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Evaluation of the Relation between Lean Manufacturing, Industry 4.0, and Sustainability

Hélio Castro and Paulo Ávila

School of Engineering, Polytechnic of Porto, Portugal

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Nowadays, Lean Manufacturing, Industry 4.0, and Sustainability are important concerns for the companies and, in a general way, for the society, principally, the influence of the two production philosophies, Lean Manufacturing and Industry 4.0, in the three main pillars of sustainability: economic, environmental, and social.

To better understand the relation between these production approaches and the by different sustainability's criteria, it will be presented a study based on a structural equation model, with six hypotheses, to quantitatively measure the effects of Lean Manufacturing and Industry 4.0, in Sustainability.

These results can contribute as an important decision support for the industrial companies and its stakeholders, even because some results diverge from mainstream opinion.

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Contents

I. Introduction

At present, Lean Manufacturing (LM), Industry 4.0 (I4.0), and Sustainability are important concerns for companies and in a general way for the society. The influence of the two production philosophies, LM and I4.0, in the three main pillars of sustainability—economic, environmental, and social—for industrial companies situated in Iberian Peninsula (Portugal and Spain) is the main objective of this work.

More precisely, the principal reasons and motivations to develop this study are related with:

(1) There is no existing study using the structural equations modeling technique for both production philosophies (LM and I4.0) and the pillars of sustainability;
(2) because the knowledge of these potential correlations can influence important decisions for the industrial companies and its stakeholders.

In fact, the topic of this work concerns all parts of society minimally affected by the outcomes of LM and, more recently, with I4.0. In relation to this, the uncertainty is large, and few concerns are now appearing from different sides of the society, e.g., related with the future of the employment.

I. Introduction

Lean Manufacturing (LM)

Lean manufacturing (LM), or lean production, in time philosophy, Toyota production system, or more often just “Lean”, is a philosophy which considers the utilization of resources for any goal with value creation for the end consumer. It targets the elimination of wasteful activities involved in the value system [1,2].

LM is supported by a set of well-known tools to operationalize its goals, either at a strategic level or at an operational level, and the basis of the philosophy considers the human being as an import issue in all its decisions.

Unfortunately, nowadays the companies that introduce LM practices tend to forget this human aspect, and principally focuses on waste reduction, a side that has brought well known results for the production systems.

I. Introduction

Industry 4.0 (I4.0)

The Industry 4.0 or I4.0 for short [3–6], is starting to revolutionize communities requiring a significant upgrade not just in terms of technology. With the advent of exponential technology and high speed and big data processing capabilities, high levels of digitalization regarding all kind of processes in companies are also required.

These processes have to become supported by appropriate infrastructures, such as: IoT, IIoT, RFID, CFS, and Cloud, [3–10] along with additional fitting hardware and software means for enabling a full vertical and horizontal integration of all companies' functions, from the administrative level down to the shop floor.

Additive manufacturing [9] and collaborative robots [11], for instance, are expected to play a crucial role in this direction, but also suitable organizational structures and business models, and along with appropriate production and decision methods and supporting tools are going to be necessary to enable a successful ingress on I4.0.

Moreover, according to [6,12] the principles of Industry 4.0 are the horizontal and vertical integration of production systems driven by real-time data interchange and flexible manufacturing to enable customized production.

I. Introduction

Sustainability

The concept of sustainability has received increasing global attention from the public, academic, and business sectors. The World Commission on Environment Development (WCED) defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [14].

Putnik and Ávila in their special issue of governance and sustainability [15] reinforce the importance of the theme and even give the character of ubiquity in the word ‘sustainability’.

Nidumolu et al., in 2009 [16] explains why sustainability is now the key driver of innovation according with their study of sustainability initiatives of 30 large corporations.

Almeida et al., in 2016 [17] says even that it is common to ignore the interdependence of the sustainability pillars for short periods of time, but history has shown that before long, mankind is reminded of it through some types of alarms or crisis.

II. Literature Review

Lean Manufacturing and Sustainability

Several organizations have successfully achieved better results and higher competitiveness through LM implementation; however, others have not, as they were unable to sustain medium- and long-term results [26].

Companies that have adopted LM to improve their results also want to be seen as socially responsible. Sustainability is considered the new LM frontier [27]. Productivity and cost-saving are necessary for the economic survival of organizations.

However, these tasks should be achieved in a sustainable way, by mitigating negative environmental and social impacts and contributing to a sustainable society [28].

