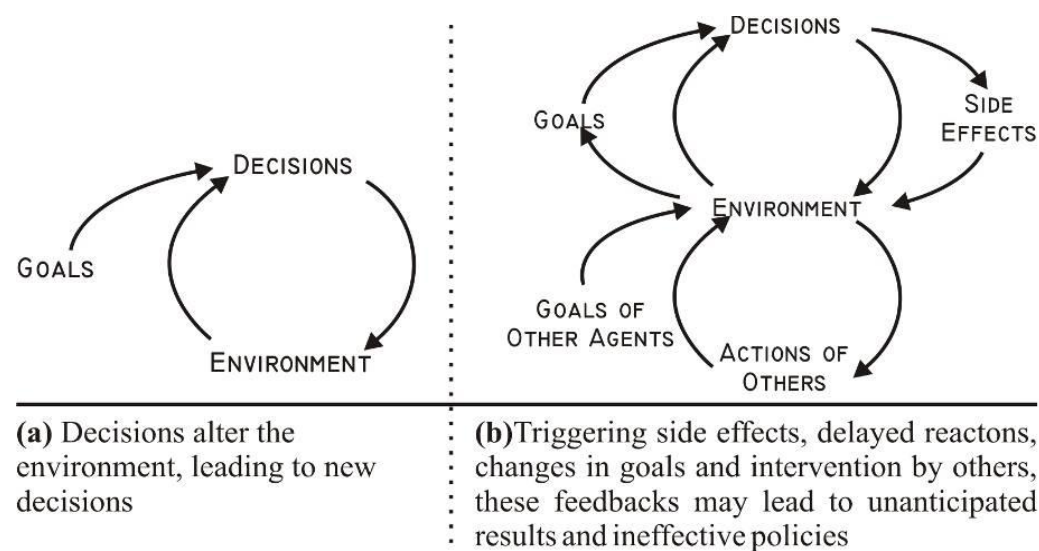


Figure 1 - The Feedback of the World (Sterman 2001)

METHOD

The research strategy is an exploratory study of the PPC behaviour, according to the hypothesis that it can be influenced by the delay of the construction site production. According to Ballard (1994) production control is exercised at the crew level by the PPC, and if the system assumes quality plans, higher PPC will correspond to doing more of the right work with given resources. To make it possible to model the Last Planner System, there was a need to simplify the variables seen in the literature. In Table is presented what were the main simplifications and why they were made.

The main structure of the model was done based on Ballard (2000) description of the Last Planner System of production control. However, the art of system dynamics modelling lies in discovering and representing the feedback processes and other elements of complexity that determine the dynamics of a system (Sterman 2001). Therefore, the influences between the rates were made based on the study hypothesis, as described on Table .

The studied model was generated in Vensim, version PLE. Vensim® (the Ventana Simulation Environment) an interactive software that allows the development, exploration, analysis and optimisation in the simulation of models. The program was developed with the purpose increase rhythm in the development and the quality of the results of the models (Morecroft; Sterman 2000).

According to Reppening (1998), the system dynamics models represents reality as stocks, flows, inputs and outputs, as shown in Figure . Each box of the representation means a stock of something that will flow to the next stock, according to the flow rate, represented by the double line arrow. Simple arrows represent rates that can be systems inputs or outputs, depending on the arrows direction. The cloud icon represents the boundary of the model, which makes the original rate origin irrelevant.

