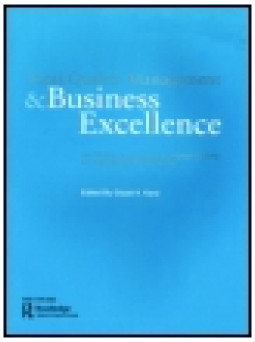

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Can IATF 16949 certification facilitate and foster Lean Six Sigma implementation? Research from Italy

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The purpose of this research is to understand whether the International Automotive Task Force (IATF) 16949 certification for the automotive sector facilitates the implementation of Lean Six Sigma (LSS) tools and methodologies. Moreover, the research evaluates to what extent the LSS tools and methodologies are implemented by companies through the IATF standard. The results of a seven-item questionnaire based on seven hypotheses derived from a review of the IATF 16949 standard were tested. The online questionnaire was completed by 135 Italian practitioners. Italy has about 1500 automotive-related companies that are IATF 16949 certified and has a tradition in terms of the automotive industry. The results from the questionnaire were augmented by the respondents' notes. The results indicated that 16949 does not facilitate the implementation of Design for Six Sigma and Six Sigma in general or the Single Minute Exchange of Die tool and Total Productive Maintenance methodology. On the other hand, the respondents' indicated that IATF 16949 had a strong effect on the implementation of the problem-solving methodology, and it affected 5S and other tools as well as tools for improving material flow management. Some particular considerations concerning how companies are obliged by the standard and customers to implement LSS tools and methodologies emerged.

Keywords: IATF 16949; quality management; Lean Manufacturing; Six Sigma; automotive industry

Introduction

Lean Six Sigma (LSS) is a management system which combines the benefits brought by Lean Manufacturing with Six Sigma benefits (George, 2002; Pepper & Spedding, 2010). Lean Manufacturing stems from the Japanese carmaker Toyota and, according to Pepper and Spedding (2010), the automotive sector has been one of the sectors that has had the most interest in LSS over the last decades. LSS best practices can be found in Volkswagen Audi, Porsche, Volvo as well as FIAT, Chrysler, General Motors and other automotive component manufacturers and according to Schonberger (2008), LSS has affected the automotive industry as a whole.

IATF 16949:2016 is the standard issued by the International Automotive Task Force (IATF) in 2016; it was previously known as ISO/TS 16949, first issued in 1999. The standard describes a specific quality management system (QMS) for the automotive sector. Manufacturing companies which produce automotive-related products, including products and relevant service parts organisations, can ask for third-party certification from an ITAF-accredited certification body. According to the International Organization for Standardization (ISO), by the end of 2015 an estimated 63,000 companies around the world had obtained the 16949 certification and of these companies, approximately 1500 are located in Italy. In fact, Italy has a significant automotive component industry due to several Fiat

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Chrysler Automobiles (FCA) plants around the country. The Italian automotive industry represents one-tenth of all the manufacturing employees in Italy and 8.8% of all vehicles produced around the world. With over one million vehicles produced in 2016, Italy is the fifth car producer in Europe after Germany, France, the UK and Czech Republic (OICA, 2016). In any case, Italy has a tradition for manufacturing high value and performance cars such as Ferrari, Lamborghini and Maserati.

IATF 16949 comprises basic ISO 9001 requirements (ISO, 2015) plus particular addenda for the automotive sector. According to the IATF (2016, p. 7), the goal of the standard is:

> the development of a QMS that provides for continual improvement, emphasizing defect prevention and the reduction of variation and waste in the supply chain.

From this statement, it is clear that IATF 16949 wants to override the main goal of ISO 9001 certification, which is focused on the efficacy of the processes and customer satisfaction (Galetto, Franceschini, & Mastrogiacomo, 2017). The precise reference to a reduction in variation is reminiscent of the more advanced management system Six Sigma and its Define–Measure–Analyse–Improve–Control (DMAIC) methodology which contains many statistical tools (Pyzdek & Keller, 2014). Indeed, according to many authors (Klefsjö, Wiklund, & Edgeman, 2001; Antony, 2004; Drohomeretski, Gouvea da Costa, Pinheiro de Lima, & Garbuio, 2014; Jacobs, Swink, & Linderman, 2015; Sabbagh, Ab Rahman, Ismail, & Wan Hussain, 2016), Six Sigma aims for defect prevention and customer satisfaction through a reduction in variation within processes. The reference in the goal of the IATF 16949 to a reduction in waste has connections with the Japanese Toyota Production System (TPS), known as Lean Manufacturing in the West (Chiarini & Vagnoni, 2015). In fact, it is well known that the aim of Lean Manufacturing is to reduce seven specific wastes within processes (Ohno, 1988; Womack & Jones, 1996; Pakdil & Leonard, 2014; Shaaban & Darwish, 2016; Liu, Niu, Chang, & Zhang, 2017; Marodin, Frank, Tortorella, & Fetterman, 2017). Moreover, IATF 16949 (2016, p. 21) in a note at the end of a page highlights that some requirements should include the application of Lean Manufacturing principles. Therefore, IATF 16949 through its addenda dedicated to automotive processes seems to foster Lean and Six Sigma tools and principles and could be considered by companies in the automotive sector as a vehicle for facilitating LSS implementation.

In this light, this research seeks to answer to these questions:

- What really are the LSS tools and methodologies supported by IATF 16949?
- Does IATF 16949 facilitate the implementation of LSS tools and methodologies?
- To what extent are LSS tools and methodologies implemented by companies through the IATF standard?

