# EVALUATION OF CURRENT USE OF PRODUCTION MANAGEMENT PRINCIPLES IN CONSTRUCTION PRACTICE

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## ABSTRACT

The present paper discusses the current state of some core production management principles in the construction practice. The analysis concentrates on four principles described in the report "*Application of the New Production Philosophy to Construction*", written by Koskela (1992). Due to the nature of the theme, it has been decided to adopt the case study research strategy. Six case studies were carried out, three in Brazil and three in England, focusing on the bricklaying process. Additionally, a meta-case supplied additional information for those situations where the case studies did not have sufficient empirical evidence.

The study unveiled empirical evidence matching all individual principles and correspondent heuristic implementation approaches. Notwithstanding, the same empirical evidence also unveiled a serious deficiency on the integration of literal replications with other complementary practices. The best performers were those sites that presented a small but well connected set of practices matching the theory. Therefore, the authors concluded that the agenda of construction research should include the need for systemic integration of the various heuristic implementation approaches in construction practice.

## KEY WORDS

Production management, lean construction, construction management.

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> *"In theory, there is no difference between theory and practice; in practice, there is."*
> *Chuck Reid*

## INTRODUCTION

The prospect of continuous reduction of cost and time in transportation and communication is encouraging the study of mechanisms that enable learning of best production practices across the world. In this respect Lilrank (1995) proposed that practices would more effectively transported across different cultures if they were translated into abstract ideas. Indeed, multi-purpose abstract ideas are less likely to suffer the impact of cultural differences and more flexible to allow adaptation to different economic and technological environments.

Abstraction of practices and the subsequent transformation into theories has been a common practice in operations/production management since the early days of scientific management. The most recent wave of theories comes from the combination of two production philosophies, JIT and TQC, and also a number of methodologies such as Visual Management, Total Productive Maintenance and Re-engineering.

However, the current miscellany of theories causes unproductive semantic disputes, leading to confusion and conflict among researchers and practitioners in the field. The boundaries of these theories are rarely clear and the overlaps are not always admitted or pointed out by their authors. Fortunately, recent literature has brought new prospects assuming that the contemporary theories and practices have a common core (Koskela 1992, Womack and Jones 1996).

The authors intend to contribute to the production management field by investigating the current application of some of the core principles of contemporary theories within the construction environment. Construction is one of the birthplaces of the first theories of production management with the motion studies of Gilbreth (1911). Nevertheless, the sector still is known as a dirty, dangerous, and dull environment where productivity levels are low and waste is generally high. The present situation demands a critical reflection of current construction practices in order to establish the critical areas for improvement in theory and practice.

## PRINCIPLES IN STUDY

This investigation focused on the heuristic implementation approaches of four principles listed on Koskela's (1992) report. These heuristic implementation approaches correspond to: reduction of cycle time, reduction of variability and increase of transparency. In recent history, some of these heuristics ideas date back to the pioneer time-motion studies of Frederick Taylor and Frank Bunker Gilbreth (Gilbreth 1911, Taylor 1985). More recently, important developments in the car industry have pushed production performance to new frontiers. The observation and abstraction of these practices have generated a range of new ideas. The works of Shingo (1988) at the Toyota Production System is perhaps the most important in this period. Table 1 illustrates the evolution of these heuristic approaches throughout history.

