

MATHEMATICAL ANALYSIS FOR THE DIAGNOSIS OF THE LEAN CONSTRUCTION IMPLEMENTATION

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OBJECTIVE

- Analyze the application of the Lean diagnosis tool, considering the potential of different kind of average (arithmetic, weighted, fuzzy).
- The aim is not compare the averages, but evaluate the potential of the use of each one.

APPLICATION OF THE CAMARGO FILHO QUESTIONNAIRE (2017)

- The main theoretical underpinning of the questionnaire developed by Camargo Filho (2017) is based on Womack and Jones (1996).
- The questionnaire was created to evaluate the level of implementation of LC practices in six construction companies in Goiânia/Brazil.
- The final version of the questionnaire created 4 categories: Quality Management, Supply Chain Management, Planning Production and Control and Project Management – Lean Construction Assessment Tool (LCAT).
- Among these categories, there are 84 lean practices, in which the final percentage of its fulfilment defines how lean the company is.

| CATEGORY | PREREQUISITE | CRITERIA |
|---------------------------------------|--|---|
| Quality Management | Certified Quality Management System | Worker training |
| | | Problem Solving |
| | | Internal and External Benchmarking |
| | | Use of Poka-yokes and Technological Innovation |
| | | Performance Evaluation |
| | | Motivational Policies and Worker Satisfaction |
| | | Organization of the workplace and construction site |
| Supply Chain Management | Defined criteria for supplier selection | Supplier Selection |
| | Control of delivery of materials in compliance with specifications and quality | Supplier relations |
| | | Buying process |
| | | Stock and material storage control |
| | | Physical space control |
| | | Internal distribution of supplies |
| Controlling costs in the supply chain | | |
| Planning Production and Control | Planning Production and Control Process formalized | Long-term planning |
| | Transparent long-term plan | Medium-term planning |
| | | Short-term planning |
| | General defined activity stream | Value Stream Mapping |
| | | Production Control |
| Project Management | Internal department responsible for project management | Cost Control |
| | Project verification process regarding quality and specifications | Project Development Planning |
| | | Compatibility and validation of projects |
| | | Identification of the value required by the client |
| | | Identification of problems in projects |

DATA PROCESSING

- The companies were classified as medium to large organizations, with more than ten years in operation.
- The data obtained were analyzed in three different ways: arithmetic average, weighted averages (based on the experience of expert in lean construction) and average of results using Fuzzy Logic.
- Based on these three results, it will be possible to produce bar graphs to support the analyses and their potential results.

DATA PROCESSING

ARITHMETIC AVERAGE

- The percentage of fulfilment for each category is calculated as the average of the scores for the criteria, in relation to the total fulfilment of the criteria.

DATA PROCESSING

WEIGHTED AVERAGES

- The weights used to calculate the weighted averages were obtained from the analysis of **six specialists in the area of Production Management/Lean Construction.**

WEIGHTED AVERAGES

- The aspects analyzed were: importance, complexity, time of implementation of practices and ideal time of implementation of LC.

DATA PROCESSING

| Importance | Complexity | Time of implementation of practices | Ideal time of implementation of lean construction (5 years) |
|----------------|--------------|-------------------------------------|---|
| Essential | Complex | Initial phase | Initial phase |
| Very important | Intermediate | Maturation phase | Maturation phase |
| Not important | Basic | Continuous improvement phase | Continuous improvement phase |
| Irrelevant | | | |

- The average scores attributed by the experts will be used as a weighting to determine the percentages of fulfilment.

WEIGHTED AVERAGES

- Table 1 below shows an example of how this weighting was presented for the variable "implementation time" and in Table 2 we can see the factors corresponding to this weighting.

