Fazinga, W.R., Saffaro, F.A., Isatto, E.L., and Kremer. A. (2016). "Difficulties in Work Design in the Construction Sector. "In: *Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction*, Boston, MA, USA, sect.6 pp. 13-22. Available at: <www.iglc.net>.

DIFFICULTIES IN WORK DESIGN IN THE CONSTRUCTION SECTOR

Wanessa Roberta Fazinga[1], Fernanda Aranha Saffaro[2], Eduardo Luis Isatto[3], and Alessandro Kremer[4]

ABSTRACT

Work standards are an essential component of lean production systems. The unique and one-of-a-kind nature of construction products adds an additional layer of complexity when designing work standards in such a particular context. This research focuses the process of designing work standards for construction. The purpose was to highlight the difficulties observed when designing the specifications that make up the standard. An in-depth case study was carried out in a company that had been struggling to meet a stable cycle time for the reinforced concrete structure phase of multi-story buildings. An analysis of the current process was undertaken and a literature review of the work standards was conducted in order to identify possible ways to specify the work elements. The study suggests that a large amount of time is spent on the work design owing to (a) the level of uncertainty (lack of productivity data to support the design of the work packages over the cycle time; frequent moving of the workers from one work package to another; lack of resources near the workstation); (b) a project being created very close to the start of the actual production and, therefore, suffering from conditions imposed by the decisions previously taken; and (c) a team of workers unaware of lean concepts.

KEYWORDS

Standard, Work Design, Workflow

INTRODUCTION

Standardized work is one of the main means used by lean systems to reduce variability. It is based on specifying a work routine for workers that allows production within a certain deadline according to the customers demand, and with a low level of inventory (Monden 1997; Productivity Press Development Team 2002). According to Monden (1997), a work standard must specify the desired work rate (by takt time), work in

[1] MSc., Professor, Construction Department, University Campus –Rodovia Celso Garcia Cid (PR 445), Km 380, State University of Londrina, Londrina-PR, ZIP 86051-990, Brazil, 43 371-4455, FAX 43 371-4082, wanessa@uel.br

[2] Dr., Assistant Professor, Construction Department, University Campus –Rodovia Celso Garcia Cid (PR 445), Km 380, State University of Londrina, Londrina-PR, ZIP 86051-990, Brazil, 43 371-4455, FAX 43 371-4082, saffaro@uel.br

[3] Dr., Associate Professor, Building Innovation Research Unit (NORIE), Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, RS, Brazil. isatto@ufrgs.br

[4] MSc., Master of Engineering - Rodovia Celso Garcia Cid (PR 445), Km 380, State University of Londrina, Londrina-PR, ZIP 86051-990, Brazil, 43 371-4455, FAX 43 371-4082, engkremer@gmail.com

progress, and standard operations routine. The purpose is to organize the way workers should act, the sequence in which they must perform their individual operations, the deadlines they must comply with, and how they can identify the occurrence of deviations that may compromise the results of the production line.

The application of the standardized work concept in the construction context presents difficulties due to the low repeatability of the processes and high degree of variability. Mariz, et al. (2012), after an extensive bibliographical research on the standardized work approaches in construction, recognized that there are only isolated and incomplete applications, using only part of the standardized work original elements. Improving the use of work standards requires adaptations to the conceptual elements involved, so that they become applicable in construction. For this purpose, a series of research studies have been developed in the post-graduate program ENGES/UEL[2]. Initially, Saffaro, et al. (2008) identified the conceptual standardization deficiencies in four construction companies. As a result, Fazinga (2012) identified the standard content for the production of reinforced concrete structures, making relevant conceptual adjustments in relation to the standardized work described in the lean context. As the set of standard elements was identified, there remained a gap in the knowledge concerning the specifications of these elements in a real case (work design) and putting them into practice, on a trial basis called First Run Study – FRS, to validate the contents of the standard. The use of FRS as a tool to develop standard work is described in Hackett, et al. (2015) and Martinez, et al. (2015). The purpose of the article herein is to point out the difficulties faced while developing the above-mentioned work design.

