Impact of Digital Transformation on the Automotive Industry

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Abstract

Digital technologies are transforming the automotive industry and disrupting traditional business models. New business opportunities related with the Industry 4.0 are emerging, so that companies must adapt to the new environment.

The study presents an application of fuzzy-set qualitative comparative analysis (fsQCA) to analyse the future impact of digital transformation on the business performance models and actors´ satisfaction. A wide range of aspects and actors derived from the digital transformation process in the automotive industry are considered.

The study cover connected and autonomous driving, mobility as a Service, digital sources in cars, big data, etc. The disruptive effect of the gradual introduction of electric vehicles into the market is also considered, which is boosted by environmental policies on climate change and directives for the potential use of renewable energy sources to power electric vehicles.

On the other hand, the study analyses the digital transformation impacts in automotive industry from the point of view of different actors, ranging from the automobile manufacturers, service providers, public transportation providers, consumers to governments.

The methodology has been successfully applied to a complex case study-based empirical analysis. It presents a novel application using fsQCA to digital transformation in the automotive industry in Spain.

The conclusions show that the investing in the adequate measures for adaptation to the digital transformation are necessary, and manufacturers will end up having greater profits, productivity and competitiveness. From the point of view of consumers there will be access to more and better services and greater satisfaction with the required services.

Keywords: Digital transformation; automotive industry; productivity; competitiveness; fsQCA; Greenhouse Gas Emissions

1. Introduction

We are witnessing a time of continuous changes due to the irruption of digital technologies that are causing a transformation in the way the market and business operate in general. This generates a disruptive effect with respect to the traditional manner of proceeding both in the way of producing products and exchanging them, and also how business is done and benefits are obtained for producers and customers (Fichman, Dos Santos & Zheng, 2014).

The effects of the digital transformation in the world are evident and they produce enormous benefits for entrepreneurs, consumers and society in general, although there are issues related to the environment that must be addressed (Yoo, Henfridsson & Lyytinen, 2010).

The disruptive effect resulting from digitalization has also reached the automobile industry and it is the most important phenomenon in 140 years of industry history. Digital transformation, globalization and more severe competition are leading the way (Gao et al., 2016).

Digital transformation strategies are important, because they reflect the omnipresence of the changes brought about by digital technologies in an organization (Chanias & Hess, 2016). Hence, organizations have to change traditional business models, which have been robust for many decades, and transform their organizations to adapt these trends, e.g., car sharing platforms or new telematics services (Kotarba, 2018; Riasanow et al. 2017).

The factors that affect the automobile industry with an increasing influence and complexity are diverse (Winkelhake, 2019; Fritschy & Spinler, 2019; Wells et al., 2020). Among these factors, globalization stands out, which gives manufacturers the opportunity to expand into new markets, the diversification of consumers, and the accelerated modification and diversification of products. The diversification of consumers will contribute to new patterns of behavior and the need to satisfy their tastes individually, while the diversification of products will imply the reduction of the life cycle of the models to react to the fast and changing demand of consumers with innovative products (World Economic Forum, 2016). The average lifecycle of a vehicle was eight years while today manufacturers have changed and modified their models in a margin of 3 years, (Jain & Garg, 2007).

Nowadays digital technologies of vehicles represent at least 50% of the total value of a vehicle (CCOO, 2018). The integration of software and hardware has increased not only the functionality of a car, but also its complexity. Key aspects have been identified that contribute to accelerating the process of digitalization of the automotive sector such as driver connectivity, location-based services and the type of driver based on their tastes and preferences, a feature that did not exist 20 years ago. Another key aspect is the autonomous driving where the driver will only need to press a button to go to his destination. In this regard, assisted driving and the autonomous driving can be highlighted. The assisted driving covers the functions for assisting the driver, which will become increasingly common until the driver becomes a passive element in the transport process, while autonomous driving entails that vehicles are capable of moving and navigating on their own in adequate traffic conditions on all types of roads (Farahani et al., 2017).

Digitization will bring significant improvements in the value chain by boosting efficiencies, reducing costs, generating greater collaboration and innovation. It will allow to evolve from business-to-business approaches through their dealerships to a business-to-consumer model, with new ways to engage with customers, partners with suppliers interacting through data. Increasingly connected vehicles will change business strategies from selling a product to offering value focused on customer experience (Marcus Hoffmann, 2019). According to Accenture, (2017), digitization will have an influence on the connected supply chain, which has the advantage costs reduction and a better management of the whole process from the beginning to the end Additionally digital manufacturing will play a major role, with new generations of robots that allow multiple assemblies, and the increasing importance of robotics, artificial intelligence and the internet of things that will be part of the new industrial revolution.

Other factors should also be considered in the digitalization transformation of the automotive industry. The effect on the retailer, which cover manufacturers, commercials and consumers that are dynamically redefining the way they interact and communicate with each other. Moreover, clients expect a fluid interaction both physically and digitally when buying products or services. Maintenance and connected services, which will provide predictive maintenance are sophisticated diagnostic systems. For instance, intelligent components and ubiquitous connectivity will allow certain components to send a signal when they need maintenance or replacement Digital transformation in the aftermarket will facilitate both hardware and software updates, but manufacturers and suppliers should make their systems compatible. Car data market will also be a key factor, where the commercial promise of more precisely targeted customer offers, new business models, and increased efficiency from data and analytics will make these new businesses a veritable gold mine for automotive players. Furthermore, connected infrastructure V2V and V2I (Vehicle-to-Vehicle and Vehicle-to-Infrastructure, respectively) are key enablers of intelligent transportation will create an integrated communications network of continuously moving digital information to increase safety and improve traffic flow. They cover sensors, transponders, radio-frequency identification (RFID) readers in the road, traffic lights, bridges and parking lots).

