Applying Lean Thinking to Smart Cities: Environmental Sustainability and Resources Waste Reduction

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Abstract—**Inequality in population distribution between urban and rural areas tends to increase in the next years, in favor of cities. As this trend is not expected to revert in the next years, cities should be eager to receive their share of inhabitants; at the same time, they must be prepared to offer citizens the services matching their expectations, although hosting more people requires either a higher need of resources or a better usage of the available ones. In this article, the authors propose applying Lean Thinking to develop an integrated administration system for a city within the Smart Cities' paradigm, allowing urban managers to take advantage of Information and Communication Technologies (ICT) for a better utilization of resources, minimizing waste of the available reserves.**

Index Terms—**Lean Thinking, waste, resources, Smart City, ICT**

I. Introduction

Following the recent trend, it is expected that more than half of the world population will live in cities until 2050, with the number becoming more expressive if only considered the most developed regions of the earth [1]. Therefore, it is up to the cities to ensure they are (or they become) sufficiently attractive to guarantee their share of the future urban population.

The higher the ability of a city to attract people to live, work, study or visit, the higher its development potential and level of competitiveness when compared to other cities. For that to happen, it is fundamental that the city meets the needs of its inhabitants, workers, students, and tourists, in several domains such as, for example, mobility, education, or security. However, increasing the attractiveness of a city, and the consequent population growth, presents the challenge of hosting a higher number of consumers of resources such as water, electricity, housing, healthcare, or solid waste treatment. Cities and their governments can opt for (i) increasing the level of resources used or (ii) increasing the efficiency of the current resources. In a context of public expenditure reduction, the second option presents itself as the better one.

The concept of Smart City comes in as the city which can conjugate the two sides of the same coin, a city able to attract individuals while managing the available resources efficiently, able to promote economic and social development considering environmental conservation, able to satisfy its citizens' needs in a sustainable way [2]. This is only possible if cities provide their researchers and citizens tools to stimulate the needed creativity in the development of solutions to sustain these premises. A way of leveraging the creation of solutions for Smart Cities is real-time data sensing, transmission and analysis, supporting the optimization of several processes composing the function of the urban ecosystem.

Efficient resources management and process optimization are also attributes of Lean Thinking. With its origins in the post-World War II, within the Japanese automobile industry, and more specifically in Toyota Motor Company, this management paradigm was developed in a scarcity context, having to focus on efficient resource utilization. Lean Thinking also advocates a great proximity between managers and field workers, in a way to quickly identify and mitigate problems in the front line. With the results obtained in Toyota, other automotive companies have adopted the strategy; with proper adaptions, other industries have embraced it as well.

This research intends to bring together these two realities, suggesting a framework within the Smart Cities paradigm and after reviewing its fields of action, based on the Lean Thinking methodology. The framework will be presented to relevant specialists, so it can be validated and criticized, to obtain conclusions regarding the utility of Lean Thinking in managing a Smart City

II. Smart Cities

A. Background

Populations tend to concentrate in urban areas: in the most developed areas of the world it is expected an increase from 54,6% in 1950 to 85,4% in 2015 – an absolute increment of 30,8% in a hundred years [1].

However, urban growth results in social, economic and organizational issues to the cities as, for example, an increase in traffic, pollution or social inequality [3]. These issues, if not addressed properly, may jeopardize economic and environmental sustainability of the cities; the Smart City concept arises as an answer to this trend, as the paradigm for evolution, development and

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sustainable growth of current cities. The Smart Cities approach seeks to find solutions for planning, livingness, viability and sustainability of urban areas, via technological evolution [4].

The term "Smart Cities" may have had its origin in the Smart Growth Movement, in the late 1990s, which advocated new urban planning politics. Subsequently, technological companies adopted the expression to define the information systems integration within urban infrastructures and services, such as buildings, transportation, or water and electric supply. Today, the term covers mainly any technological innovation contributing for planning, developing and operationalization of urban infrastructures or services [5].

B. Fields of Action

The considered fields of action in a Smart City for this investigation are based in a research distinguishing two types, the tangible and intangible fields, more and less subject to be affected by the capabilities of ICT, respectively. (Table I)

TABLE I. FIELDS OF ACTION IN A SMART CITY [4]

Tangible domains	
Domain	Main objective(s)
A. Energy grid	Effective energy provision, exchange of information regarding electricity consumption
B. Street lighting	Street lighting network management
C. Water management	Measurement of water consumption and leakage
D. Solid waste management	Definition of solid waste collection flow, destruction and recycling of solid waste
E. Environment	Usage of technology for environmental resources protection, pollution control
F. Transportation and mobility	Optimization of transportation networks considering traffic and energy consumption, real-time provision of traffic information
G. Buildings	Adoption of technology to create 'living' buildings
H. Healthcare	Technology usage in remote assisted healthcare, diseases prevention and diagnose
I. Security	Real-time data transmission to security forces
Intangible domains	
Domain	Main objective(s)
J. Education and culture	Utilization of ICT tools in educational institutions, promotion of cultural events in online platforms
K. Social inclusion	Development of tools to decrease social barriers
L. Public administration and e-government	Development of online public services, electronic voting, shared governance
M. Economy	Promotion of innovation, entrepreneurship, the integration of the city in global markets, of a circular economy model