STANDARD ADAPTATIONS IN CONSTRUCTION

Improving and measuring the performance of the workflow has been a common subject in studies investigating lean concepts in construction. Kalsaas (2011) points out that the workflow is influenced by the configuration of several other flows, materials, information, people, and equipment, as well as the conditions of the context in which the production develops, such as the work location and site characteristics. Under these conditions, the work design is a means to adequately combine these mutually dependent aspects, in order to improve the production capacity of teams and ensure stability in results. For Nerwall and Abdelhamid (2012), designing the work to be performed by a team involves determining the number of workers, variety of skills, sequence of operations, and their durations. The specifications of these elements are then tested and the rules are gradually refined. Mariz and Picchi (2013) demonstrated the work standard as a result of an evaluation of the actual situation in the construction site and the design of the future status. This evaluation was based on questions about what operations are really necessary, their duration, how they will be distributed among workers, and the resources and equipment involved in the work. These are different but complementary approaches, which exemplify the current concern in assessing processes and operations jointly, and establishing work standards in order to reduce waste and guarantee stability.

In the Brazilian scenario, the studies by Fazinga (2012) and Mariz and Picchi (2013) stand out. These latter authors focused on the execution of mechanized driven foundation piles. Fazinga (2012) focused on the implementation of reinforced concrete structures. In this last research, the contents of the standard were the results of an eight-

[2]ENGES/UEL: Post-graduation Program in Building and Sanitation Engineering (MSc)

month case study on a construction site. The takt time of each structure's floor (resulting from the long-term schedule) and the conditions that limited or impeded the production development (constraints), such as shared resources and definitions of the work in progress were taken as the starting point for the other specifications. Table 1 reports the elements to be specified in a work design and the evidences justifying them, taken from such a case study.

Table 1 - Standard elements in construction (Table 7 in Fazinga 2012)

Elements	Evidence leading to the elements
Work content (Operations)	- Operations described by the engineer were incomplete
	- There was uncertainty about the volume of work in each floor
Sequence for the operations flow	- Complying to the technical sequence inherent to the construction process
Work packages	- Tendency to work on large batches
	- Work not completely finished and variations of runtime operations
Sequence within each package	- Long walks and constant moving of scaffolding
Number of workers in each package	- Constant variations in the size and team configuration
Resources kit of the package	- Leaving the work station in search of resources
	- Receiving damaged and unusable resources
Transport procedures	- Variation between manual and crane transport
	- Workers engaged in unsafe transport or great physical effort
	- Improvisations during transport
Resources storage	- Changes in the storage location, dirty floor, and blocked access
	- Repeated transport of resources to the ground floor
Key points	- Errors, rework, and constant experimentation
Crane operations routine	- Shared use and apparent work overload of the crane
	- Labor force idle waiting for resources or crane support
Production monitoring points	- Lack of data on the team production capacity
	- Long and variable cycle time

An important peculiarity of these specifications is the need to group the production operations in construction, which supports the notes of Kalsaas and BØlviken (2010). These groups were named "work packages", and were assigned to teams with specific skills. Each package maintained an internal flow of processing operations, transportation and inspection, and waiting situations. In addition, various packages were executed simultaneously, in different locations of the construction, and with dependency relationships between them. The completion of a package indicated its delivery to the subsequent team, although on this occasion, there may be delays, overproduction, waiting, rework, movement of workers and transport of resources to start new packages. To structure the workflow in this context is a very complex task. Therefore, in the content of Fazinga (2012), specifications were included with the purpose of maintaining adequate availability of resources (kits, transport, and storage procedures on the working area), mitigating the effects of shared resources (crane routine), and enabling constant control on the production evolution (monitoring points).

The results of Fazinga (2012) encouraged the continuation of the research on other construction sites of the same town (Londrina, Paraná, Brazil) and same construction company. The advancement refers to the studies of Kremer (2016), showing the difficulties faced in order to structure a work design, i.e. specifying the set of elements, which after tested and adjusted, could become a standard for production.

METHOD

The research strategy adopted was the case study (Yin 1989). Two construction sites were chosen for the work design: both buildings had approximately 22 floors, and the same construction process. Researchers, based on the standard content presented by Fazinga (2012), drew up an action strategy to formulate the work design, as shown in Figure 1.

