CONCEPTS AND METHODS FOR MEASURING FLOWS AND ASSOCIATED WASTES

Cristina Pérez[1], Dayana Costa[2] and Jardel Gonçalves[3]

ABSTRACT

This paper is based on the operationalization of flows and identification of wastes along these flows. Ideas are derived from this article for why and how to measure the flows in order to minimize wastes.

The aim of this paper is to present the different existing flow concepts, as well as the characteristics, principles and preconditions proposed by the Lean authors for the sound process. For that, concepts of flow in the construction management field, from logistic and lean perspective, are presented in order to identify core principles which support the measurement of the flow and its potential wastes. In addition, three methods for the measurement of the flows are described.

The present paper contributes with a better understanding of the nature of flow, and in particular, the process flow, the workflow and the physical flows, and their measurement.

KEY WORDS

Flows, measurement, wastes, lean construction.

INTRODUCTION

Of the 207 papers submitted to IGLC until 2001, 99 mentioned the term flow. This is almost half of the total amount of papers, which means that researchers on Lean Construction are concerned with the concept of flow, although sometimes it is misunderstood (Kramer et al. 2012).

Another point is the widespread use of the term of flow in production and logistics, that seems a good reason to invest effort in unpacking an appropriate concrete meaning of the term as it relates to the thinking surrounding construction industry production and daily operations (Kalsaas and Bølviken 2010).

Methods and practices based on the flow concept have become common, especially in the last years; however, the concept itself has not generally been acknowledged (Koskela 2000). Additionally, after reading the literature, it was observed that the concept of flow is still unclear and imprecise; moreover, there are only a few effective methods to measure it.

Therefore, the aim of this paper is to present an overview on previous studies that discuss the concept of flow from different perspectives in the construction industry,

[1] Post graduation Student of the Program in Environmental Urban Engineering, Federal University of Bahia, Brazil, Phone +55 (71) 9709-1564, cristina.toca.perez@hotmail.es

[2] Assistant Professor, Engineering School, Department of Structural and Construction Engineering, Master of Environmental Urban Engineering, Federal University of Bahia, dayanabcosta@ufba.br

[3] Assistant Professor, Engineering School, Department of Structural and Construction Engineering, Master of Environmental Urban Engineering, Federal University of Bahia, jardelpg@ufba.br

aiming to identify the better concept suitable for the goal of this research and also to identify different existing methods that are able to measure wastes along the flows.

For that, an extensive literature review concerning the concept of flows and methods for the measurement of them were carried out, including papers from IGLC conferences and journal papers, such as Journal of Management in Engineering, Journal of Construction Engineering and Management, Engineering, Construction and Architectural Management and Journal of Quality in Maintenance Engineering. This investigation is the first step of a Master's dissertation research which aims to measure transportation wastes along the physical flows.

GENERAL VIEW OF TERM FLOW

This item presents the concept of flow in the construction management field from the logistic and lean perspective in order to identify core principles which support the measurement of the flow and its potential wastes.

LOGISTIC VIEW OF THE TERM FLOW

The logistics business has been gaining attention in the research groups of construction that have adopted lean construction as the new production philosophy (Cruz 2002).

According to Ballou (1999), business logistics deals with all handling and storage activities that facilitate the flow of products from the point of raw material purchase to the point of final consumption, as well as the information flows that place products in motion, with the purpose of providing adequate levels of service to customers at a reasonable cost.

According to Bowersox and Closs (1996), the logistics management term most widely accepted by logistics professionals, includes the design and administration of the material flow control systems, products, processes and finished product inventories to support the company's competitive strategy. The overall goal of logistics is the balance between the level of service desired by the customer and the aim to lower total costs.

In this manner, there are three types of flows: (a) material flow, (b) information flow and (c) financial flow. Systemic management of these flows and the company's activities linked to them are actions that add value to the final product. These three flows are presented briefly below (Bowersox and Closs 1996):

- **Material flow**: the operational management of logistics is concerned with the movement and storage of materials and finished products. Logistical operations start with the initial shipment of materials or components from the supplier and end when a finished product or a semi-manufactured product is delivered to a customer. To better understand the material flow, it is divided into three areas: physical distribution, production and supplies.
- **The information flow**: identifies and specifies different requirements in a logistics system. The main objective of the development and specification of requirements is to plan and execute the operations of integrated logistics. The flow of information runs from parallel to the existing material flow from the supply order through production, and encompassing the physical distribution of the product.

