



An initial assessment of the current quality management methods to industry 4.0

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Abstract

Purpose: The purpose of this paper is to present the results of an assessment into how well the Lean Management method will support continuous improvement in the world of Industry 4.0.

Design/methodology/approach: Using thematic analysis of literature, the Lean Management method and Industry 4.0 were deconstructed into its constituent elements. Semi-structured interviews were then carried out with five Quality Specialists in manufacturing to gather opinions on how well each Lean element supported each theme of Industry 4.0.

Findings: This initial research highlighted that the Lean method can integrate new technologies, to allow it to better support continuous improvement in the world of Industry 4.0. It found the supportive elements of Lean in the world of Industry 4.0 would include Continual Improvement, Engaging the Supply Chain, Pull Systems and having a Customer Focus.

Research limitations/implications: This was a scoping study as a pre-cursor to further research, and was based on the opinions of five Quality/Lean Specialists. However the results determine that Lean can be supported by Industry 4.0 technologies.

Practical implications: Those constituent elements of Lean which might be updated to better support quality improvement in the world of Industry 4.0 have been identified. A methodology by which expanded research may be undertaken has been demonstrated.

Originality/value: The findings contribute to knowledge by providing a focus on the key supporting elements of Lean implementation for industry 4.0 in the manufacturing sector.

Keywords: quality, industry 4.0, i4.0, lean, management, manufacturing.

Article Classification: Conceptual Paper

1. Introduction and Background

1.1 Industry 4.0

The concept of Industry 4.0 (i4.0), synonymous with the fourth industrial revolution, appeared as early as 2011 at the Hanover Messe (trade fair) (Kagermann and Lukas, 2011) and has been widely studied and reported (Hannover Messe, 2019; Plattform Industrie 4.0, 2019; Plattform Industrie 4.0, 2013; Rojko, 2017; Sony 2018; Xu, Xu and Lil, 2018). It describes the evolution within manufacturing to smart and highly networked enterprises and 'similarly to the past industrial revolutions, Industry 4.0 aims to transform working (and living) environments' (Müller, Buliga and Voigt, 2018, p.4). Industry 4.0 depicts the recent trend in automation technologies which is gaining popularity in the manufacturing industries (Sony, 2018).

The first industrial revolution took place from the late 1700's into the early 1800's and represented the first change from an agricultural to an industrial economy powered by water and steam machinery. The second industrial revolution commenced in the later 1800's and involved the use of electricity to power the first mass production lines and it was supported by the developing oil and steel industries. The third industrial revolution commenced in the 1970's with the advent of mass-produced microchips and automation enabling the introduction of CAD / CAM systems into manufacturing with machines able to perform more complex tasks previously performed by humans. (Bauernhansl, Hompel and Vogel-Heuser, 2014); Rojko, 2017).

There is no standard definition for i4.0. It is described by various authors including: the German Government's group Plattform Industrie 4.0,(2013) and (2019), Rojko (2017), Sony, (2018); Zhong et al. (2017), Qin, Liu and Grosvenor(2016), and these can be summarised as:

- Smart products which can sense and react to their conditions;
- Smart manufacturing processes which can self-optimize;
- The 'internet of things' (IoT) where physical assets share and act upon data;
- The availability of large amounts of process/product data for analysis ('Big Data');
- Highly integrated enterprises both horizontally and vertically;
- The use of cyber-physical systems (CPS) which link data collection and analysis to mechanical actuators;
- Cloud computing where data and computing power is shared; and
- The use of new technologies such as 3D printing.

It must be noted that whilst the first, second and third industrial revolutions are historical, evidenced events; i4.0 is a prediction for the future as it has not yet happened (Zavadska and Zavadsky, 2018; Müller, Buliga and Voigt, 2018). According to Halang and Unger (2014), it is the first time that a revolution is proclaimed before it happens.

1.2 Lean Management

Lean Management is a quality method, which has been widely applied worldwide since the latter half of the 20th Century. It has been applied in a number of sectors but especially the

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3 automobile industry and is closely associated with the Toyota Production System (Liker,
4 2004; Ohno, 1988; Womack, Jones and Roos2007). It is an approach which encourages flow
5 through the elimination of waste (Bicheno and Holweg, 2016; Douglas *et al.*, 2015. Lean
6 Management thinking is used to differentiate between waste and value within an
7 organization. (Sony, 2018)
8
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10 As with industry 4.0, there is no standard definition of Lean (Hobbs, 2004; Stone, 2012),
11 although published definitions do share some common elements including:
12

- 13 • Waste removal; (Bicheno and Holweg, 2016;Liker 2004; Ohno, 1988)
- 14 • Engagement of people and culture change (Liker, 2004; Mascarenhas, Pimentel and
15 Rosa, 2019; Rand, Womack and Jones,, 1997; Sugimori *et al.*, 1977; Vilda, Yagüe
16 Fabra and Torrents, 2019 *et al.*, 2019)
- 17 • Continuous improvement (Costa *et al.*, 2019; Pearce and Pons, 2019; Womack, Jones
18 and Roos, 2007; Worley 2004)
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22 Lean has had some success during its lifetime (Bortolotti, Boscari and Danese, 2015)).
23 However, since Lean was devised, the business environment has greatly changed with, for
24 example: the internet, globalisation, outsourcing, over-supply, ‘services’, rapid technology
25 change, increasingly complex products and now i4.0. This paper assesses the continuing
26 suitability of Lean in the world of i4.0.
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29 **2. Research Methodology**