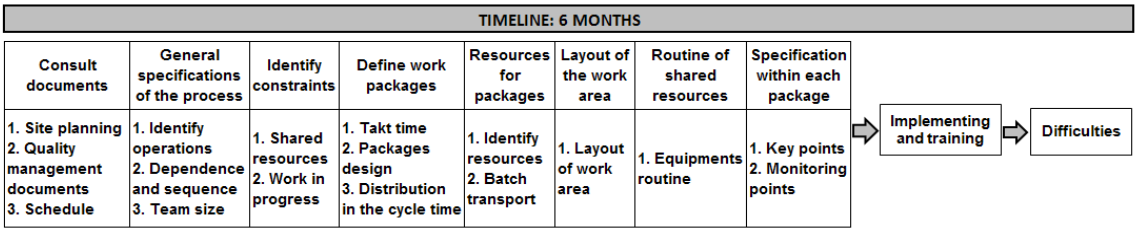

Figure 1- Timeline for the elaboration of the production design

After the analysis of the documents, there was a daily intense observation of one cycle of the production process (third floor of the site 1). The aim of this period of observation was to understand the context (construction system, how to specify the elements proposed by Fazinga). These data resulted a work design that was not implemented because the activity was too far advanced to interfere in the production process. Once the construction system of the both sites was the same, the outcomes of the case study 1 (site 1) supported the elaboration of the work design in the case study 2 (site 2). The collected data (site 1) were discussed in meetings with the engineers of construction site, foremen, and workers team leaders in order to define the specifications (site 2). When the elaboration of the work design started the activity (reinforced concrete structure) was not yet in execution. After the work design was completed, there was a training session for the full team of workers in a classroom with projection of 3D images, including the work packages that should be carried out every day and other specifications of work design. After the training session, there was a period of observation on site, to test the production process and check the relevance of the specifications. The case study 2 lasts 4 months and after this there was a conceptual reflection based on the literature to highlight the difficulties encountered in preparing the design. The detailed work design can be found in Kremer (2016).

CASE STUDIES

Before reporting the results of the studies, it is necessary to present a brief characterization of the construction process, similar to both construction sites. The slabs were of the ribbed type with a metal shoring system on which a floor of wooden plates was laid. Crane equipment for vertical and horizontal transport was available to production. The beams were prefabricated in a central on site. The size and weight of the columns' formwork required crane support for movement and positioning. Each slab for a floor was divided into two stages of implementation, named phase "A" and "B", as shown in Figure 2, with the purpose of reducing the size of the production lot. The teams of workers were divided between the phases of the slab, working in parallel, although always starting phase "B" a few days later, so that some materials could be shared. That is, while one stage was dedicated to work on columns and beams, the other phase was assembling the slab.

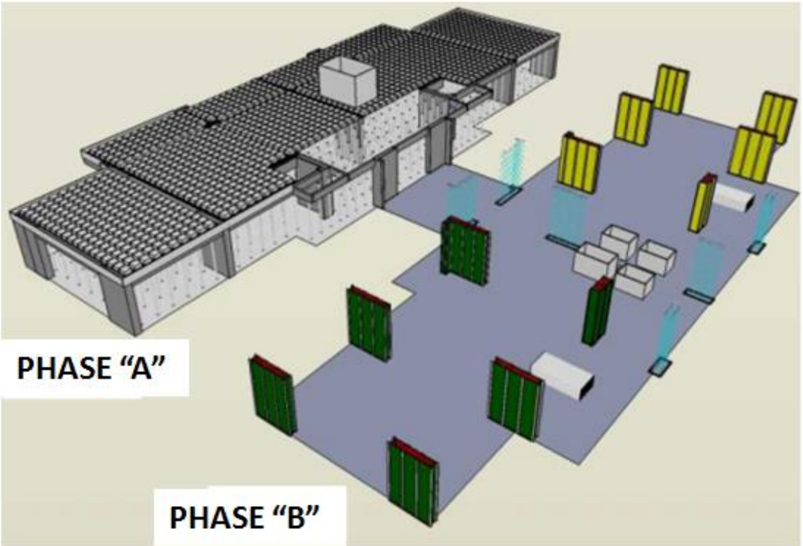

Figure 2 - Representation of the floor and its respective phases of execution.