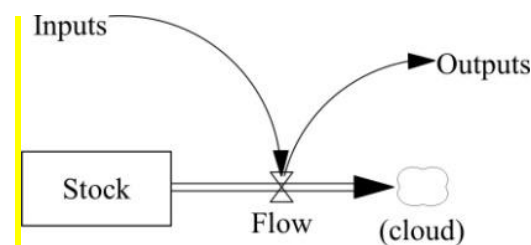


Figure 2 - Model Representation

Table 1 - Adaptations of the variables

Variable	Kind of adaptation
Long-term and Medium-term showed in packages	The work packages are defined just in the short-term planning. But, in order to maintain a compatible unit all over the model, it was decided to present the Long and medium term planning in number of packages.
Average of Constraints per package	Actually, a constraint can be related to an amount of packages, and a package can have a lot of constraints. However, the intention of showing the constraints was to see the relation of the removal constraints index in the inventory of short term packages. So, this variable was included to link a parallel model that uses constraints as unit, but interfere in the main model.
Production Commitment Rate	This rate defines the assignments of the week. For the model it was considered an influence from the Time Deviation rate in a way that the production delay forces the team to commit more packages than the estimated capacity.
Produced Packages Rate	The produced packages rate is conditioned, in the model, to a relation between the commitment rate and the capacity of production. Therefore, if there is more capacity available than what was committed, it will be produced the commitment packages. However, if there are more assigned packages than work capacity, it will be produced just what the capacity can do.
Real Productivity Rate	The Productivity was considered the number of packages a team is able to do. The only rate that has a random variation, between 0.8 until 1.2.
Not produced Packages Rate	This is just an auxiliary rate that is the opposite of the produced rate, avoiding the creation of an inventory of assignment packages, since the packages that are not produced need to be committed again for the next week.
Time Deviation	Usually represented as a project rate, calculated in the conclusion of the production through the comparison between the estimated and the real period. In the model, the rate was measured weekly, so that it could influence the commitment rate.

According to Kiyuzato (1999) there are some steps to start the modelling and simulation process that are explained in the following (Figure 3).

- **Problem definition:** the first step consists in identifying the problem and to decide what will be the object of study. It is important to highlight that dynamic problems involve values which vary with time.
- **System conception:** the second step consists in identify and relate the variables that can influence or act over the system. These relationships can be represented through a list of causes or graphs.
- **Model representation:** the model must be expressed in a computer language through specific software or mathematic equations.

- **Model behaviour:** the computer simulation is used to validate the model itself and determine how the system variables behave as time passes, according to the input values inserted.
- **Model evaluation:** once the simulation is over, it is necessary to analyse the logic consistency of the results according to the output graphs generated by the system. This data can be compared to real data or to statistic tests. If the system is not similar to a real behaviour, it will have to be adapted to the previous steps in order to be reliable.
- **Model use strategies:** the model is used to test different possibilities of behaviour and analyse the individual results.

According to Sterman (2001), simulations are tools to create a virtual world or a microworld where experiments can be conducted and play what enables decision-making skills development.

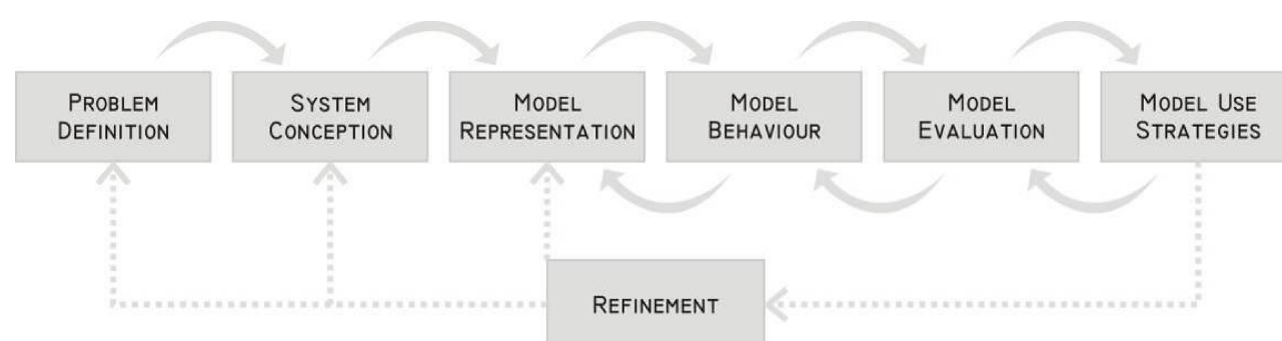


Figure 6- The modelling process

It is important to emphasize that all these steps are dynamic, so it needs continuous improvement through the refinement of each step according to the feedback of the previous ones. Since the purpose of system dynamics models is to explain the behaviour of a system before it becomes stable, it was defined that the model would have a horizon planning of a medium term of 5 weeks.

RESULTS AND DISCUSSIONS

A simulation model of the last planner was generated based on the propositions on dynamic models and with the help of computational specialised software. For a more detailed explanation and for a better understanding, the model was separated in three parts, which will be explained in parts. At the end, the complete model is presented.