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31 An organisation evolving through i4.0 will undergo some change. Its products, processes,
32 people-roles and relationships with other organisations will be significantly affected. A
33 question which arises is whether Lean be applied successfully within this changed
34 environment? If not, then how can Lean be modified in order to successfully apply it?
35

36 The aim of this study was to determine and test how well will lean support quality
37 improvement in the world of i4.0
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39 This was an initial, scoping study of limited scale however, a key purpose was to facilitate the
40 development of a questionnaire for the full employment of a future Delphi study. Therefore,
41 the selection of Quality Specialists was undertaken on a purposive basis from a locally
42 accessible group. The study provided an opportunity to test the research methodology as a
43 pre-cursor to further larger-scale research.
44

45 This study drew conclusions from:
46

- 47 • The review and critical analysis of existing knowledge, and deconstruction of Lean
48 into its constituent elements, and of i4.0 into its constituent themes through a
49 systematic literature review. These were arranged in a matrix (Appendix A). This
50 matrix enabled a systematic assessment to be undertaken of the support which each
51 Lean element might give to each i4.0 theme.
- 52 • The elicitation of knowledge through semi-structured interviews, the basis of which
53 was the completion of the questionnaire through interviews lasting between 30 and
54 90 minutes.
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3 The approach required Quality Specialists to make judgements on future outcomes based on
4 their own knowledge. The interviews were used to test a questionnaire on its effectiveness for
5 determining how Lean might support i4.0.
6

7 Five Quality/Lean specialists assessed how well each Lean element might support
8 improvement in each theme of i4.0. The allowable responses being:
9

- 10 • Positive (+) – Strong support to improvement;
 - 11 • Neutral (0) – Little or no support to improvement;
 - 12 • Negative (-) – Opposes or hinders improvement;
 - 13 • Don't know () – Insufficient knowledge to assess.
- 14
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17 The responses were consolidated in order to facilitate analysis.
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19 **3. Lean Management and Industry 4.0**

20
21 Kolberg and Zuhlke (2015), Mrugalska and Wyrwicka (2016) pointed out basic
22 philosophical contradictions between Lean and i4.0 including the apparent contradiction
23 between the Lean approach of a smooth production flow and the i4.0 approach of highly-
24 customised, unique products. Ghobakhloo and Fathi, (2019) however argue that while Lean
25 can exist without IT, IT and digitalisation can facilitate the effectiveness of the Lean process.
26

27
28 Mrugalska and Wyrwicka (2016) noted the contradiction between the people-focus of Lean
29 and the machine-focus of i4.0. They proposed that the role of the operator will become much
30 more wide-ranging and encompass strategic decision-making and flexible problem-solving.
31 Gilchrist (2016) also concedes that as robots become more dexterous, their role will increase
32 shifting the role of the operator. The lack of clarity in the role of the worker in i4.0 was
33 supported by Ruttimann and Stockli (2016). They explored the role of the human employee
34 within i4.0 and noted how Lean has historically valued its employees for their knowledge and
35 Kaizen, whereas i4.0 appears to see them as trouble-shooters only with the bulk of the work
36 being carried out by machines.
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39 On a positive note, Sanders, Elangeswaran and Wulfsberg, 2016 note the potential job
40 enrichment which i4.0 may bring. Employees may move into roles with less physical
41 monotony and more intellectual stimulation. Becker and Stern (2016) stated that, the future
42 human work areas will be different but not fully replaced by automated solutions. They noted
43 that 'unique human abilities will play a more significant role for human task design' and that
44 'humans will be absolutely necessary in the factories of the future'
45

46
47 Mayr et al (2018) described a model of Lean which was in general supportive to i4.0. This
48 Lean model was focused on processes (JIT, Kanban, SMED) rather than people (leadership,
49 develop people). They concluded that a key area for future research is the integration of
50 employees into the Lean i4.0 concept.
51

52
53 Martinez, Jirsak and Lorenc (2016) investigated whether Industry 4.0 may be the end of Lean
54 through the analysis of the abstracts of 556 Industry 4.0 related publications, there
55 conclusions while suggesting a limited correlation were inconclusive. According to Kolberg
56 and Zühlke (2015) however, Industry 4.0 technologies implementations are most beneficial
57 for sectors, in which the cost-saving and simple Lean methods do not have the capability to
58 fulfil requirements effectively. Possible approaches aim to improve Flexibility, Productivity,
59 Speed, Quality and Safety (Küpper et al. 2017). One of those approaches is predictive
60 maintenance, which enables completely new possibilities for zero-defect-manufacturing in

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3 order to increase productivity. In defence of Lean, Kolberg and Zuhlke (2015, p1) noted how
4 Lean surpassed the short-lived computer integrated manufacturing (CIM) era due to the
5 simplicity of the former over the '*unruly complexity*' of the later. Ultimately, Lean clearly
6 aims to improve business performance (reducing waste, increasing efficiency), whereas the
7 relationship between the complex i4.0 and improved business performance is not yet
8 established. It is this business performance which ultimately decides the success of any
9 enterprise irrespective of whether it has adopted Lean, i4.0, both or none. This subject was
10 explored by Ruttimann and Stockli (2016) who identified and defined the mandatory, generic
11 requirements of a production system as speed, punctuality, quality and return (to
12 shareholders). They argue that irrespective of the manufacturing methodology, failure in
13 these areas will ultimately lead to failure of the enterprise. They also highlighted that i4.0
14 may not outperform batch and queue and Lean JIT under all conditions. For example, the
15 high product flexibility in i4.0 leads to high variability of cycle time at machines and so to
16 variable bottlenecks which will have to be managed. Ruttimann and Stockli (2016) concluded
17 that the existing approach to i4.0 has '*a high probability to fail*' (p499) as its impact upon the
18 basic mandatory requirements of manufacturing is not being considered.