- **Financial flow:** the key to managing the logistic's system is the analysis of the total cost; in other words, at a given level of customer service, management must minimize the total logistical cost and not try to minimize the cost of individual activities. The managing of the financial flow should monitor and support the decision-making involving costs related to logistics activities of the company or of a particular contract. Figure 1 illustrates the logistic flows presented above.

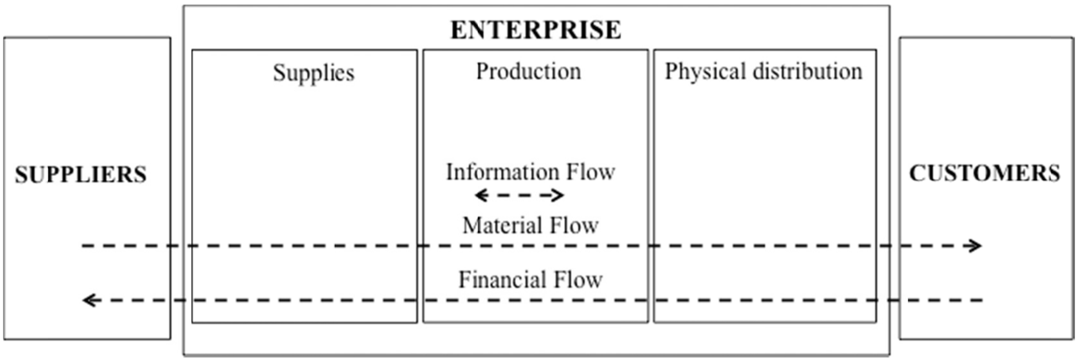

Figure 1: Logistic Flows. Source: Cruz and Taboada Rodrigues (1998)

The objective of the logistics system at the construction site can be summarized as follows: to achieve the greatest and most convenient level of service to external customers (consumers) and internal customers (business and workers involved), whereas the lowest total costs and the trade offs (Cruz 2002).

Therefore, according to Cruz (2002) the material flow (logistics management), by itself, does not add value to external or internal customers, but proper management of the material flow does add value. The proper logistics management will provide the right products, in the right places, at the right time.

In the logistics management, some methods to measure how the flows are running can be used, such as: the work sampling recommended by Barnes (1977) or the application of the time study. In the second method, the really important aspect is in which activity of the construction process the worker is working within 30 minutes ofthe observation.

The development of indicators to assess the set of component activities is also critical to the successful planning, implementation and control of the logistic's system. The information provided by indicators will support the decision making process at the managerial level. Some of these indicators should reflect productivity levels of labor-work linked to internal logistics at construction sites, such as Productivity (total men hours per unit produced) or (money per unit produced).

Lean View of The Term Flow

In Lean Production, Shingo (1985) understands the term flow as a chain of events, distinguishing processes and operations. For this author, **process** refers to the flow of products from one worker to another, that is, the stages through which raw materials gradually move to become finished products; and **operation** refers to the discrete stage at which a worker may work on different products, i.e. a human temporal and spatial flow that consistently centers on the worker. Shingo (1988) argues that the process should take priority over the operation, and this analysis has been followed by most Lean theorists.

Thus, the most important principle for Shingo (1985) is the elimination of the waste, and this is possible through the measurement of the non-value-adding activities. One of the main wastes is generated by the non-value-adding time. For example, lead time refers to the time required for a particular piece of material to traverse the flow. On the other hand, cycle time can be represented as the sum of processing time, inspection time, wait time and move time.

Shingo (1985) defines the flow process and operational flow as consisting of processing (direct work), waiting/delay, movement/transport, and inspection. This subdivision is probably appropriate for manufacturing, which is Shingo's main focus area. However, in the construction context, Kalsaas (2013) found these categories to be too narrow, as the workmen in the building and construction industry perform a wide selection of tasks that cannot be fitted into Shingo's taxonomy.