The first part of the model is shown in Figure 4. The model begins with the planning of the Long Term Packages. In the long term, the total amount of packages are defined as well as the total period of work including quantitative, budget and data referring other construction sites.

The next part in the model comprises the planning of medium term packages. The hand-off of packages between the long and the medium term is controlled by the weekly definition of packages rate. This rate is influenced by the medium number of packages per week. This same rate will be used, further on this paper, for the calculation of the period deviation index.

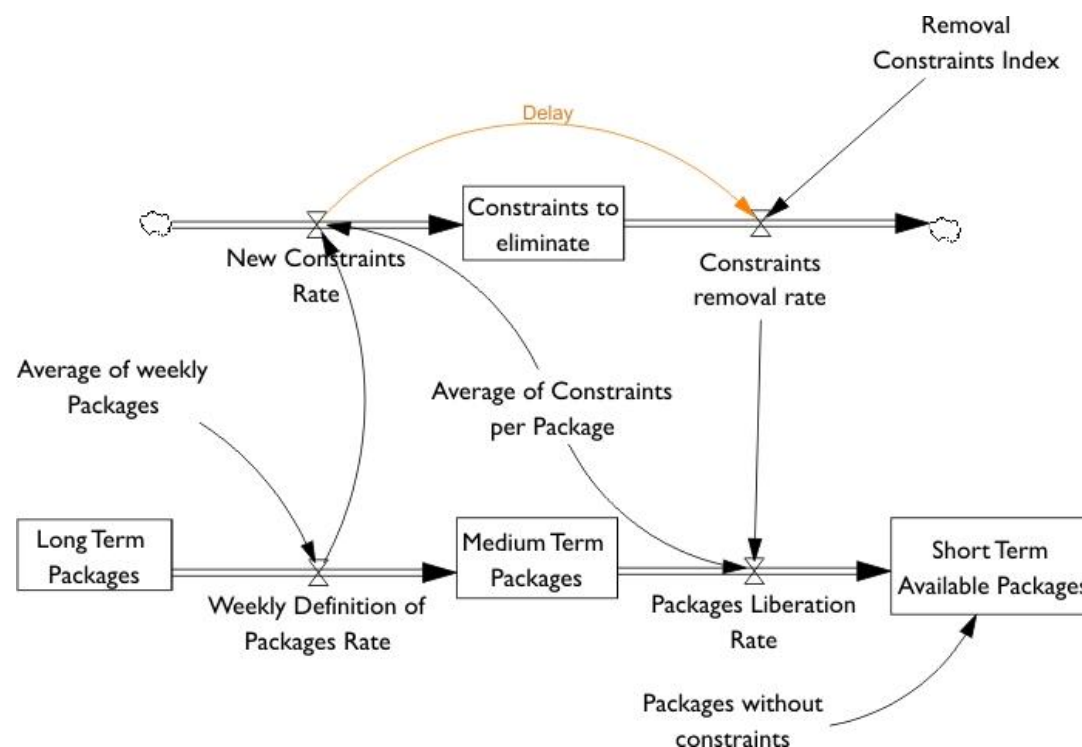


Figure 4 - Medium Term Model

The next level in the model comprises the available packages in the short term (Figure 5) – a closer level to the production. The hand-off of packages between the medium and the short term is controlled by the Liberation of Packages Rate, which in turn will depend on the effective removal of associated constraints.