An initial period of observations on site was held in order to be better acquainted with the construction system and the design of operations flow. Additionally, the observation was held to detect situations that would characterize the occurrence of variability. These situations include frequent changes in the number of workers, constant interruptions in the production, lack of materials, and a strong dependence on crane support without a coherent synchronization of its use between the two stages of the slab. At the stage where the columns and beams positioning were made, the crane was necessary for both the transport of resources to the floor, and to perform the assembly operations of the steel, formworks, and beams. On the other hand, during the slab production, the crane provided resources only, and the operations could be performed manually by the workers. The design of the operations flow of the floor in observation, shown in Figure 3, was too dependent on the site observations, since the engineers did not describe in detail the construction process.

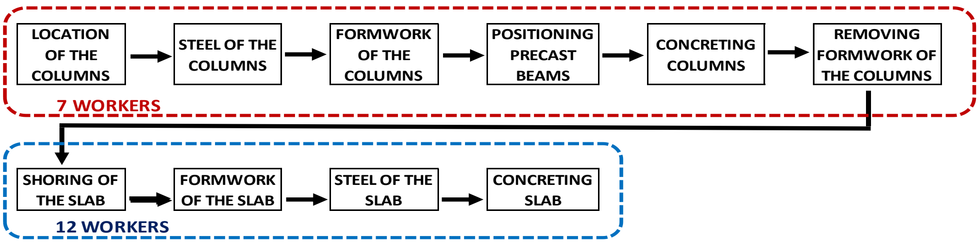

Figure 3 - Flow of operations for the structure floor

In the constraints analysis, a debate took place on the real need for the crane equipment to assist the beams production centre in the construction site. Since the location of the beams production centre in the site restricted the access for the concrete trucks, the participation of the crane in the beams concreting, removing them from the moulds and transferring them to the storage position, had to be maintained. On such occasions, the production in the floors should only contain operations performed manually, restricting the work packages on these days.

The sizing of the work packages was constrained by the takt time. For the first case study, the takt time was 12 days per floor. The engineer decided to structure the work design for a cycle time of 10 days, adopting a buffer of time. On the second case study, the takt time was 8 days and the work design provided a cycle time of 7 days. From then on, the definition of work packages to be executed every day in each of the phases, A and B, was based on the technique outlined in Figure 3 and the identified constraints. The company had no formal and historical data about the teams' productivity, and the duration of the operations was not measured in this study. Therefore, the packages were formatted based only on the experience of the team leaders. They pointed out milestone dates in the evolution of the production (taking as example the first case study) as follows: a) packages related to the columns and beams should finish at the end of the 4th day of the cycle; b) formworks and slab shoring should finish by the end of the 7th day; c) steel of the slab by the end of the 9th day; d) slab concreting should take place on the 10th day, closing the cycle. During the meetings to define these specifications, it was noticeable that the team leaders were concerned about interrupting their activities on site by participating in the meetings, claiming that their role was only to fulfil what had been decided. Only after a few meetings, they began to register their objections.

The researchers encouraged the reduction of production batches formatting small packages, although the team leaders showed difficulties in understanding this principle and favoured, for example, a single concreting for all the columns on each stage of the slab. For mounting the shoring and slab floor, the sectoring of the floor was determined by common consent, i.e., the delimitation of stretches to be executed, one by one, until the total area was completed. It was intended that when the carpenters move on to the second stretch of slab, steel benders could immediately start the first stretch. However, the steel benders' leader was strongly against this kind of operation and virtually demanded that the whole formwork of the slab was finished to start the placement of the steel. The final decision was that shoring and formwork would remain segmented into smaller packages, although the steel would only start when the whole area was ready.

After the definition of the packages, a survey took place on the resources necessary for the execution of each one in order to form resources kits to be transported with the crane. This calculation used the structural design and the observations on the use of resources in the floor, requiring a large amount of time and resulting in a fairly large number of information. However, investigations gathered from the team of workers on the transport of kits revealed some drawbacks, such as, some kits had many items and it was not possible to transport them all at once; others were too small and it seemed incoherent to use the crane only for them; at the start of every package there was a need to separate and count the resources to create the kits and, finally, if there were any adjustments and changes in the packages during the production, all the task for specifying the kits would have to be carried out again. On the other hand, it was thought more appropriate to define transport batches of the same material, and no longer depend on the type of package. In the second case study, only the means of transport (metal boxes of varying sizes) that would be used to supply workstations were defined, in order to make the crane lifting easier. Each box would accommodate resources up to the maximum capacity, and this amount could supply more than one work package.