In addition, customer experience has been and will continue to be a key differentiator in the automotive market, whether during the sales process, the in-car driving experience or the aftersales market.

As for electric vehicles (EV), there will also be competition between manufacturers to deliver the latest EV model. An area that will absorb a special interest and will be a challenge is the aftermarket.

Currently, OEMs are heavily investing to adapt to these trends. However, it remains unclear which technologies will prevail, leading to tensions in the automotive industry, as OEMs do not want to give up their leadership in product and technology (Simonji-Elias et al., 2014; Farahani at al., 2017).

The present paper analyses how the digital transformation impacts in automotive industry in Spain from the point of view of different actors, ranging from automobile manufacturers, service providers, public transportation providers, consumers to governments. This include the role of new actors that are arising due to the digitalization transformation in the automotive industry such as mobility service platforms, i.e., private or commercial car sharing, peer to peer (P2P) lending or service platforms from original equipment manufacturers (OEMs).

The methodology applied enables to define the trends and effects of the digital transformation in the automotive industry. The purpose is to provide the set of measures to be undertaken by the automotive industry in order to stay competitive because of the digital transformation. This is measured by the actors’ satisfaction while considering a wide range of factors or antecedent conditions. Among these factors several impacts are analysed, such as the disruptive effect of electric vehicles, the obligation to fulfil the environmental regulations or the emergence of new business and services. By knowing the actors’ satisfaction regarding these aspects, the automotive industry can come up with better strategies for the future adaptation to the digital transformation. Eventually, it can be used as a Decision Support System (DSS) during the decision-making process for the different actors.

Results show how the digital transformation will rapidly change the global landscape of the automotive industry. Consequently, the measures to be adopted to favour the digitalization process and ultimately the effectiveness in the production, sales and connectivity processes with the user / client will be presented.

In the discussion and conclusions section, the paper´s outcomes are summarized and further research is proposed to follow the digital transformation in the global automotive industry.

2. Material and Methods

2.1. Theoretical framework

In recent years, the fuzzy-set qualitative comparative analysis (fsQCA) has gained popularity among scientists interested in analysing and comparing data that are associated with cases. Although it was primarily applied to political science and sociology, nowadays it is exhaustively applied in many research areas (e.g. Berbegal-Mirabent & Llopis-Albert, 2015; Llopis-Albert, Merigó, Xu, & Liao, 2017; Llopis-Albert & Palacios-Marqués, 2016; Llopis-Albert, Rubio, & Valero, 2019).

The fsQCA is an empirical method based on Boolean algebra that allows for a configurational examination of the causal relationship between a set of antecedent conditions and a related outcome (Ragin, 2008). The methodology enables a systematic cross-case comparison and leads to a case-sensitive approach. The methodology is especially suitable for cases with small data samples and favour the generalization of conclusions for larger populations. In addition, it overcomes some of the limitations of strictly qualitative or quantitative methods, and allows complex causations, counterfactual analysis and to systematically analyse conjunctural causal patterns.

The theoretical aspects of this comparative method are explained in detail in Mendel and Korjani (2012, 2013), but the main principles are those based on conjunctural causation. This means that usually not one factor but a combination of factors will lead to the outcome; different combinations of factors may lead to the same outcome; and one condition can provide different impacts on the outcome, depending on its combination with other factors and the context (Rihoux 2007).

The term conjunctural refers to fact that it is generally a combination of factors (which is called as a configuration) rather than a single factor that leads to an outcome. Then not only the presence but also the absence of a specific factor may be influential to reach the outcome, and hence, is measured. That is QCA logic considers that different factors are complementary and often interdependent. Even if the influence of one factor is small, it might be necessary to trigger another factor, and hence, contributing to the overall outcome (Ragin, 2008).

As a result, the fsQCA method offers a set-theoretic approach to causality analysis due to its capability to identify and assess different combinations of conditions that describe certain outcomes. The method assumes complex causality and focuses on asymmetric relationships to determine which combination of factors -named as a configuration or pathway- is minimally necessary and/or sufficient to attain a certain outcome, rather than focusing on how one individual independent variable relates to the outcome. In addition, it allows to identify which groups of cases share a specific combination of conditions (Meyer, Tsui, & Hinings, 1993). A condition is necessary if a specific outcome cannot be achieved in the absence of this condition, while a condition is sufficient if it leads to the outcome by itself, without the presence of other conditions (Ragin, 2008). Furthermore, it allows dealing with the concept of equifinality, which refers to the fact that multiple configurations to a desired outcome may coexist.

The application of fsQCA to cross-case evidence comprises four different steps: (1) selecting cases and factors; (2) performing a calibration procedure over available information; (3) constructing and reducing the truth table; (4) analysing the results.

Once the cases and factors have been selected, variables must be transformed into sets according to the degree of membership to a given condition. This is performed based on theoretical or substantial knowledge external to the empirical data, which allow to categorize meaningful groupings of cases (Ragin, 2008). For that purpose, the limitation of dealing only with binary variables is overcome using a fuzzy-set approach, thus allowing to incorporate non-dichotomous conditions into the analysis. Therefore, the causal conditions and the outcome are defined as fuzzy sets, in which membership functions (MFs) must be established.