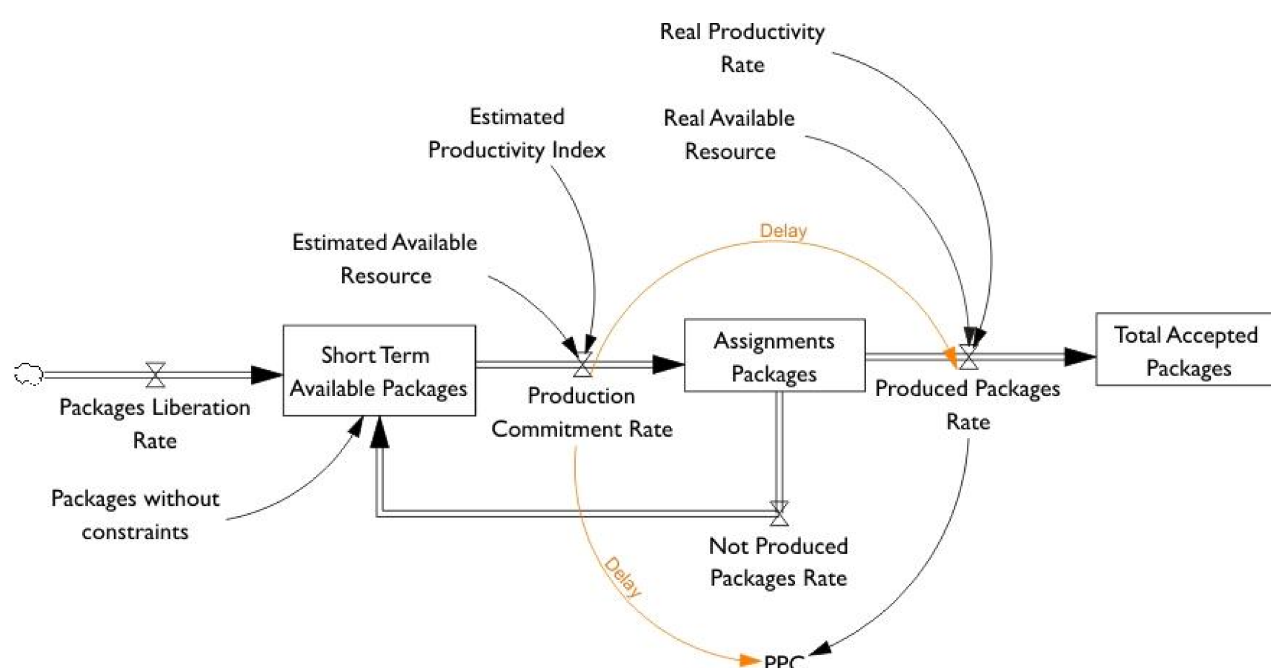


Figure 5 - Simplified short term model

In the short term there are the Short Term Available Packages. These packages will be influenced by the Production Commitment Rate. This specific one is influenced by the Estimated Productivity Index and by the Estimated Available Resources. The packages that pass through this rate are the assignments packages. In other words, the packages that are accepted by the person in charge of each activity and that will be also be accomplished in the following week.

Then, the assignments packages will pass through the Produced Packages Rate. Its result being the Total Accepted Packages. It is important to notice that the Produced Packages Rate is the second influence on the PPC.

To finalise, Figure 6 represents the final model with some artifices meaning the delays represented in the model. Those delays take the rates that are connected to, which will influence the following week.