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22 Researchers are being captivated by the technological elements of i4.0 but are not considering
23 it in a business context. Ruttimann and Stockli (2016) singled out cyber physical production
24 systems as having '*the flavour of dreams of engineers supported by government*
25 *benevolence...*' (p499). Whilst i4.0's smart factories and big data may appeal, the issues of
26 how these are funded, what return will they give and what will the impact on overall business
27 profitability be, are issues largely unexplored.

28
29
30 Much of the work published so far has concentrated on what is the potential support which
31 Lean and i4.0 might give to each other. Tortorella and Fettermann (2017) undertook a
32 practical study of i4.0 and Lean, and their impact upon the actual performance of companies.
33 They surveyed Brazilian manufacturers to understand whether their operational
34 improvements were related to Lean or i4.0 implementation.

35
36 Tortorella and Fettermann (2017) found that companies who had achieved higher levels of
37 performance improvement were more likely to be those who either had or were implementing
38 both i4.0 and Lean. Companies exhibiting lower levels of performance improvement tended
39 to have lower levels of Lean and i4.0 implementation. This was a robust study as it elicited
40 information from >100 companies. This would indicate that, not only are i4.0 and Lean
41 compatible, but also their implementation can lead to improved business performance.

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44 The above was further supported by Sony (2018). His work concluded that although lean
45 management can have a positive contribution towards the integration of Industry 4.0 this
46 integration, has to be vertical, horizontal and end-to- end engineering in order to have
47 successful outcomes.

48
49 Overall, the authors reviewed concluded that Lean and i4.0 were generally but not completely
50 compatible.

51 52 **4. i4.0 and its Constituent Themes**

53
54 A number of common themes emerged and these are described as follows.

55
56 The concept of the smart factory in which flexible and highly configurable manufacturing
57 systems respond to changes in market demand was explored by many authors (Ghobakhloo
58 and Fathi, 2019; Rojko, 2017; Sony 2018; Sony *et al.*, 2020; Qin *et al.*, 2016)) describes the
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3 smart factory as one in which cyber-physical systems (CPS) integrated with ICT components
4 make their own decisions based on data capture and machine learning.
5

6 Zhong *et al.* (2017) described smart factories as intelligent manufacturing facilities which use
7 intelligent systems to achieve high levels of quality, efficiency, and optimisation, and which
8 are highly reconfigurable to meet particular customer needs.
9

10 The concept of smart products was described by Qin, Liu and Grosvenor(2016). Smart
11 products are fitted with sensors and processors enabling them to track their own progress and
12 monitor their status. Smart products are able to storage a large amount of data, self-process
13 and communicate with industrial systems (Nunes et al, 2017). They are thus enabled to make
14 decisions on their own and can manage their own flow through the factory.
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Rojko (2017) extended this concept by claiming that smart products could monitor their status throughout their in-service life too. This would allow extensive use of condition-based maintenance of these products.

The impact of i4.0 on the customer was described by Qin et al. (2016) who stated that customers: would be able to order highly customised products, could make changes to these at late stages, and would be able to monitor their products progress in real time.

The German Government's focus group Platform Industrie 4.0 (2013) noted how i4.0 would lead to high levels of product tailoring to meet individual customer requirements and that factories could manufacture these items profitably. Aheleroff et al. (2019) noted that 'mass personalisation has arisen as a manufacturing paradigm in the fourth industrial revolution and leans towards affordable personalisation close to mass production'.

An Internet of Things (IoT) was described by Zhong et al. (2017) in which resources such as facilities, machines and products would collect and share data to enable production operations and material flows to be managed and optimised.

Platform Industrie 4.0 (2013) described the integrated enterprise as extending from the business to its entire supply chain. This would bring efficiencies and cost saving through maximising utilisations and efficiencies. Such benefits strongly align with the aim of any quality improvement programme.

CGI (2017) described cloud computing as businesses having the ability to access low cost computing solutions including both processing and data storage, and through the use of shared computing assets.

The collection and use of large amounts of process and product data ('Big Data') was described by many authors including Zhong et al (2017) and CGI (2017). Big Data involves large amounts of data relating to the manufacturing processes being obtained, analysed and communicated thus allowing improved decision making leading to better process optimisation.

The authors (Ghobakhloo, and Fathi, 2019; Zhong et al., 2017; Sony, Antony and Douglas, 2020)) highlighted a number of underpinning technologies which will support the progress of i4.0 implementation (2017) highlighted the use of a unified information and communications technology (ICT) which enables quick and effective decision making.

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3 These common themes are summarised in Table I and were the themes of i4.0 used in this
4 research.
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8 [Insert Table I: Consolidated Themes of i4.0]
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12 **5. Lean Manufacturing and its Constituent Elements**

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14 A range of published material was reviewed in order to deconstruct Lean into its constituent
15 elements. A number of common elements emerged and these are discussed in this section
16 and presented in Table II. It should be noted that these identified elements from literature and
17 are not to be confused with critical success factors for lean implementation rather they are the
18 driving operational elements and principles necessary as part of the lean process.
19
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21 Teamwork and employee involvement has been noted as a key feature of Lean by a number
22 of authors (Mascarenhas, Pimentel and Rosa, 2019; Rand, Womack and Jones., 2003;
23 Sugimori *et al.*, 1977; Vilda, Yagüe Fabra and Torrents, 2019 *et al.*, 2019, Liker (2004)
24 describes Lean as the ‘Toyota Way’ and how one of its two pillars is respect for people. He
25 then sets out how this is enacted through: growing leaders, developing people, becoming a
26 learning organisation and using people to drive continuous improvement
27
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29 Ohno (1988) describes the operation of pull systems or ‘Kanban’ in detail as part of an aim to
30 achieve zero-inventory. The concept of ‘just in time’ in which parts arrive on the production
31 line just as they are required also supports the zero-inventory principle.
32