The calibration procedure is performed to transform the actors' preferences with regard to factors into fuzzy variables so that they match or conform to external standards. Fuzzy sets have the advantage that they can deal with both quantitative and qualitative measurements, thus overcoming some of the limitations of both. Moreover, fuzzy sets allow to properly deal with multiple data sources, as is the problem in hand. A direct method for calibration is usually followed, which consists of defining three qualitative anchors representing the degrees of membership into a certain set: the threshold for full non-membership, the crossover point indicating maximum ambiguity regarding membership to the set, and the threshold for full membership. To anchors are generated using the 5th, 50th, and 95th percentiles, respectively (Ragin, 2008). These anchors do not represent probabilities but rather transformations of the quantitative scale into degrees of membership in each category.

The next step is to construct a truth table, a matrix with 2^k rows in which k is the number of causal conditions (i.e., configuration or pathway) and each column represents an antecedent condition (i.e., condition or factor). The number 2 is selected since both the causal condition and its complement are considered. The truth table represents all logically possible combinations of causal conditions and classifies the cases according to their possible combinations. Each empirical case matches a specific configuration depending on which antecedent conditions the case meets (Fiss, 2011).

Subsequently, a reduction in the number of rows of the truth table is carried out using the Quine–McCluskey algorithm (Quine, 1952). By means of Boolean algebra the minimally sufficient configurations to produce the outcome is obtained. This procedure is based on several indicators, such as the consistency and the coverage (Ragin, 2008). The consistency illustrates the degree to which instances sharing similar conditions display the same outcome (Ragin, 2008). Hence, it measures the degree to which membership in the solution (i.e., the set of solution terms) is a subset of membership in the outcome. The coverage expresses the empirical relevance of a solution, thus measuring the proportion of memberships in the outcome explained by the complete solution. The raw coverage indicates the share of the outcome that is explained by a specific configuration (i.e., solution). The unique coverage quantifies the share of the outcome that is exclusively explained by a specific configuration.

2.2. Case study: Spanish automotive industry overview

The fsQCA approach is applied to provide insight about the impact of digital transformation on the Spanish automotive industry and to assess the respective adaptation strategies. A wide range of aspects and actors derived from the digital transformation process in the automotive industry are considered.

The study covers from connected and autonomous driving, to mobility as a Service (MaaS) and servitization, connected supply chain and manufacturing, digital sources in the car buying and marketing processes, shared driving and vehicle ownership, big data and analytics and cloud, and how to guarantee safety, security and privacy. The disruptive effect of the gradual introduction of electric vehicles into the market is also considered, which is boosted by environmental policies on climate change and directives for the potential use of renewable energy sources to power electric vehicles. In this way, the automotive industry will be forced to adapt to new government regulations in relation to Greenhouse Gas Emissions (GHE) reduction policies and energy resource efficiency and sustainability (Rubio et al., 2019).

The methodology has been successfully applied to a complex case study-based empirical analysis. A great deal of information has been collected to conduct the study. Obviously, the level of participation and degree of influence on the measures to be undertaken for the digitalization transformation is different for each type of actor, size of companies or individual consumers, legal system in different countries, etc.

At this regard, the methodology applied has the advantage to properly cover all these considerations and realities.

2.2.1. Characterization of the Spanish automotive industry.

In Spain, the automotive sector (considering manufacturing companies and suppliers), exceeded 100,000 million euros in turnover in 2018 which implies a weight of 8.6% of the sector over the Gross Domestic Product (GDP), reaching 10 % if marketing, after-sales and financial services are considered (Fig. 1). This gives an idea of the importance of the sector in Spain (Anfac,2018).

