# THE ROLE OF PRODUCTION SYSTEM DESIGN IN THE MANAGEMENT OF COMPLEX PROJECTS

**Fábio K. Schramm[1], Alana A. Rodrigues[2] and Carlos T. Formoso[3]**

## ABSTRACT

Production system design (PSD) is one of the core activities of production management. It translates the intended production strategy into a set of decisions. It establishes the structure that will manage different activities, and creates appropriate conditions for control and improvement. The design of production systems should begin at the early stages of product design, including not only on-site production itself but also on suppliers' and consumers' processes. In operational terms, a major concern is to devise the layout and the material and information flows in order to create favourable conditions for a more efficient production system. Despite its importance, very little attention is usually given to production system design in the construction industry. This paper discusses the implementation of production system design in complex construction projects, such as hospitals, industrial and commercial buildings. This discussion is based on the findings of two case studies, using a model for production system design devised for low cost repetitive house-building projects as a starting point. Differently from low cost house-building, in complex projects the client requirements are not usually well defined at the beginning of the project. This requires the production system design to be carried out in several stages. Another difference is the large number of subcontractors and suppliers involved and the high degree of interdependence between them. Some prototyping tools were used for reducing uncertainty, and to increase transparency. The main contribution of this paper is to propose the PSD as a way to cope with certain features of complex construction projects. It proposes the scope of decisions involved, and the requirements that are necessary to perform this task effectively in such projects. The results indicated that production system design can potentially improve the performance of production systems in such projects, and improve the understanding of the impacts of client requirements and design changes.

## KEY WORDS

Production system design, complex projects, production management.

[1] M.Sc., Assistant Professor at Federal University of Pelotas – UFPel, Ph.D. Candidate at NORIE/UFRGS, fabioks@ufpel.edu.br

[2] Civil Engineer, M.Sc., Researcher at NORIE/UFRGS, alana@ppgec.ufrgs.br

[3] Ph.D., Associate Professor, Federal University of Rio Grande do Sul (UFRGS), Building Innovation Research Unit (NORIE), formoso@ufrgs.br, Av. Osvaldo Aranha, 99 – 3º andar, CEP 90035-190, Porto Alegre – RS, Phone: +55 51 3316 3959

## INTRODUCTION

The increasing complexity of construction projects has been pointed out by many authors (Baccarini 1996, Williams 1999, Beckerman, 2000, Bertelsen 2003, Calvano and John 2004), who have stressed the need of devising managerial systems that are suitable for such complex environments.

Part of this complexity comes from uncertainty, both in methods and goals, and from the structural complexity, which is related to the number of elements and interdependences (Williams 1999, 2002; Gidado, 1996). It is also the result of the lack of knowledge on customers' requirements or from changes in those requirements during the execution of projects (Williams 2002; Bertelsen and Emmitt, 2005). In this situation, the design has to be developed simultaneously to site installation. , and the production system cannot be fully designed at the beginning of the project.

Designing is usually associated to the product design. However, designing should also be concerned with the production system that will make the product. According to Gaither and Frazier (2001), when a product is designed its features and production processes are established.

According to Skinner (1985), the production system design (PSD) aims to establish a set of manufacturing policies, which are grouped into two parts. The first is related to facilities and equipment, resource capacity, and technologies to be used. The second is related to infrastructure, including vertical integration, production planning and control, workforce management, quality control and so forth. Askin and Goldberg (2002) state that PSD involves the management of the production resources in order to meet the customer's demands.

Some authors (Slack et al. 1997; Gaither and Frazier 2001 and Askin and Goldberg 2002) state that production system design should begin early, at the product design stage. This enables decisions to be made on product design by taking into account the production processes, in order to increase the performance of the production system.

Despite its importance, very little attention is usually given to production system design in the construction industry. Only recently some IGLC papers have explicitly discussed the production system design in construction projects (Ballard et al. 2001; Schramm et al. 2004, for example).

A previous paper published by the authors (Schramm et al. 2004) indicated the potential of PSD for improving the performance of repetitive house-building projects. It has created opportunities for an in-depth discussion on the production system, encouraging the production management staff to develop a systemic view of the production system, considering a wide range of variables and decisions, such as defining resources, establishing production capacity, choosing technologies and devising workflows, reducing uncertainty and establishing feasible goals.