From the study of the concepts and principles within the theory of Lean Construction by Koskela (1992), it is possible to note the importance of flows in order to control and improve the enterprise. Through the management of flows it is possible to eliminate or reduce losses in connection therewith (Koskela 1992). But, to achieve such disposal reduction, it has become necessary to make the processes directly observable, and expose their limitations and problems so they can be identified and resolved. Thus, the principle of transparency is to give visibility to production (Koskela 1992). In the flow view, the basic thrust is to eliminate waste from flow processes.

Some of these flows are easily identified, such as material flow, while others are immaterial flows, such as flow of information, crew, space and external conditions. However, all are required for the soundness of the process (Bertelsen et al. 2006).

Kalsaas and Bolviken (2010) also defined flow according to Oxford Advanced Learner's Dictionary (1995) in order to understand the real meaning of the term. For the dictionary, "to flow" means to "move freely and continuously" and "flow" is "the flowing movement / continuous stream of something". Using this definition of flow, it makes sense to ask whether the production has flow, whether the flow is good, etc. this is the way the term has been used in many Lean Construction-based discussions on "How to improve work flow". Used this way, the flow term is not necessarily very precise, but is has some important intuitive qualities that have made it popular among both practitioners and academics, such as a chain of events (sequence), continuous movement, moving freely, and adding value.

To be able to understand the term flow in construction, Koskela (2000) defined six principles that should be pursued to achieve the flow, as the following: (a) reduce the share of non-value-adding activities; (b) reduce lead time; (c) reduce variability; (d) simplify by minimizing the number of steps, parts and linkages; (e) increase flexibility; and (f) increase transparency.

Koskela (2000) also identifies seven preconditions for the sound process, such as: (a) construction design, (b) components and materials, (c) workers, (d) equipment, (e) space; (f) connecting works and (g) external conditions.

Koskela (2000) meant by waiting time, this time for the inspection and handling. This author defends time as the only unit to measure the flow, whereas the best alternative is to measure the costs and quality. Koskela (2000) also presents **three type of flows which identifies: (a) materials; (b) location and (c) assembly.**

Ballard et al. (2002) present a more general **three flow model** based on the **nature of the flows**: **(a) directives; (b) prerequisite work and (c) resources**.

Alves (2000) defined **physical flows** as flows of materials and labor within the production environment, in order to differentiate them from the flow of information. So, for that author, management of physical flows is understood as the planning and control of these flows associated with the production tasks.

For Bertelsen et al. (2006) there are physical flows in the traditional sense, comprising the flow of materials and equipment, but there are also the flow of information, staff, space and external conditions (time, approvals managers, etc). The sum of all types of flows formed the theory of **Construction Physics** (Bertelsen et al. 2006), which is based on understanding the **nature of the flows and their interactions in the construction process**. Construction Physics deals with the flow of all the prerequisites that make the process flow, based on the theory of the Transformation-Flow-Value (TFV).

Thus, Bertelsen et al. (2006) aim to identify and act in the flow, or combination of flows, which contain slow rates of productivity, discontinuity, constraints, and bottlenecks for the whole process: flows that they call the Critical Flow. Construction Physics has the construction process as its focus point and construction is not understood as a chain of discrete activities;

Construction Physics has one basis in queuing theory and is thus inspired by Factory Physics (Hopp and Spearman 2001). The doctrine of Factory Physics contends that by means of queuing theory, various insights, which have been used as heuristics in the framework of JIT, can be mathematically proven.

Bolviken and Kalsaas (2011) focus their research on the measurement of workflow and not from any other flow in construction (such as the flow of information, flow of materials, work in progress, etc.). Workflow is defined as the transportation of materials and information through network units, each of which processes before releasing the product to the succession activity (The Lean Construction Institute 1999). Thus, Bolviken and Kalsaas (2011) focus on the study of the term workflow which is part of operational flow.

Discussion of Flow Concepts

The first point for discussion is the main goal of the measurement of flow from logistic and lean perspective. Whereas the logistics management is focused on the cost reduction, the lean philosophy aims for the reduction and, if possible, the elimination of losses, which in consequence will allow cost reduction. This is not, however, the primary objective of the Lean philosophy.