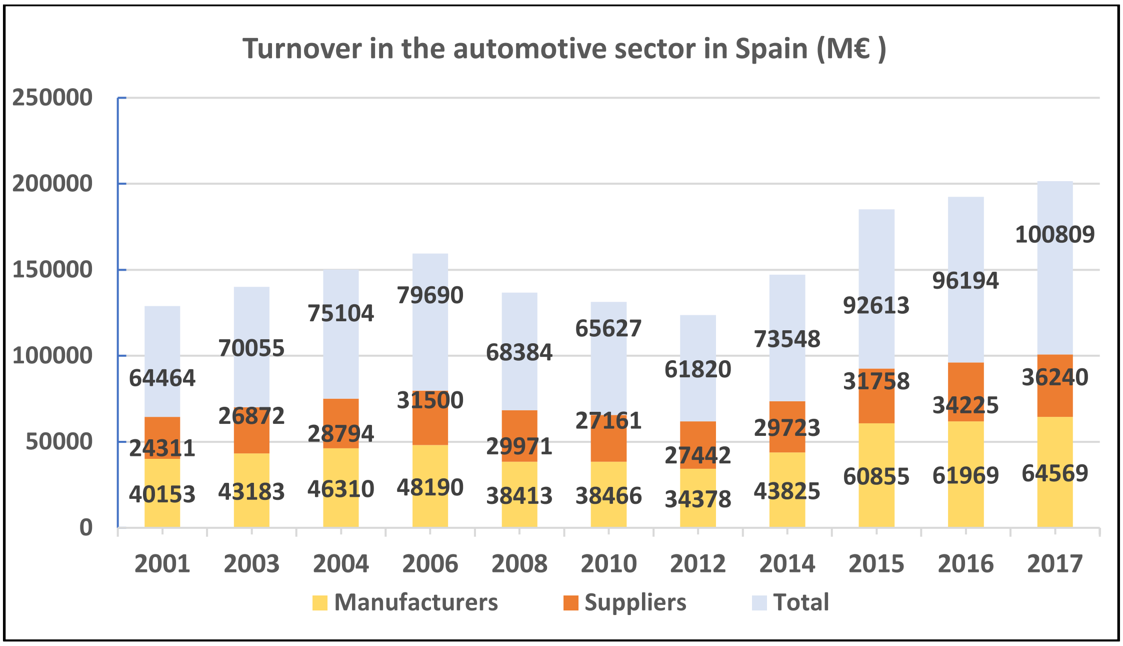

Figure 1. Turnover of the automotive sector in Spain

It must be also highlighted the resources that the sector has in Spain. There are 9 manufacturers and 17 factories, which mobilize 70,000 people. There are 2.8 million vehicles and 1.5 million registrations, which involve 160,000 people in sales and maintenance of vehicles; 2.3 million vehicles are exported, representing 17. 9% of the national exports and 13.1% of imports; the Spanish car park is made up of 29 million vehicles and 9 % of the total active population is working in this sector (Anfac, 2018).

Regarding investments, in the last four years the automotive companies in Spain have invested up to 12,000 M€, focused on new technologies and innovation (Fig. 2). Investments for innovation are mainly devoted to areas such as safety, energy efficiency or the environment. But also, to aspects related to the improvement of the quality of the industrial processes, from the adaptation of the assembly lines to the new assigned models which they have undergone from 36 to 42 and, therefore, of the own productivity. For the year 2019-2020, a dozen new models are engaged, half with an alternative version (electric, hybrid or gas), (Anfac, 2018).

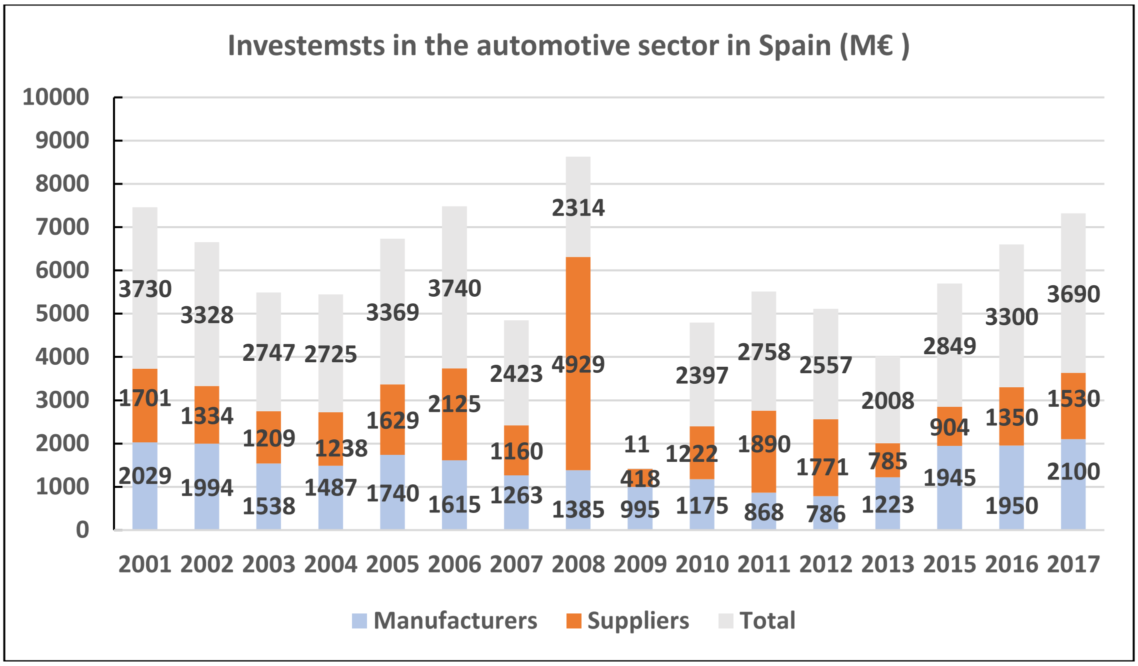

Figure 2. Investments of the automotive sector in Spain

The small and medium-sized enterprises (SMEs) devoted to the equipment and suppliers for the automotive industry are also considered. There are more than one thousand companies, which generate 4% of the Total Industrial Gross Value Added and the same percentage of investment in R & D & I (4.2% of its turnover), creating 225,000 direct jobs and another 100,000 indirect (Anfac, 2018).

Suppliers companies will increase the percentage of added value to the vehicle in the near future, due to the increase in higher value electronic systems and components. In this sense, the new scenario that occurs in the presence of electric vehicles, connected and autonomous, is reorienting the components demanded by vehicle manufacturers, adapting promptly to such demand.

The greater complexity of the set of accessories (with each new car version launched to the competition of the market), configures an industry with high presence of suppliers of first level equipment - with a high technological level - of foreign capital, showing the weaknesses of national manufacturers, due to the limited capacity for research and technological development of the majority of companies.

The internationalization of the automotive industry also plays an important role since it makes it more difficult for the Spanish industry to remain in the market of the first equipment because the designs of the models that are mounted in Spain are decided and executed in the mother companies.

The EVs in Spain only represent 0.3 % of total vehicle production. Hybrids cars represent 0.1% of the total produced and those of natural gas 0.2%.

Financial products are playing a fundamental role in the purchase of vehicles. Founding for renting and subscription will continue to dominate, which will cover special offers such as monthly fee with insurance, maintenance, change of tires, without initial entry or final fee.