The discussion and formalization of decisions involved in PSD contribute to reduce improvisation in production management and also provide a focus to deal with uncertainty before the beginning of the construction stage (Schramm et al. 2004).

The aims of this paper are to discuss the role, the contributions and the scope of decisions of production system design in complex construction projects, and to propose a set of guidelines and tools for effectively performing that task. This research work was based on two case studies carried out in a medium-sized construction company from the State of Rio Grande do Sul, South Brazil. Two research questions have been addressed in this study:

(a) What should be the role of PSD in the management of complex projects?

(b) How should PSD be produced in this context?

## COMPLEX PROJECTS

Williams (1999 and 2002), describes project complexity in terms of structural complexity and of uncertainty (Figure 1). Structural complexity, as discussed by Baccarini (1996), is concerned with the underlying structure of the project, i.e. organizational complexity – defined by the number of hierarchical levels, number of formal organizational units, allocation of tasks and the degree of operational interdependences between the organizational elements – and technological complexity – defined by the number of inputs, outputs, tasks or specialities and the interdependences between tasks, teams, technologies or inputs (Williams, 1999).

The production speed compounds the structural complexity. According to Williams (1999), projects have become more time-constrained, and the ability to deliver a project quickly is becoming an important competitive advantage. As projects become shorter in duration, this enforces parallelism and concurrency, which increases project complexity further (Williams 1999).

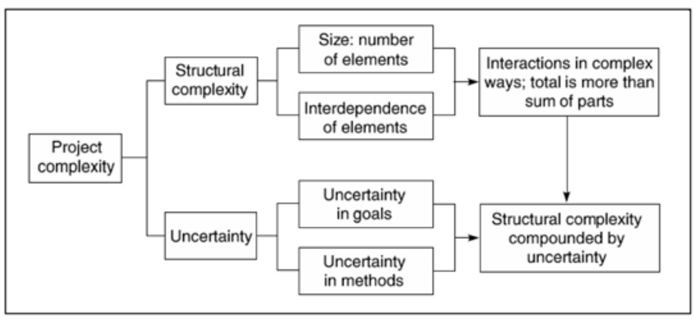


*Figure 1: Dimensions of complexity (Williams 1999)*

Uncertainty includes both stochastic elements and those resulting from lack of knowledge (epistemic uncertainty) (Williams, 2002). Besides uncertainty in the methods, another dimension of added complexity comes about when there is uncertainty in goals, i.e. projects in which methods are known but goals are uncertain, or are often changing (Williams, 2002). In the construction industry, Gidado (1996) states that uncertainty can be related to many aspects: (a) lack of complete specifications for the activities to be carried out; (b) unfamiliarity of the inputs or of the environment by the managers; (c) lack of work uniformity; and (d) unpredictability of the environment.

According to Gidado (1996), there are basically two perspectives of complexity: (a) the managerial perspective, which involves the management of the numerous activities to form a workflow; and (b) the operative and technological perspective, which involves the difficulties of executing individual tasks (originate from the resources used and the environment in which the work is conduced).

Another important source of complexity is the client. Bertelsen and Emmitt (2005) stress the relevance in considering the clients as sources of complexity because of the difficulty in understanding their requirements and values. Client related uncertainties tend to affect the goals of the project. Thus, understanding and predicting how the customer will behave is a key-factor to manage a project (Williams 2002).

The size of a project is not necessarily related to its complexity level. Although the project size can be directly related to structural uncertainty, Williams (2002) emphasizes that a small project can be more complex than a large one if there were a great amount of uncertainty, either in goals or in methods, added to time and cost constraints.

Gidado (1996) states that project complexity has been related to the difficulty of implementing a planned production workflow. An efficient implementation of managerial functions (production planning and control) can influence the effect of project complexity on project success. Therefore, managers can influence the effect of project complexity by using appropriate planning and controlling adjustments.