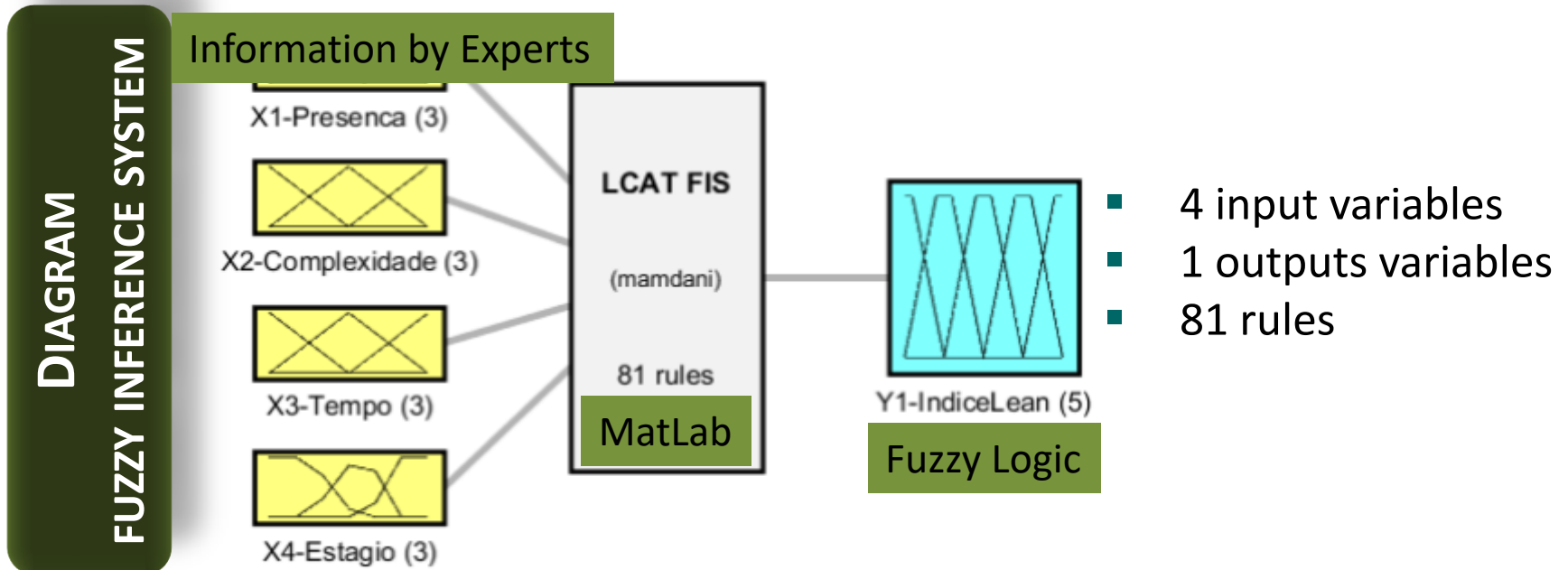
| IMPLEMENTATION TIME BY SPECIALISTS | | | | | | | | | |
|------------------------------------|----------|--------------|------------------------|------------------------|----------|----------|----------|------------------------|---------|
| Category | Criteria | Sub-Criteria | S1 | S2 | S3 | S4 | S5 | S6 | |
| Quality management | 1 | 1.1 | initial | initial | initial | initial | initial | initial | initial |
| | | 1.2 | maturity | initial | initial | initial | initial | maturity | initial |
| | | 1.3 | continuous improvement | maturity | maturity | maturity | maturity | maturity | initial |
| | | 1.4 | continuous improvement | continuous improvement | maturity | maturity | maturity | continuous improvement | initial |

| Weighting factors | | | | | | | | | |
|--------------------|----------|--------------|----|----|----|----|----|----|--------------------|
| Category | Criteria | Sub-Criteria | S1 | S2 | S3 | S4 | S5 | S6 | Average of factors |
| Quality management | 1 | 1.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| | | 1.2 | 1 | 0 | 0 | 0 | 1 | 0 | 0.33 |
| | | 1.3 | 2 | 1 | 1 | 1 | 1 | 0 | 1.00 |
| | | 1.4 | 2 | 2 | 1 | 1 | 2 | 0 | 1.33 |

- The average scores attributed by the experts will be used as a weighting to determine the percentages of fulfilment.