Manufacturers' suppliers will be the most affected by the digitization process, which will be forced to intensively use new connectivity and manufacturing developments, covering 3D manufacturing, computer numerical control CNC, injection molding, reverse engineering, etc. Furthermore, commercial activity such as online sales and car sharing will also needed to be improved.

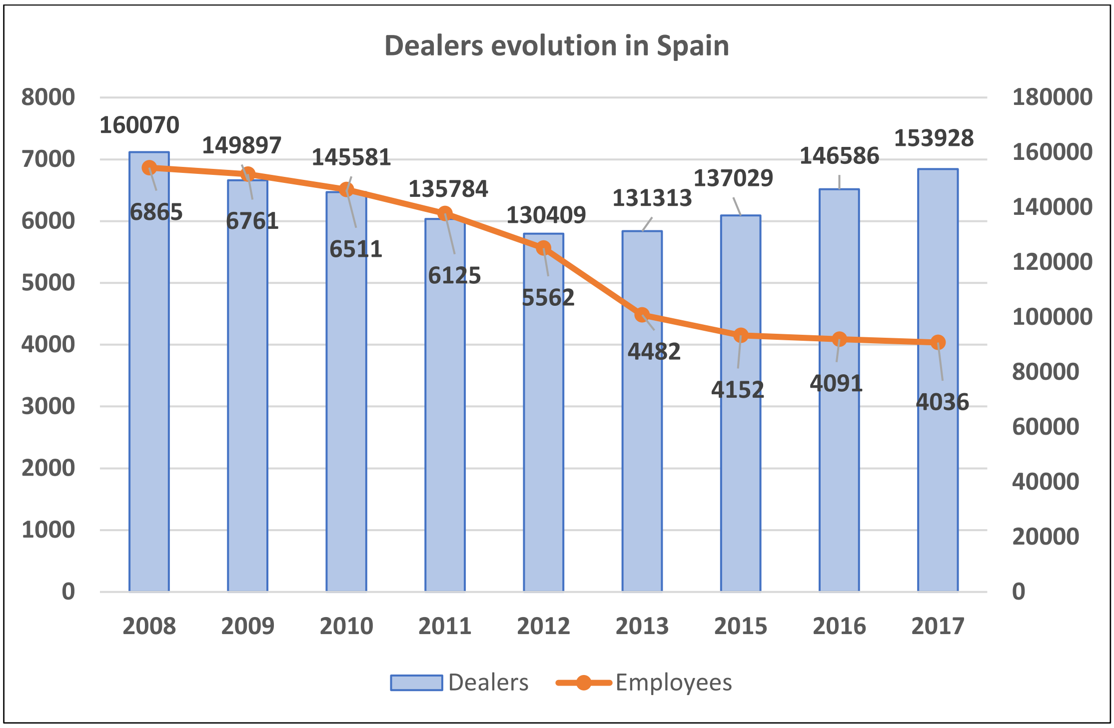

Figure 3. Number of dealers and employees in Spain

In 2017, there were 4036 dealers in Spain, covering sale and repair points, with an average annual sale of 287 cars. They are managing to maintain profitability thanks to the reduction in the production costs of the vehicles and the increase in sales.

It is also necessary to consider the policies of emissions and alternative vehicles in the analysis of the impact of digitalization, which has resulted in the Spanish Strategy for the Promotion of Electric Vehicles, a tool of government policy to try to reduce emissions of polluting gases.

In Spain, diesel vehicles have a 42% share in production. The objective towards an ecological transition in the automobile sector implies a comprehensive environmental approach and measures that promote the crushing of vehicles and making consistent use of the tax policy that includes the registration and circulation tax.

The automobile industry faces two outstanding challenges: the integration of the electric vehicle, which is changing the rules of the game in the sector, and the application of the new WLTP (World Harmonized Light-duty Vehicle Test Procedure) approval protocol, which requires significant modifications of the brands in its commercial offers and ranges of vehicles, with direct consequences in Spanish factories.

3. Application of the fsQCA technique to the case study

The fsQCA allows dealing with uncertain environments because the heterogeneous nature of the actors involved and the diverse factors leading to their satisfaction. Moreover, actors' heterogeneity leads to substantially different interests with regard to how the digital transformation in the automotive industry should be carried out, which complicates the problem. This technique enables the consideration of the actors' level of participation and their degree of influence when designing strategies for the implementation of the digital transformation.

The outcome of the multi-criteria decision-making (MCDM) problem in hand is the actors' satisfaction. For that purpose, the point of view of different actors is considered ranging from the automobile manufacturers (including shareholders, managers, labour unions, and workers), service providers, public transportation providers, consumers to regional and national governments. This study covers small and medium-sized enterprises (SMEs), which are suppliers of products or services to the automotive industry, and multinational companies operating in Spain.

This include the role of new actors that are arising due to the digitalization transformation in the automotive industry such as mobility service platforms, i.e., private or commercial car sharing, peer to peer (P2P) lending or service platforms from original equipment manufacturers (OEMs). A similar percentage of the different actors is used in this study to homogenize results.

The actors comprise all groups who will be somehow affected by the digital transformation in the automobile industry. This covers those who have some kind of interest and those who are likely to suffer the consequences.