II. Literature Review

Lean Manufacturing and Sustainability

Influence of Lean Manufacturing in Economic Dimension

Table 1. Influence of Lean Manufacturing in economic dimension.

Dimension	Influence	References
Economic	Increase profits	Pampanelli et al. (2014) [28]
	Increase turnover	Not identified
	Increase market share of the products	Wilson (2010) [29]
	Decrease operational costs	Zhu, et al., 2008 [30]; Mollenkopf et al., 2010 [31]; Sezen et al., 2011 [32]; Lozano and Huishingh, 2011 [33]; Azevedo et al., 2012 [34]; Díaz-Reza, et al., 2016 [35]; Gupta, et al., 2018 [36];
	Increase process performance	Shah and Ward, 2007 [37]; Sezen, et al., 2011 [38]; Ng, et al., 2015; Díaz-Reza, et al., 2016 [35].

II. Literature Review

Lean Manufacturing and Sustainability

Influence of Lean Manufacturing in Environmental Dimension

Table 2. Influence of Lean Manufacturing in the environmental dimension.

Sustainability Dimension	Influence	References
Environmental	Decrease industrial waste	Souza and Alves, 2017 [26]; Wilson, 2010 [29]; Torielli, et al., 2011 [43]; Vinodh, et al., 2011 [44]; Gupta, et al., 2018 [36]; Azevedo, et al., 2012 [34]; Hajmohammad, et al., 2013 [45].
	Decrease energy consumption of non-renewal energy sources	Ioppolo, et al., 2014 [46].
	Increase the production of renewal energy	Not identified
	Increase the practice of circular economy	Nunes and Bennett, 2010 [47]; Zhao and Chen, 2011 [48]; Ming and Xiang, 2011 [49]; Ashish, et al., 2011 [50]; Liao, et al., 2013 [51].
	Increase the collaboration with partners that follow good environmental practices	Not identified

II. Literature Review

Lean Manufacturing and Sustainability

Influence of Lean Manufacturing in Environmental Dimension

Table 3. Influence of Lean Manufacturing in social dimension.

Dimension	Influence	References
Social	Increase the number of employees	Not identified
	Increase the salary remuneration	Not identified
	Increase the quality of work conditions	Ng, et al., 2015 [41]; Taubitz, 2010 [53]; Lozano and Huishingh, 2011 [33]; Vinodh, et al., 2011 [44]; Ioppolo, et al., 2014 [46];
	Increase the conditions of the surrounding society	Not identified
	Decrease working accidents	James, et al., 2013 [54];
	Increase the participation of its employees in decision-making	Taubitz, 2010 [53]; Vinodh, et al., 2011 [44]; Jabbour, et al., 2012 [39].
	Increase the number of employees with some degree of disability.	Not identified
	Increase the contract duration of its collaborators	Not identified

II. Literature Review

Industry 4.0 and Sustainability

It is expected that I4.0 will drive companies, for instance industrial ones, to more favorable economic situations, though massive savings to be reached by reducing operators or manpower, by saving energy, and by doing work effectively and efficiently, and by reducing production time and improving productivity, among other beneficial situations [11,40,55,56].

II. Literature Review

Industry 4.0 and Sustainability

Influence of I4.0 in Economic Dimension of Sustainability

Table 4. Influence of Industry 4.0 (I4.0) in economic dimension.

Dimension	Influence	References
Economic	Increase: profits, value creation, efficiency, flexibility, and competitiveness	Müller, et al., 2018 [56]; Nagy, et al., 2018 [57]; Laudien, et al., 2017 [58]; Rennung, et al., 2016 [59]; Erol, et al., 2016 [5]; Rehage, et al., 2013 [60]; Rudtsch, et al., 2014 [61]; Brettel, Klein, and Friederichsen, 2016 [62]; Stock and Seliger, 2016 [63];
	Increase turnover, and create new business models	Arnold, et al., 2015 [64]; Brettel, et al., 2014 [62]; Burmeister, et al., 2016 [65]; Hofmann and Rüsch, 2017 [66]; Duarte and Cruz-Machado, 2017 [67]; Bechtsis, et al., 2017 [68]; de Sousa Jabbour, et al., 2018 [40]; Gilchrist, 2016 [7]; Branke, et al., 2016 [66]; Schmidt, et al., 2015 [67]; Schmidt, et al., Branke, et al., 2016 [69]; 2015 [70]; Nagy, et al., 2018 [57]; Glas, et al., 2016 [71];