III. LEAN THINKING

A. Background

Effective administration of resources and optimization of processes are two characteristics of Lean Thinking. With its origins on the post-World War II, within the Japanese automobile industry and more specifically in Toyota Motor Company, this management paradigm was developed in a scarcity context, having to focus on efficient resource utilization. Lean Thinking also advocates a great proximity between managers and field workers, in a way to quickly identify and mitigate problems in the front line. With the results obtained in Toyota, other automotive companies have adopted the strategy; with proper adaptions, other industries have embraced it as well.

B. Lean Thinking Principles

Womack & Jones [6] established in their book, Lean Thinking, the five aspects they consider to be the main principles of the methodology.

1) Value identification

It is crucial to identify value, expressed in terms of a specific product or service, and from the client's point of view; providing the client a product or service he doesn't want, or need, is considered waste.

2) Value-chain identification

Determining all the activities composing the production process gives visibility to value added, non-value added (but inevitable) and waste activities. It is then possible to remove all waste activities, rethink the need for non-value-added activities and refine value added ones.

3) Flow

When all waste is eliminated, the remaining activities must be organized in a way to avoid interruptions, delays or bottlenecks.

4) Pull

With clear value definition, and with a flowing value-chain free of waste, time from beginning of production until delivery decreases. Thereby, it is the customer pulling the product or service, instead of the organization pushing it.

5) Perfection

The fifth and last principle consists in the continuous application of the previous four: continuously looking for waste, redefinition of value, and repeated perfection of value-chain activities – kaizen, the Japanese word frequently found in Lean Thinking literature.

C. Value and Waste

The main objectives of Lean Thinking are the clear identification of value as something provided to the customer at the right time by the right price, and the elimination of waste as any activities within the processes of an organization that absorbs resources without adding value [7]. Researchers identify seven types of waste[1], as described on Table II.

TABLE II. TYPES OF LEAN THINKING WASTE [8]

Type of Waste	Description
1. Overproduction	Effective energy provision, exchange of information regarding electricity consumption
2. Waiting	Street lighting network management
3. Transportation	Measurement of water consumption and leakage
4. Overprocessing	Definition of solid waste collection flow, destruction and recycling of solid waste
5. Inventory	Usage of technology for environmental resources protection, pollution control
6. Motion	Optimization of transportation networks considering traffic and energy consumption, real-time provision of traffic information
7. Defects	Adoption of technology to create ‘living’ buildings

IV. THE ‘LEAN SMART CITIES’ FRAMEWORK

Taking into consideration the fields of action in a Smart City and the types of waste contemplated within Lean Thinking, a framework of action consisting in proposals crossing these two aspects was developed and presented to three relevant specialists.

For ease of proposal identification, letters were attributed to the Smart Cities fields of action while numbers were attributed to Lean Thinking types of waste, as contained in the tables above.

A. Framework Proposals

1) A-15 Utilization of technology to adjust the production levels of energy.

This can be done by the development of a system that senses consumptions of a certain area, creating patterns and defining the right amount to produce, therefore eliminating overproduction and the need for inventory storage as much as possible.

2) A-3 Least-effort principle applied to energy grid.

If the energy grid is designed to run across the minimum possible distance, decreasing energy transportation, loss of energy can be avoided.

3) A-7 Detection of failures in the energy grid.

Sensing the energy grid for faulty zones can reduce the impact of defects on energy supply.

4) BI-1 Motion sensor for people and vehicles.

Sensing the presence of people or vehicles can help to adjust the intensity of public lightning, reducing the overproduction of light needed and increasing the levels of security.

5) C-3 Least-effort principle applied to water grid.

If the water grid’s course is as minimal as possible, and therefore reducing water transportation, there will be less points where leakage occurs.

6) C-7 Water leakage detection.

Water leaks may occur, but sensing the whole grid for defects will help detecting them faster, reducing water loss.

7) DM-1 Limitation to non-recyclable waste deposit.

By limiting the amount of non-recyclable waste that an individual can deposit, with the help of proper containers, it is expected the individual will reduce the overproduction of this type of solid waste and will recycle more; moreover, having a bigger amount of recycled waste re-entering the production will also help the economic agents.

8) D-46 Dumpster filling level sensing.

Receiving data from dumpster with the level of filling will allow an optimized planning of the collection routes, reducing the movement of collection trucks, and avoiding the work of collecting dumpsters at a sub-optimal level.

9) E-1 Pollution levels sensing.

Overproduction of noise and atmosphere pollution can be sensed, so proper measures to mitigate these problems can be taken.

10) E-4 Humidity sensors for green areas.

Sensing green areas for humidity may avoid unnecessary irrigation if it rained recently

11) EF-6 Least-effort principle applied to urban roads.