A great deal of information has been collected to conduct the study. It covers surveys, meetings, personal interviews, workshops, reports, public domain information, mass media information and expert judgment. Furthermore, three levels of participation are considered, namely information (actors are only informed), consultation (actors express their opinions, which are considered in the decision-making process), and active involvement (actors are engaged in seeking solutions and have the power to co-decide). Obviously, the level of participation and degree of influence on the measures to be undertaken for the digitalization transformation is different for each type of actor, size of companies (based on the number of employees and invoicing volume) or individual consumers, legal system in different regions or countries, etc. In addition, the actors' level of participation is different covering only an information procedure (which is the case of workers and services or products consumers, for instance, related to the acquisition of vehicles), consultation (this is the case of SMEs, which are suppliers of products or services to the automotive industry) or an active involvement (which is the case of regional or national governments, multinational stakeholders and managers). In this regard, the methodology applied has the advantage to properly cover all these considerations and realities.

Table 1 shows the conditions or factors used in fsQCA that may lead to the actors' satisfaction when designing future strategies for the adaptation to the digital transformation in the automotive industry. Five factors are considered, which encompass a total of forty subfactors. They cover a wide range of issues, such as management, legal, financial and technical factors, the disruptive effect of electric vehicles, environmental regulations, and new services or business. The actors' degree of preference or acceptance regarding the factors considered is analyzed using a continuous fuzzy set.

This analysis uses fuzzy-set theory rather than simple presence/absence dichotomies or crisp sets. This is because we deal with non-dichotomous conditions (such as the actors' satisfaction), thus allowing to address partial membership in sets.

The calibration procedure makes use of all available information and is organized using variables on interval scales or Likert scales. These psychometric scales are exhaustively employed for scaling information, which can be structured using linguistic labels. For instance, "degree of membership in the set of willingness to invest more than a certain percentage of the company's turnover for adaptation to the digital transformation". Consequently, the actor's degree of agreement with regard to a certain statement can be categorized using a five-level Likert scale, for example: "strongly disagree", "disagree", "neither agree nor disagree", "agree", and "strongly agree". The conversion between these verbal labels and the fuzzy scores is performed using different qualitative anchors that structure fuzzy sets. The fuzzy scores are associated with degree of membership and range from 0 (which represents a low degree of acceptance or agreement) to 1 (which display high degree of acceptance or agreement). The threshold used for the different factors to represent the degrees of membership are the 5th (full non-membership), 50th (crossover point dividing "more in" from "more out" with regard to a specific statement), and 95th percentiles (full membership). The transformation into fuzzy scores must also consider the type of actor, the actors' level of participation and their degree of influence on the automotive industry. We use the size, number of employees and turnover of the company to homogenize results. In this way, the values obtained are more comparable across different companies and realities. For instance, shareholders, the management board of multinational automotive corporations and governments have more influence in the digital transformation than small and medium-sized enterprises (SMEs), consumers, workers or labour unions. A clear example of the different level of influence is the disruptive effect of the gradual introduction of electric vehicles (EVs) into the market and its subsequent reduction in greenhouse gas emissions, where governments and the powerful automotive industry lobbies exhibit higher influence or pressure regarding the other actors. This process is boosted by environmental policies on climate change and directives for the potential use of renewable energy sources to power electric vehicles. In this way, the automotive industry will be forced to adapt to new government regulations in relation to Greenhouse Gas Emissions (GHE) reduction policies and energy resource efficiency and sustainability (Rubio, Llopis-Albert, Valero, & Besa, 2019; Rubio and Llopis-Albert, 2019). These implications have been taken into account when assigning the fuzzy scores, with the aim of weighting and homogenising the results.

Hence, fuzzy-set membership scores are appropriately assigned to actors with higher influence and a greater level of participation. They are considered in this study to be more difficult to satisfy.

Additionally, the aggregated final score for each factor is calculated through the arithmetic average of the fuzzy scores of each subfactor. The results strongly depend on the calibration process, so that it is of utmost importance to convert the verbal labels of the scales into metrics without any loss of information. An adequate calibration should allow to scale the degree of membership while considering qualitative differences between actors and factors.

After the calibration procedure, a truth table is constructed and analysed via the fsQCA 3.0 software (Ragin & Davey, 2017) and the R package (Medzihorsky et al., 2018).

Since there are five factors, the matrix dimensions are (25) rows (i.e. 32 possible configurations) and 5 columns. First, the matrix is tested for necessary factors for the outcome and also for the negation of those factors, expressed by the tilde (~) sign in Table 2.

A condition is considered necessary if the consistency is higher than the threshold value of 0.9 (Schneider & Wagemann, 2012). Table 2 illustrates the consistency and coverage values for all conditions. As the highest consistency value among all conditions is 0.8650, none of the variables is a necessary condition to produce the outcome. Consequently, there are not any conditions that need to be present for achieving actors' satisfaction. This demonstrates that actors' satisfaction depends on a wide variety of conditions due to the high actors' heterogeneity with conflicting interests.

The truth table is minimized by means of Boolean algebra using the coverage and consistency values. It leads to a set of combinations of causal conditions in which each configuration is minimally sufficient to gain the outcome.

Table 3 depicts the nine configurations that are returned by the algorithm. Following Ragin's (2008) recommendation, the intermediate solution is presented. In accordance with the notation introduced by Ragin and Fiss (2008), black circles (●) mean the presence of a factor, white circles (○) indicate its absence, and blank cells represent ambiguous factors. All configurations display acceptable consistency values (<0.80), while the raw coverage values range from 0.0507 to 0.3423. Then results show a great diversity of configurations so that no unifying path explains the outcome, which implies that they are sufficient but not necessary.