## RESEARCH METHOD

The case studies were carried out in two different construction projects. Both projects were built by the same company, which has much experience in the design and construction of complex projects. The first project was the extension of a large hospital complex in Porto Alegre, including the construction of four floors on the top of an existing building. The second project was the construction of an industrial building located in a steel mill industrial site. In both projects the regular client operations could not be disturbed, causing much interference in the site installation. Moreover, both clients also demanded many changes after the production stage had started, mostly due to the lack of definition of their requirements. There was also much pressure to limit project costs and to reduce the project duration in order to start operating the new facilities as soon as possible. The number of subcontractors was fairly large, especially in the hospital project, due to the high variety of tasks to be performed. Therefore, despite being relatively small projects, both can be considered as complex due to the high degree of uncertainty involved

The production system design was developed by the production management team of each project supported by the researchers[4] in several weekly meetings. This team was typically formed by the production manager, the foreman, key subcontractors and the main suppliers. An agenda for discussion was prepared, and the participants were encouraged to discuss different alternatives for the production system design. The aim was to accomplish an agreement on how the production system should be organized, including the definition of the main resources (equipment and workforce), and production flows. The decisions made in each meeting were documented by the research team and then sent back to the production manager team members.

The main sources of evidence were participant observation in the meetings, meeting minutes, and interviews with the contract manager and production engineers.

---

[4] The research team was formed by four postgraduate students: Fábio K. Schramm and Alana A. Rodrigues, directly involved in PSD, Marcel G. Trescastro, involved in a study on design planning and control process, and Fernanda A. Saffaro, involved in a study on prototyping.

The model proposed by Schramm et al. (2004) for the production system design of low-income housing projects was used as a starting point for the first case study. That model intends to guide the decision making process involved in the structuring of the production system, emphasizing the design of a continuous production workflow, and the management of hand-offs between crews. Figure 2 presents the main steps involved in that model.

The model establishes six main steps for the production system design: (a) definition of the base-unit installation sequence and capacity pre-planning; (b) study of base-unit workflows; (c) definition of the execution strategy; (d) study of project workflows; (e) definition of production resources capacity; and (f) identification and design of critical processes. In spite of the sequential representation of these steps, the decisions are usually interdependent. For this reason, several iterations are usually necessary (represented by decision and revision flows), as indicated in Figure 2.

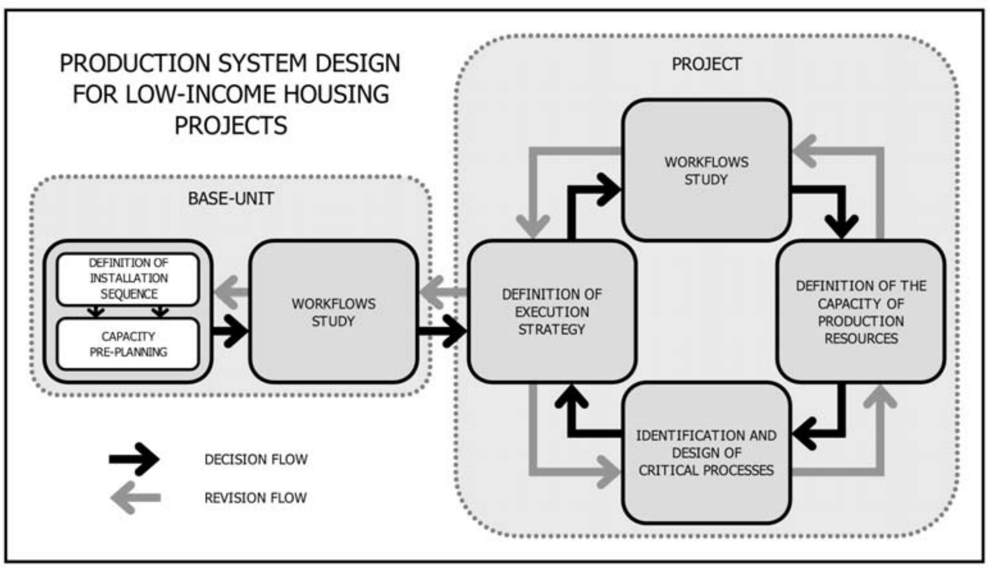


*Figure 2: The Model of Production System Design for Low-income Hosing Projects (Schramm et al. 2004)*

Based on the first case study, changes were proposed in the model, in order to adapt it to the context of complex projects. Such propositions were further tested in the second case study. After that, a set guidelines and tools for performing the PSD in complex construction projects were proposed.

## CASE STUDIES

### Case Study 1 – Hospital Complex Extension

The production system design was devised for part of the project, which consisted of the construction of fifty-six hospital rooms, located in three different floors. At the beginning of the study, the reinforced concrete structure and the external walls of the building had already been built. Thus, the production system design was limited to the internal drywall partitions, building services, and door installation. However, other construction processes (external wall finishing, windows installation, for example), which were not included in the design, had to be considered in the study, since these were bound to cause interferences in the hospital room construction sequence.