As a consequence, this research can be positioned in the debate concerning how to implement LSS. Indeed, some authors (Shah, Chandrasekaran, & Linderman, 2008; Jeyaraman & Kee Teo, 2010; Pepper & Spedding, 2010) tried to pursue a pattern or vehicle for easing LSS implementation, and IATF 16949 could be one of these vehicles. Secondly, this research wants to bring new theory concerning the possibility of integrating and improving QMS standards through tools and principles borrowed from other management systems. In this way, this research brings contributes to practitioners who are dealing with LSS implementation and QMS standards as well as academics who are investigating these subjects. Considering that LSS and IATF 16949 QMS are affecting the automotive industry as a whole, results can be easily generalised. Moreover, the automotive industry is well-known for being very careful in relation to the cost of poor quality, product reliability and cost reduction in general. Therefore, the results of this research could potentially affect automotive organisations which have not implemented LSS and/or IATF 16949 so far.

To answer these questions, this research employed a quantitative and a qualitative approach through a survey of 135 Italian practitioners familiar with IATF 16949 QMS. The survey contained a questionnaire which was based on seven hypotheses derived from a literature review and an analysis of the standard and its requirements. The results from the questionnaire were tested through chi-square and Cramer's *V* tests. The questionnaire also asked respondents to leave some notes on the questions, which provided useful qualitative information to better understand the phenomena behind the quantitative results.

The remainder of this paper is as follows. The next section presents the IATF 16949 standard and reveals the LSS tools and methodologies described in IATF 16949. The following section summarises the research methodology and then a specific section analyses and discusses the quantitative and qualitative results. Lastly, the conclusions section discusses the novel findings of the research, especially for practitioners, and its limitations, and proposes some avenues for further research.

IATF 16949:2016 and LSS background

IATF 16949:2016 is the upgrade of the previous standard ISO/TS 16949 first issued in 1999. ISO/TS 16949 can be considered as the standardisation of several standards fostered by specific automotive industry groups. In particular, it is the standardisation of the QS 9000 linked to Ford, Chrysler and General Motors, the Italian AVSQ 94 linked to FIAT, the German VDA supported by all the German car manufactures and the French EAQF 94 (Rosak-Szyrocka & Borkowski, 2014). In this way, IATF 16949 is the international standard reference for all the automotive and heavy goods vehicle industries around the world. ISO 16949:2016 is based on the ISO 9001:2015 requirements, while the previous ISO/TS standards were based on the older versions of ISO 9001 requirements. Each organisation which wants to achieve IATF certification has to implement several requirements according to the standard, documenting several processes. An independent body accredited by IATF assesses through an audit, firstly the documentation, and then its real implementation. Once the organisation has got the certificate, the external body assesses the organisation processes yearly.

In the literature, there is no trace of research dedicated to the IATF 16949 standard and LSS tools and methodologies at the same time. Some discussions can be found on QMS specialised Internet forums where practitioners argue informally on the subject. In any event, there are some papers dedicated to a more general integration between the past ISO/TS standard and LSS as well as ISO 9001 requirements and LSS. Starting with ISO 9001 requirements and Lean, some authors (King & Lenox, 2001; Marash, Berman, & Flynn, 2004; Terlaak & King, 2006) discussed the potentiality of integrating ISO 9001 and Lean from a general point of view. The results of these papers mainly claimed that ISO 9001 QMS can benefit in terms of a more efficient performance from the tools and the approach of Lean.

Liu (2009) investigated the effect of ISO/TS 16949 on Six Sigma in Taiwan; Liu (2009) reported that the IATF 16949 standard had a positive effect on Six Sigma because it provides systematic procedures that help companies to rapidly and effectively develop Six Sigma programs to improve performance. However, Liu's (2009) research, which is based on the previous version of the standard, is confined to Taiwanese companies and to Six Sigma. All in all, it can be confirmed that in these papers there is no precise correlation between the ISO 9001 requirements and the kinds of tools and principles which could be integrated.

On the other hand, two other researches (Chiarini, 2011; Karthi, Devadasan, & Murugesh, 2011) tried to deeper analyse and correlate ISO 9001 requirements and LSS tools. As a result, Chiarini (2011) has shown a strong correlation between the ISO requirements dedicated to infrastructure management, planning and material management flow tools, as well as ISO 9001 documentation and Lean standard work and visual management. While Karthi et al. (2011) saw a specific correlation in the ISO 9001 continuous improvement requirement and Six Sigma problem-solving.

Like ISO 9001, for the development of the QMS, IATF 16949 follows the Plan–Do–Check–Act cycle starting with the leadership and planning requirements, the support and operation, performance evaluation and lastly the requirements dedicated to the improvement processes (ISO, 2015, p. VIII).

The IATF 16949 standard is also supported by supplemental automotive guidelines issued by automotive associations such as the American AIAG, the German VDA, the Italian ANFIA and the UK SMMT. Some guidelines are specifically dedicated to tools such as Failure Modes and Effects Analysis (FMEA), Measurement System Analysis (MSA) and Statistical Process Control (SPC), which are mandatory for getting the IATF 16949 certification of compliance (Yeh, Pai, & Huang, 2013). As a consequence, Six Sigma tools such as FMEA, MSA and SPC are directly indicated and strictly connected to the IATF standard.