FUZZY AVERAGE

| Importance of criteria | Importance of item | Complexity of practices | Time of implementation of practices | Time of implementation of LC (5 years) |
|------------------------|--------------------|-------------------------|-------------------------------------|--|
| Essential | Essential | Complex | Initial phase | Initial |
| Very important | Very important | Intermediate | Maturation | Maturation |
| Not important | Not important | Basic | Continuous improvement | Continuous improvement |
| Irrelevant | Irrelevant | | | |

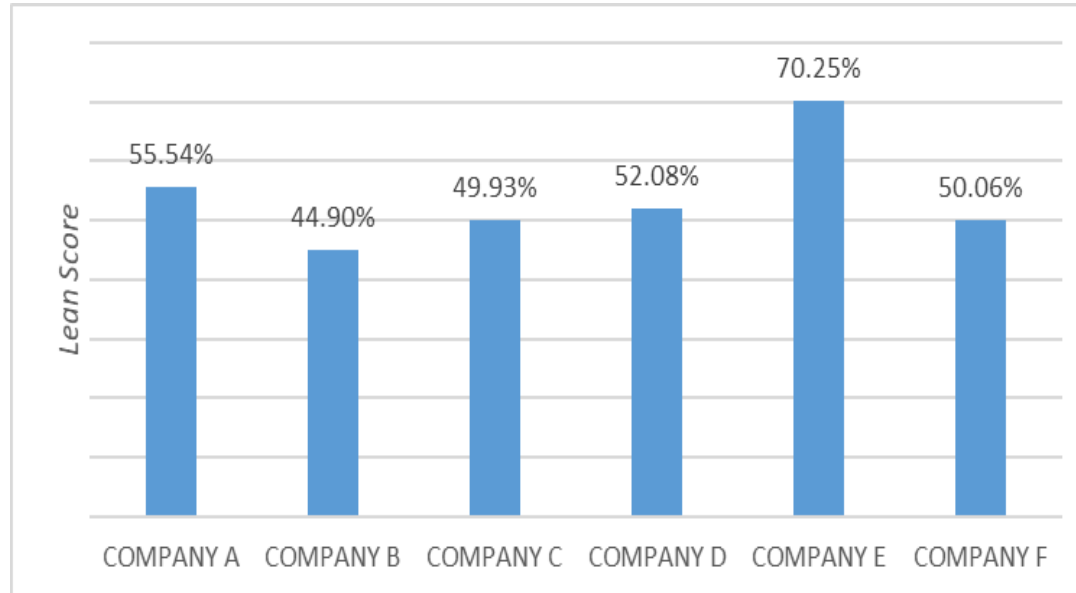


RESULTS AND DISCUSSIONS

- Based on the application of the LCAT in the companies, the **Lean Score** of each company was obtained.

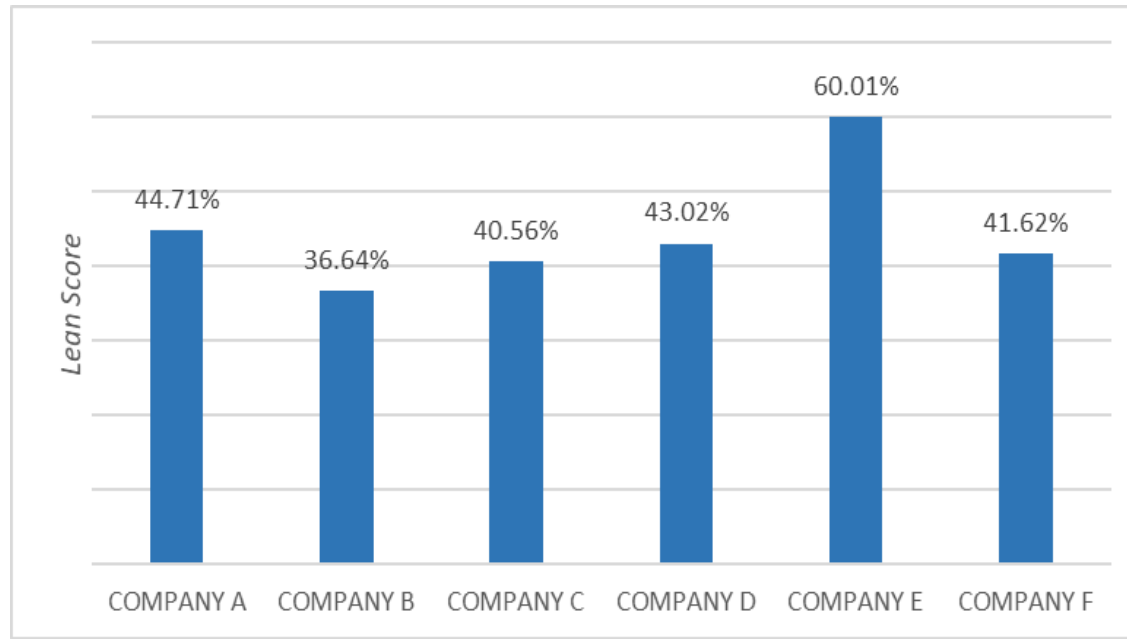
| Degree of Implementation | <i>Lean Score</i> |
|--------------------------|-------------------|
| Very Low | 0 - 20% |
| Low | 20% - 40% |
| Medium | 40% - 60% |
| High | 60% - 80% |
| Very High | 80% - 100% |