Table 1: Tracing the Evolution of Heuristic Approaches Throughout History

| | PERIOD | | | |
|---|---|---|---|---|
| | **1900-1920** | **1920-1940** | **1940-1960** | **1980-1999** |
| **REDUCTION OF CYCLE TIME** | | | | |
| Reduction of Batch Size | | | ○○◉◉ | ●●●● |
| Reduction of Work-in-Progress | | | ○○◉◉ | ●●●● |
| Minimisation of Distances | ○○◉◉ | ●●●● | ●●●● | ●●●● |
| Change in the order of the process | ○○○○ | ◉◉◉◉ | ●●●● | ●●●● |
| Synchronisation and Smooth of Flows | | ○○○○ | ◉◉◉◉ | ●●●● |
| Isolation of Value Add. from Support. Activities | | | ○○◉◉ | ●●●● |
| Solving Control and Constraint Problems | ○○◉◉ | ●●●● | ●●●● | ●●●● |
| **REDUCTION OF VARIABILITY** | | | | |
| Measuring, Finding and Eliminating Problems | ○○◉◉ | ●●●● | ●●●● | ●●●● |
| Standardisation | ○○◉◉ | ●●●● | ●●●● | ●●●● |
| Poka-Yoke | | | ○○◉◉ | ●●●● |
| **INCREASE OF TRANSPARENCY** | | | | |
| Reduction of Interdependence | | | ○○◉◉ | ●●●● |
| Number of Visual Controls | | ○○○○ | ○○◉◉ | ●●●● |
| Making the Process Directly Observed | | ○○○○ | ◉◉◉◉ | ●●●● |
| Installing Information into the Workplace | | ○○○○ | ○○◉◉ | ●●●● |
| Maintenance of Clean and Orderly Workplace | ○○◉◉ | ●●●● | ●●●● | ●●●● |
| Rendering Invisible Attributes into Visible | ○○◉◉ | ●●●● | ●●●● | ●●●● |
| **BUILD CONTINUOUS IMPROVEMENT** | | | | |
| Setting Stretch Targets | | | ○○◉◉ | ●●●● |
| Sharing the Responsibility for Improvements | ○○○○ | ○○○○ | ◉◉◉◉ | ●●●● |
| Using Standards to Challenge Practices | ○○◉◉ | ●●●● | ●●●● | ●●●● |
| Measuring and Monitoring Improvements | ○○○○ | ○○○○ | ◉◉◉◉ | ●●●● |
| Linking Improvements to Control | ○○◉◉ | ●●●● | ●●●● | ●●●● |
| Change Push Orders to Pull Orders | | | ○○◉◉ | ●●●● |

**Key:**

○ Relevant Initial Developments ◉ Consolidation of Ideas ● Widespread Use in Industry/Services

In theory, all these principles and implementation approaches are part of the same inter-dependent continuum since they derive from the same concept: production as a flow. The simultaneous and coherent application of these principles should lead production to greater effectiveness and efficiency, as demonstrated on the current accounts of the Toyota Production System (Monden 1998). Therefore, the analysis of practice have to consider not only the current use of each individual heuristic approach in practice but also the integration among these heuristic approaches.

## RESEARCH METHOD

This research could be classified as a "testing-out" research, due to the nature of theme. Thus, it had to be carried out in real world conditions where the kind of control present in a laboratory was not feasible and even not ethically justifiable. In this way, the researchers decided to adopt the case study research strategy. The study consisted of six case studies, three in Brazil and three in England, focusing on the bricklaying process (the same process analysed by Frank Gilbreth). A protocol was devised for data collection, defining the data collection techniques, the sequence in which they were applied, the analytical process and the presentation of results for the host companies. A meta-case supplied some of the evidence for those situations where the case studies did not have a literal replication or where the examples available were not sufficiently clear.

The cross-case study analysis was carried out comparing empirical evidences against theoretical propositions (and vice-versa). In order to do that, it used the analytical approach that Yin (1994) calls **replication logic**. Based on that approach, **literal replication** exists when an empirical evidence matches with a theoretical proposition and the predictable are observed. On the other hand, if empirical evidence does not match with the theoretical proposition but presents the consequences predicted in the theory, it is classified as a **theoretical replication** (Yin 1994). The intra-case study analysis used both replication logic and **explanation building** approach and the focus has been on the interaction between empirical evidence (Yin 1994). Therefore, the intra-case study analysis explore the match between theoretical inter-relationship and the observations of practice.

Searching for the typical behaviour and limits of quantitative indicators was paramount to increase the accuracy of pattern-matching and explanation building judgements. Jones (1970) defines the aim of "**boundary searching**" as "**to find limits within which acceptable solutions lie.**" This approach tries to identify acceptable and extreme values and the expected progression that characterises the quantitative indicators. The literature review and the case studies themselves have supplied fundamental clues with respect to the possible range of values for each indicator.

## ANALYSIS

### SUMMARY OF DATA

The pattern matching approach relied on sufficient understanding of abstract concepts and principles, as well as on correct abstraction of reality. The researchers adopted short working definitions for each "implementation approach" and instrumental indicators as a strategy to clarify the exact parameters used in the analysis of empirical evidence. Table 2 summarises the instrumental indicators collected in the case studies.

