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Production Cells in Construction: Considering Time, Space and Information Linkages to Seek Broader Implementations

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Abstract: The use of production cells in manufacturing has achieved many benefits, motivating researchers to apply them in the construction environment. The aim of this research is to identify time, space, and information linkages in construction's production cells applications, seeking opportunities for broader implementations. We adopted a literature review approach focusing on cases in the Brazilian construction sector that addressed cell applications. Subsequently, comparative tables of these publications were prepared, analyzing the consideration of time, space, and information linkages, as well as identified results. The article pointed out that there is a gap in publications that address the application of a production cell in almost all construction flows, except the job site flow, reflecting the tendency of most companies of applying lean concepts firstly in physical flows. By analyzing these aspects (group of features that enhance the use of the cell), it was found that "material flow and pull systems" and "operators interaction" were the aspects most often considered, but mostly partially. Few cases reported the use of "flexibility" and "equipment maintenance". No case reported comprehensive considerations of the three important linkages of time, space, and information. Space was the linkage better considered compared to time and information linkages. Lead time reduction, cost savings and increased productivity were among the greatest benefits reported from the applications of production cells. There is also a positive correlation between the linkages coverage and the number of benefits obtained. Further research is suggested in order to investigate the results of a more comprehensive application considering all linkages.

Keywords: Production cell, flow, and construction.

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1. Introduction

Construction industry is under pressure to improve production management practices, due to some factors, such as: low productivity, social demands, high levels of waste, and bad image when compared with other industries (Santos, 1999). Moreover, some process in construction relies on techniques which are passed on from master to apprentice, leaving little room for a culture of continuous improvement (Ko et al, 2011).

For some time, various efforts have been developed to minimize these problems, such as: computer integrated construction, prefabrication, and modularization (Koskela, 1992). Although, the problem in production management in construction is the conceptual basis (Koskela, 1992). Thus, Koskela (1992) proposed a new production philosophy as an alternative to change this scenery because this philosophy focuses on the waste elimination in the value stream (latter, this philosophy was named Lean Thinking). As implementation result, lead time and cost are reduced and quality improved (Ohno, 1988). Lean Thinking is a generalization of the Toyota Production System for other industrial sectors (Womack and Jones, 1996).

Since the pioneering proposition by Womack and Jones (1996) regarding the five principles of lean thinking, the principle of flow has been highlighted as a cornerstone of this philosophy. A tool widely utilized to put this principle in place is production cell, which aims to keep the production as close to the continuous flow as possible (Liker, 2004). Production cells have steadily gained popularity over the past two decades. Studies show that cells are now adopted by between 43 and 53 per cent of manufacturing companies in the USA and the UK (Johnson and Wemmerlov, 2004). The benefits brought by cell applications in manufacturing are: reduction of setup time, in-process inventory, lead time, and cost; increased product quality; simplified programming; among others (Pattanaick and Sharta, 2009). A real production cell must have equipment, material and labor connected in terms of time, space and information. If these three linkages are not connected, limited results can occur (Hyer and Brown, 1999).

To the best of our knowledge, Santos et al (2002) was the pioneering study in relation to production cells implementations in construction. From there on, others studies were conducted in partial formats and some of them reported limited results. Thus, Hyer's and Brown's framework highlights opportunities for investigating what is the real cause of these limited results in production cells. Therefore, the aim of this research is to identify time, space and information linkages in construction production cells, seeking opportunities for broader implementations. This paper is a revised version of an article first presented to the International Group for Lean Construction Conference in Lima, Peru in July 2011 and included in the Proceedings of that Conference.

2. Research Methods

The methodological approach used consisted of a literature review (from 2001 to 2010) addressing the production cell implementation in the construction environment. The context of analysis was limited to Brazilian construction cases. Figure 1 shows the steps followed in this research.

Firstly, we propose a grouping of Hyer and Brown´s 25 enablers into 6 aspects: (i) cell design and flow, (ii) material flow and pull system, (iii) flexibility, (iv) visual management and feedback, (v) operators interaction; and (vi) equipment maintenance. The proposed grouped aspects consider proximity among groups of the original enablers' focus and the relationship of these groups with important concepts discussed in literature related to lean implementation in manufacturing, such as Rother and Harris (2002), Lean Enterprise Institute (2003), Liker (2004) and Narusawa and Shook (2009). Making the discussion considering the broader aspects aim to facilitate the generalization and understanding for non-manufacturing environments, such as construction and others. Sixteen Brazilian construction cases reported in the literature provided evidences for our research.