The rating flows from the logistics perspective are similar to rating performed from the Lean point of view, due to the fact that the two philosophies differentiate between material flows and information flows, in a addition to the financial flows presented by the logistic view, and the labor flow submitted by the Lean philosophy.

On the other hand, although the term flow in construction has been studied by many authors over the last two decades (Koskela 2000, Alves 2000, Ballard et. al. 2002, Bertelsen et al. 2006, Kalsaas and Bolviken 2010, Kalsaas 2012;2013), there is still a lack of a common understanding about the concept. In order to simplify all the concepts of flow previously mentioned, Figure 2 presents all the overlays about the term flow according to the different authors.

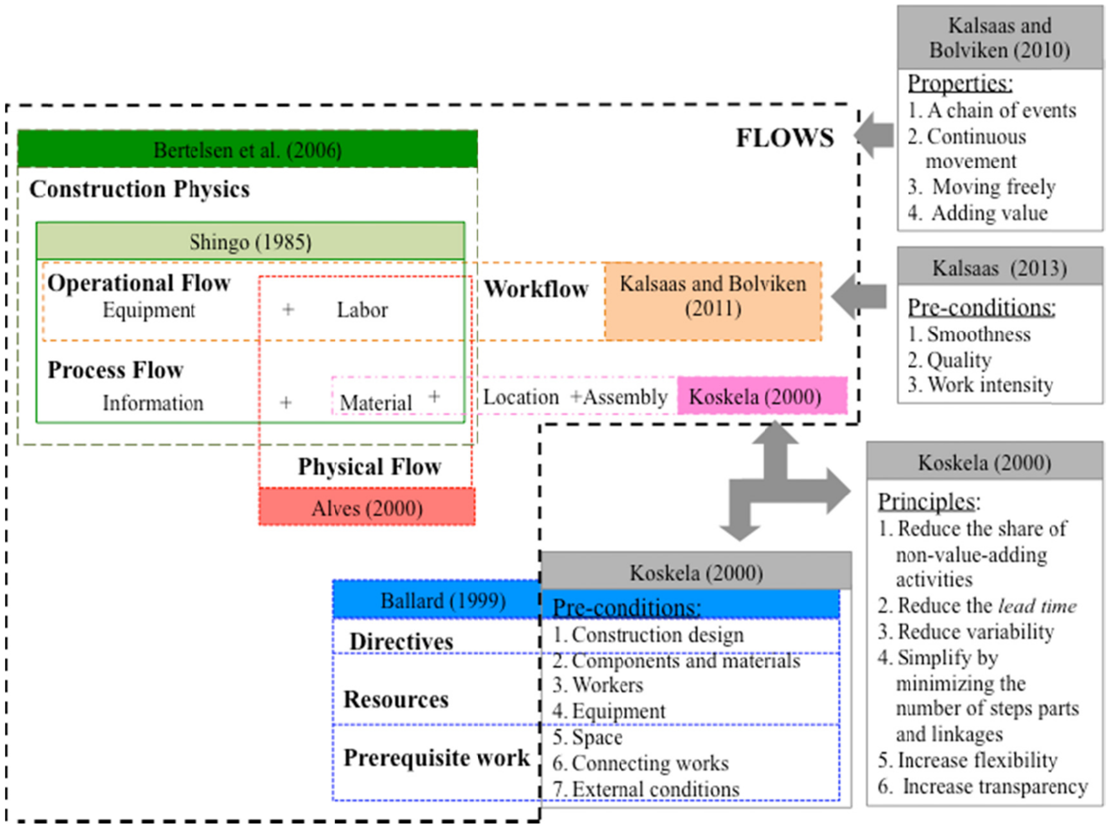

Figure 2 – Summary of the different flow concepts

The first classification by Shingo (1985) divided the **flows into processes and operations**. The first one is formed by the information flow as well as the material flows, and the second type of flow consists of equipment and labor flows. Construction Physics (Bertelsen et al. 2006) looks at the interaction between the flows and all the flows proposed by Shingo (1985). The Operational Flow proposed by Shingo (1985) is tied to Kalsaas and Bølviken (2010) and Kalsaas (2012, 2013) as **workflow.** For Kalsaas (2013) three preconditions are necessary for the sound process of workflow, which are: smoothness, quality and work intensity. Koskela (2000) also presents three types of flow models which identify: materials, location (space) and assembly (previous work). While for Alves (2000), physical flows are the flows of materials and labor.