33 Lean seeks efficiency through the elimination of waste. Ohno (1988) sets out the seven
34 wastes: over-production, waiting, transportation, over-processing, inventory, movement and
35 defective product. Any production process can be made more efficient – or leaner – by
36 identifying and reducing one or more of these wastes. Liker (2004) also includes ‘unused
37 employee creativity’ as an eighth type of waste in the system.
38
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40 By following the Lean principles, these wastes can arguably be reduced and eliminated
41 realising greater efficiencies and a reduction in costs. Lean principles include: specifying
42 value, identifying the value stream, flow, customer pull and pursuit of excellence (Hines *et*
43 *al.*, 2004; Womack and Jones, 2003).
44

45 Liker (2004) describes one pillar of the Toyota Way as continuous improvement or Kaizen.
46 He continues by noting that the key to this is creating that culture of continuous learning
47 which accepts and embraces change.
48

49 Toyota (2018) use the term ‘Jidoka’ to describe their culture of stopping to fix problems.
50 There are a number of Lean elements which support this approach. Ohno (1988) sets out a
51 key pillar of TPS as ‘auto-activation’ whereby a production machine stops automatically in
52 the event of an error and so the production of defective product is prevented.
53

54 Ohno (1988) also notes the use of ‘Andon’ where typically a light is used to indicate that a
55 process has been stopped due to a problem. Attention can then be focused on fixing that
56 problem.
57

58 Liker (2004) noted how the corporate culture must accept that production will be halted to fix
59 problems. He also noted how visual management can be used to make problems visible to
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3 all, and also how 'go look see' can encourage managers to leave their offices and investigate
4 problems on the shop floor.
5

6 Engaging the supply chain within Lean was described by a number of authors (Bicheno and
7 Holweg, 2016; Liker 2004; Womack Jones and Roos, 2007). Womack, Jones and
8 Roos(2007) noted the complexity of modern automotive supply chains and how these had
9 developed historically through the strategies of Ford, GM and Chrysler. Within the Lean
10 enterprise, suppliers are engaged as partners. Long term contracts are placed with these
11 suppliers primarily on the basis of quality rather than cost provided that the suppliers embrace
12 lean methods and work to reduce their costs through efficiencies.
13
14

15 The concept of customer value embraces a number of elements including the value stream.
16 Womack and Jones (2003) described the value stream as the tasks and actions required to
17 design and make a particular product for a customer. By identifying those tasks which add
18 value to the product and those which do not, then the process can be focused on creating
19 customer value.
20

21 Arguably standard work systems predated Lean as repetitive tasks were an inherent feature of
22 Henry Ford's production lines in the early 1900's. Liker (2004) describes standardised tasks
23 as the foundation for continuous improvement and employee empowerment. He quotes
24 Henry Ford as describing standardisation as the necessary foundation on which tomorrow's
25 improvement will be made.
26

27 Workflow also featured strongly as expected, as expected notwithstanding that Womack,
28 Jones and Roos, (2007) refer to flow as one of the underpinning principles of lean
29 manufacturing but can be closely related to elements such as Just in Time and waste
30 reduction as well as impact on inventory management and the supply chain.
31
32

33 Liker (2004) describes the unpredictability of customer orders and how the purest form of
34 Kanban can lead to significant inefficiencies in plant utilisation coupled with potential
35 dissatisfaction due to extended product lead times.
36

37 These common elements are summarised in Table II and were the elements of Lean used in
38 this research.
39

40 [Insert Table II: Consolidated Elements of Lean]
41

42 **6. Results and Analysis**

43
44 Five Quality Specialists undertook the assessment through semi-structured interview and
45 using the matrix in Appendix **Error! Reference source not found.** The results obtained
46 from all of these were consolidated in order to facilitate further analysis.
47
48

49 Whilst this was a pilot study undertaken as a pre-cursor to future research, the results are
50 worthy of analysis both in themselves and as a demonstration of the data which results from
51 the matrix-based methodology.
52

53 The responses given by the participants for each of the nice Lean elements (shown in Table
54 II) were inserted in a matrix format. For example, in the case of the 'Pull Systems', the
55 responses were summarised as follows (Table III):
56
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58
59 [Insert Table III: Responses for Lean, Pull Systems]
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3 The same analysis was applied for each of the nine lean elements. The graphical
4 representation of the total of responses are shown in Figure 1.
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8 [Insert Figure 1: Total Number of each Response]
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14 The respondents were in general positive about the support Lean gives to i4.0. More positive
15 responses (172 or 48% of the total) were received than any other category and there were
16 only a minority (28 or 8% of the total) of negative responses.
17

18 There were a significant number (141 or 39% of the total) of neutral responses where Lean
19 was judged to be of little or no benefit to i4.0. Taking this further, in just under half (39 + 8 =
20 47%) of all responses, Lean was judged to have little, no or negative impact in i4.0. This
21 result questions the ability of Lean - in its current form at least – to provide effective support
22 within i4.0.
23

24 As a result, for further analysis, the neutral responses were considered alongside the negative
25 responses. The justification being that if implementing an element of Lean in an organisation
26 results in little or no benefit, then what would be the point of its implementation? Doing so
27 would cost money and if no benefit was accrued from that investment then its impact would
28 be negative.
29