Some of the heuristic implementation approaches were quite straightforward to identify in the practice of the case studies. The approach "minimisation of distances", for instance, was easily identified already from the first visit on site. Still, the researchers used various sources of information in order to confirm the findings in this respect and mixed both positivist and phenomenological methods. The work sampling technique showed the percentage of time spent with transportation. Filming showed the effect of short or long distances in real time. Flow charts enable the understanding of the entire process and have brought attention to excessive number of process stages. Layout diagram was a powerful tool for understanding the root causes and the implications of long distances across the horizontal plan. Documents and archival records revealed how often the layout was revised. The indicator "Number of Bricklayers per Labourer" reflected how effective was the workflow and layout planning. Open ended interviews brought further insights into the information

Table 2: List of Instrumental Indicators that Substantiated the Pattern Matching Findings

| **INDICATOR** | **CASE** | | | | | |
|---|---|---|---|---|---|---|
| | 1 (UK) | 2 (UK) | 3 (UK) | 4 (BR) | 5 (BR) | 6 (BR) |
| Single Unit Batch (A) (m3/hour) | 0,33 | 0,21 | 0,18 | 0,19 | 0,29 | 0,23 |
| Average Storage (B) (m3/hour) | 6,12 | 3,54 | 5,30 | 2,62 | 10,38 | 6,34 |
| Flow Efficiency (A/B) | 0,05 | 0,06 | 0,03 | 0,07 | 0,03 | 0,04 |
| N$^{o}$ of Visits to the Workplace to Complete the Main Processing Activity | 3 | 3 | 3 | 3 | 3 | 3 |
| Average time between Visits (hours) | 120 | 48 | 96 | 72 | 120 | 120 |
| N$^{o}$ of Bricklayer per Labourer | 2 | 3 | 2 | 2 | 2 | 1 |
| Number of Revisions in Layout per Month | 1 | 1 | 0 | 1 | 0 | 0 |
| N$^{o}$ of Parallel Activities Carried out by the Bricklayer | 2 | 2 | 2 | 2 | 0 | 2 |
| Workstation Changeover Time (min) | 60 | 20 | 60 | 30 | 45 | 45 |
| Waste of Bricks/Blocks (%) | 1 | 7 | 4 | 3 | (b) | (c) |
| % unproductive time | (a) | 24 | 34 | 26 | 24 | (d) |
| % auxiliary time | * | 28 | 29 | 36 | 24 | * |
| % productive time | * | 48 | 37 | 38 | 52 | * |
| N$^{o}$ of Process Stages | 11 | 8 | 8 | 8 | 12 | 12 |
| N$^{o}$ of Performance Indicators Collected Regularly | 0 | 0 | 0 | 0 | 1 | 0 |
| N$^{o}$ of Improvements Developments Based on Data | 0 | 0 | 0 | 0 | 0 | 0 |
| % of Operatives Knowing the Standard | 0 | 0 | 0 | 0 | 0 | 0 |
| N$^{o}$ of Revisions in Standards per year | 1 | 1 | 0 | 0 | 0 | 1 |
| Existence of Formal Standards | Yes | Yes | 0 | 0 | 0 | Yes |
| N$^{o}$ of Poka-yoke Devices | 1 | 0 | 0 | 2 | 0 | 2 |
| N$^{o}$ of Diff. Processes Interfering in Main Process Flow | 2 | 1 | 2 | 1 | 0 | 1 |
| Alternative Precedence Orders Between Upstream and Downstream Processes | 1 | 1 | 1 | 1 | 1 | 1 |
| N$^{o}$ of Upstream Inputs Necessary to Start the Process | 4 | 3 | 4 | 4 | 2 | 4 |
| N$^{o}$ of Visual Controls | 6 | 6 | 3 | 3 | 2 | 3 |
| % Process Observed from a Single Viewpoint | 80 | 100 | 80 | 70 | 70 | 60 |
| N$^{o}$ of Information Display Areas | 1 | 4 | 0 | 2 | 2 | 2 |
| Number of Times the Workplace is Cleaned to Produce One Batch Unit | 1 | 2 | 0 | 2 | 1 | 2 |
| N$^{o}$ of Information Displays Showing Indicators | 0 | 0 | 0 | 0 | 0 | 0 |
| N$^{o}$ of Team Meetings Involving Workers and Managers | 0 | 1 | 0 | 1 | 0 | 0 |
| N$^{o}$ of Improvements Developed with Employees Inputs/Year | 0 | 0 | 0 | 2 | 0 | 0 |
| N$^{o}$ of Suggestions per Employee/Year | 0 | 0 | 0 | 0 | 0 | 0 |
| Existence of Historical Data Showing Process Before and After an Improvement | 0 | 0 | 0 | Yes | 1 | 0 |
| % of Materials Supplied Against Downstream Order | 1 | 5 | 0 | 1 | 0 | 1 |
| Process Maturity* Transport | 0,43 | 0,69 | 0,28 | 0,49 | 0,36 | 0,43 |
| Safety | 0,37 | 0,46 | 0,18 | 0,47 | 0,66 | 0,40 |
| Facilities | 0,41 | 1,00 | 0,17 | 0,71 | 0,42 | 0,72 |
| N$^{o}$ of Explicit Targets Demanding Higher Performance/Month | 1 | 1 | 0 | 0 | 0 | 1 |
| Number of Solutions Driven by the Challenging Targets/Year | 1 | 0 | 0 | 0 | 0 | 0 |