FMEA is a relevant tool for risk reduction and defect prevention implemented during the product (Design FMEA) and process design (Process FMEA).

SPC helps determine if a process is stable and capable of meeting customer requirements. Through its application, people can measure, analyse and make decisions about special causes of variation within the process. When special causes are eliminated the process is said to be in statistical control (Oakland, 2007).

MSA is a tool to analyse and identify the sources of variation in the measurement system. It is used to quantify the magnitude of measurement errors and to ensure that inspections and controls meet product requirements (Oakland, 2007).

Other methodologies and principles directly quoted within the standard are Design For Six Sigma (DFSS), Just-In-Time (JIT) and material flow management.

DFSS and Six Sigma are methodologies usually based on advanced statistical tools and a precise pattern named DMAIC (Gijo, Antony, Kumar, McAdam, & Hernandez, 2014). DFSS is implemented in the design processes, while Six Sigma can be implemented in many different processes and both lead to the reduction of costs of poor quality. However, these improvement projects can be very complex needing particular skills depending on the kind of implemented tools. In this light, some authors (Hoerl, Montgomery, Lawson, & Molnau, 2001; Jeyaraman & Kee Teo, 2010; Gijo et al., 2014) highlighted how DFSS and Six Sigma can reveal several pitfalls and obstacles during their implementation.

JIT represents one of the pillars of the TPS – Lean Production (Ohno, 1988) which leads to the so-called pull production system. Pull production implies the entire production flow is pulled by orders (make to order) to the contrary of the push system (Spearman & Zazanis, 1992). It is well-known from the literature how JIT brings benefits in terms of inventory reduction, short lead-time and flexibility in following the customer demand (Monden, 2011); and this is one of the most important aspects of being a supplier of the automotive sector (Bennett & O'Kane, 2006).

Material flow management is a fundamental aspect of the JIT and allows companies to quickly identify products in their status and locations within the shop floor. For example, it helps workers in identifying the right routing of the products limiting at the same time the amount of inventory for each location (Monden, 2011).

Reading thoroughly the IATF 16949 requirements, we can find different methodologies and principles indirectly quoted such as 5S, Standard Work, Visual Management, Single Minute Exchange of Die (SMED) and TPM.

Another relevant aspect of the automotive sector is the contamination and the quality of the product. The 5S is an easy five-step tool for setting in order and having a workplace cleaned up (Chiarini, 2011). 5S can bring many benefits in terms of quality, productivity and safety (Ablanedo-Rosas, Alidaee, Moreno, & Urbina, 2010; Falkowski & Kitowski, 2013). Indeed, according to Pavnaskar, Gershenson, and Jambekar (2003), a messy workplace can affect working performance. 5S is usually introduced along with the Standard Work (Mann, 2005) and it is one of the most visual lean tools. 5S allows workers and managers to control and visualise immediately the waste at the workplace and on the shop floor in general. In this way, the company can more easily implement the so-called Visual management system (Mann, 2005).

In order to better follow customer demand, Lean production has introduced the SMED tool that avoids dead times and reduces the set-up operations. The reduction in set-up times means that workers can change automotive part-numbers that go over the machine more frequently and consequently reduce inventories.

Similarly, the Total Productive Maintenance (TPM) is a fundamental Lean methodology for introducing preventive maintenance of the machines, equipment and raising the worker's awareness about self-maintenance. TPM, when well applied, reduces machine down-time, as well as product defects (Rizzo, 2008). However, TPM is a complex and structured methodology that sometimes can lead to failure. According to Ahuja and Khamba (2008), the failure of companies to successfully implement an effective TPM program is due to different factors such as confusion over what exactly constitutes TPM, lack of management consensus, poor knowledge and inconsistent and unclear expectations.

Table 1 shows the specific requirement number and its title along with some notes on the requirement content and the LSS tools, methodologies or principles to which the requirement refers.

From this information, we can group by issue the LSS tools and methodologies indicated by IATF 16949 and exclude the LSS tools and methodologies that are mandatory for the IATF 16949 certification of compliance. Moreover, according to Mann (2005) and Chiarini (2011), some tools such as 5S, standard work and visual management cannot be implemented in a separate way. As a consequence, we can propose some research questions (RQs):

RQ_1 IATF 16949 facilitates and supports the introduction of DFSS methodology

RQ_2 IATF 16949 facilitates and supports the introduction of Six Sigma programs based on the DMAIC methodology

RQ_3 IATF 16949 facilitates and supports the implementation of 5S, standard work and visual management tools

RQ_4 IATF 16949 facilitates and supports the implementation of material flow improvement tools and pull production

RQ_5 IATF 16949 facilitates and supports the implementation of SMED tool

Table 1. Lean Six Sigma tools, methodology and principles directly or indirectly quoted by IATF 16949.