Secondly, we identified, in those cases, the aspects and linkages considered, the main focus of the investigated cases, the construction flows by Picchi (2001) (business, job site, design, supply, and use and maintenance) to analyze the applications beyond the production, and reported benefits obtained using production cells.

Finally, we found the main gaps in the consideration of previous mentioned aspects taking into account time, space, and information linkages. Results were analyzed in detail and opportunities for broader applications of production cells in construction have been offered.

3. Production Cell

3.1. Background

Although cellular manufacturing is a concept that dates back to the early 1900's (Benders and Badham, 2000) with recorded implementations in both American and German companies, it fell into oblivion, at least in the U.S., until the early 1980's. Its revival dates to the introduction of the Just-In-Time philosophy in the American industry (Johnson and Wermelov, 2004).

The first step toward Just-in-time was taken at 1949 for Ohno. He replaced the machines in cellular layout. It permitted that one worker operated several machines (Ohno, 1988).The production cells could be regarded as an evolutionary successor of the moving-line concept of Henry Ford to meet the Japanese small market in those days (Narusawa and Shook, 2009).

Production cells have steadily gained in popularity over the past two decades. Cases show that cells are now adopted by between 43 and 53 per cent of manufacturing companies in the US and the UK (Johnson and Wemmerlov, 2004). The benefits brought by cell applications in manufacturing are: reduction of setup time, work-in-process, lead time and cost; increased product quality, simplified programming, among others (Pattanaick and Sharta, 2009).

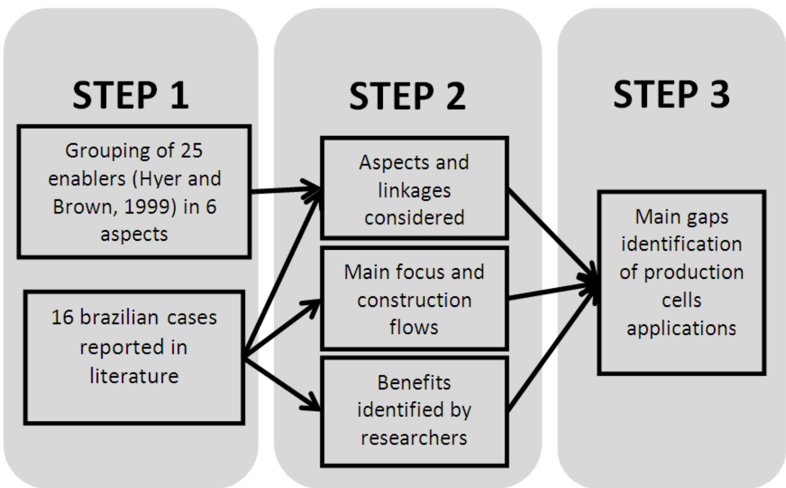

Fig. 1. Steps followed of this research

3.2. Production Cell Concept

According to Rother and Harris (2002), a cell is an arrangement of people, machines and methods in which the activities are close and occur in sequential order, whereby the parts are processed through a continuous flow (or in small batches). The U-shape is the most common form in manufacturing, because it avoids operators walking large distances and it allows different combinations of tasks for operators (Lean Enterprise Institute, 2003). In the service sector, cell production is also being applied, where teams create flows in small batches, and it reduces work-in-process (Swank, 2003).

Hyer and Brown (1999) define a production cell as: “Dedicating equipment and materials to a family of parts or products with similar processing requirements by creating a work flow where tasks and those who perform them are closely connected in terms of time, space and information”.

The significance of the three critical linkages is as follows (Hyer and Brown, 1999):

• Time transfer and waiting times between sequentially dependent tasks are minimized;

• Space all cell tasks are performed in physical proximity to one another; and

• Information people and machines responsible for cell activities have access to complete information about the disposition of work within the cell.

Time, space, and information interactions are depicted in Figure 2. At the center of the model, there are four performance criteria: quality, cost, delivery, and flexibility (Hyer and Brown, 1999). Moving to the outer perimeter of the triangle, there are a set of arrows depicting complementary relationships among the three linking mechanisms (time, space and information) and their directions of influence (Hyer and Brown, 1999).

Thus the authors emphasize two characteristics: (1) the dedication of equipment and material to a family of parts, and (2) the creation of a work flow connected in terms of time, space and information.