* obtained through the application of a check-list of current Brazilian best practices obtained through a co-operation with NORIE/UFRGS, Brazil.

collected on site and led to additional empirical evidence to substantiate the researcher's own findings.

### EXAMPLE OF PATTERN MATCHING: REDUCTION OF BATCH SIZE

In short, the reduction of batch size in production processes means to reduce the size of production or transportation volumes in order to speed up the delivery of products or sub-products. Among the underlying objectives of this approach is to drive the practice of identification and correction of errors between phases of a process or between processes. The main instrumental indicator used in the pattern matching of this approach is the indicator of "Flow Efficiency" that links the average storage with the single batch unit. In a way it translates the amount of material present in the flow into multiples of the single batch unit. Ideally, there should be only the correspondent material to a single batch unit. However, the researcher set a more realistic minimum value of 0.50 since there are limitations in the structure of the construction supply chain that cannot be changed by the construction company alone. At the same time, a value of 0.9 has been arbitrarily established as a challenge for the sector.

Not all six case studies presented a comprehensive literal replication of "Reduction of Batch Size". There were considerable variations in the delivery and production volumes even in the best construction sites. Yet, the reduced number of empirical evidence identified in this respect was sufficient to substantiate the conclusion that this approach is applicable to the construction environment. Figure 1 presents the overall evaluation of case studies in this respect:

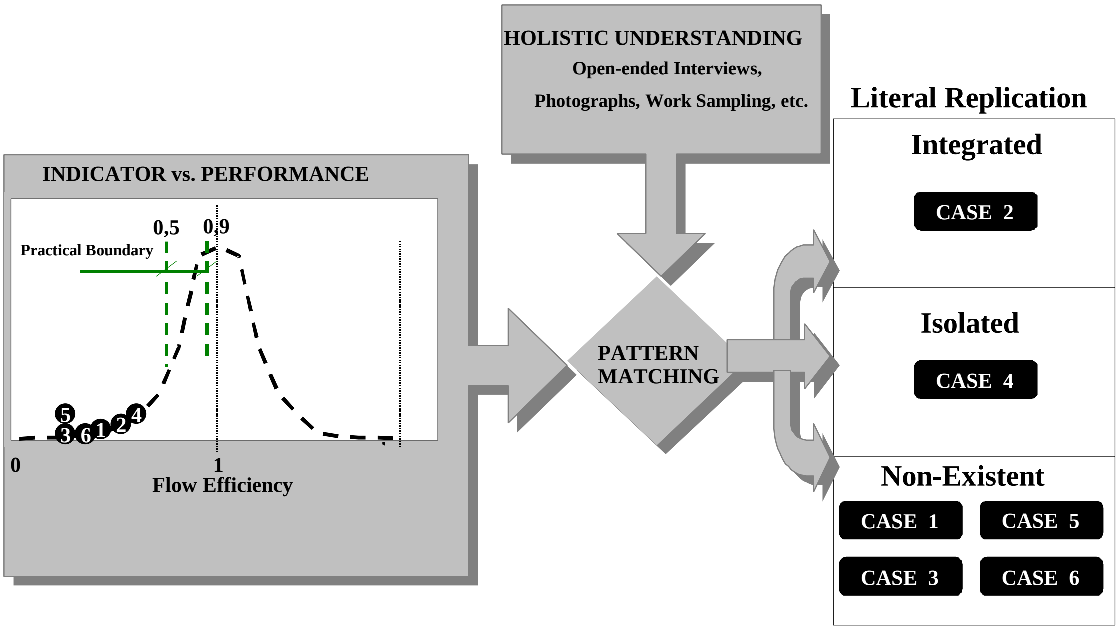

Figure 1: Assessment of Case Studies with respect to Reduction of Batch Size

Case Study 2 had more literal replications throughout the bricklaying process, although not reaching the highest mark in terms of Flow Efficiency among the case studies (Figure 1). This construction site revealed batch size reductions in sand, bricks/blocks, and cement, resulting in lower need for storage space and less material handling. This practice was economically feasible because the truck transported other materials in the same load. In fact, even the same pallet could contain different materials, as Figure 2 illustrates for the case of cement. The supplier benefited from the reduction of batch size by using smaller and faster trucks, confirming Shingo's (1988) arguments with respect to the benefit of small batches.

Figure 2: Literal Replication of Reduction of Batch Size (Case Study 2)

According to the literature, "Reduction of Batch Size" demands dynamic and continuous communication between all parties since adjustments in schedule are almost inevitable and, to a certain extent, expected. Therefore, a partnership atmosphere is a necessary condition to apply this approach in practice (Monden 1998). Indeed, the reduction of batch sizes in Case Study 2 was only feasible due to a partnership atmosphere between the contractor and suppliers. The commitment of the project manager to partnerships translated into a formal commitment to maintain the same suppliers throughout the entire project.

The case studies revealed that most equipment, packing methods and containers used in the construction sites have not being developed with the aim of practising small batches. Indeed, most of the equipment observed had been developed using the paradigm of mass production of large batches. Notwithstanding, the examples available in the meta-case revealed some isolated initiatives aiming to change this situation. Figure 3 shows an example: a set of plastic containers developed during an ergonomic study in a Brazilian construction company. These containers are small and light and allow direct transportation to the workplace or, at least, a reduced number of intermediary stops. However, such small batches demand better synchronisation between the mixer and the bricklayer's workstation. Any variation in the bricklayer's production rate has to be followed by rapid changes in the mixer's production rate.

In the case studies practising large batches the outcome corresponded with what predicts the theory (theoretical replication). Among the most evident consequences were the difficulties to identify process problems and the increase in transportation distances. Figure 4 below shows an example of a large production batch observed in Case Study 3. In this site, the construction of two houses initiated almost at the same time by a group of four bricklayers and two labourers. From a batch size point-of-view, production in this site would be more efficient if the same four bricklayers have focused their efforts on the construction of only one house at time. This practice would reduce the transportation distances, reduce the number of equipment necessary and promote direct communication and co-ordination among bricklayers.

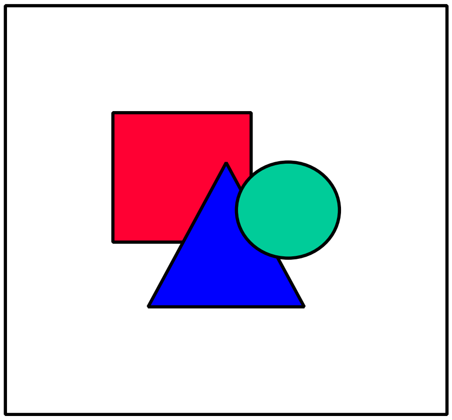

Figure 3: Literal Replication of Reduction of Batch Size (Meta Case)