30 The data was then analysed to the next level of detail in order to determine which elements of
31 Lean provide the greatest, and which elements provide the least levels of support to i4.0.
32
33

34 The numbers of positive and combined neutral/negative responses were totalled up for each
35 element of Lean. The results are shown in Figure 2.
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38 [Insert Figure 2: Lean Elements – Positives and Neutral/Negative Support to 4.0]
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44 There was a range in support given by the Lean elements from 63% positives to 30%
45 positives and this is illustrated in 2. There is a rough inverse relationship between the
46 number of positives and the number of neutral/negatives. The exclusion of the small
47 percentage of 'don't know' responses leads to this not being an exactly inverse relationship.
48

49 Four elements of Lean returned a net positive response, these being: Continuous
50 Improvement, Engage the Supply Chain, Pull Systems and Customer Value.
51

52 Continuous Improvement (CI) should be a feature of any successful organisation and on that
53 basis this result might be expected. However, current CI models are often people-focused
54 and how these might translate into the automated i4.0 world remains to be seen.
55

56 Integrated Supply Chains are a feature of i4.0 and so it appears sensible that the Lean element
57 of Engage the Supply Chain will provide positive support.
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3 The inclusion of Pull Systems as a positively supporting element is more surprising as these
4 are traditionally associated with high-volume, repeatable manufacturing rather than low
5 volume, highly customised products. It may be that the high levels of computerisation in i4.0
6 could facilitate efficient automated pull systems.
7

8 Customer Value returns a positive rating and this may be related to the promised ability of
9 i4.0 to deliver highly customised products at 'mass-produced prices'.
10

11 All other Lean elements have a net neutral/negative response with the least positive being
12 Stop and Fix Problems, and Teamwork and Employee Involvement. The neutral/negative
13 support from the people-centred element of Teamwork and Employee Involvement is not
14 surprising given the highly automated nature of i4.0. The neutral/negative support offered by
15 the element Stop and Fix Problems is more surprising. Perhaps this was viewed by the
16 respondents as being people focused and involving the use of visual methods such as Andon?
17
18

19 Similarly, the net neutral/negative response returned for Standard Work Systems may be that
20 this element is associated with improvements for human operators which have no relevance
21 to robots.
22

23 The same data was analysed to determine which themes of i4.0 are best supported by Lean.
24 The numbers of positive and combined neutral/negative responses were totalled up for each
25 element of i4.0. This is shown in Figure 3.
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31 [Insert Figure 3: i4.0 Themes - Positive and Neutral/Negative Support from Lean]
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36 This data shows (Figure 3) that there is a range in support given to each i4.0 theme by Lean
37 ranging from 69% positive to 13% positive. It can be seen that four i4.0 themes receive a net
38 positive support from Lean with another four i4.0 themes receiving a net neutral/negative
39 support.
40

41 Underpinning Technologies (e.g. robotics, 3D printing), Smart Factories, Integrated
42 Enterprise and the Internet of Things received net positive support from Lean.
43

44 That Underpinning Technologies and Smart Factories receive positive support may be due to
45 their being tangible, hardware-based concepts to which Lean principles can be applied. The
46 support to i4.0's Integrated Enterprise may be as a result of Lean's focus on the entire Supply
47 Chain.
48

49 Surprisingly, the Internet of Things received a net positive support from Lean. Perhaps again
50 the consideration was that these are basically items of tangible hardware to which Lean
51 principles can be applied and equally so the technologies which can assist the lean process.
52
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54 Smart Products, Cloud Computing, Customised Products and Big Data received the most
55 neutral/negative support from Lean. This would need further investigation.
56

57 For Cloud Computing and Big Data, this is understandable as these are new concepts which
58 have emerged with the advent of i4.0. They are concepts which do not feature in the world in
59 which Lean evolved. However, this argument is somewhat weakened with the earlier finding
60

of higher levels of support for other new i4.0 themes such as Underpinning Technologies and Smart Factories.

The lack of support to Customised Products is more surprising as businesses have been making customised products for generations. Perhaps this is an inherent limitation of Lean that it works best when applied to an operation producing high volumes of a standard product.

While the results are on the whole, comparable to some other studies in the area (Sanders et al., 2017; Satoglu et al, 2018), The findings from this research differ markedly in the area of positive factors for support. Sanders et al (2017) found the most supportive elements of Lean to be TPM, Heijunka, Waste (elimination) and Autonomation whereas this research found those to be Continual Improvement, Engage the Supply Chain, Pull Systems and Customer Focus. While Satoglu et al (2018) considered the most supportive Wastes to i4.0 being Waiting and Defectives, with all wastes offering overall positive support to i4.0. This is somewhat at variance with this research where Lean's Elimination of Waste returned a small net neutral/negative response.

This analysis has generated useful data which has highlighted: those elements of Lean which might not well support i4.0, and also those themes of i4.0 which might not be well supported by Lean. This data can inform future work to determine how best Lean might be changed to better support i4.0.

7. Conclusions

This work set out to understand the level of support which Lean will provide to the world of i4.0. The results showed that Lean is partly - but by no means wholly - supportive to i4.0. Whilst overall some 48% of responses were positive, 39% were neutral with a small percentage (8%) of negative.

It would be reasonable to conclude that Lean is supportive to i4.0 due to the low percentage of negative returns. However, this does not take into account the large proportion of neutral responses. A Lean element which provides little or no support to i4.0 must be regarded as a negative impact as it will cost money to implement but generate no return on that investment. This must call into question the suitability of Lean – in its current form at least – to effectively support i4.0.