In construction, the applications generally focus on the implementation of a production cell in a specific set of services, so the first characteristic of dedication of resources is frequently attended. The second characteristic mentioned by the authors, of linkages between people and tasks, generally present gaps even in manufacturing (Hyer and Brown, 1999), and it deserves more attention. Hyer and Brown (1999) present enablers that allow the application of production cells comprising the three linkages.

In order to facilitate further analysis, we propose a grouping of Hyer and Brown´s enablers in aspects. The grouped aspects contribute to generalize the analysis for non-manufacturing environments, such as construction and others.

Table 1 presents these proposed aspects and related enablers, as well as their impact in each linkage, adapting the correlation of enablers and linkages proposed by Hyer and Brown (1999).

In Table 1, one can observe that some aspects affect many linkages, while others have more specific impacts. For example, the aspect “cell design and flow” influence the three linkages: time, space, and information. Despite this, only its application would not lead to the complete treatment of these linkages, as it depends on the application of other aspects. Rother and Harris (2002) emphasize, for example, that just approaching equipment, without creating a one-piece flow (related to the aspect of “material flow and pull system”), among other deficiencies, lead to what they name ‘false cell’.

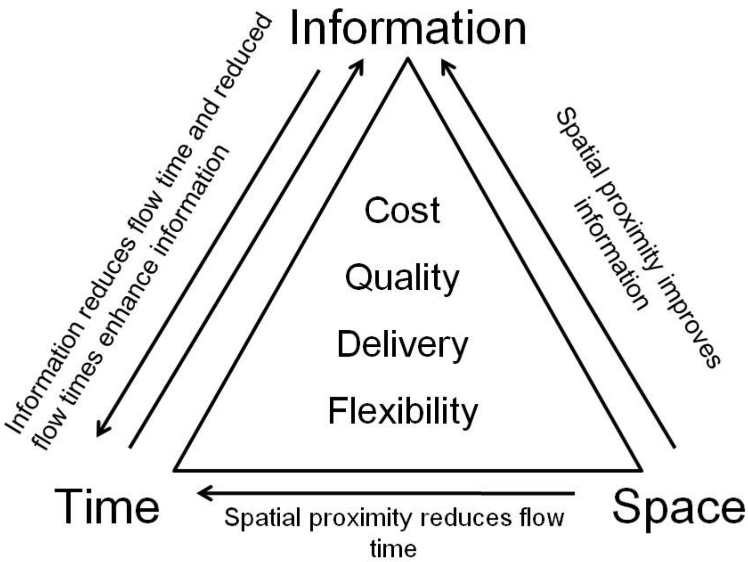

Fig. 2. Influence among linkages
Reprinted from Hyer and Brown (1999) with permission.

Table 1. Aspects considered in the implementations of cells and their correlation with linkages; adapted from enablers (Hyer and Brown, 1999)

Enablers	Aspects	Impact on the linkage: Time	Impact on the linkage: Space	Impact on the linkage: Information
• Juxtaposition of sequentially related equipment in cell arranged to accommodate dominant flow • Miniaturization of 'monument' processes • Balanced workstations • Small cell size	Cell design and flow	●	●	●
• Small lot sizes • Small transfer batch quantities • Parts delivered on time • Incoming material conforms to specifications • Effective material handling equipment/processes	Material flow and pull system	●	○	●
• Short set-up times • Cross-training and job rotation • Equipment that can be moved as cell needs change	Flexibility	●		○
• Management control systems that make information quickly available to operators • Presence of feedback loops among cell stations and between cell and customers/supplier • Job designs and other policies that permit operators to take action in response to signals	Visual management and feedback	○		●
• Job designs and other policies • Common operator language • Positive interpersonal relationships between operators • Operators continually share information • Operators skilled at teamwork • Operators have visual access to all cell activities 'line-of-sight' information • Operators have 'whole task' understanding • Low noise environment	Operators interaction	○		●
• Preventive maintenance policies • Operators skilled at preventive maintenance	Equipment Maintenance	●		

Legend: (●) stronger influence (○) medium influence; Source: adapted and grouped from Hyer and Brown (1999).

4. Results and Discussion

4.1. Application of Production Cell in Construction – The Brazilian Cases

Literature review focused on production cell application in Brazilian construction cases. Table 2 presents the cases considered, their focus and related construction flows.

The cases with asterisk directly address the application of production cells, and they have, as specific objective, the implementation and/or analysis of production cells. The others have different main focus, referring indirectly to production cells.