Requirement	Notes on the requirement (IATF, 2016)	LSS tool/methodology/principle
4.4.1.2 – Product safety	The organisation shall ensure documented processes for the management of product safety related products and manufacturing processes. The requirement directly refers to the Design and Process FMEA	FMEA
7.1.3.1 – Plant, facility and equipment planning	The organisation has to optimise and synchronise the material flow and the value-added use of floor space. Moreover, the organisation has to facilitate synchronous material flow. A specific note explains how plant, facility and equipment planning should include the application of Lean Manufacturing principles	Material flow management (Seth & Gupta, 2005; Chiarini, 2011; Liker & Convis, 2011; Huo, Han, & Prajogo, 2014; Sundar, Balaji, & Kumar, 2014; Gündüz, 2015) Lean Manufacturing principles in general
7.1.4.1 – Environment for the operation of processes	The organisation has to maintain its premises in a state of order and cleanliness that is consistent with the product and manufacturing process needs	5S (Bayo-Moriones, Bello-Pintado, & Merino-Díaz de Cerio, 2010; Hodge, Goforth Ross, Joines, & Thoney, 2011)
7.1.5.1.1 – Measurement system analysis	MSA and studies are required to reduce the variation in the results of inspections and measurements	MSA – Gage R&R (Snee, 2004; Gijo et al., 2014; Doshi & Desai, 2017)
8.3.2.1–8.3.5.1 – Design and development planning; Design and development outputs	The requirements deal with several tools such as Project Management, FMEA, Design for Manufacturing and Assembly (DFM and DFA) and Fault Tree Analysis (FTA) which belong to the DFSS methodology	DFSS (Basem, 2008; Lee & Chang, 2010; Watson & DeYong, 2010)
8.5.1.1 – Control plan	The requirement supports FMEA and SPC implementation	FMEA and SPC (Pai & Yeh, 2013)
8.5.1.2 – Standardised work, operator instructions and visual standards	The organisation shall ensure standardised and visual instructions. In this system rules are requested for the operators including rules for safety too.	Standard work and visual management (Chiarini, 2011; Lu & Yang, 2015; Dennis, 2016)
8.5.1.3 – Verification of job set-ups	The requirement encourages the reduction and verification of set-up times and the implementation of material change-over.	SMED (Baker, 2016; Braglia, Frosolini, & Gallo, 2016; Reza, Gayosso, Fernández, Macías, & Muro, 2016)

(*Continued*)

Table 1. Continued.

Requirement	Notes on the requirement (IATF, 2016)	LSS tool/methodology/principle
8.5.1.5 – Total productive maintenance	The title and the contents directly take into account the TPM methodology and its implementation path. The organisation shall develop, implement and maintain a documented TPM system.	TPM (Nakajima, 1988; Kodali & Chandra, 2001; Ahuja & Khamba, 2008)
8.5.1.7 – Production scheduling	In order to meet customer demand, the requirement suggests a JIT pull system for the material flow	JIT, Pull production (Takahashi & Nakamura, 1998; Bhamu & Singh Sangwan, 2014; Chiarini, 2017)
9.1.1.2–9.1.13 – Identification of statistical tools – Application of statistical concepts	The organisation has to determine the appropriate use of statistical tools and employees have to be trained in statistical concepts	SPC and statistical tools in general
10.2.3 – Problem-solving	The organisation shall have a documented process for problem-solving. The requirement supports a structured approach to problem-solving	Problem-solving methodology

RQ_6 IATF 16949 facilitates and supports the implementation of TPM methodology
RQ_7 IATF 16949 facilitates and supports the implementation of problem-solving methodology

In the next section, the research questions have been transformed into hypotheses and operationalised by means of a survey with a questionnaire and a Likert's scale (Rea & Parker, 2012).

Research methodology

An online questionnaire which contained seven questions related to the seven hypotheses was filled in by a sample of 135 Italian practitioners: 78 of the 135 are quality managers who have been managing an IATF 16949 QMS and participating in LSS programs; 42 are consultants in the quality and LSS fields; and 15 out of the 135 are auditors who belong to IATF accredited bodies. In particular, the consultants and the auditors, over time, have dealt with dozens of IATF 16949 QMS and LSS programs.

All the respondents were in an independent position to answer the questions. Results of the questionnaire were anonymous for reducing bias as well as question order was counter-balanced (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003). At the beginning of the questionnaire, the respondents were asked how long they had performed LSS and IATF 16949 and at what level of knowledge they considered themselves to be. Through the first round of answers, 143 respondents answered to the questions and 8 of them were ruled out because they declared not to be Lean or Six Sigma experts introducing some bias.

The 143 respondents chosen were sampled from the population of LSS experts using a simple random sampling method. In this case, all possible samples of *n* respondents are equally likely to occur (Bryman & Cramer, 2011).

Initially, the 143 practitioners were invited to answer the online questionnaire through email. We received from this first step 37 answers; during the following six months, many of the practitioners were phoned to obtain a definitive answer.

The questionnaire can be found in Appendix 1. In order to avoid bias, we chose 78 quality managers who represented 78 automotive-related companies with similar characteristics. In particular, for reducing bias all the companies:

- Have received IATF 16949 or ISO/TS 16949 certification in the last 2–3 years. In this way, quality managers can better compare LSS programs and performances before and after obtaining the certification because they can remember both situations.
- Have a production flow structured with both assembling processes and machines. In this way, all the Lean tools, including SMED and TPM, could be implemented by the company. Moreover, the companies have been implementing similar LSS tools and methodologies.
- Have an engineering department and could be interested in DFSS.
- Have managed LSS programs for at least 5 years starting before obtaining IATF 16949 certification. In this way, the quality managers, as well as the consultants and auditors, are aligned from a knowledge standpoint concerning LSS tools and principles.

Of the 78 companies, 38 out of 78 have more than 250 employees and their turnover is more than 50 million euros. Thirty-five out of the 78 have between 100 and 249 employees and the turnover ranges from 20 to 50 million euros. While just 5 of the 78 companies have between 50 and 99 employees with a turnover of less than 20 million euros. All the companies were established more than 20 years ago.