The results showed that some individual elements of Lean provide positive support whereas other individual elements provide neutral or negative support to i4.0. There is a wide range in the level of this support from 63% positives for one element to 30% positives for another element. Similarly, there is a wide range in the support from Lean to the individual themes of i4.0 with one theme receiving 69% support and another only 13%.

This shows that some - but not all - elements of Lean provide support to i4.0 which leads to a further conclusion that what Lean needs is simply some updating to better address i4.0 rather than its wholesale re-invention.

A further conclusion can thus be assumed in that the needs of i4.0 can be met by reviewing and updating Lean rather than its wholesale re-invention.

For Lean there is no defined standard setting out what it consists of. It is up to the implementing organisation to decide how to apply Lean. As a result, Lean might be readily made relevant to i4.0 as its content is essentially user-defined.

This was a small-scale scoping study undertaken as a precursor to future research in this area. On the basis that Lean needs updating rather than completely rewriting, then the direction of this future work can be proposed. It is proposed that similar research be undertaken on a significantly larger scale into Lean to understand where it does and where it doesn't support i4.0. Such research would require the involvement of multiple organisations across a number of sectors. The views of organisations that are adopting or working in the i4.0 environment would be particularly useful. It is recognised that the sample size is a limiting factor however the results suggest that Lean can support i4.0 but requires further research. The matrix-based methodology has been shown here to generate valuable data and so it might inform the basis of future work using qualitative forecasting and a Delphi study.

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14 [revolution-what-it-means-and-how-to-respond/](https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/) (Accessed 18 August 2018)

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25 616-630

26 27 28 29 **Appendix A**

30 [Insert Appendix A]
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Table I: Consolidated Themes of i4.0

	Theme	Components
1	Smart Factories	Intelligent self-managed production processes, Cyber-physical systems, Highly flexible and configurable, Optimised and efficient production processes
2	Smart Products	Autonomous and intelligent, Use of sensors
3	Customised Products	Customised to individual customers' needs, Custom mass production
4	Internet of Things	Communication across people, machines and products, Internet of things
5	Integrated Enterprise	Vertically integrated product development and realisation, Horizontally integrated supply chain
6	Cloud Computing	Shared computing infrastructure
7	Big Data	Effective decision making from extensive product and process data
8	Underpinning technologies	ICT: Computers and Software, Robotics and automation, Smartphones, 3D Printing

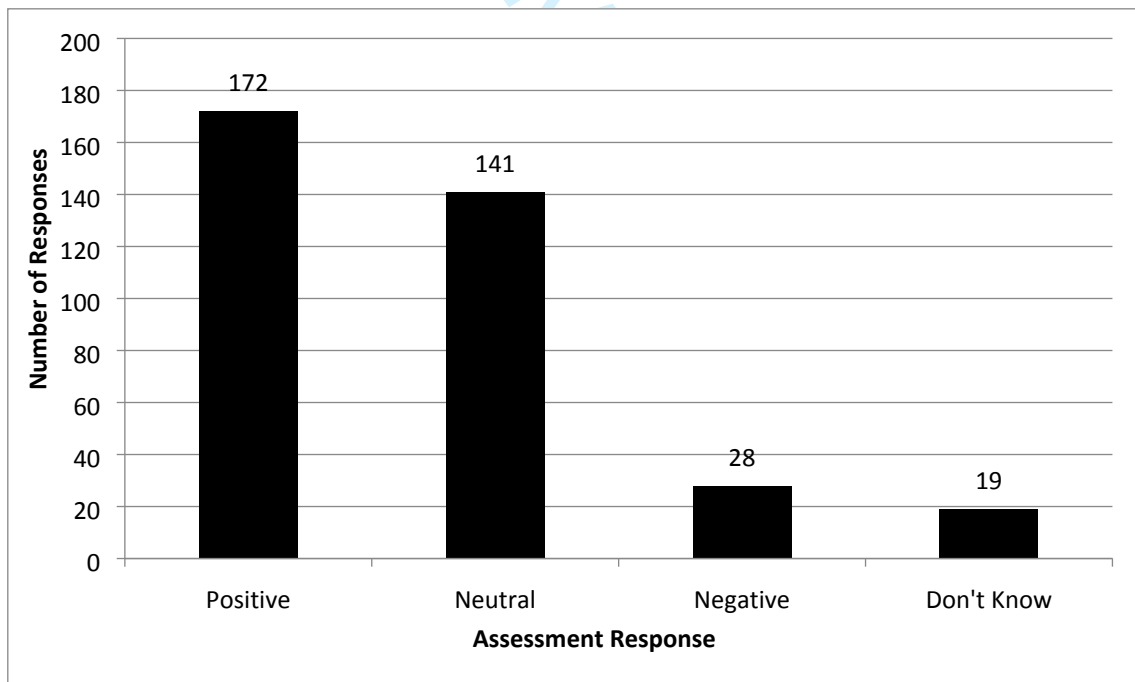
Table II: Consolidated Elements of Lean

No	Element	Components
1	Teamwork and Employee involvement	Teamwork, employee involvement, respect for people, develop people
2	Pull systems	Kanban, Just in Time, zero inventory
3	Elimination of Waste	8 wastes
4	Continuous improvement	Kaizen, learning, pursue perfection
5	Stop and fix problems	Andon, auto-activation, Jidoka, 5 Whys, go look see
6	Engage the supply chain	Supplier involvement, respect suppliers
7	Customer value	Customer focus, customer value, Lean in design, value stream, build to order
8	Standard work systems	Standard tasks, quick change over, preventative maintenance, reliable technology
9	Level work flow	Continuous process flow, level out workload