Eleven out of sixteen cases in Table 2 are related to job site flow, while few applications were identified in other construction flows. This reinforces Picchi and Granja (2004) observation that business, design, and use and maintenance flows present few applications of lean thinking tools, when compared to job site flow. The application of cells and other lean concepts and tools first in production is also a pathway frequently observed in manufacturing, and it reflects lean emphasis on the places were value is added to the products that customer pays for ,and where first results are more tangible. As Womack and Jones (1996) point out, lean is a business system and not just a production system, so the spreading to other functions and flows beyond production is expected as the maturity of implementations evolves.

4.2. Aspects and Linkages Considered in the Discussed Production Cell Applications

From the analysis of the cases reported in each study, we identified the aspects addressed in each one, as reported in Table 3. We adopted a classification of the accuracy and completeness of treatment given to each aspect in each case. For that purpose, we analyzed in each case the description of practices or analysis related to enablers associated to the considered aspect. From this analysis, we classified the case's aspect consideration as partial or comprehensive, following these criteria: if all enablers of the aspect are considered, and if the classification is comprehensive. For example: Salermo (2005) presented the two enablers (preventive maintenance policies and skilled operators) that are part of the equipment maintenance aspect. We classified as partial consideration the cases with at least one enabler in the respective aspect. Regarding the use of aspects, one can see that the aspect "material flow and pull system" was considered in all cases, with comprehensive treatment in five of them. One example of improvement on this aspect is the use of kanban in mortar production and lay-out planning for materials storage close to application (Carneiro et al, 2009). Following, the “operators interaction” aspect was also considered in all cases, but only one comprehensively. Santos et al (2002) present examples in this aspect, such as workflow and visual controls, and close communication as result of multi-skilled team working together. Still widely used were the aspects: “cell design and flow” and “visual management and feedback”.

Aspects less considered were “flexibility”, and “equipment maintenance “. Probably this is a consequence of the fact that equipment maintenance in construction is not as critical as for manufacturing. Flexibility is related to multifunctional workers skills, which is an important issue in construction, demanding future research.

Job site flow, besides having higher cell cases, presented higher frequency of comprehensive applications. The other flows had only partial applications, except for the use and maintenance flow with one comprehensive application in the “equipment maintenance” aspect.

Cases using larger number of aspects classified as comprehensive consideration were: Patussi and Heineck (2009), Santos et al (2002), Carneiro (2007) and Carneiro et al (2009), each one with two comprehensive aspects. One can observe that no research has used all aspects, and most existing applications are partial.

For an evaluation of time, space, and information linkages consideration, we adopted criteria for establishing correlation between covered aspects and linkages.

The aspect classification of: comprehensive, partial, and absent were weighted respectively as: 1,0; 0,5; and zero, and they were crossed to Table 1 correlation of aspects and linkage. Table 3 presents the resultant classification: comprehensive, partial and initial. This table is organized from lower to higher linkage coverage.

When analyzing the linkages treatment, we observe that no case covers all three linkages comprehensively. Just one research (Patussi and Heineck, 2009) presented one comprehensive coverage, in space linkage.

Space linkage presents just two cases with initial consideration, while time and information presented respectively 8 and 7 initial classifications. Besides that, in no case space linkage received a lower classification than the other linkages. One can conclude that space was the linkage better covered, tending to latent physical cells (time and information deficient), according to Hyer and Brown (1999).

The job site flow applications, besides having a better coverage of aspect discussed previously, also presented better classifications in linkages, when compared to the other flows.

Table 2. Cases related to production cell application in Brazilian construction cases

Authors	Focus	Construction flow
Bulhões et al. (2005)	Possibility of implementing continuous flow in construction	Job site
Carneiro et al. (2009)	Benefits of a successful production strategy	Job site
Carneiro (2007)*	Implementation method of production cells in the construction environment	Job site
Ferraz et al. (2005)	Model for planning and construction management	Job site
Paixão et al. (2010)*	Analysis of cost variation over time of production cell in job sites	Job site
Patussi and Heineck (2009)*	Main results of implementing the concepts of cell production in a small job site	Job site
Patussi and Heineck (2006)*	Changes in production occurred after use of the concept of manufacturing cells in small construction companies	Job site
Romano et al. (2005)*	Flow facilitation in tall buildings construction, through the rationalization of equipment and use of production cells	Job site
Santos et al (2002)*	Manufacturing cells concept application in a dry-wall service	Job site
Tavares et al. (2004)*	Results of production cells application to construction planning and execution	Job site
Ugulino and Lima (2009)*	Improvements in construction processes through the use of mobile production cell in masonry service	Job site
Reis and Picchi (2004)	Waste identification in construction business flow using value stream mapping	Business
Lima et al. (2010)	Results of value stream mapping applied to architecture executive design in a public agency	Design
Weindorfer (2001)	Productivity improvements in a, Public Works State Department	Design
Barbosa and Lima (2008)	Continuous flow implementation in the production of pre-cast foundation piles	Supply Chain
Salermo (2005)	Lean thinking concepts and tools applied to the maintenance of hospital buildings	Use and maintenance