The PSD started four weeks before the beginning of production. Two-hour weekly meetings were held over a period of six weeks.

Although most of the design had already been finished, several client's requirements were not completely defined and thus had to be changed during the study. These changes were a hindrance to the PSD since some definitions on cycle times, work sequence and process starting time, for example, had to be revised when the requirements were finally defined. Delays in choosing and contracting suppliers, which was the client's responsibility, was another hindrance. For that reason come subcontractors could not participate of the PSD.

In general, the production system design followed the sequence proposed in the previous study (Schramm et al. 2004). Therefore, the first step was the *definition of the base-unit installation sequence and capacity pre-planning*. In this project, the base-unit was defined as a module of two rooms.

There was no data related to productivity rates and activity duration available for this project type. This is why most data used were obtained from the development of a physical prototype[5] carried out for the room installation. Such data helped reducing the uncertainty in the initial steps of the production system design: the installation sequence, the most adequate crew size, productivity rates, and equipment capacity.

In the second PSD step, the *study of base-unit workflows*, the workflows of several production crews along consecutive base-units were established, both in terms of space and time. As the base-unit was relatively small, this step was limited to the analysis of the work sequence defined in the prototype construction.

The *definition of the project execution strategy*, the third step, included the segmentation of the project into work zones, in order to create "small projects", containing a limited number of base-units, within the whole project. Work could be carried out independently in such zones, either in a parallel or sequential manner. The transfer and production batches were defined as equal to a base-unit (two rooms), making it easier to establish a synchronised workflow.

Each floor was further divided into two sections, related to the front and the back building façades. The work crew's paths were defined according to the sequence of the external windows installation, since the drywall erection depended on that process due to the necessary protection from bad weather. The workflows were defined starting from the back side section of the lower floor as shown in Figure 3.

---

[5] The prototype was part of a research study carried out by the researcher Fernanda A. Saffaro. The possibility of using data from this study was discussed and accorded during the initial PSD meetings. The evaluation of its usefulness to improve the PSD elaboration was a researcher's interest.

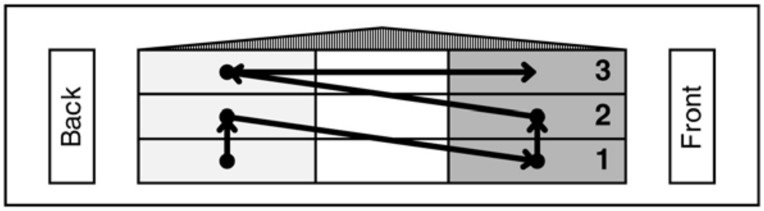


*Figure 3: The work crew's path in the building*

In the *study of project workflows*, the fourth step, the impact of the execution strategy on the relationships between base-unit workflows were analysed. The complexity of the processes and the possibility of interferences between work crews were also addressed in this step.

The Line of Balance (LOB) technique was used to plan the workflows providing a visual device to support the discussion among production management team members on several aspects: (a) the work pace; (b) the work crews daily location; (c) the interferences between work crews; (d) the time buffers needed between processes; (e) the timing for the beginning and conclusion of each construction process; and (f) the total duration of the project.

Other important information made possible by the LOB was the timing for the conclusion of the external windows in each floor, since that data established the earliest time for beginning the drywall erection. The LOB produced is shown in Figure 4.