Defining the shortest roadway from the most important points in the city, to reduce the movement needed to go from one to another, impacting positively the environment as well.

12) FI-2 Smart traffic lights.

Having a dynamic system according to the current flow of traffic to reduce overall waiting in red lights, with impact in the fields of mobility and security

13) F-6 Smart public-parking system.

Providing real-time information to drivers regarding free parking slots, through a mobile app, to reduce the movement needed to find one.

14) G-1 Room presence sensors.

Turning on the appliances of a room such as lights, air conditioning or wi-fi, when presence is detected, turning them off when the room is empty, to reduce overproduction of energy needed to support these appliances.

15) G-6 Smart underground-parking system.

Ensuring real-time information to drivers in an underground automobile park, decreasing movement to find a free parking slot.

16) H-26 Healthcare remote monitoring.

Establishing several healthcare monitoring points through the city, collecting data to create patterns; when a measurement is out of the pattern the citizen is immediately notified to go to a health care center, but if everything is in normal levels he avoids traveling and waiting for his time to be seen, reducing also waiting time for other more urgent situations of other people.

17) J-2 Cultural infrastructures online guide.

Raising awareness to less known cultural infrastructures of a city, to avoid overcrowding of the most demanded ones, is expected to reduce waiting time for visits.

18) J-246 Online educational services.

Digitalizing bureaucracy around educational services avoids movement to the building, waiting time and paper processing.

[1] Some researchers identify an eighth type of waste, Non-Utilized Talent, but it is not consensual. Therefore, it was not considered for this research.

19) K-7 Promotion of technological learning for those in greatest need.

Assuring everyone has the access to technological equipment and learning will ensure equal opportunities and reduce defects of learning.

20) L-26 Online public bureaucratic services.

Digitalizing services that do not required the presence of the citizen reduces movement and waiting time in public authority buildings.

21) L-37 Interactive guide for public bureaucratic processes.

Having a single digital document containing all the information regarding every public bureaucratic process (e.g., where to handle the process, all the documents needed) avoids the transportation of unnecessary documents and starting a process that cannot be finished due to lack of documentation, leading to rework.

22) M-1 Incentive to the acquisition of recyclable materials.

Encouraging the purchase of recyclable materials reduces the need for production of new raw material, and can be done, for example, by attributing tax benefits.

B. Framework Discussion

All the specialists enquired consider that, in a theoretical plan, the framework presented may be useful for a Smart City manager. They believe, however, it is fundamental to consider other aspects such as, for example, the education of the citizen in order to take advantage of the solutions developed, the clear definition of the responsibilities of the actors involved in urban operations (management and utilization), a distribution of intervention competences making processes flow, a cost/benefit analysis to the proposals, and the development of recommendations for the citizens in the value co-production point of view.

It is unanimous for all the specialists that Lean Thinking is useful in managing a Smart City, being waste reduction the focus referred by them all. Among the recommendations, highlights for the structured way as Lean Thinking addresses waste, the transversal nature of the methodology to every kind of governance, the usefulness of the methodology in creating fluid processes and integration of systems, and the available technology allowing us to put Lean Thinking further into practice in a real-time logic of action supported by sensing and data analysis.

Specialists also suggested improvements and criticized the framework. One of the critics addresses the economic feasibility of the solutions: despite the decreasing cost of technology, for the present time it is necessary to assess the cost and impact of each one of the solutions and (i) prioritize the low cost and high impact solutions; (ii) plan the implementation of high cost and high impact solutions; (iii) equate the implementation of low cost and low impact solutions; and (iv) discard high cost and low impact solutions. Another criticism refers the fields of action, considering there are other fields where there are opportunities to work on. Finally, it is criticized the role of the citizen in the framework, it should be a central role with an active participation but was seen as a passive agent that only uses the proposed solutions.

V. Conclusions

A. Investigation Results

This research sought to find value in the utilization of Lean Thinking for managers of Smart Cities. Considering the opinions of relevant specialists, it was possible to meet the objectives of the research and assess this value.

It is essential to create an articulated Lean governance model, so the decision-making process is also free from waste, meaning, devoid from unnecessary steps. The adequate autonomy must also be attributed to the correct entity to avoid simple decisions to go through too many entities.

Not being possible to apply all the proposed measures to improve urban operations, the creation of a prioritization matrix will help to unveil the ones with a better cost/impact relation. Thus, the decision making regarding which proposals to implement is facilitated.

Citizens must have a fundamental role in urban operations, not being limited to a passive role of just using the services the city provides. A city must grant them the tools and skills necessary for them to use the technological solutions provided, but also to educate them in a way to use services and resources in a responsible and sustainable way.

B. Future Work

Smart Cities solutions implementation itself must be smart. It is suggested therefore an analysis to the governance models in place, to assess and eliminate waste in the decision-making processes that may delay or negatively impact the realization of the solutions.

It is also proposed an analysis to the role of the citizen in a Smart City. This analysis should include not only measures to educate the citizen to live in the city of the future, but also recommendations on attitudes to have in the context of a sustainable and shared urban living.

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