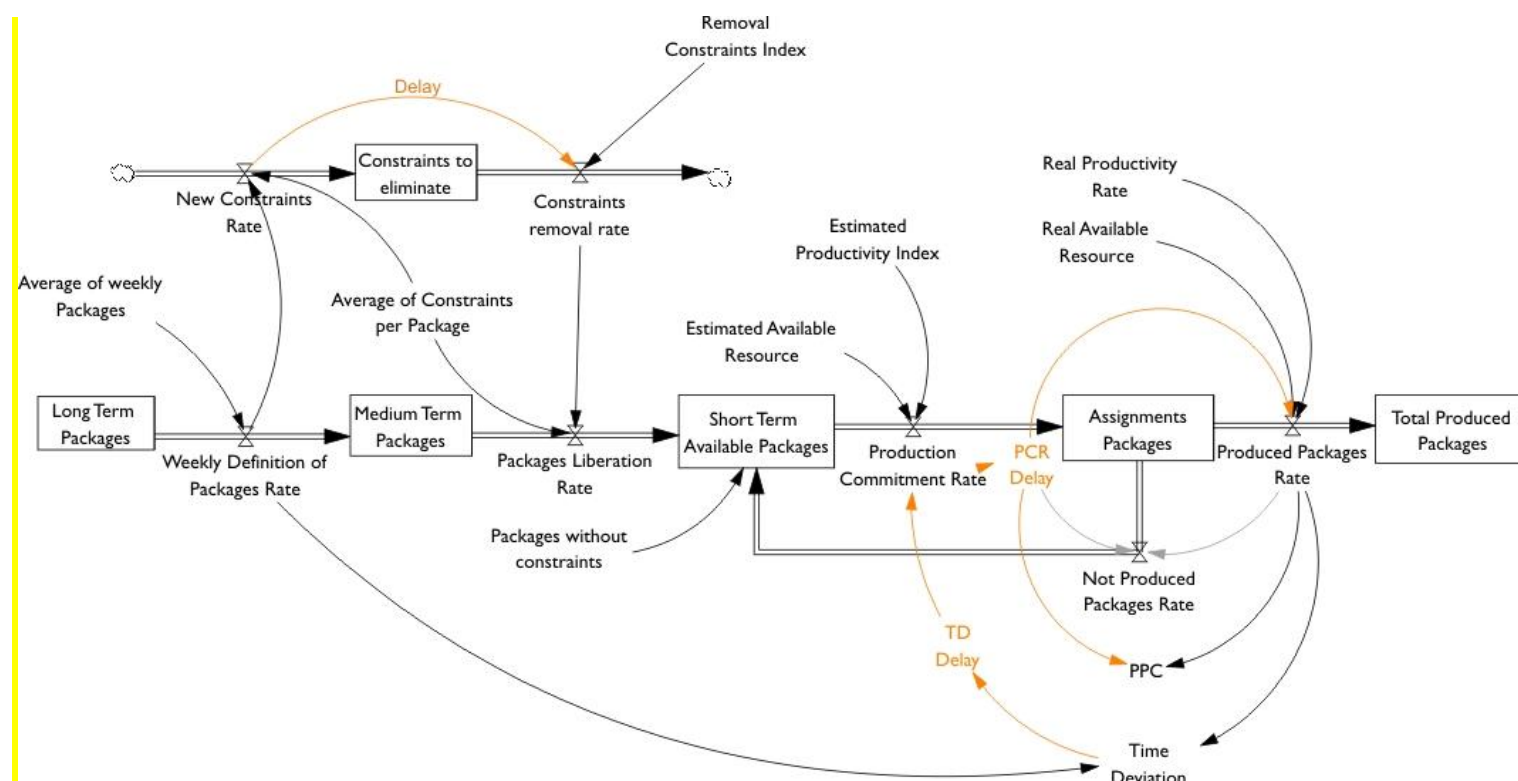


Figure 6 - Final model with artifices

The relation among the Production Commitment Rate (PCR) Delay, the Produced Packages Rate and the Not Produced Packages Rate is also represented in the model. The consideration of this relation was intended to avoid inventory of packages that come from the Assignments Packages.

OUTPUTS

The model simulation generated graphs for each variable of the system. In Figure 7, is shown two examples of outcomes: the time deviation and the PPC. The PPC graph, showed in Figure b, is an attempt to represent the real behaviour of this rate.