Each question of the questionnaire in Appendix 1 is divided into two parts. The first part refers to the situation of the company before obtaining 16949 certification and the second part to the situation after having obtained 16949 certification. The respondents answered using a Likert's scale from 1 to 5 (5 = Very Good, 4 = Good, 3 = Acceptable, 2 = Poor, 1 = Very Poor) to rate whether in their opinion IATF 16949 facilitated and/or fostered, in some way, the specific LSS tool or principle stated in each of the seven hypotheses. For instance, if a respondent thinks that DFSS methodology has been at a very good level of implementation for several years but IATF 16949 certification did not contribute to this, the respondent could rate 5 for both questions (without IATF 16949 certification and after having implemented 16949). On the other hand, if the respondent thinks that IATF 16949 certification improved DFSS programs, the respondent could rate 5 for the 'after having implemented 16949' question and, for example, 1 or 2 for the 'without 16949 certification' question.

A chi-square test was performed to validate the hypotheses. According to Bryman and Cramer (2011), the sample size has to be not too small; this is taken into account by the number of contingency cells. More than 20% of these cells have to have an expected count value less than 5. A chi-square test requires enunciation of the null and alternative hypothesis (Bryman & Cramer, 2011). The alternative is confirmed when the null hypothesis is rejected. For each question in the questionnaire, the null hypothesis is that there is no association between IATF 16949 certification and the improvement in the implementation of the specific LSS tool or methodology. The alternative hypothesis naturally is that there is an association between IATF 16948 certification and the improvement in the implementation.

The chi-square results can be associated with a test of the strength of association. The non-parametric Cramer's *V* test is usually the most used test in combination with chi-square (Bryman & Cramer, 2011). In fact, chi-square does not enable comparison of the relative strengths of association between the nominal variables. Cramer's *V* varies between 0 and +1. The closer the statistic is to +1, the stronger the association.

Finally, in the questionnaire, there was a space for collecting comments and suggestions from the respondents on each of the questions. This qualitative part of the methodology enabled us to collect more information on the phenomena, which we could use to help make sense of the results or to interpret them in terms of the meanings the respondents brought to them.

According to Bowen (2009), first of all, the gathered information has to be organised into what relates to the central questions of the research. Then a content analysis can be used as a first-pass document review (Bowen, 2009, p. 32). In this way, the researcher can identify meaningful and relevant passages within the answers, avoiding notes and discussions not relevant with the central research. As a further step a thematic analysis can per performed. According to Bowen (2009), thematic analysis can be considered a form of pattern recognition within the text. This analysis provides emerging themes, categorising them for further analysis. It includes a focused reading of data and information, as well as coding and category statements (Bowen, 2009). These emerged themes and statements can be useful for integrating quantitative data, giving a confluence of evidence that increases credibility and reduces the impact of potential bias (O'Leary, 2014).

Lastly, potential sources of common method biases were tested. Among these sources, there could be the propensity for respondents to try to maintain consistency in their responses to questions (Podsakoff et al., 2003, p. 882), the propensity for respondents to agree (or disagree) with questionnaire items independent of their content and the use of a common scale format. The test has been performed by means of factor analysis for the answers before and after the certification. Table 2 shows the results of this test.

Table 2. Factor analysis for the common method bias before and after certification.

	Initial Eigenvalues		
	Total	% of variance	Cumulative %
Factor (before)			
1	1.62057	23.151	23.151
2	1.45915	20.845	43.996
3	0.92386	13.198	57.194
4	0.84861	12.123	69.317
5	0.79576	11.368	80.685
6	0.71337	10.191	90.876
7	0.63868	9.124	100.000
Factor (after)			
1	2.04036	29.148	29.148
2	1.09606	15.658	44.806
3	0.84021	12.003	56.809
4	0.84007	12.001	68.810
5	0.80157	11.451	80.261
6	0.69272	9.896	90.157
7	0.68901	9.843	100.000

The eigenvalue in the second total column is a measure of how much of the variance of the variables a factor explains. More importantly, in both cases (before and after certification), the percentage of variance of the third column tells that the first factor accounts for less than 50%. That means that common method bias does not affect the results (Podsakoff et al., 2003).

Discussion of the quantitative results

The quantitative results of the chi-square and Cramer's *V* clarified whether there is an association between the variables or the pattern is random (see Table 3). For example, the first null hypothesis is: 'No association exists between IATF 16949 certification (first variable) and the implementation of DFSS methodology (second variable)'. For testing, the association between the variables the *p*-value or Pearson chi-square (Schumacker & Tomek, 2013) can be taken into account. Chi-square tests the difference between the observed frequencies (f_o) and expected frequencies (f_e). A cut-off value for the *p*-value has to be set. In this case, it was $\alpha = 0.05$ (5%). When the *p*-value is less than the cut-off, the researcher rejects the null hypothesis and takes the alternative hypothesis to be true. Defining H_0 the null hypothesis:

$$P(H_O \text{ true} | \text{ how inconsistent data were with } H_O) = \alpha.$$

For example, the third question gave a *p*-value much lower than .05 (1.09156E-10); therefore, the null hypothesis was rejected and we can claim that IATF 16949 certification affects 5S, standard work and visual management implementation (alternative hypothesis). Table 3 summarises the results for each hypothesis. The results of the null hypothesis test can be analysed along with the cross-tabulation in Appendix 2 where for each question, the frequencies of the Likert's scale answers can be found.