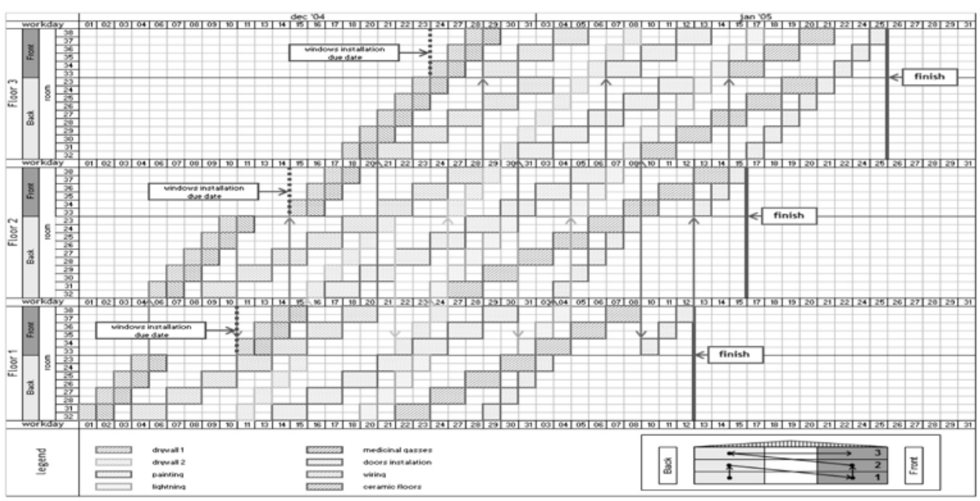


*Figure 4: Project's line of balance*

Some visual tools were devised to represent the LOB data different ways, in order to increase transparency. These tools aimed to make the communication easier between the production manager, subcontractors and the work crews, as well as to control the work crew path and sequence in accordance with the LOB decisions. The first tool was a *workstation map* for each work crew (Figure 5). In that map, the path to be followed by each crew was represented for each floor. All three maps were given to the work crews before the start of the construction process.

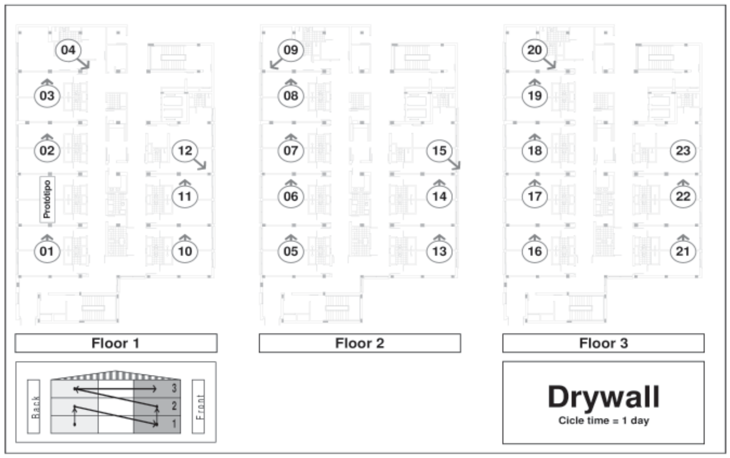


*Figure 5: Workstation map for the drywall erection process*

The second tool used was the *work crew location map*, which indicated the daily location of each work crew, the start and finishing time of each process. A general location map with all processes was given to each sub-contractor enabling them to have a broader view of the interdependences among different crews.

The third tool, the *work path control sheet*, was proposed to improve the control of the crews' workflow. It was placed in the front door of each room, informing directly the work crew about the process sequence, the starting and the finishing due dates and the next room to be installed. Besides informing the finishing due date there was a blank place to be filled out with the real starting and finishing dates by the work crew leader. At the end of the working day, the production manager collected the sheets and updated the short-term plan.

In the *definition of the capacity of production resources*, the fifth step, data from project execution strategy and pre-planned capacity were used to define the capacity of the main production resources. The number of work crews was then established by the production management team, with the participation of the sub-contractors.

The last step, the *identification and design of critical processes*, was not formally undertaken because most of the necessary information about these processes had already been collected from the prototyping exercise.

### Conclusions of Case Study 1

Based in this case study, some conclusions on the adaptation of PSD model for this kind of project were made. Although the prototyping study had initially contributed to decrease the level of uncertainty on the construction methods, several process changes had to be made during the construction phase, mostly due to design changes and late selection of subcontractors. The need for late process changes that the production system design should be able to deal with those uncertainties, being progressively redefined based on the definition the design, and also and supplier's requirements. It is also helpful if client representatives are invited to participate in PSD meetings, so that their new requirements can be properly discussed and they can perceive the impacts of their late decisions in the production system.

Secondly, during the construction phase some subcontractors failed to comply with the agreements made in the PSD meetings, in relation to crew sizes, as well as work paces and work paths to be followed. In dealing with this difficulty, the visual tools devised were applied to help the control of adherence of the construction process to the PSD decisions.

These are the main conclusions of the first case study: (a) it is necessary to explicitly include the capture of the client's requirements as part of the PSD in order to reduce uncertainty; (b) PSD should be produced in stages, starting with a not very detailed plan, concerned with a small number of general decisions related to the overall project, and gradually evolving to a more detailed plan, by adding the production system design of construction phases; and (c) the PSD meetings should emphasize the need of making agreements among suppliers and between suppliers and the production manager to ensure their commitment to the plans.