II. Literature Review

Industry 4.0 and Sustainability

Influence of I4.0 in Economic Dimension of Sustainability

Table 4. *Cont.*

Dimension	Influence	References
	Improve: market share of the products, supply chains, and its management performance and security	Dubey, et al., 2017 [72]; Branke, et al., 2016 [69]; Hofmann and Rüsch, 2017 [66]; Stock and Seliger, 2016 [63]; Tjahjono, et al., 2017 [73]; Sommer, 2015 [74]; Wang, et al., 2015 [20]; Lee, Kao, and Yang, 2014 [13]; Luthra and Mangla, 2018 [75]; Nagy, et al., 2018 [57];
	Decrease operational costs	Shrouf, et al., 204 [4]; Waibel, et al., 2017 [76]; Yang, 2014 [13]; Schmidt, et al., 2015 [70]; Stock and Seliger, 2016 [63];
	Improve processes performance, increase renewable resources, and improve circular economy	Jabbour, et al., 2017 [40]; Oettmeier and Hofmann, 2017 [77].

II. Literature Review

Industry 4.0 and Sustainability

Influence of I4.0 in Environmental Dimension of Sustainability

Table 5. Influence of I4.0 in environmental dimension.

Sustainability Dimension	Influence	References
Environmental	Decrease industrial waste	Shrouf, et al., 2014 [4]; Waibel, et al., 2017 [76]; Yang, 2014 [13]; Oettmeier and Hofmann, 2017 [77]; Stock and Seliger, 2016 [63]; Wang, et al., 2015 [20];
	Decrease energy consumption of non-renewal energy sources	Hofmann and Rusch, 2017 [66]; Fritzsche, et al., 2018 [79];
	Increase production of renewal energy	Lund, and Mathiesen, 2019 [80];
	Increase practice of circular economy	Jabbour, et al. (2017) [40]; Branke, et al., 2016 [66];
	Increase collaboration with partners that follow good environmental practices	Zawadzki and Żywicki, 2016 [78]; Hofmann and Rüsch, 2017 [66];
	Decrease resources consumption, global warming, climate changes, and energy requirements	Tseng, et al., 2018 [81]; Fritzsche, et al., 2018 [79].

II. Literature Review

Industry 4.0 and Sustainability

Influence of I4.0 in Social Dimension of Sustainability

Table 6. Influence of I4.0 in social dimension.

Dimension	Influence	References
Social	Increase number of employees	Branke, et al., 2016 [69]; Brettel, Klein, and Friederichsen, 2016 [62];
	Improve working conditions (e.g., for employees with some disability, training courses, salary, among others)	Shamim, et al., 2016 [82]; Hirsch-Kreinsen, 2014 [83]; Kiel, et al., 2017 [55];
	Improve conditions of the surrounding society	Branke, et al., 2016 [66]; Shamim, et al., 2016 [82];
	Decrease working accidents	Brettel, Klein, and Friederichsen, 2016 [62];
	Increase participation of employees in decision-making	Branke, et al., 2016 [69]; Brettel, Klein, and Friederichsen, 2016 [62].
	Increase contract duration of employee and collaboration among stakeholders	Yang, 2014 [13]; Duarte and Cruz-Machado, 2017 [67]; Pfohl, et al., 2017 [84]; Shamim, et al., 2016 [82].

II. Literature Review

Main Remarks from State-of-the-Art Research

The main remarks that should be pointed out are the following:

- The first remark is that none of the researchers in their works did cover all the considered main influence criteria exposed in Tables 1–6;
- The second remark is that none of the works analyzed treats this subject through SEM;
- The third remark is that some criteria's influence are more considered than others, namely, for few of them were not found any reference.

III. Research Model

General Model

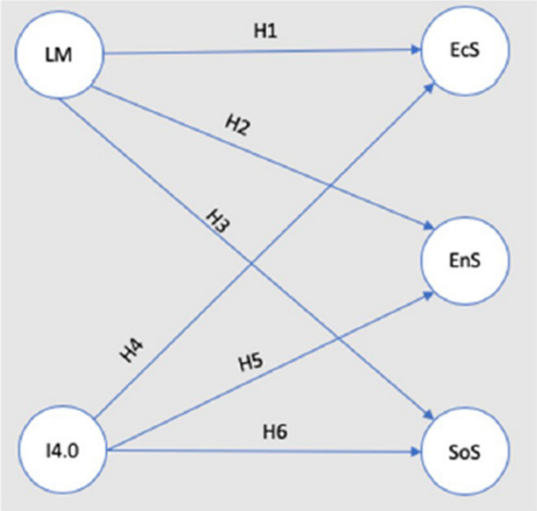

Figure 1. Initial general model.