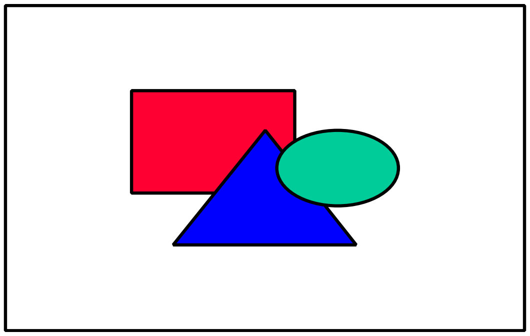

Figure 4: Theoretical Replication of Reduction of Batch Size (Case Study 3)

## SUMMARY OF FINDINGS FOR ALL PRINCIPLES AND CASE STUDIES

Tables 3 presents a general view of the situation of the case studies with respect the four principles in study. None of the case studies offered literal replications for all heuristic implementation approaches. This deficiency is more evident on the principles “reduction of variability” and “build of continuous improvement”. The direct consequence of this scattered replication of the theory was the sub-optimal performance of the production systems, as illustrated on the indicators presented on Table 2.

Since all four principles in study derived from the same core concept (production as a flow) it was reasonable to expect that they should be complementary to each other in practice. The intra-case study analysis dedicated to assess the degree of integration of practices within the case studies. Figure 2 shows the severe deficiency of the case studies in terms of inter-relationships among the heuristic implementation approaches.

Case Study 2 presented the largest number of literal replications of the theoretical propositions in study (Table 3). It also presented the best situation in terms of integration of practices, as demonstrated in Figure 2. The majority of the literal replications concentrated on the approaches aimed at "reducing cycle time" and "increase transparency". Indeed, this site presented the largest number of literal replications on "reduction of batch" and "visual controls".

Table 3: Literal Replications Identified across Case Studies

| **INDICATOR** | **CASE** | | | | | |
|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** |
| **REDUCTION OF CYCLE TIME** | | | | | | |
| Reduction of Batch Size | □ | ■ | □ | ▨ | □ | □ |
| Reduction of Work-in-Progress | □ | ■ | ▨ | ■ | □ | ▨ |
| Minimisation of Distances | ▨ | ■ | □ | ▨ | □ | □ |
| Change in the order of the process | ■ | ■ | ■ | ■ | □ | ■ |
| Synchronisation and Smooth of Flows | □ | ■ | ▨ | ■ | □ | □ |
| Isolation of Value Add from Support Activities | □ | ■ | ▨ | ■ | □ | ▨ |
| Solving Control and Constraint Problems | ▨ | ■ | □ | ■ | □ | ▨ |
| **REDUCTION OF VARIABILITY** | | | | | | |
| Measuring, Finding and Eliminating Problems | □ | □ | □ | □ | □ | □ |
| Standardisation | ▨ | ▨ | □ | □ | □ | ▨ |
| Poka-Yoke | ▨ | □ | □ | ▨ | □ | ▨ |
| **INCREASE OF TRANSPARENCY** | | | | | | |
| Reduction of Interdependence | □ | ▨ | □ | □ | □ | □ |
| Number of Visual Controls | ■ | ■ | ■ | ■ | ■ | ■ |
| Making the Process Directly Observed | □ | ■ | □ | ▨ | □ | □ |
| Installing Information into the Workplace | □ | ■ | □ | ▨ | ▨ | ▨ |
| Maintenance of Clean and Orderly Workplace | ■ | ■ | □ | ■ | ▨ | ▨ |
| Rendering Invisible Attributes into Visible | □ | □ | □ | □ | ▨ | □ |
| **BUILD CONTINUOUS IMPROVEMENT** | | | | | | |
| Setting Stretch Targets | ■ | ▨ | □ | □ | □ | ▨ |
| Sharing the Responsibility for Improvements | □ | □ | □ | ▨ | □ | □ |
| Using Standards to Challenge Practices | ▨ | ▨ | □ | □ | □ | □ |
| Measuring and Monitoring Improvements | □ | □ | □ | ▨ | ▨ | □ |
| Linking Improvements to Control | □ | □ | □ | □ | ▨ | □ |
| Change Push Orders to Pull Orders | ▨ | ■ | □ | ▨ | □ | ▨ |

Key:
■ Integrated Literal Replication ▨ Isolated Literal Replication □ Theoretical Replication

Some of the most visible effects of these practices in the process performance of this case study were: best gang composition (3:2), reduced storage, efficient flow of materials, reduced time between visits to the workplace, fastest changeover time and reduced waste of material (Table 2).