Contradicting the literature review and the IATF 16949 suggestions, the statistical results seem to demonstrate that neither DFSS nor the DMAIC pattern of the traditional Six Sigma is affected by the IATF 16949 QMS. As for the Lean tools and methodologies, one of the most relevant tools implemented for machines and equipment, SMED (Panwar, Nepal, Jain, & Rathore, 2015), also seems to be unaffected by the introduction of an IATF 16949 QMS. However, IATF 16949 does affect the implementation of the TPM methodology, although the *p*-value is .0421 and therefore it is very close to the cut-off value of 0.05.

Table 3. Results of the null hypothesis tests.

H_i	*p*-value	Null hypothesis	Cramer's *V*	Conclusions in brief
1	.6776	Accepted	0.0927	IATF 16949 certification does not affect DFSS
2	.9610	Accepted	0.0479	IATF 16949 certification does not affect DMAIC Six Sigma
3	1.0916E-10	Rejected	0.4409	IATF 16949 certification affects 5S, standard work and visual
4	6.6225E-12	Rejected	0.4646	IATF 16949 certification affects material flow
5	.8006	Accepted	0.0782	IATF 16949 certification does not affect SMED
6	.0421	Rejected	0.1915	IATF 16949 certification affects TPM
7	6.9418E-36	Rejected	0.7954	IATF 16949 certification affects problem-solving

If a null hypothesis is rejected and consequently there is an association between the two nominal variables, the strength of the association is unclear. It can be helpful to perform a non-parametric Cramer's V test in terms of association. The third column of Table 3 shows the Cramer's V for each hypothesis along with the p-values.

The Cramer's V value varies from 0 to 1 and Table 4 shows the convention in terms of association magnitude (Rea & Parker, 2012, p. 203).

Tables 3 and 4 show that the association between IATF 16949 certification and the implementation of problem-solving can be considered strong, whereas the association between IATF 16949 certification and the implementation of 5S, standard work and visual management, and material flow are relatively strong. Furthermore, through the Cramer's V value it is now clearer that the association between IATF 16949 certification and the implementation of TPM methodology can be considered weak.

In order to better understand what is behind these quantitative results and the meaning the respondents gave to them, the following subsections will analyse the results including the qualitative notes the respondents added to the questionnaires.

IATF 16949 and DFSS methodology

According to Table 1, the IATF 16949 requirements foster DFSS along with other tools such as DFA, DFM, FMEA and FTA which are usually grouped within the DFSS methodology (Basem, 2008).

From the statistical results, respondents accepted the null hypothesis indicating that they considered there is no relationship between IATF 16949 certification and the implementation of DFSS methodology. However, Appendix 2 reveals that there are not as many 'good' and 'very good' answers as there are poor and acceptable ones for both the questions (before and after IATF 16949). These findings indicate that the implementation of DFSS methodology is not significant either with IATF 16949 certification or without it.

Of the notes left by the respondents, nine comments, in similar words, highlighted that the respondents entertained the possibility of introducing DFSS but they forgot about it because of some difficulties. First, the respondents thought that DFSS is a methodology for engineers with good statistical knowledge. Second, it is very difficult to make up a team dedicated to DFSS that have such skills; as a consequence, DFSS tends to be a methodology for few and very specialised people (Ben Romdhane, Badreddine, & Sansa, 2017). This finding also emerged from the literature review. However, Ben Romdhane et al. (2017) highlighted more specifically how companies could face financial difficulties in implementing Six Sigma and DFSS methodologies. In a different way, the results from these respondents are more focused on organisational difficulties such as training and skills.

According to 12 other respondents, single tools, such as FMEA, DFA and DFM, are used more than the DFSS methodology with its specific pattern by the companies. In

Table 4. Cramer's V value convention.

Cramer's V value	Association magnitude
0.00 and under 0.10	Negligible
0.10 and under 0.20	Weak
0.20 and under 0.40	Moderate
0.40 and under 0.60	Relatively strong
0.60 and under 0.80	Strong
0.80–1.00	Very strong

fact, some comments also highlighted that the FMEA tool is implemented because it is mandatory for the standard and asked for by the customers; the company is essentially obliged to implement FMEA.

IATF 16949 and DMAIC Six Sigma

According to the statistical results, IATF 16949 certification did not affect the implementation of the DMAIC Six Sigma methodology. According to the Appendix 2 cross-tabulation results, the situation is very similar to the DFSS one. The respondents had not introduced Six Sigma programs either with or without IATF 16949 certification. Comments by 16 respondents indicated that it is difficult to implement an effective Six Sigma program. As with the DFSS methodology, they suggested that a company needs specific team leaders named 'Black Belts' as well as 'Green Belts' (Hoerl et al., 2001), and staff who are capable in statistics and mathematics.

Some respondents stated that they do not intend to apply Six Sigma programs because they are not strictly required by the standard or by their customers.