Results may be somehow distorted because the lack of an adequate knowledge regarding the complex digital transformation implications of some actors (such as the consumers). As a further research, it should be advisable to carry out different rounds during the implementation of fsQCA to better explain to all actors such implications and allowing to share their conflicting point of views. This would lead to more consensus about the future strategies for adaptation to the digital transformation.

The uncertainty in the results can be assessed by means of robust tests, which are based on several adjustment parameters such as the unique coverage, the raw coverage and the consistency. Tables 2 and 3 present the validity and reliability of the results, in which those parameters show satisfactory levels of confidence in the diverse solution terms as defined by Ragin (2008).

Concerning the non-necessary conditions results are imprecise. Although these conditions are presented in several configurations, their absence is significant in other pathways. The absence or presence of such conditions in a specific configuration can be explained by the actors' heterogeneity.

It is worthwhile mentioning that in order to obtain satisfactory outcomes actors should be engaged at early stages of the decision-making process and be provided with clear targets, information, and organization (e.g. suitable mechanisms to capture them and a reasonable agenda). In this way, there will be more probability that actors support decisions and less to hamper them. such as less likely to hinder decisions and more likely to support them. Moreover, satisfied actors are less prone to delay the decision-making process by means of their opposition, for example, by litigation regarding the deadline to achieve a complete fleet of electric vehicles (EVs) or the imposition by the government of more restrictive standards defining acceptable limits for exhaust emissions of new fuel vehicles sold (Berry, Portney, & Thomson, 1993).

4. Discussion and conclusions

Digital transformation is gaining momentum in the automotive industry and will rapidly change the global landscape of the automotive industry. Moreover, it is causing a significant shift in the way car manufacturers and service providers are delivering goods and services to market, which is boosted by the environmental government legislations and the high consumers' demands.

Results shed light about the impacts and adaptation strategies for the digital transformation on the automotive industry, which is analysed from the point of view of a wide range of actors. In this regard, this work presents the factors and measures to be adopted that the actors consider appropriate to favour the digitalization process and ultimately the effectiveness in the production, sales and connectivity processes with the user / client are posed.

Results show that all configurations leading to the outcome (i.e., actors' satisfaction) for all actors entail a combination of factors with high demands of improved or new digital services, electric cars increasingly competitive, economical and autonomous and the use of efficient renewable energy resources. The results also exhibit that there are conditions that appear in most of the configurations leading to the outcome, for example, the implementation of new services and business (C5). Consequently, the companies that take the lead in developing new services and products related to the digitalization process will have a significant advantage to compete in the automotive industry. Therefore, results suggest that investing in the adequate measures for adaptation to the digital transformation are necessary, and manufacturers will end up having greater profits, productivity and competitiveness. For better adaptation to such impacts results lead to the conclusion that car manufacturers should carry out a major investment on the digital transformation to gain a competitive advantage in the global market representing the automotive industry. This investment should encompass both capital for infrastructure projects and Research, Development and Innovation (R&D&I) activities.

However, we have detected that companies are somehow reluctant to devote substantial capital to the effort. This is because there is no immediate payoff, which entail risk of capital, and the return on investment is uncertain. Note that some impacts, such as the gradual introduction of electric vehicles, have a far-reaching effect on business profits. Therefore, there is a delay between the current investment in the required technologies and the future expected benefits. As a result, a small number of organizations have completed their roll out, being the majority still defining their procedures of implementation or performing mid-term test projects to ensure that their approach is appropriate.

Moreover, some small and medium-sized enterprises (SMEs) lack digital transformation strategies, which may cause a dramatic effect in the automotive sector in Spain in the medium- and long-term. This is because the high demands in capital and human resources pose a significant barrier to those companies to attain the digital transformation.

The actors' satisfaction strongly depends on their role in the automotive industry, which has led to consider a broad variety of factors. For instance, results show that manufacturers or supply chain and logistics companies pay more attention to the profit and productivity, while consumers' satisfaction with regard to a product or service purchased is analysed in terms of accessibility, connectivity and simplicity, cost and quality, real-time services, users' choice and support, possibility of personalization, deliverability, etc. Workers and labour unions are more interested in preserving the existing jobs, about the difficulty in handling new technologies and in safety considerations

From the point of view of consumers results suggest that there will be access to more and better services and greater satisfaction with the required services, since they are highly demanded by them. In this sense, consumers will play a major role due to the strength to choose vehicles and services. However, they are still reluctant in the short run to buy electric or hybrid vehicles since consumers pay more attention to the high purchase price of the vehicles, long battery recharge times, low autonomy (driving range), and scarce recharging points. Nevertheless, if any improvement is made in this regard together with their lower energy cost and emissions, the higher energy efficiency, lower car repair and maintenance, to enable specific parking areas, and to provide tax incentives can tip the balance in favour of electric cars. Results suggest that car manufacturers prefer a gradual implantation of EVs due to the high investment required for the transition from fuel vehicles, and that they oppose the highly restrictive environmental regulations. Contrary, consumers show greatest awareness about environmental problems. Again, results exemplify the conflicting and competing interests of actors.

In addition, consumers' opinions allow to the other actors to better identify the threats and opportunities (e.g., to tackle new emerging markets and services) that the digitalization transformation poses to the automotive industry.

Finally, the methodology seeks to provide a Decision Support System (DSS) in order to address the trends and challenges of the digital transformation in the automotive industry that can be used during the decision-making process for the different actors.

As a further research, since the automotive sector is worldwide, other countries should be analysed to confront the conclusions obtained in this case study. That is regional and cross-country comparisons should be carried out. t would also be advisable to evaluate whether the causal configurations remain unchanged over time, consider other core factors (such as the confidence in the management team), the reliability and validity of results when applied to other industrial sectors.