Figure 2 also shows that Koskela (2000) identifies seven types of preconditions for the sound process and six principles that should be pursued to achieve the flow. Kalsaas and Bolviken (2010) present four properties that the flow should have, such as: a chain of events (sequence), continuous movement, moving freely, and adding value.

For the present authors the three flows, based on nature, proposed by Ballard (1999) are not flows in themselves, since those flows match with the seven preconditions proposed by Koskela (2000). The directives flow will be equivalent to the precondition construction design; the resources flow will be equivalent to the preconditions components and material, workers and equipment and the flow of prerequisite work will be the preconditions space, connecting work and external condition.

Thus, all the flows presented above can be summarized in three flows: (1) **process flow:** formed by the flow of material and information, (2) **operational flow or workflow**: formed by the flows of the equipment and the flows of the labor and (3) **physical flow:** flows of material and labor.

METHOD FOR THE MEASUREMNT OF FLOW

From the aforementioned discussion, it can be observed that the existence of three different flows, therefore, depends on the type of flow that we want to measure. There are different methods and tools to be used. Therefore, despite the large amount of methods for measuring the flow, this paper presents a method for each type of flow identified, that were chosen because they are the most effective for the authors.

MEASURING PROCESS FLOW (1)

Within the production flow, the movement of material is the flow that usually comes to mind. There is, however, another flow, that of information, which tells each process what to make or do next (Rother and Shook 1999). At Toyota, it is known as "material and information flow mapping".

Value-stream mapping (VSM) is a pencil and paper tool that helps to see and understand the flow of material and information as a product makes its way through the value stream. According to Rother and Shook (1999) the main purpose of VSM is to identify the occurrence of waste and try to eliminate them through a project of the production system, or a future state of the system, in which the continuous flow and pull production are adopted.

As the focus of the value stream includes the complete value adding (and non-value adding) process, from conception of requirement, back through to the raw material source and back again to the consumer's receipt of the product, there is a clear need to extend this internal waste removal from the complete supply chain (Hines and Rich 1997)

The MFV works as a photography, illustrating how inventories, demand, cycle time, takt time, among other variables find themselves at that moment. Thus, it should be redrawn at different times in order to reveal new opportunities for improvement (Rother and Shook 1999).

Drawing the Map Value Stream should be made simple, using a standardized set of symbols or icons, which were proposed by Rother and Shook (1999).The first step is to choose a particular product or product family as the target for improvement. The next step is to draw a current state map that is essentially a snapshot capturing how things are currently being done. This is accomplished while walking along the actual process, and provides one with a basis for analyzing the system and identifying its weaknesses. The third step in VSM is to create the future state map, which is a picture of how the system should look after the inefficiencies in it have been removed. Creating a future state map is done by addressing a set of questions on issues related to efficiency, and on technical implementation related to the use of lean tools. This map then becomes the basis for making the necessary changes to the system Rother and Shook (1999).

MEASURING WORKFLOW (2)

Bolviken and Kalsaas (2011) believe that it is necessary to measure workflow as directly as possible. The measurement however, of indicators, or a combination of direct and indirect measurements, is a possible solution. Furthermore, it is possible to distinguish between different methods of measurement based on whether they involve self-assessment, a more subjective manner, or observations of others, of a more neutral way. Both types of approaches have advantages and disadvantages.

In this way, Bolviken and Kalsaas (2011) present ten strategies for measuring workflow, three of which involve self-assessment and the other seven involve the observation of others.

The self-assessment measurement strategies presented by Bolviken and Kalsaas (2011) are: (1) the actors' perception of work stoppages (extent and causes); (2) the actors' perception of the degree of workflow and (3) the actors' perception of the distribution between flow, making do, and stoppages.