The amount of resources on the floor had influence on the duration of the packages, as often materials were deposited in places that would disturb the execution of the operations, or that required constant displacements in order to use them. The specification to ease these problems was the design of a storage layout on the floor area. In the second case study, as the dimensions of the transport boxes were known, it was easier to define the layout. However, even so, in both cases it was lengthy specifications with many changes, and full of uncertainties for decision-making. When the layout was finished, the difficulty was then to determine a means to document it for the crane operator to be able to follow the rules. The first attempt produced 14 A3 pages, which is a not suitable option to be used by the operator. After that, 3D drawings were made showing the floor with the representation of the day packages and the transport means positioned on the slab, similar to Figure 2.

The next step was the attempt to specify a routine for the crane operations according to their relevance in the evolution of production. However, there were no parameters for decision-making, as the necessary times to perform the transports were unknown and there was no formal scheduling for the days when the crane was needed at the beams production centre. There were occasions when it was necessary to decide which operation should be carried out first, either the resources supply on phase A or the packages support on phase B; additionally, there was also no defined criteria established for that. Therefore, the routine specifications were abandoned. It was considered that if the operator would follow the storage layout and support to the packages established daily, he would be, indirectly, following a systematized routine on each cycle.

To finalize the work design, specifications relative to the internal operations flow for each work package were missing. The first decision was to define in which sequence each element of the package should be executed; as for instance, by which sequence should the steel or formwork of several columns be assembled. Researchers thought that the sequence would help to reduce the work force displacements and give priority to the work completion in smaller batches. However, the engineer of the first case study was against the specification of the sequence, arguing that it would be a strict rule, making the workers 'operation more difficult. On the second case study, the sequence definition was accepted for the columns related packages only.

There were no investigations on key-points. There remained the definitions on the monitoring points to help the team keeping control on compliance with the takt time. As there was no data for the duration of each package, it was assigned to a work shift (morning or afternoon). In this case, the completion of packages on time should represent a reference to monitor the production speed. Additionally, there were key dates for partial completion along the cycle.

WORK DESIGN TEST

When the work design was completed, one of the researchers provided one day training to the workers team. Another observation period of the construction site was then started to check the relevance of the specifications. There was an initial interest from the workers in checking the specifications of the work design. On several later occasions, the specifications was not followed, with changes mainly in the size of the packages defined, as the workers tended to perform the same operation for the whole floor, instead of focusing on smaller batches as had been defined. One of the main reasons for the lack of adherence in two case studies was the poor involvement of the engineers in the work design implementation. There was an overload of work on the crane and a high number of requests for transport out of the floor, which affected the supplying process and caused waiting periods for the workers. The specifications of the storage layout were not followed by the crane operator, who stated that he was confused in relation to the documents. Regarding the use of transport means, workers related ergonomic unfavourable conditions during loading and unloading of materials, although they reacted positively in relation to the larger quantities of resources transported on each lifting.

Concerning the packages executed, approximately 43% had longer durations (work shift) than those foreseen in the project. However, there was not a single day during the observation period in which the team was complete, due to workers absenteeism. The key date for concreting the columns was accomplished in 60% of the cycles, while the key date for the slab concreting was never fulfilled.

CONCLUSION

In view of the objectives of this article, we should point out the difficulties encountered in drawing up the work design for concrete structures:

a) Limited contribution from engineers. The specification of operations required observations of the first completed cycles to obtain information. Additionally, there was no effective incentive of the engineers in the work design test. This situation caused the FRS abortion.

b) Strategic decisions for the construction site were already taken, imposing constrains on the floor’s workflow.

c) Workers team unaware of lean concepts and standards contents, and only modestly participating in the decisions.

d) Difficulties in applying the concept of small-batches production due to the lack of understanding of this concept by engineers and team leaders.

e) Lack of data on the production capacity of the teams to assist in the sizing of work packages.

f) Underutilisation of crane capacity causes overload in the use of this equipment imposing difficulties to establish a routine.

g) Difficulty in organizing the supply of material resources, without ever reaching a specification truly capable of supplying the floor in due time and quantity.

In addition, while using the work design, 43% of the packages had duration longer than expected. However, the results do not lead to the conclusion that the cause was the wrong sizing of packages (durations estimated by the experience of the leaders) or was a consequence of changes in the team size during the execution.