## REDUCTION OF CYCLE TIME

The construction sites investigated in this research supplied empirical evidence that matched all approaches for reducing cycle time. However, the case studies (summarized in Figure 5) revealed very few literal replications matching the approach "reduction of batch size" and "reduction of work-in-progress".

Reduction of Batch Size
Reduction of Work-in-Progress
Minimisation of Distances
Changes in the Order of the Process
Synchronisation and Smooth of Flows
Isolation of Value Adding from Supporting Activities
Solving Control Problem and Constraints to a Speedy Flow
Measuring, Finding and Eliminating Root Causes
Standardisation
Poka-Yoke
Reducing the Interdependence between Workstations
Visual Controls
Making the Process Directly Observable
Installing Information into the Production Environment
Maintenance of a Clean and Orderly Workplace
Rendering Invisible Attributes Visible Through Measurements
Setting Stretch Targets
Sharing the Responsibility for Improvement with All Employees
Use of Standards as Hypothesis of Best Practice to be Challenged
Measuring and Monitoring Improvements
Linking Improvements to Priorities Set by the Control
Changing Push Orders to Pull Orders

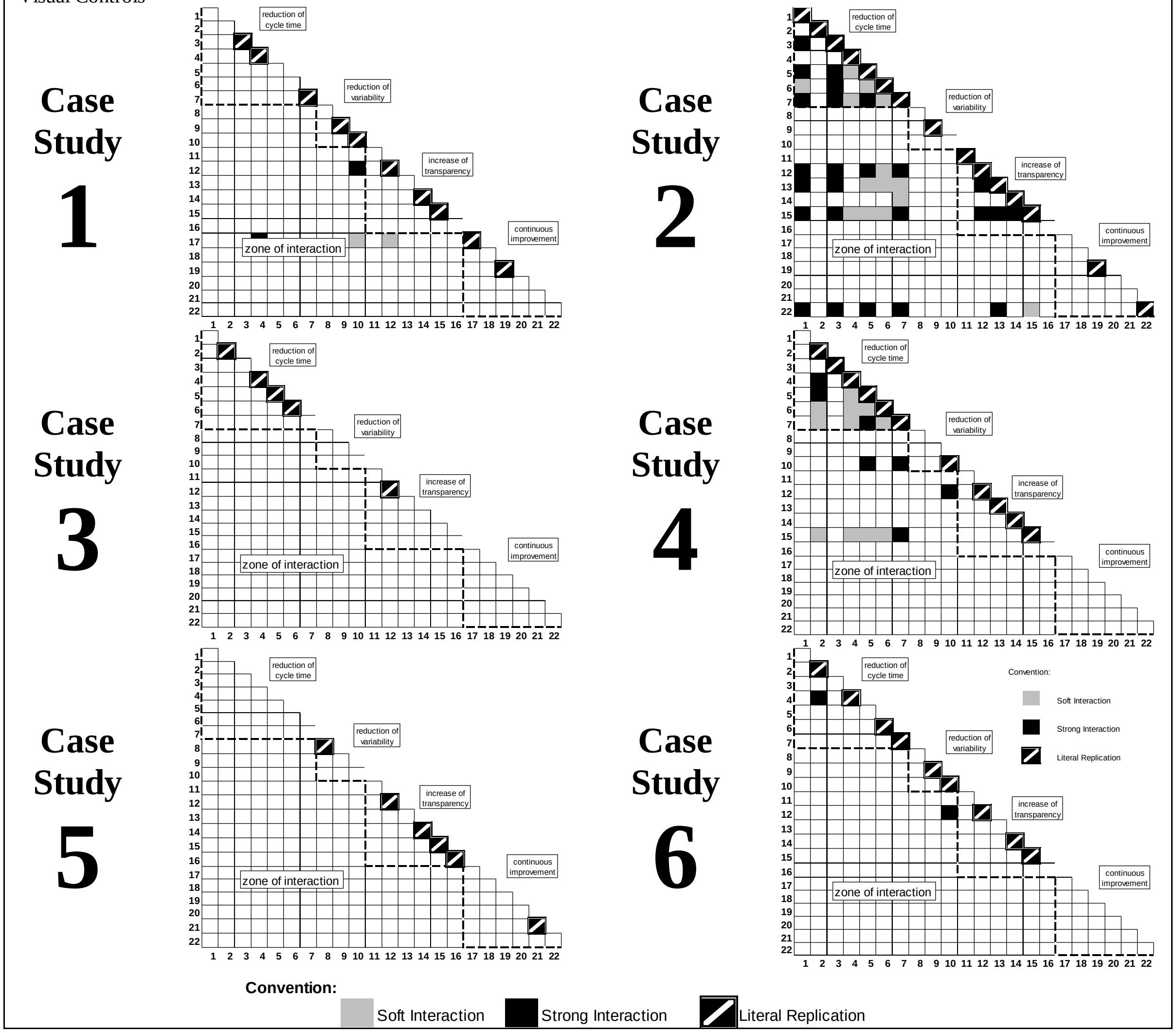

Figure 5: Pattern Matching of Implementation Approaches and respective Inter-relationships

The paradigm of mass production was a barrier for implementing small batches. Construction managers did not seem to understand that the use of resources in their full capacity, producing more sub-products than necessary, was a waste of resources. In fact, for some managers, waste due to overproduction does not exist in a construction project since the sub-products have to be produced anyway. Indeed, the demand for sub-products is guaranteed during a construction project and one could be tempted to initiate the production of large batches. However, construction managers did not acknowledge the benefits of immediate identification and correction of errors that the practice of small batches can bring.

### REDUCTION OF VARIABILITY

The reduced amount of evidence matching the theoretical propositions suggests that this is a principle that still needs considerable effort to be completely integrated in the daily construction practice. Very rarely, systematic activities of measurement, identification and elimination of root cause of variations were performed in the case studies. The lack of application of this approach in practice resulted in a reinforcing cycle, in which more variability reduced even further the time available for reducing variability. Managers and workers often argued that measurements were not practised in their construction sites because it is a time consuming activity. Co-operation with other industries, particularly the electronic industry, could bring innovative developments for construction in this respect. For instance, automatic data collection tools could be developed to construction processes using electronic devices where process data would be collected and processed in real time.