The third-party observation measurement strategies are: (1) percentage of Plan Completed (PPC); (2) actual time used compared to estimate; (3) perfect person-to-person handover of work; (4) perfect handover of work between trades; (5) detailed breakdown of planned activities and individual studies of time use (work sampling); (6) piece-work earnings and (7) turnover per person per time unit.

Kalsaas (2012 and 2013) shows the importance of developing tools to assess how projects are running from introducing some new ideas, such as the term **Overall Equipment Effectiveness** (OEE). O OEE identifies efficiency wastes caused by activities that absorb resources without adding value, based on continuity, quality and intensity of work (Jeong and Phillips 2001).

OEE is a method to measure productivity of industrial production. It has also been proposed as an aid to achieve a production with zero losses. The objective of OEE is to identify the losses, which can be defined as activities that absorb resources but create no value. It is essentially a bottom-up approach where an integrated workforce strives to achieve OEE by eliminating the six big losses (Nakajima 1988).

Nakajima (1988) identified and classified what he regarded as the most important causes of loss of efficiency of the equipment; it took as its starting point three dimensions of efficiency, in other words, the availability (A), performance (P) and quality (Q). This author classified six types of losses in these three dimensions: (1) downtime losses (**breakdown losses** and **set-up and adjustment losses**, (2) speed losses: (**idling and minor stoppage losses** and **reduced speed losses)** and (3) quality losses (**quality defects and rework** and **start-up losses)**

The six big losses are measured in terms of OEE, which is a function of availability (A), performance rate (P) and quality rate (Q), as shown in equation (1):

$$\text{OEE} = \text{Availability } (\%) \times \text{Performance rate } (\%) \times \text{Quality rate } (\%) \qquad (1)$$

According to Nakajima (1988), the OEE measures the "effectiveness" of equipment, and in manufacturing terms effectiveness as opposed to `"efficiency". The measurement method now includes production losses that were not part of the original parameters of Nakajima's (1988) OEE. Other differences, in terms of losses that are now included, also emerged. These differences make it difficult to use OEE as a benchmarking tool, when two or more companies are involved. However, it has retained its value when it comes to its most important function, namely as a tool in the work of continuous improvement (Bolviken and Kalsaas, 2011).

MEASURING PHYSICAL FLOW (3)

For Alves (2000) the main objective of the management of physical flows is the elimination or reduction of wastes, for there is a need to make the processes observable, based on the principle of transparency of Koskela (1992). Process and flow diagram are tools to run the measurement in the physical flow.

The use of the process diagram and flow diagram to document a process through the use of graphics and symbols makes it easier to understand the processes (Ishiwata 1991), helping to combat the three major problems that occur between the different activities, and can be said to be: loss, thoughtless attitudes and inconsistencies.

The process diagram represents the sequence of the various activities that make up a process. The flow diagram, besides indicating the different activities developed, identifies the location where they are performed, because the symbols for the representation are positioned in a blueprint, indicating your location (Ishiwata1991).

Thus, the use of the process diagram and the flow diagram can document how processes are being developed at the construction site, enabling the identification of possible improvements (Ishiwata 1991). Therefore, the use of these tools can: (1) study the process, (2) find the points where the wastes are occurring, (3) consider the possibility of redefining the process with a more efficient sequence, (4) consider whether the flows are continuous if there are problems in transportation and (5) whether the activities in the process are really necessary.

However, the use of the process diagram and the flow diagram does not allow the following aspects to be viewed: (1) analyze if the processing activities are really being productive, (2) analyze if the productivity of processing activities are being uniform, (3) analyze if the production volume is occurring as planned, (4) find the existence of unwanted stops during transport activities.

DISCUSSION OF ALTERNATIVE METHODS

Table 1 presents a summary of three methods studied in order to identify the main characteristics of each method to measure the flow and also to identify the type of wastes that it is possible to measure through each of them. However, the comparison among the methods is difficult due to their different nature.

In the Value Stream Mapping, the mapping process is simple, real-time, and iterative, as this method allows for simple correction. The OEE method is more focused on the analysis of equipment, since it came from the industrial production and it is a method to measure the workflow. The process and flow diagram focus on the process as a whole, the use of these tools improve the process of transparency. Moreover, they are simply and have a low cost of implementation. Nevertheless, process and diagram flow are unable to analyse the continuity, quality and intensity of work, since they just describe the activity that is being performed without analyzing in depth if it is being executed effectively and productively.