IATF 16949 and 5S, standard work and visual management

The results indicated that IATF certification could be of some help with Lean tools and principles such as 5S, standard work and visual management. Appendix 2 showed that after having obtained IATF 16949 certification, the number of 'good' and very good' answers significantly increased and many comments left by the respondents confirmed it. There were 22 notes, with similar concepts, that stressed that these Lean tools are particularly suitable for the automotive environment. According to the respondents and the results from the literature review, 5S, standard work and visual management were very useful for increasing the quality of the product as well as productivity. Similarly with what Ablanedo-Rosas et al. (2010) found in a Mexican automotive plant, tidiness, cleanliness, standards and visual control help in decreasing the possibility of product contamination as well as assembling and machine errors. Furthermore, 5S and standard work create a specific organisational culture for quality and productivity (Falkowski & Kitowski, 2013). In addition to this, the respondents highlighted how the tools were directly requested and assessed by customers during their audits of the supplier plant.

IATF 16949 and material flow improvement tools

Similarly to 5S and standard work, the respondents believe that IATF 16949 QMS could boost the improvement of material flow. Appendix 2 shows a marked difference between responses for before and after IATF 16949 QMS: there is an inversion in the ratings from 'very poor' to 'very good'. According to 21 respondents, the reasons lie behind the mandatory requirements of the standard and probably to a greater extent on the assessment made by customers. Indeed, some respondents clarified in their notes that as soon as customers know the company is implementing IATF 16949, they tend to impose a precise material flow for their products and ask for a JIT delivery system where product demand has to be aligned with production capacity. Other respondents declared that, practically, they have two material flows within the same shop floor: one for automotive products under the IATF 16949 QMS and the other for non-automotive products.

IATF 16949 and SMED tool

IATF 16949 encourages the reduction and verification of set-up times even if, to be precise, the kind of tool to be used for this is not directly mentioned. Figures from Appendix 2 showed that the situation does not change significantly before and after IATF 16949 certification and the null hypothesis was accepted. It could be concluded that there is not a relationship between IATF 16949 and the SMED tool. However, the notes left by the respondents indicate that the situation is not that clear. First, 12 respondents left a laconic note where they simply declared the company does not know anything about the tool. Second, 18 other respondents reported that set-up reduction is more a matter of technological investments and machine revamping or changing. On the other hand, 11 respondents stated that they had been implementing SMED with some success, even though SMED is not linked with the IATF 16949 QMS.

IATF 16949 and TPM methodology

TPM is a very structured methodology usually divided into the so-called autonomous maintenance activities, managed daily by workers, and the professional maintenance activities where preventive and predictive maintenance plans are managed by engineers (Gajdzik, 2014). Furthermore, TPM includes design activities linked to the early equipment management process (Nakajima, 1988; Ireland & Dale, 2001).

The statistical results showed a moderate influence of IATF 16949 certification on TPM; the cross-tabulation results in Appendix 2 did not reveal a relevant difference between 'before IATF 16949' and 'after IATF 16949' and the majority of ratings were 'acceptable'. Similar to the SMED tool, the notes and suggestions left by the respondents depicted contradictions and confusion. First, the respondents declared that the company does not have a clear concept of what TPM actually is. Ten respondents wrote they have implemented TPM as a maintenance plan for replacing in advance critical components of the machines before a possible failure event happens. Nobody referred to statistical analysis for issuing the right frequencies in the plan, nor to potential failure analysis, nor to machine performance measurements such as Overall Equipment Effectiveness or similar (Nakajima, 1988). There were nine comments indicating that some difficulties were experienced in implementing such a structured methodology and they suggested that practitioners should begin with a 5S (Ohno, 1988) program before involving operators and then professional maintainers. There were even two notes in which respondents declared that TPM was outsourced to an external consulting and engineering company.

These findings confirm in part what was found out from the literature review, specifically from Ahuja and Khamba (2008). The authors claimed that the failure of companies to successfully implement an effective TPM program could be due to a general lack of knowledge and confusion with the TPM methodology.

IATF 16949 and problem-solving methodology

As previously discussed, the statistical results concerning problem-solving are the clearest. There is the highest correlation in terms of Cramer's *V* value between IATF 16949 certification and problem-solving methodology implementation and figures from Appendix 2 show a very precise overturning of results from the 'before IATF 16949' to the 'after IATF 16949' questions.

There were 23 similar notes left by respondents which drew attention to the impressive structured approach introduced by the standard. According to the respondents, for problem-solving IATF 16949 offers an effective approach with a powerful method of reducing defects and process variability. They linked this with the mandatory SPC requirements of the standard. Interestingly, 12 respondents argued in their notes that IATF 16949 improves the alignment of problem-solving processes and records between the company and its customers.

Conclusions

This research was carried out with a sample of 135 Italian practitioners in order to understand the relationships between IATF 16949 certification and seven LSS tools and methodologies. Italy has about 1500 automotive-related companies certified in compliance with the standard and has a tradition in terms of automotive industry due to the FCA group. In the automotive sector, there is a general interest towards the standard itself, LSS and all tools and methodologies for improving quality and productivity. In this way, the results from this research could be generalised to the automotive sector as a whole and not just to the Italian automotive sector.

Our research produced some novel findings not yet discussed in the LSS as well as IATF 16949 literature. An unexpected result was that the sample of Italian practitioners did not consider that IATF 16949 could foster or facilitate the implementation of DFSS and DMAIC Six Sigma. Previously some authors demonstrated how Six Sigma and DFSS can introduce difficulties especially from a financial point of view. From this research, it came out that Six Sigma and DFSS were considered to be for statistically minded engineers with faint possibilities of involving other staff; IATF 16949 cannot be of any help in implementing DFSS and Six Sigma. The practitioners also indicated that the implementation of a SMED tool is unaffected by the IATF 16949 standard.