Table III: Responses for Lean, Pull Systems

		i4.0 Theme							
		Smart Factories	Smart Products	Customised Products	Internet of Things	Integrated Enterprise	Cloud Computing	Big Data	Underpinning Technologies
Response	Positive	5	4	2	2	2		2	5
	Neutral				2	2	5	4	
	Negative			3					
	Don't Know		1		1	1			

Figure 1: Total Number of each Response



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Figure 2: Lean Elements – Positives and Neutral/Negatives Support to i4.0

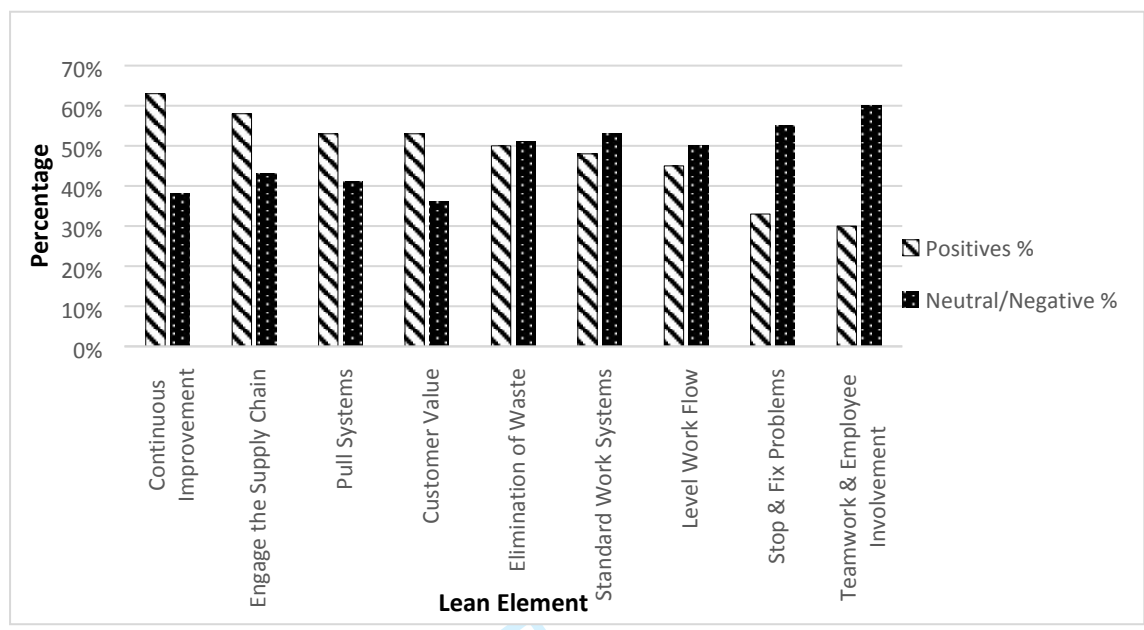
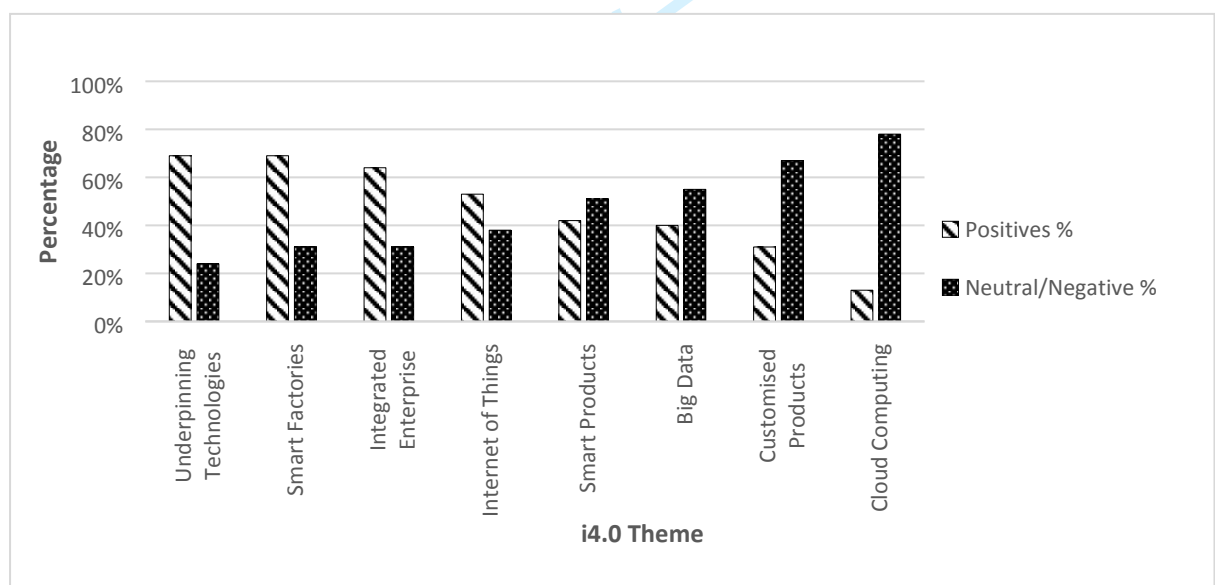


Figure 3: i4.0 Themes - Positive and Neutral/Negative Support from Lean



Tables and Figures for insertion

Appendix A

	Lean	Industry 4.0 Themes							
	Key: Fill in each cell: How much will that Lean element support improvement in that i4.0 theme? + strong support to improvement 0 little or no support to improvement - opposes or hinders improvement Leave blank if you have insufficient knowledge	Smart Factories	Smart Products	Customised Products	Internet of Things	Integrated Enterprise	Cloud Computing	Big Data	Underpinning Technologies
Lean Elements	Teamwork and Employee involvement								
	Pull systems								
	Elimination of Waste								
	Continuous improvement								
	Stop and fix problems								
	Engage the supply chain								
	Customer value								
	Standard work systems								
	Level work flow								