4.3. Benefits of Production Cells Applications

Table 4 presents the benefits identified by the authors directly related to the application of production cells. Other benefits mentioned in the cases resulting from other tools were not reported in Table 4. This table follows the same organization of the Table 3.

The benefit most often cited in Table 4 was lead time reduction, mentioned in 13 of the 16 cases. The second one was cost reduction, identified in 8 cases, followed by increased productivity, mentioned in 7.

When analyzing the Figure 3, one can observe that there is a tendency that production cells that had better linkages coverage presented more benefits. However, the graph presents some outline points; this tendency is aligned with Hyer and Brown's hypothesis that argue: "The real physical cells (comprehensive considerations of the 3 linkages) contribute in an optimal way to the achievement of competitive priorities, such as quality, cost, delivery and flexibility". This alignment should be object of further research, since the data analyzed has limitations, for example Table 4 shows the number of benefits identified, not quantified.

Table 3. Aspects and linkages considered in the discussed cases

Authors	Aspects						Linkages			Construction Flow
	Cell design and flow	Material flow and pull system	Flexibility	Visual management and feedback	Operators interaction	Equipment Maintenance	Time	Space	Information	
Tavares et al. (2004)		○			○		□	□	□	Job site
Paixão et al. (2010)		○			○		□	□	□	Job site
Bulhões et al. (2005)	○	○		○	○		□	▣	□	Job site
Ugulino and Lima (2009)	○	○		○	○		□	▣	□	Job site
Lima et al. (2010)	○	○			○		□	▣	□	Design
Weindorfer (2001)	○	○		○	○		□	▣	□	Design
Barbosa and Lima (2008)	○	○			○		□	▣	□	Supply Chain
Reis and Picchi (2004)	○	○		○	○		□	▣	□	Business
Salermo (2005)	○	○		○	○	●	▣	▣	□	Use and maintenance
Ferraz et al. (2005)	○	○	○	○	○		▣	▣	▣	Job site
Santos et al. (2002)	○	○	●	○	●		▣	▣	▣	Job site
Patussi and Heineck (2006)	○	●	○	○	○		▣	▣	▣	Job site
Romano et al. (2005)	○	●		○	○		▣	▣	▣	Job site
Carneiro (2007)	○	●		●	○		▣	▣	▣	Job site
Carneiro et al. (2009)	○	●		●	○		▣	▣	▣	Job site
Patussi and Heineck (2009)	●	●	○	○	○		▣	■	▣	Job site

Legend of aspects: (●) comprehensive consideration of all enablers of the respective aspect; (○) partial consideration of at least one of enabler of the respective aspect; (no symbol): absent
Legend of linkages: (■) comprehensive; (▣) partial; (□) initial;

Table 4. Benefits identified by authors resulting from applications of production cell in construction

Authors	Lead time reduction	Reduced Costs	Increased Productivity	Increased financial return received by Employees	Employee satisfaction	Waste Reduction	Skilled employees	Planning simplification	Cleaner and more organized workplace	Increased transparency	Improved ergonomics	Lower employee turnover	Inventory reduction	Increased Quality	Variability Reduction	Others	Number of benefits referred
Tavares et al. (2004)						X		X									2
Paixão et al. (2010)	X	X													X		3
Bulhões et al. (2005)	X																1
Ugulino and Lima (2009)	X	X	X	X	X	X			X			X					8
Lima et al. (2010)	X	X														X	3
Weindorfer (2001)			X		X											X	3
Barbosa and Lima (2008)	X															X	2
Reis and Picchi (2004)	X																1
Salermo (2005)	X						X									X	3
Ferraz et al. (2005)								X								X	2
Santos et al. (2002)	X						X				X						3
Patussi and Heineck (2006)	X	X	X	X			X										5
Romano et al. (2005)	X	X	X	X	X				X			X					7
Carneiro (2007)	X	X	X	X	X	X		X		X							8
Carneiro et al. (2009)	X	X	X	X	X			X		X						X	8
Patussi and Heineck (2009)	X	X	X	X	X	X	X						X	X			9
Number of citations	13	8	7	6	6	4	4	4	2	2	1	1	1	1	1	6	

For accuracy analysis about the relation between benefits and linkages covered, we crossed Table 3 with Table 4 and it generated a graph. Figure 3 shows this graph.