Hypothesis 1 (H1). *The industrial companies' perception on Economic Sustainability is positively related to Lean Manufacturing.*

Hypothesis 2 (H2). *The industrial companies' perception on Environmental Sustainability is positively related to Lean Manufacturing.*

Hypothesis 3 (H3). *The industrial companies' perception on Social Sustainability is positively related to Lean Manufacturing.*

Hypothesis 4 (H4). *The industrial companies' perception on Economic Sustainability is positively related to Industry 4.0.*

Hypothesis 5 (H5). *The industrial companies' perception on Environmental Sustainability is positively related to Industry 4.0.*

Hypothesis 6 (H6). *The industrial companies' perception on Social Sustainability is positively related to Industry 4.0.*

III. Research Model

Survey and Data Collection

Table 7. Constructs and manifested variables.

Constructs	Manifested Variables
Exogenous	
Lean Manufacturing ($\xi 1$)	Pull production (X1) Product defects (X2) Failures (X3)
Industry 4.0 ($\xi 2$)	Big data (X4) Autonomous robots (X5) Digitalization (X6)
Endogenous	
Economic Sustainability ($\eta 1$)	Profits (Y1) Turnover (Y2) Market share (Y3)
Environmental Sustainability ($\eta 2$)	Energy consumption (Y4) Circular economy (Y5) Environmental practices with partners (Y6)
Social Sustainability ($\eta 3$)	Salary remuneration (Y7) Work conditions (Y8) Surrounding society (Y9)

III. Research Model

Survey and Data Collection

The survey was applied in industrial companies located in Portugal and Spain, and it was collected 252 validated answers in a total of 306 answers obtained.