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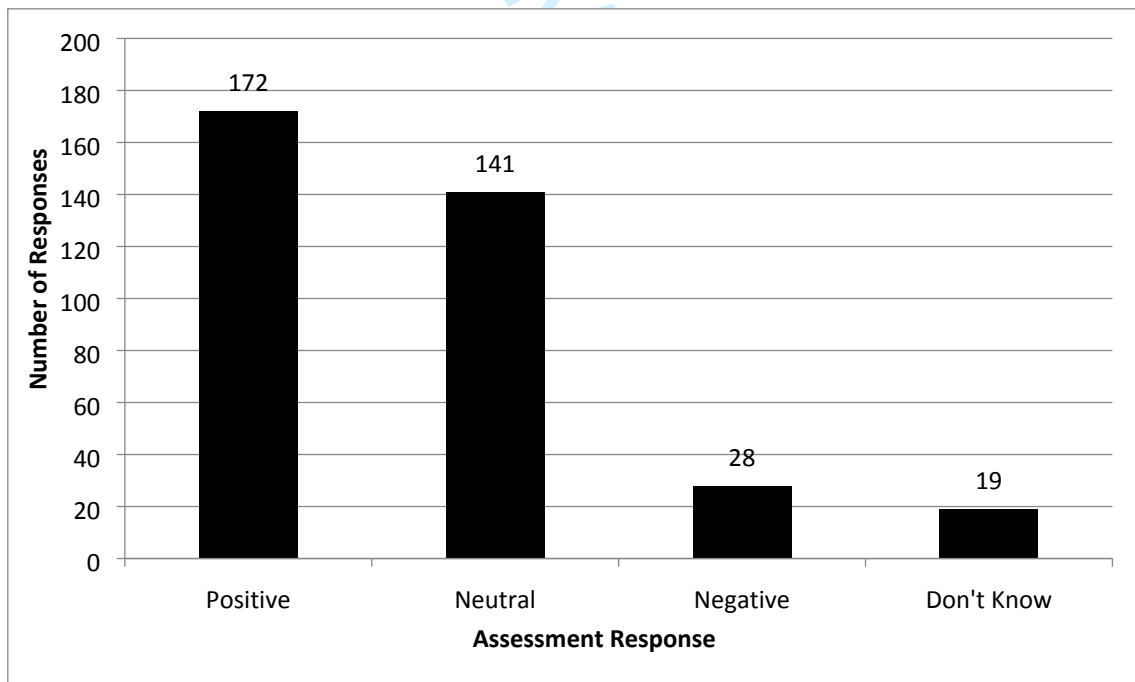
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		i4.0 Theme							
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	Neutral				2	2	5	4	
	Negative			3					
	Don't Know		1		1	1			

Figure 1: Total Number of each Response



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Figure 2: Lean Elements – Positives and Neutral/Negatives Support to i4.0

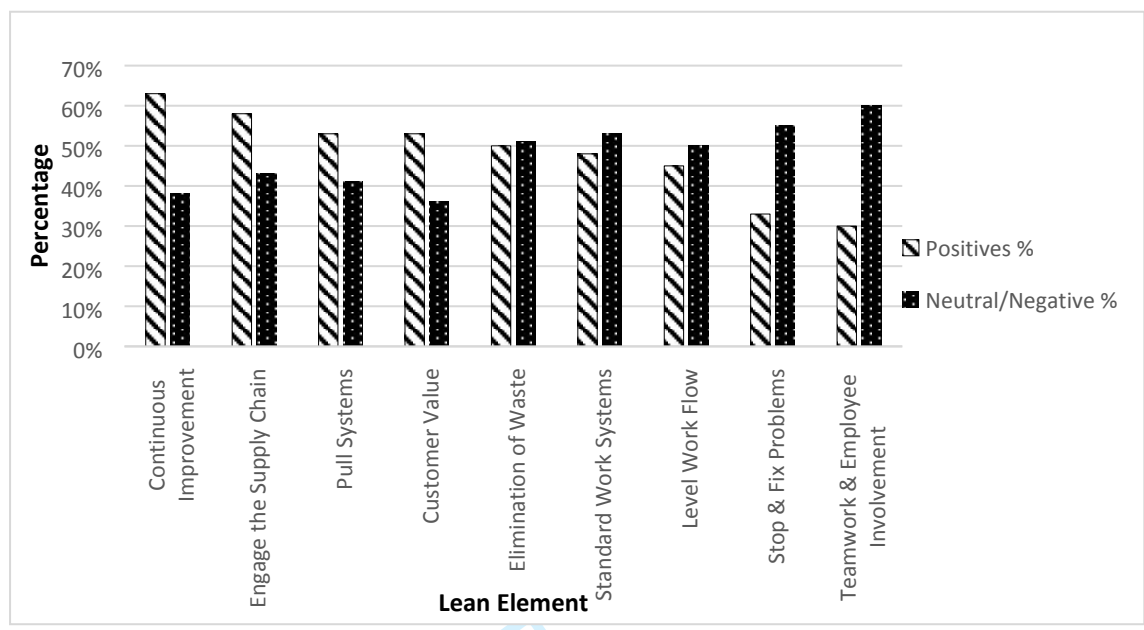


Figure 3: i4.0 Themes - Positive and Neutral/Negative Support from Lean