### Case Study 2 – Industrial Building Construction

The second project consisted of the construction of an industrial building of nearly 3,000 square meters for a steel mill company. The building had a modular pre-cast concrete structure (columns, beams and slabs), brick walls, steel roof structure and aluminium tiles. The building design was being developed by a client's designer simultaneously to its construction, i.e. the design was supplied in small batches while the building was being constructed.

The study started four weeks before the beginning of the production stage, and took four weeks. Over that period, eleven two-hour meetings were held. The project base-unit was defined as one of the twelve building modules. The transfer and production batches were also defined as one module.

The *base-unit installation sequence and the capacity pre-planning* were based on discussions between the production engineer and the general foreman once the construction techniques were already known. Whenever the production engineer needed to obtain more specific information about the assembly and fabrication of the pre-cast concrete structure and about the metallic roof structure, specific meetings were carried out with the suppliers' representatives in order to obtain the necessary information. A resource capacity spreadsheet and a precedence diagram were prepared with the data from those discussions.

The *study of base-unit workflows* was not carried out since the base-unit was relatively simple, and the workflows were easily manageable.

The *definition of project execution strategy* was based on site workflow constraints. Thus, considering that there would be a small working area to erect the steel roof structure, the assembly of the pre-cast concrete structure was defined to be from the right to the left of the building side in order to allow trucks and cranes to move.

The *study of project workflows* was based on the execution strategy and on the installation sequence. The LOB technique (Figure 6) was also used in this study to support the decision making process. However, compared to the previous study, the processes were considered in a more aggregate form, i.e. only the main processes were represented.

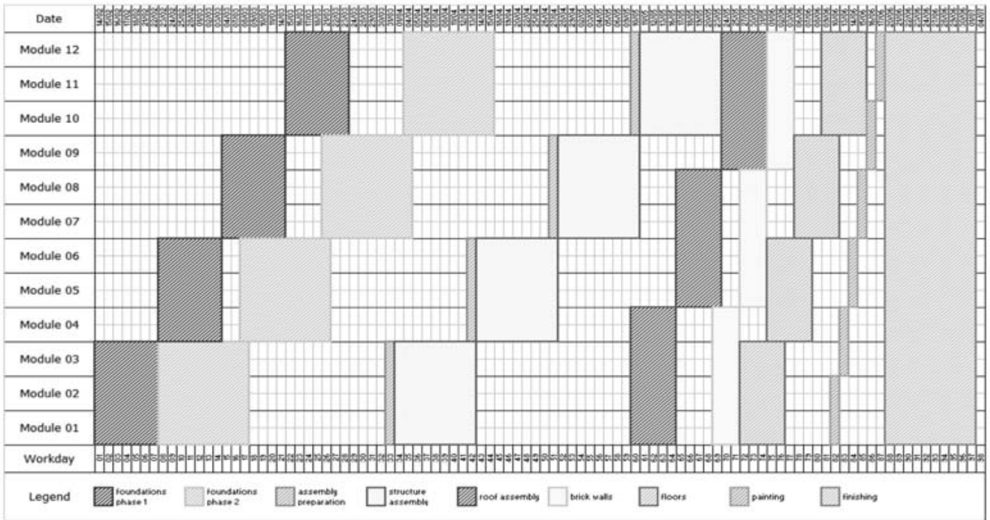


*Figure 6: Project's line of balance*

From the LOB it was possible to check if the completion of the proposed date would match the deadline defined by the client. The due dates for the structure design batches, steel bars supply, concrete structure fabrication and assembly (Figure 7) were also provided by this tool. These dates were defined considering the design, fabrication and assembly lead times.