LEAN SCORE BY COMPANY USING ARITHMETIC AVERAGE



- Companies A, B, C, D and F had a Lean Score that vary from a 44% to 56%, demonstrating that there is a process of implementation of lean construction principles.
- However, it was noted that there are some important issues missing in the consolidation of this implementation, such as value flow mapping and medium term planning, both of which are part of the production planning and control.

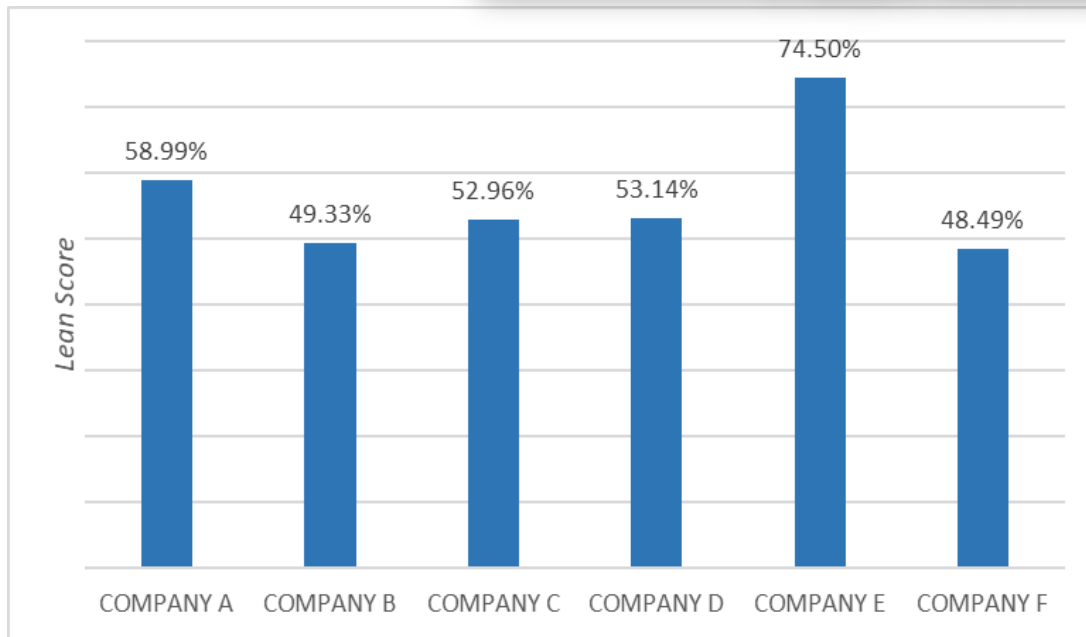
LEAN SCORE PER COMPANY USING WEIGHTED AVERAGE



- The expert-weighted average had the **lowest indices** when compared to the other averages in all companies.
- This result is mainly due to the fact that the specialists concentrate of classification in the items of the initial or maturation stage of implementation.