### INCREASE OF TRANSPARENCY

The case studies supplied empirical evidences matching all approaches aimed to increase transparency. However, comparison of these case studies with the cases presented in the literature reveals that the construction industry applies the transparency principle in considerably less intensity than manufacturing. Construction workers frequently spent precious time searching, wandering, or waiting for tools, materials, and information instead of adding value to the final product. Piles of unneeded and sporadically used materials often obstructed pathways and direct visibility. Moreover, the open-ended interviews have shown that workers did not know what exactly was expected of them or how was their performance, for instance. All construction companies had few visual mechanisms to inspire or motivate workers to carry out their jobs more effectively, efficiently and safely.

### APPLICATION OF CONTINUOUS IMPROVEMENT

The number empirical evidences matching the implementation of continuous improvement approaches was very small. Most striking was the lack of participation of workers in problem solving activities and the little use of data collection to identify and eliminate the root cause of problems. Continuous improvement is a central principle to obtain the successful implementation of all other production management principles. Thus, this deficiency certainly has a direct impact in the coherent application the entire theory.

## CONCLUSION

Although construction practice presented empirical evidence matching all principles in study, the analysis unveiled a serious problem of systemic integration and a lack of complementary practices throughout all construction sites. In this respect, the case studies presenting the best performance were those that presented a small but well-connected set of practices matching the theory. Apparently, the reason for the lack of systemic application of the theory in practice was twofold. Firstly, there was an actual gap of knowledge among practitioners in all sites analysed with respect to a number of approaches such as batch size reduction and visual controls. In this respect, there is an urgent need for more research into ways for disseminating the theory so as to help construction practitioners to be more effective. Secondly, some practitioners did not have the structure, motivation and support to apply the theory thoroughly. The end result of that situation was production systems working under sub-optimal levels of performance. The main recommendations for industry and academy are:

- **opportunities for industry:** development knowledge among personnel that emphasises the integration of the concepts, principles, heuristic implementation approaches and tools of the modern production management theories.
- **opportunities for research:** consolidation of the inter-relationships among the main principles of production management through systemic application in construction practice.

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