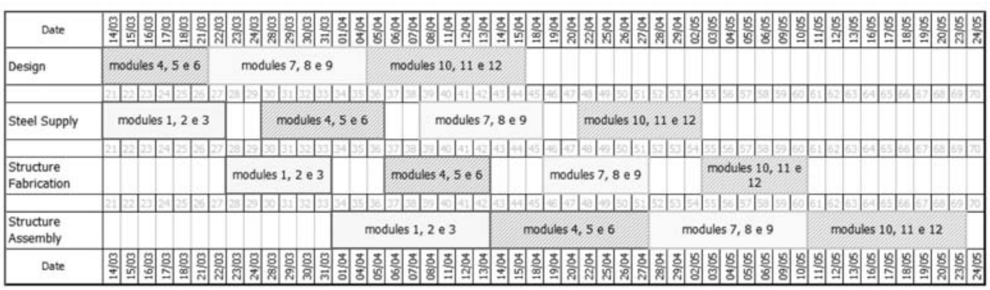


*Figure 7: Design batches due dates*

Comparing the initial long-term plan devised before the PSD, and the one devised from the PSD, the latter was more realistic. In the original long-term plan, some processes had not been properly considered.

Discussions about the definition of production resources capacities were carried out based on the subcontractors' experience, since they were in charge of the majority of the processes.

The concrete pre-cast structure assembly was identified as the critical process. Besides the need of specialised crews, this process provided the necessary conditions for starting other processes.

During the PSD meetings, much attention was given to the production-assembly synchronisation in order to promote a continuous workflow. Based on the execution strategy, a list of the necessary structure parts was prepared and sent to the supplier. Thus the fabrication sequence was established in accordance with the assembly process.

Two weeks before the beginning of the assembly process a First Run Study was carried out, providing an opportunity for furthering discussing the process. The FRS checklist proposed by Howell and Ballard (1999), addressing questions about activity duration, required materials, interferences in the assembly places, site access, work safety, assembly sequence, and buffers was applied to guide these discussions.

During the first assembly cycle the cycle time, sequence, and work paths were monitored in order to be discussed at the following PSD meeting. Although opportunities for assembly lead time reduction were identified during the analysis of the process, they were not adopted to reduce the project duration since the concrete structure supplier delivery time was within the duration established in the contract.

### Conclusions of Case Study 2

In this study the PSD was produced in stages, in accordance with the first case study conclusions. The initial decisions were very broad, becoming more detailed as more information on the project was released. For example, the design of critical processes was produced only two weeks before the start of the construction. Only then, the necessary information for designing that process was sound enough, avoiding further revisions.

Similarly to the first case study, the main difficulties found in this study were related to lack of definition of client requirement. Moreover, the client was in charge of developing some of the designs and also for supplying some materials, such as the steel for the concrete structure and roof structure. During the construction phase the client delayed both the design and the material supply leading to a production stop. The consequences of such delay were made explicit to the client's representatives through the LOB.

Other difficulties were related to some suppliers' commitment to the PSD decisions. Even though the suppliers had participated in all meetings and agreed to follow the decisions made, several changes concerning dates had to be made.

## PRODUCTION SYSTEM DESIGN IN COMPLEX PROJECTS

The findings of the case studies indicated that the PSD model previously proposed for low-income housing projects can easily adapted for complex projects. Three main changes are necessary in that process: (a) the consideration of other inputs to the elaboration process; (b) the progressive elaboration; and (c) the use of tools that support the reduction of the uncertainty level.

The case studies showed that one of the major difficulties in managing complex projects is related to the client's requirements changes, i.e. uncertainty in goals, according to Williams (2002). In both projects the client demanded changes which postponed the decision making, causing disruptions in the production processes. When that occurred, some PSD decisions had to be revised, requiring some additional meetings to make new arrangements. Therefore, capturing the client's requirement should be part of the PSD elaboration. Two mechanisms for capturing such requirements should be considered: (a) overlapping product and production system design, in order to improve client's requirement capture both in terms product and production processes; and (b) inviting the client representatives to participate in the PSD meetings, making them aware of the impact of such changes in the production processes.

An additional difficulty was related to the number of suppliers and subcontractors in the projects, structural complexity (Williams 2002). That demanded considerable efforts to manage them during the PSD as well as during the production stage. The PSD promoted opportunities for the suppliers, subcontractors and production managers to discuss about the features and goals of the project. In the PSD meetings the suppliers and subcontractors could identify interfaces and interdependences between their processes and reach agreements about adequacy of production procedures.

In both studies the PSD decisions were used as an input for the planning and control process. According to the projects' production managers, the long term plans devised from the PSD were more realistic, in contrast with the plans devised before the PSD implementation, since the capacity of key resources and the interdependence between processes were being effectively considered in the plans. Several tools to control the adherence of processes execution to the plans were devised. Besides control and visualisation tools, the two techniques used – prototyping and first run study (FRS) – improved the PSD elaboration.