Another difficulty appeared when the set cycle time had an odd number, of 7 days. The floor area was divided into two nearly equal parts, having very similar work volume, however, one of the parts had to be completed with one day less of work.

The preparation of the work design took months, requiring observations and various meetings, which means that the first floors were completed without providing workers with clear rules. After this initial period it became more difficult to intervene and change the working method.

The construction site had many unstable conditions that hindered the inclusion of a standard. The number of workers in teams never remained constant, and the supply of materials depending on the crane did not have an organized schedule of arrival. Additionally, the concreting of beams in the production centre was not following a formal schedule. The workers were not encouraged to understand the benefits of working in a standardized way, nor were satisfactorily informed on the concepts involved in standardization.

It is not possible to consider that the work design developed was solved in such a way as to become a standard for production, requiring further investigation and refinement of specifications. It is important to deepen studies on organization, transport, and storage of materials on the work area, since the work design failed to stabilize the supply of resources. A deeper insight would also be valid on how to specify operations routine for the crane, as there is an extensive reliance on this equipment on the floors and this research has not made progress on this specification. The difficulties faced during work design development in this study must be considered in further researches in order to propose a model to conceptualise the work design. This could help to speed up the process of specifying the work design and the standard work improvement.

REFERENCES

Fazinga, W.R. (2012). *Particularidades da construção civil para implantação do trabalho padronizado* [*Peculiarities for implementing the standardized work in construction*]. MSc Dissertation. Programa de Pós-Graduação em Engenharia de Edificações e Saneamento. Universidade Estadual de Londrina. Londrina. Brazil. (in Portuguese).

Hackett, V., Pasquire, C., Stratton, R. and Knight, R. (2015). "The use of First Run Study to develop standard work in liquefied natural gas plant refurbishment." *Proc of the 23th Annual Conference of the International Group for Lean Construction.* Perth, Australia.

Kalsaas, B.T. (2011). "On the discourse of measuring work flow efficiency in construction: A detailed work sampling method." *Proc. of the 19t Annual Conference of the International Group for Lean Construction*. Lima, Peru.

Kalsaas, B.T. and Bolviken, T. (2010), "The flow of work in construction: A conceptual discussion." *Proc of the 18th Annual Conference of the International Group for Lean Construction.* Haifa, Israel.

Kremer, A. (2016). *Diretrizes para elaboração do projeto da produção para atividades da construção civil* [*Guidelines for elaboration of the work design for construction*]. MSc Dissertation. Programa de Pós-Graduação em Engenharia de Edificações e Saneamento. Universidade Estadual de Londrina. Londrina. Brazil. (In Portuguese).

Mariz, R.N. and Picchi, F.A. (2013). "Application of standardized work in Franki piles concrete work." *Proc. of the 21st Annual Conference of the International Group for Lean Construction.* Fortaleza, Brazil.

Mariz, R.N., Picchi, F.A., Granja, A.D. and Melo, R.S.S.D. (2012), "A review of the standardized work application in construction." *Proc. of the 20th Annual Conference of the International Group for Lean Construction.* San Diego, USA.

Martinez, E.H., Alvear, A.M, Tommelein, I.D. and Ballard, G. (2015). "Formwork standardisation and production flow: Lessons learned from an affordable housing project in Ecuador." *Proc of the 23th Annual Conference of the International Group for Lean Construction.* Perth, Australia.

Monden, Y. (1997).Toyota production system: an integrated approach to just-in-time. 3ed. Industrial Engineering and Management Press, Norcross, GA.

Nerwal, N. and Abdelhamid, T. (2012). "Construction crew design guidelines: a lean approach." *Proc. of the 20th Annual Conference of the International Group for Lean Construction.* San Diego, USA.

Productivity Press Development Team. (2003). Standard work for the shopfloor. Productivity Press, New York.

Saffaro, F.A.; Silva, A. C. and Hirota, E.H. (2008). "Um diagnóstico da padronização em canteiro de obras: estudo de caso em empresas de Londrina/PR [A diagnosis of the standardisation process on site: a case study in companies at Londrina/PR]". *Proc of the XII Encontro Nacional de Tecnologia do Ambiente Construído*. Fortaleza. Ceará.

Yin, R. 1989. Case study research: Design and methods. SAGE publications, Newbury Park.