5. Conclusions

The application of the production cell concept in the onsite construction flow is still very partial. In the remaining construction flows, such as business, design, supply and use and maintenance, the applications are even more limited and partial.

No cases reported comprehensive considerations of the three linkages. Space was the linkage better considered than time and information linkages in the investigated domain. This result suggests a propensity in construction environments, that production cell is seen just as an issue of selecting the best layout design.

We could not identify a real physical cell implementation in construction cases under study. However, it was concluded that production cells with a tendency for the comprehensive consideration of the three linkages have more benefits, and this is aligned with Hyer and Brown’s hypothesis. Results of this research provide additional insights for further studies seeking broader cell applications in construction.

The analysis of both aspects and linkages pointed out that there is still great room for improvement in the application of the production cell concept in construction. Further research could investigate the collaboration among project managers, site supervisors and foremen to design production cells. This team would determine the influence degree of the aspects in the three linkages, and, on the conclusion of this analysis, first run studies could be conducted.

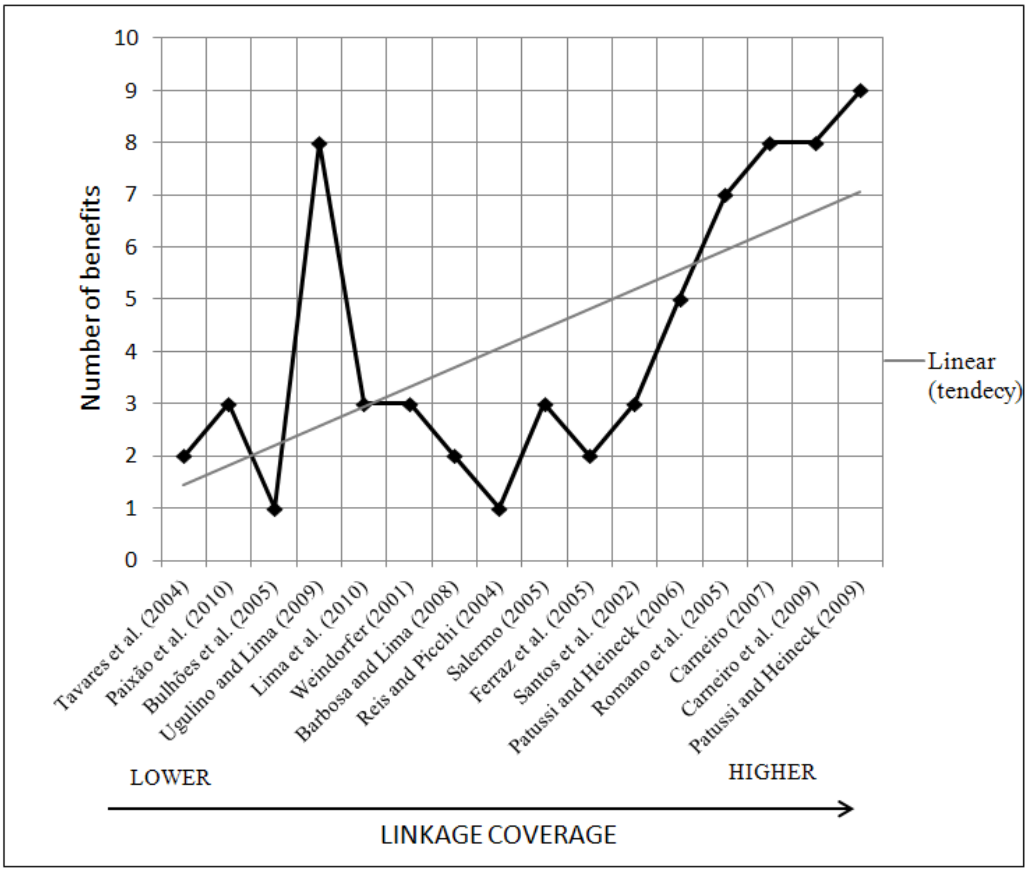

Fig. 3. Relation between referred benefits and linkages in production cells analyzed

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