LEAN SCORE PER COMPANY USING FUZZY AVERAGE

DUBLIN | IRELAND | IST - 7TH JULY 2019



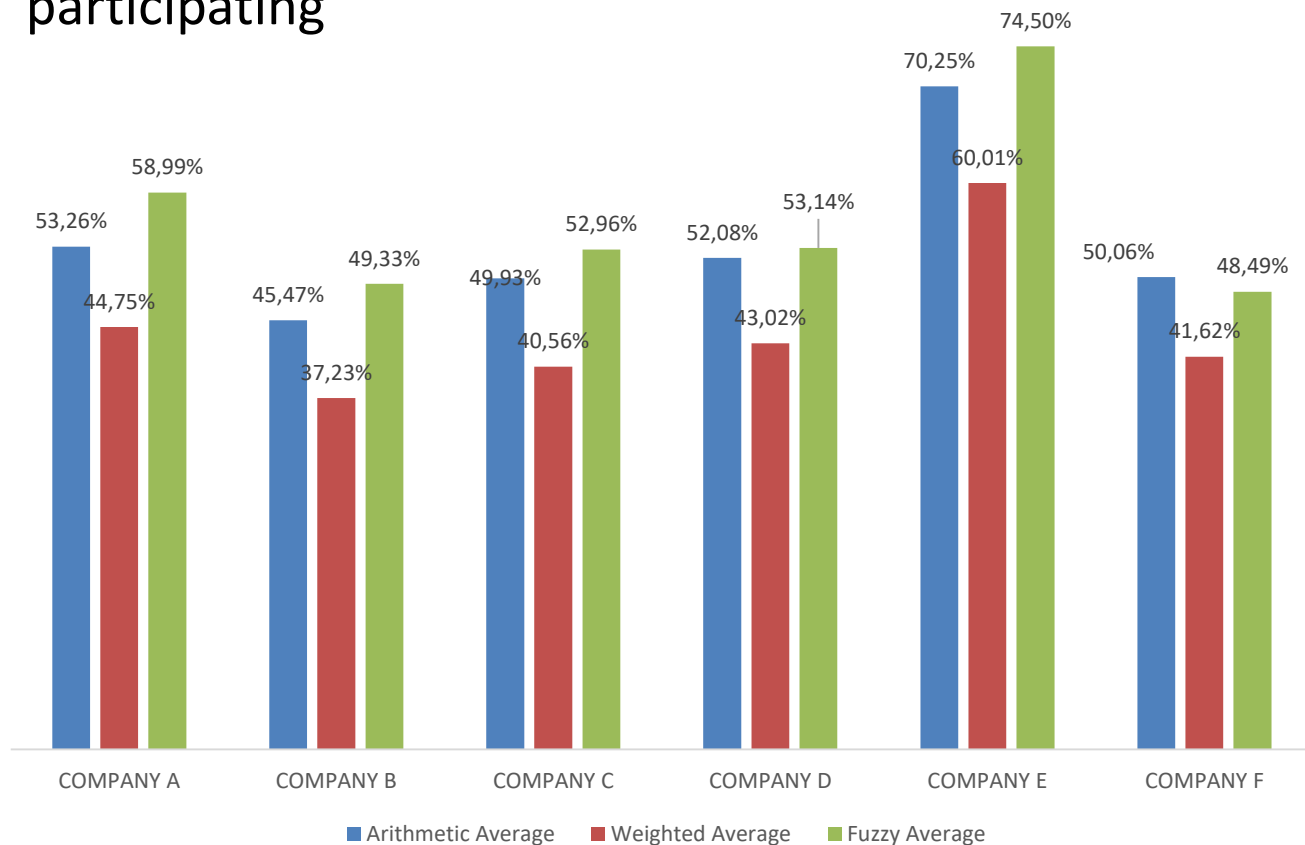
- All the results were similar 50%

- The implementation stage considered for all companies was zero, i.e. the companies were just beginning the implementation process and the evaluation was less demanding, with some items not applied.
- Good performance in the categories was supported by quality management system and supply chain management of companies.

SUMMARY OF THE LEAN SCORE BY COMPANY

DUBLIN | IRELAND | 1ST - 7TH JULY 2019

The result shows that the weighted average has the lowest values in relation to the other averages in all participating companies.



CONCLUSION

- The three types of average used to calculate the degree of implementation of lean construction attend their objectives and had specific advantages.
- The arithmetic average is the easiest to interpret. However, it does not present the necessary statistical analysis, but has its limitation

CONCLUSION

- The weighted average attributed by specialists enables the opinions of third parties to be considered in the results.
- The averages calculated using the Fuzzy Inference System enables various variables to be considered, such as: importance, complexity, time and stage of implementation.
- This analysis helps to minimize the influence of the evaluator's judgment, and present more accurate Lean diagnosis.



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