By analyzing Table 1, it can be noted that the three methods enable the identification of the activities that absorb resources, but do not create value.

Additionally, it is possible to observe that the methods can complement each other.

The VSM and OEE focus on the measuring of time indicators, and both methods are interested in identifying the available working time. However, VSM aims to measure time indicators such as: cycle time, lead time and tack time, and the indicators measured by the OEE are: operation time, net operation time and value creating time. On the other hand, the indicators identified by process and flow diagram are focussed on the quantity of activities, regardless of the time destiny in each activity.

Table 1 – Summary of the different methods

	Value Stream Mapping	OEE	Process and Flow Diagram
Flow focus	Process flow	Workflow	Physical flow
Objective	To identify the occurrence of wastes	To Identify efficiency losses caused by activities that absorb resources without adding value	Document how processes are being developed at the construction site
Measures	-Cycle Time -Lead Time -Tack time -Number of people -Trading time -Size of production batches -Available working time	The productivity and Effectiveness: -Available working time -Operation time -Net operation time -Value creating time	The number of activities: -Transport (T) -Inventory (S) -Inspection (I) -Processing (P)
Symbols	Icons and symbols: (process, material, information and general symbols)	There is no specific symbols	Graphics and symbols forT, S, I and P
Results	-Identification of the current map -Proposal for a future map	Measures of performance (OEE = (P, Q, A) and six big losses) A tool of intern Benchmark Classification of losses in 6 categories	Studying the process; Find the points where the losses are occurring; Consider the possibility of redefining the process with a more efficient sequence; Consider if the flows are continuous if there are problems in transportation; Examine whether the activities in the process are really necessary.
Wastes	-Waiting -Inventory	-Equipment failure -Setup and adjustment -Idling and minor stoppage -Reduced speed -Defects in process -Reduced yield	-Waiting -Transport -Inappropriate processing -Unnecessary motion

CONCLUSION

This paper presented an overview of the concept flow from different perspectives in the construction industry. Reading the literature helped clarify the authors' understanding of the flow concept. Moreover, the Lean literature review allowed them to choose the physical flows as the object of a future research, due to their operationalization to reduce transportation wastes. The logistic literature review allowed for the understanding of how the flows of materials, which are part of the physical flows, are seen from another point of view. Therefore, this paper is the first step of research which intends to propose a method for the measurement of the physical flows in construction processes in order to reduce the transportation wastes. The initial method proposes the use of some tools for data collection, such as: (1) process and flow diagram; (2) performance indicators: (a) total man hours required for the unit production; (b) total man hour required for transport activity / total man hours required for the unit production, and (c) number of transport activities and (3) work sampling.

However, due to the fact that there are large amounts of flow definitions, there is still a lack of a common understanding about the concept. For instance, some model flow is just a precondition from the point of view of other authors, such as the three model flow proposed by Ballard (2000) based on nature. The three flows proposed by Ballard (2000) are not flows by themselves, since those flows match with the seven preconditions proposed by Koskela (2000). Three flows have been identified in the lean literature, as well as the characteristics and preconditions that they must have in order to be understood as a good flow: moreover, a method for the measurement of each of them was presented. The overlays in the definitions of the term were presented in Figure 2

Further work is necessary to identify more methods to measure the wastes along the different flows, in order to find a method, which allows it to be measured properly. It may be necessary to use multiple methods or the combination of some tools, since the use of only one may not meet all requirements needed.

REFERENCES

Alves, T.C.L. (2000). “Diretrizes para gestão dos fluxos físicos em canteiros de obra: proposta baseada em estudo de caso”. Master Dissertation. Núcleo Orientado para a Inovação da Edificação Programa de Pós- Graduação em Engenharia Civil, Universidade Federal do Rio Grande do Sul, Porto Alegre. In portuguese.