IV. Evaluation Model

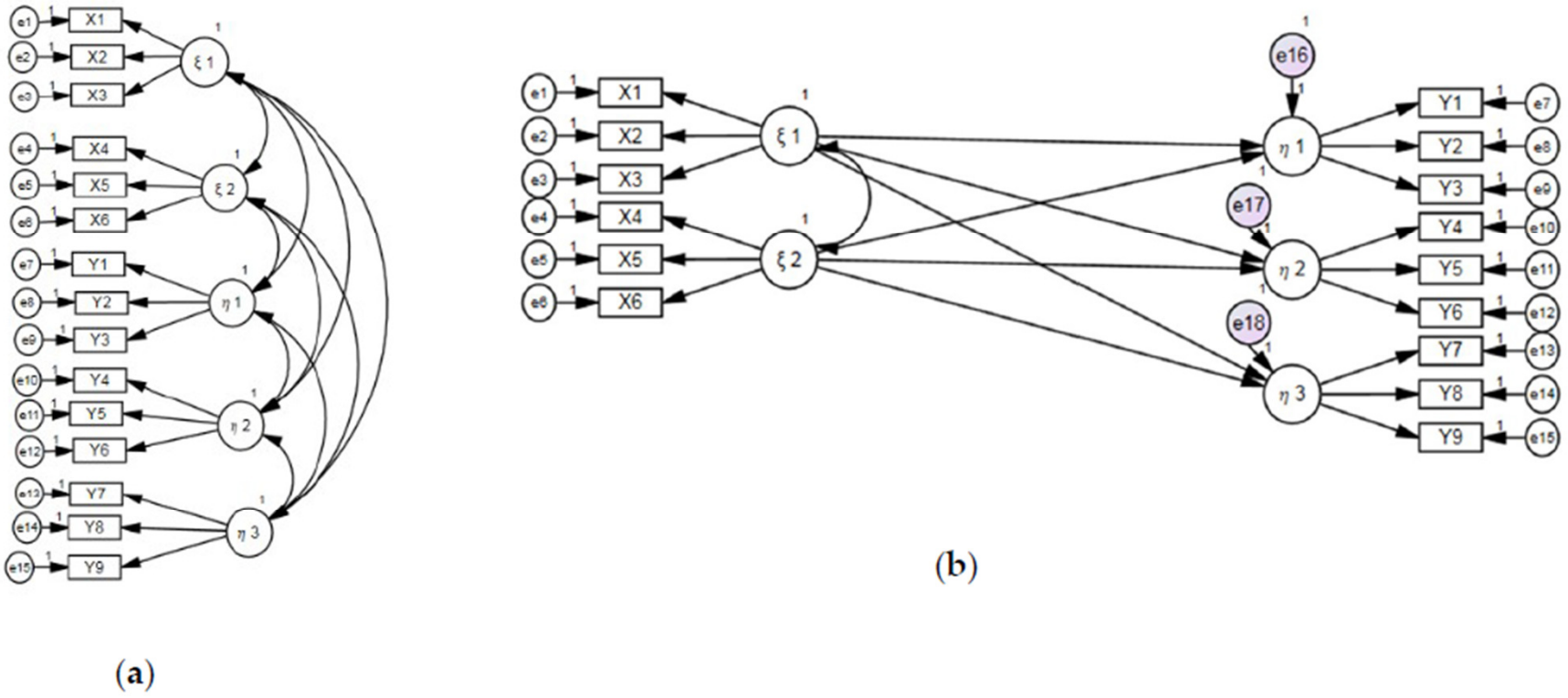

Figure 2. (a) Measurement model (b) structural model.

IV. Evaluation Model

Table 8. Adjustment indices and measures.

Adjustment Indices	Adjustment Measures	Macro in Amos SW	References
$\chi 2/df$	<3	\cmindf	(Hu and Bentler, 1999), (Wei et al., 2010) [92,93];
GFI	>0.9	\gfi	(Hu and Bentler, 1999), (Wei et al., 2010) [92,93];
CFI	>0.9	\cfi	(Hu and Bentler, 1999) [92]; (Wei et al., 2010), (Singh, 2009) [93,97];
TLI	>0.9	\tli	(Hu and Bentler, 1999), (Singh, 2009) [92,97];
IFI	>0.9	\ifi	(Santora and Bentley, 1990), (Wei et al., 2010) [93,94];
PCFI	>0.6	\pcfi	(Mulaik et al., 1989) [95];
PGFI	>0.6	\pgfi	(Mulaik et al., 1989) [95];
RMSEA	<0.08; $p > 0.05$	\rmsea \pclose	(Hu and Bentler, 1999), (Wei et al., 2010) [92,93];
AIC	Smaller than the independent model	\aic	(Schmitt, 2011) [96].

V. Results Discussion and Practical Implications

Results Discussion

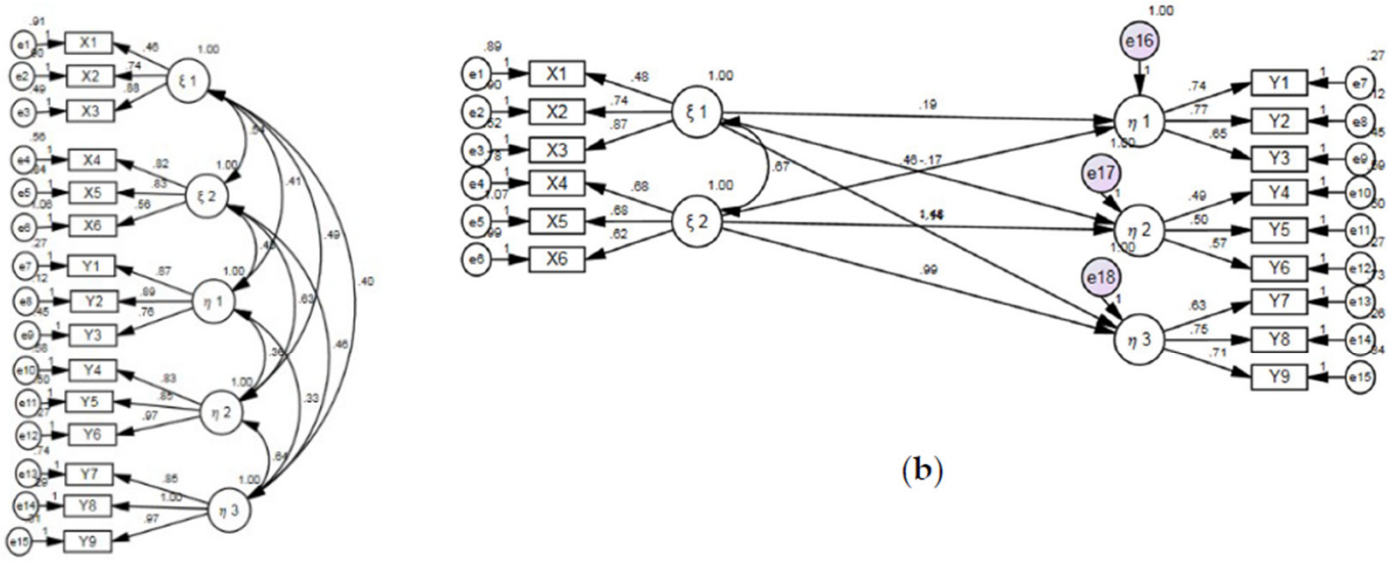

Figure 3. (**a**) Relation between the constructs of Measurement Model (MM), (**b**) Structural Model (SM), factorial weights, and fit.