On the other hand, the respondents thought that Lean tools such as 5S, standard work and visual management, which were grouped together, and material flow management are affected by IATF 16949. According to previous results from the literature, 5S and standard work can really help companies in improving quality, productivity and health and safety management. Audits and assessments from customers can further push the company in this direction. Similarly, IATF 16949 had a strong effect on the problem-solving methodology, whereas the TPM methodology was weakly affected by the standard.

In this light, it seems that when IATF 16949 facilitates the implementation of a tool or methodology it is because of the mandatory requirements of the standard and the customers.

Moreover, the respondents did not have a clear concept of what it exactly means to implement structured and complex methodologies such as TPM or tools such as SMED. According to the results, as well as the literature review, this situation could lead to some difficulties in implementing TPM, regardless of having a QMS.

A limitation of this research was that it was confined to Italy, even if the automotive sector has many similarities all around the world. Moreover, the results come from a quantitative survey without analysing what really happens within these organisations. Besides, we chose and trusted the respondents as LSS experts. In fact, they could be unaware of a potential lack of knowledge on the subject. Academics and practitioners should try to confirm or disconfirm with the findings of this research using samples from other countries as well as designing case studies that investigate the implementation of IATF 16949 QMS along with LSS tools and methodologies. In particular, they should analyse the implementation of some complex methodologies such as SMED and TPM. The latter deserves specific research with or without an IATF 16949 QMS. The findings show a lack of know-how and even confusion regarding the method. In addition, they should investigate the real achievable performances, especially considering that some tools and methodologies are implemented under a sort of compulsion from the customers and the standard. For instance, FMEA and SPC seem tools which are taken for granted and well implemented through the standard. However, this research did not investigate whether IATF 16949 really improves their implementation.

Last, but not least, findings from this research could be of some interest to practitioners who are thinking of implementing LSS. Specifically, in the automotive sector they could use IATF 16949 for strengthening the implementation of the LSS tools and methodologies requested by the standard. This was validated by the quantitative test as well as suggestions from the Italian respondents.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Appendix 1. The questionnaire administered to the quality managers

Think about the introduction of your IATF 16949 quality management system and your Lean Six Sigma implementation. Please, in a scale from 1 to 5 (5 = Very Good, 4 = Good, 3 = Acceptable, 2 = Poor, 1 = Very Poor), rate whether in your opinion 16949 has facilitated and/or fostered, in some ways, the following issues. For instance, if you think that DFSS methodology is at a very good level of implementation but IATF 16949 certification has not contributed at all to this, you should rate 5 for both questions (without IATF 16949 certification and after having implemented 16949). On the other hand, if you think that IATF 16949 certification has improved DFSS programmes, you should rate 5 for the 'after having implemented 16949' question and, for example, 1 or 2 for the 'without 16949 certification' question.
Please leave also a note at the end of each question concerning your point of view or comments on the issue.

1 Introduction of DFSS methodology (without 16949 certification)
Introduction of DFSS methodology (after having implemented 16949)
Please leave your comments on this issue

2 Introduction of Six Sigma DMAIC methodology (without 16949 certification)
Introduction of Six Sigma DMAIC methodology (after having implemented 16949)
Please leave your comments on this issue

3 Implementation of 5S, Standard Work and Visual Management tools (without 16949 certification)
Implementation of 5S, Standard Work and Visual Management tools (after having implemented 16949)
Please leave your comments on this issue

4 Implementation of Material flow improvement tools and pull production (without 16949 certification)
Implementation of Material flow improvement tools and pull production (after having implemented 16949)
Please leave your comments on this issue

5 SMED implementation (without 16949 certification)
SMED implementation (after having implemented 16949)
Please leave your comments on this issue

6 Implementation of TPM methodology (without 16949 certification)
Implementation of TPM methodology (after having implemented 16949)
Please leave your comments on this issue

7 Implementation of problem-solving methodology (without 16949 certification)
Implementation of problem-solving methodology (after having implemented 16949)
Please leave your comments on this issue

Appendix 2. Cross-tabulation results divided by hypothesis

Question	Frequencies				
			H_1		
	Very poor	Poor	Acceptable	Good	Very good
Before IATF 16949	38	55	19	16	7
After IATF 16949	33	50	23	17	12
			H_2		
	Very poor	Poor	Acceptable	Good	Very good
Before IATF 16949	59	28	12	18	18
After IATF 16949	62	28	14	15	16
			H_3		
	Very poor	Poor	Acceptable	Good	Very good
Before IATF 16949	33	42	8	27	25
After IATF 16949	8	11	9	54	53
			H_4		
	Very poor	Poor	Acceptable	Good	Very good
Before IATF 16949	12	28	29	26	40
After IATF 16949	5	5	10	52	63
			H_5		
	Very poor	Poor	Acceptable	Good	Very good
Before IATF 16949	18	54	19	17	27
After IATF 16949	13	50	23	18	31

(*Continued*)

Continued.

Question	Frequencies				
	H₆				
	Very poor	Poor	Acceptable	Very	Very good
Before IATF 16949	5	14	60	35	21
After IATF 16949	8	10	47	42	28
	H₇				
	Very poor	Poor	Acceptable	Very	Very good
Before IATF 16949	51	59	15	6	4
After IATF 16949	5	6	30	43	51