Ballard, G. (1999) Can Pull Techniques be Used in Design Management? Concurrent Engineering in construction: Challenges for the New Millennium. CIB Publication 265. VIT, Espoo. Pp. 149-160

Ballard, G. (2000). “The Last Planner System of Production Control”. PhD Diss., School of Civil Engineering, University of Birmingham, UK.

Ballard, G., Tommelein, I., Koskela, L., and Howell, G. (2002). Lean Construction tools and techniques (Chapter-15). In Design and Construction: Building in Value, Oxford-England-UK, 227-255.

Ballou, R.H (1999). Business logistics Management.Prtntice-Hall, Inc. 4th ed. 1999.

Barnes, R.M (1977). “Motion and Time Study”.

Bertelsen S.; Koskela L.; Henrich G.; Rooke J. (2006) “Critical Flow Towards a construction Flow theory”. Proceedings of International Group for Lean Construction, IGLC14, Santiago-Chile.

Bølviken, T. and Kalsaas, B.T. (2011).“Discussion on strategies for measuring work flow in construction.”Proceedings of International Group for Lean Construction IGLC19, Lima, Peru.

Bowersox, D. Closs, D. Logistical management. “The integrated supply process”. New York: McGraw Hill, 1996.

Cruz, A. E. and Taboada Rodrigues, C. M., E Novaes. (1998) Modelo logístico para a construção civil. VII Encontro Nacional de Tecnologiado Ambiente Construído, Florianópolis/SC-Brazil.

Cruz, A. E. (2002) Método para o estudo do comportamento do fluxo material em processos construtivos, em obras de edificações, nai ndústria da construção civil. Uma abordagem logística Tese de doutorado em Engenharia de Produção - Programa de Pós-Graduação em Engenharia de Produção da Universidade Federal de Santa Catarina, Florianapolis, 2002. In Portuguese

Hines P. and Rich P., (1997),"The seven value stream mapping tools", International Journal of Operations & Production Management, Vol. 17 Iss: 1 pp. 46 - 64

Hopp, W. J., and Spearman, M. L. (2001). Factory physics : foundations of manufacturing management. Irwin/McGraw-Hill, Boston.

Ishiwata, J. (1991) “IE for the shop floor: productivity through process analysis”. Portland: Productivity Press, 182p.

Jeong, K. and Phillips, D.T. (2001). “Operational efficiency and effectiveness measurement.” Int’l J. of Oper. & Prod. Mgmt., 21 (11) 1404-1416.

Kalsaas, B.T. (2012). “Further work on measuring workflow in construction site production”. Proceedings of International Group for Lean Construction, iglc20, San Diego, USA.

Kalsaas, B.T. (2013) “Measuring waste and workflow in construction”. Proceeding Proceedings of International Group for Lean Construction, iglc21, Fortaleza, Brazil.

Kalsaas, B.T., and Bølviken, T. (2010). “Flow of work in construction – a conceptual discussion.” Proceedings of International Group for Lean Construction, IGLC18, Haifa, Israel.

Koskela, L. (1992). “Application of the New Production Philosophy to Construction”.Standford, EUA: CIFE. (Technical Report 72.).

Koskela, L. (2000). “An exploration towards a production theory and its application to construction”. Espoo, Finland: VTT, 2000. (VTT Publication, 408).

Kraemer K., Henrich G., Koskela L. and Kagioglou M. (2012) “How Construction Flows Have Been Understood In Lean Construction”. 4th International Research Symposium (SCRI), University of Salford. March 2012

Nakajima, S. 1988, Introduction to TPM: Total productive maintenance, Productivity Press, Cambridge, MA.

Oxford Advanced Learner‘s Dictionary (1995). Oxford Advanced Learner‘s Dictionary (5th ed.). Oxford: Oxford University Press.

Rother, M., & Shook, J. (1999).Learning to see. Value stream mapping to create value and eliminate muda. A lean tool kit method and workbook.(Version 1.2). Brookline – Massachusetts: The lean enterprise institute

Shingo, S. (1988). Non-Stock Production: The Shingo System for Continuous Improvement. Productivity Press, New York, USA.

Shingo, S. “A revolution in manufacturing: the SMED system”. Portland, Oregon: Productivity Press, 1985.