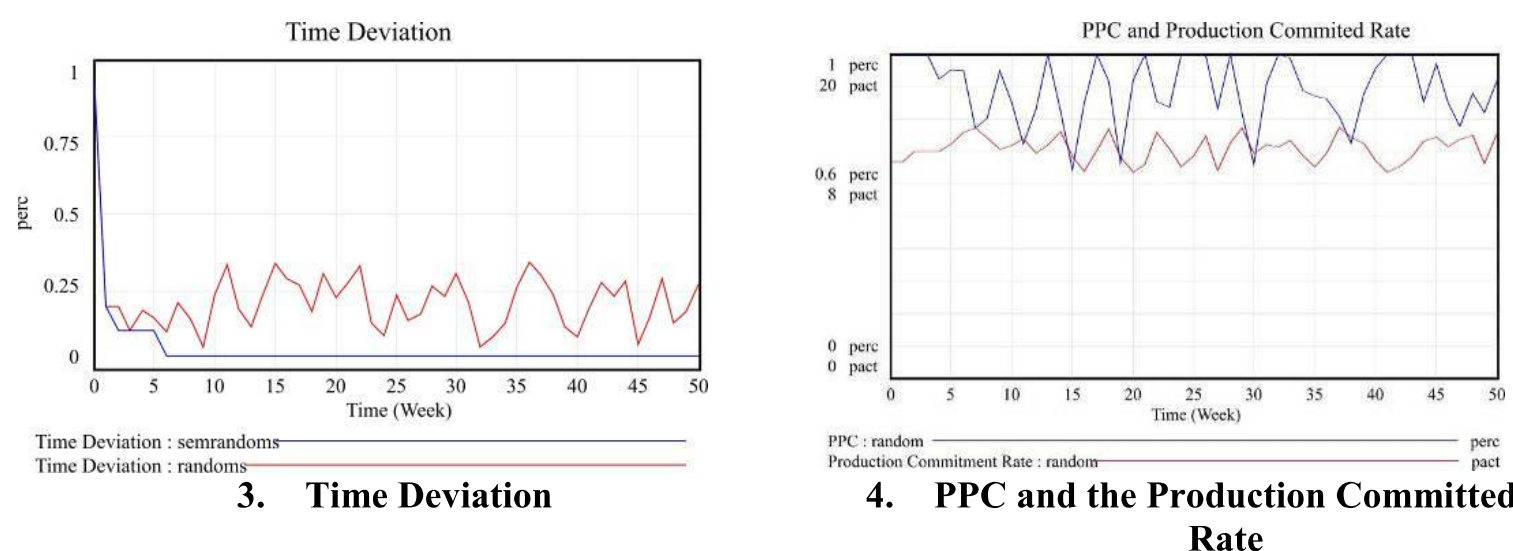


Figure 7 - Model Outcomes

According to the analyzed studies (Olano et al. 2009; Alsehami et al. 2009; Kalsaas, Skaar and Thorstensen 2009; Ballard et al. 2009) the tendency of the PPC is to have a high variability in the beginning of the implantation, and to stabilise around an average after a certain period of time. The cyclic fluctuations and the high variability of the PPC denote the dynamic nature of the Last Planner System, reflecting the existence of a control loop and an associated time delay. Those are important ingredients in understanding the behavioural implications of the Last Planner System.

DISCUSSION

The model enables a wide visualisation of the Last Planner System. Looking at the Medium Term planning in detail, the model shows a relation between the Removal Constraints Index and the Package Liberation Rate, so that a low on that index would decrease the rate of package liberation. As a result, the short term packages would have fewer packages than the available estimated capacity.

A consequence of this situation, which is not explicitly shown in the model, is the tendency of generating a making-do waste, discussed on Koskela (2004), since when there is a pressure to start the task, even when constraints are not completely removed, thus causing risky improvisations.

Another model issue that enables discussion is the cycle derived from one of the study hypotheses, that is, the influence of the time deviation over the Production Commitment Rate. This hypothesis assumes that high PPC levels do not mean that the construction development is on time, but it measures the extent to which the craft supervisors commitment was done (Ballard 1994). In other words, how well the load was matched to the available capacity.

To ensure that the construction will be finished on time, there should be a pressure on the workers to assign tasks as much as possible. However this situation can lead the workers to commit with more packages than the available capacity, which make the PPC decreases, thus causing the cyclic effect that is observed in many PPC diagrams (Olano et al. 2009; Alsehami et al. 2009; Kalsaas, Skaar and Thorstensen 2009; Ballard et al. 2009).

CONCLUSIONS

The analysis of the elements that influences the last planner is quite complex. Unlike deterministic systems, the last planner possesses several characteristic elements that distinguish it from the others. The focus deviates from the processes to the relationships and interactions.

According to data, rates, taxes and behaviour analyses through real experiences in construction sites and to theoretical references, this paper has shown how a simple production model, implemented in a simulation model, can be used to explore production strategies and to illustrate the impact of some index in the project performance. The model can also be used to design and evaluate new policies before implementing them in the real world. The results of these experiments in the real world can then lead to revisions and improvements in both the simulation model and the mental models of the decision makers, thus speeding the learning process

The paper provides a preliminary example of this approach and the authors believe that the model can be extended to explore other concepts and practical situations. By doing so, the main benefits will be a larger control in relation to the established requirements (deadline, deliveries and costs), reduction of uncertainties, more managerial control, reduction of the time to develop solutions and storage solutions for future projects (lessons learned).

The authors would like to suggest that this approach can be used further to the use of system dynamics simulation software not only as analysis tool, but also as a management tool; the use of dynamic models for project planning, helping foreseeing the necessary allocation of resources to maintain deadlines and costs; and to improve the model proposed in this paper. Simulation experiments may suggest new data to

collect and new types of experiments to run to resolve uncertainties and improve the model structure.

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