Prototyping was used in the first case study to improve the understanding the production processes procedures, their execution sequence and lead times, reducing the uncertainty level, both in methods and goals. However, as the client changed his requirements after the production beginning, some information produced by the prototyping study became outdated. This indicates that this tool can be useful for the PSD when the prototype is used to improve and validate the production processes instead of the product design, when a great amount of the client's needs had already been defined.

A first run study (FRS) was carried out in the second case study to improve the pre-cast concrete structure assembly. This tool was useful to reduce the level of uncertainty in methods, detailing the execution procedures and improving them. However, FRS is useful to study and improve each process separately instead of the whole set of processes which form the production system. In that case, a prototyping study could be a more adequate choice.

## CONCLUSIONS

This paper has discussed the role and the contributions of the production system design in the management of complex projects. Based in the findings of the two case studies, it was possible to assess the positive impact of PSD in the management of those projects. PSD contributed to deal with complexity by helping production managers, suppliers and client to discuss and evaluate the production system features, making clearer how the impact of changes in the production processes as well as the client's requirements could affect the production system performance.

The findings indicated that PSD helped to organise and structure the production system by making the production methods and the project goals less uncertain to the participants.

In this kind of project, PSD decisions should be taken in a progressive manner as long as uncertainties, specially the ones related to the product design, have been removed. Consequently, PSD should not be an isolated activity but an ongoing one, from the product design stage up to the construction stage.

Further studies are needed to evaluate the adaptation proposed for the PSD model in complex projects with different features, like larger projects than those studied and projects in which a base-unit (production repetitive unit) cannot be clearly identified.

## ACKNOWLEDGEMENTS

The authors would like to thank CAPES (PQI Programme) and CNPq for the research grants that supported the development of this research study, and also the construction companies that were partners in this study. Special thanks are due to the reviewers of this paper for their opportune commentaries and suggestions.


## REFERENCES


Askin, R. G. and Goldberg, J. B. (2002). *Design and Analysis of Lean Production Systems.* John Wiley.

Baccarini, D. (1996). “The concept of project complexity – a review”. *International Journal of Project Management,* Vol. 14, No. 4, pp. 201-204.

Ballard, G., Koskela, L., Howell, G., and Zabelle, T. (2001). Production System Design in Construction”. Proceedings of the 9th Annual Conference of the International Group for Lean Construction, Singapore.

Beckerman, L. P. (2000). “Application of Complex Systems Science to Systems Engineering”. *Systems Engeneering*, Vol. 3, No. 2.

Beckerman, L. P. (2000). “Application of Complex Systems Science to Systems Engineering”. *Systems Engendering*, Vol. 3, No. 2.

Bertelsen, S. (2003). “Complexity – Construction in a new Perspective”. Proceedings of the 11th Annual Conference of the International Group for Lean Construction, Blacksburg.

Bertelsen, S. and Emmitt, S. (2005). “The Client as a Complex System”. Proceedings of the 13th Annual Conference of the International Group for Lean Construction, Sidney.

Calvano, C. N. and John, P. (2004). “Systems Engineering in an Age of Complexity”. *IEEE Engineering Management Review*, Vol. 32. No 4. pp. 29-38.

Gaither, N. and Frazier, G. (2001). “Production and Operations Management”. Pioneira Thomson Learning. São Paulo.

Gidado, K. I. (1996). “Project Complexity*:* The Focal Point of Constriction Production Planning”. *Construction Management and Economics*, Vol.14, pp. 213-225.

Howell, G. Ballard, G. (1999). “Design of construction operations.” *White Paper* 04. [S.l.]: Lean Construction Institute.

Schramm, F. K., Costa, D. B. and Formoso, C. T. (2004). “The Design of Production System in Low-Income Housing Projects”. Proceedings of the 12th Annual Conference of the International Group for Lean Construction, Helsingor.

Skinner, W. (1985). “Manufacturing, The Formidable Competitive Weapon”. New York: John Wiley & Sons.

Slack, N. Chambers, S., Harland, C., Harrison, A. and Johnston, R. (1997). “Operations Management”. São Paulo: Atlas.

Williams, T. (1999). “The need for new paradigms for complex projects”. International Journal of Project Management Vol. 17, No. 5, pp. 269-273.

Williams, T. (2002). “Modelling Complex Projects”. New York: John Wiley & Sons.