V. Results Discussion and Practical Implications

Results Discussion

Table 9. Adjustment validation of the MM. GFI: Goodness of Fit Index; CFI: Comparative Fit Index; TLI: Tucker Lewis Index; IFI: Incremental Fit Index; PCFI: Parsimony CFI; PGFI: Parsimony GFI; RMSEA: Root Mean Square Error of Approximation; AIC: Akaike Information Criterion.

Adjustment Measures	Adjustment Obtained Value	Adjustment Criterion
χ^2/df	2.015	<3
GFI	0.923	>0.9
CFI	0.951	>0.9
TLI	0.936	>0.9
IFI	0.952	>0.9
PCFI	0.724	>0.6
PGFI	0.615	>0.6
RMSEA	0.064 ($p = 0.058$)	<0.08; $p > 0.05$
AIC	241.163 < 1787.589	Smaller than the independent model

V. Results Discussion and Practical Implications

Results Discussion

Table 10. Adjustment validation of the SM.

Adjustment Measures	Adjustment Obtained Value	Adjustment Criterion
χ^2/df	2.273	<3
GFI	0.908	>0.9
CFI	0.936	>0.9
TLI	0.919	>0.9
IFI	0.937	>0.9
PCFI	0.740	>0.6
PGFI	0.628	>0.6
RMSEA	0.071 ($p = 0.006$)	<0.08; $p > 0.05$
AIC	262.657 < 1787.589	Smaller than the independent model

V. Results Discussion and Practical Implications

Results Discussion

Table 11. Estimates of the SM and synthetized frame of the hypothesis.

Hypothesis	Exogenous Construct	Endogenous Construct	Est.	SE	CR	*p*-Value	Conclusion
H1.	Lean	Economic Sustainability	0.187	0.133	1.405	0.16	Not confirmed
H2.	Lean	Environmental Sustainability	−0.167	0.365	−0.457	0.648	Not confirmed
H3.	Lean	Social Sustainability	−0.142	0.280	−0.508	0.611	Not confirmed
H4.	Industry 4.0	Economic Sustainability	0.457	0.132	3.466	<0.001	Confirmed
H5.	Industry 4.0	Environmental Sustainability	1.482	0.477	3.108	0.002	Confirmed
H6.	Industry 4.0	Social Sustainability	0.994	0.297	3.341	<0.001	Confirmed

V. Results Discussion and Practical Implications

Practical Implications

In terms of practical implications for the companies and their stakeholders, this study assures:

- that it is not confirmed that LM is related to Sustainability, when faced with a decision-making process to implement LM.

- the existence of relation between I4.0 and Sustainability, meaning a stronger knowledge to further decide about I4.0 implementation and its implications in sustainability.

VI. Conclusions

As a global conclusion, the results obtained through the study carried out enable to state that exists a relation between I4.0 and Sustainability, and a not confirmed relation between LM and Sustainability.

These conclusions can contribute as an important decision support for the industrial companies and its stakeholders, even because not all the results are in line with other opinions and studies.

Moreover, this can mean that companies have now a stronger knowledge to further decide about the implementation of LM and I4.0, and its implications in Sustainability.

VI. Conclusions

The results of this study are limited by the region object, in this case the Iberian Peninsula, and for industrial companies. For that reason, further studies should consider other countries.

Also, because social sustainability is an important concern for the future of society, namely, concerning the influence of I4.0, more variables will be considered in the presented model to evaluate more deeply its influence in the ambit of social sustainability.

References

All the references mentioned in this Webinar are presented in the following published paper:

Varela, L., Araújo, A., Ávila, P., Castro, H., & Putnik, G. (2019). Evaluation of the Relation between Lean Manufacturing, Industry 4.0, and Sustainability. *Sustainability, 11*(5), 1439. MDPI AG. Retrieved from http://dx.doi.org/10.3390/su11051439

Thank you for your attention!