Also, digital transformation should be considered to overcome faster the severe economic slowdown due to COVID-19 health crises. This should be empirically corroborated in next studies about this topic.

References

Anfac (2018). Annual report from the "Asociación Española de Fabricantes de Automóviles y Camiones" https://anfac.com/publicaciones/informe-anual-2018

Berbegal-Mirabent, J., & Llopis-Albert, C. (2015). Applications of fuzzy logic for determining the driving forces in collaborative research contracts. *Journal of Business Research*, 69(4), 1446–1451. https://doi.org/10.1016/j.jbusres.2015.10.123.

Berry, J. M., Portney, K. E., & Thomson, K. (1993). The rebirth of urban democracy. Washington D.C.: Brookings Institution Press.

Chanias & Hess (2016). Understanding Digital Transformation Strategy Formation: Insights from Europe's Automotive Industry. PACIS 2016 Proceedings. 296. http://aisel.aisnet.org/pacis2016/296

Accenture, (2017). Digital Economic Opportunity in Spain. How digitalization may boost the Spanish Economy.

Dziallas, M. (2019). How to evaluate innovative ideas and concepts at the front-end? A front-end perspective of the automotive innovation process. Journal of Business Research. https://doi.org/10.1016/j.jbusres.2018.05.008.

Farahani P., Meier C., and Wilke J. (2017). Digital Supply Chain Management Agenda for the Automotive Supplier Industry. Oswald G., Kleinemeier M. (eds) Shaping the Digital Enterprise. Springer, Cham, https://doi.org/10.1007/978-3-319-40967-2_8

Fichman, R. G., Dos Santos, B. L. & Z. Zheng (2014). "Digital Innovation as a Fundamental and Powerful Concept in the Information Systems Curriculum." MIS Quarterly 38,(2), 329-343

Fiss, P. C. (2011). Building better causal theories: A fuzzy set approach to typologies in organization research. The Academy of Management Journal, 54(2), 393–420.

Fritschy, C., Spinler, S. (2019). The impact of autonomous trucks on business models in the automotive and logistics industry–a Delphi-based scenario study 148, 119736. https://doi.org/10.1016/j.techfore.2019.119736

Gao, P., N. Müller, H.-W. Kaas, D. Mohr, D. Wee, R. Hensley, M. Guan, T. Möller, G. Eckhard, G. Bray, S. Beiker, A. Brotschi, & Kohler, D. (2016). Automotive Revolution Rerspective Towards 2030, McKinsey Report.]

Jain, S., & Garg, R. K. (2007). Business Competitiveness: Strategies for Automobile Industry. Indian Institute of Management Kozhikode.

Kotarba, Marcin. 2018. Digital Transformation of Business Models. Foundations of Management, 10, 123-142. DOI: 10.2478/fman-2018-0011.

Llopis-Albert, C., Rubio, F., &Valero, F. (2019). Fuzzy-set qualitative comparative analysis applied to the design of a network flow of automated guided vehicles for improving business productivity. *Journal of Business Research*, 101, 737-742. https://doi.org/10.1016/j.jbusres.2018.12.076

Llopis-Albert, C., Merigó, J. M., Xu, Y., & Liao, H. (2018). Application of fuzzy set/qualitative comparative analysis to public participation projects in support of the EU water framework directive. Water Environment Research, 90(1):74-83. https://doi.org/10.2175/106143017X15054988926550.

Llopis-Albert, C., & Palacios-Marqués, D. (2016). Applied mathematical problems in engineering. Multidisciplinary Journal for Education, Social and Technological Sciences, 3(2), 1–14. https://doi.org/10.4995/muse.2016.6679.

Marcus Hoffmann, 2019, A Survival Guide for Europe's Car Dealers, https://www.bain.com/insights/a-survival-guide-for-europes-car-dealers

Mendel, J. M., & Korjani, M. M. (2012). Charles Ragin's fuzzy set qualitative comparative analysis (fsQCA) used for linguistic summarizations. Information Sciences, 202, 1–23.

Mendel, J. M., & Korjani, M. M. (2013). Theoretical aspects of fuzzy set qualitative comparative analysis (fsQCA). Information Sciences, 237, 137–161.

Medzihorsky, J., Oana, I. E., Quaranta, M., & Schneider, C. Q. (2018). SetMethods: functions for set-theoretic multi-method research and advanced QCA. R package version 2.1.

Meyer, A. D., Tsui, A. S., & Hinings, C. R. (1993). Configurational approaches to organizational analysis. *The Academy of Management Journal,* 36(6), 1175–1195.

Hacia un nuevo concepto de conducción: conectividad, autonomía y ciberseguridad, 2017, https://www.revistacesvimap.com/hacia-un-nuevo-concepto-de-conduccion-conectividad-autonomia-y-ciberseguridad/

Paluch, S., Antons, D., Brettel, M., Hopp, C., Salge, T.O., Piller, F., & Wentzel, D. (2019). Stage-gate and agile development in the digital age: Promises, perils, and boundary conditions. *Journal of Business Research*. https://doi.org/10.1016/j.jbusres.2019.01.063.

Peters, S., Chun, J.-H, & Lanza, G. (2016). Digitalization of automotive industry – scenarios for future manufacturing. *Manufacturing Review 3(1)*. https://doi.org/10.1051/mfreview/2015030.

Piccinini, E., Hanelt, A., Gregory, R., & Kolbe, L. (2015). Transforming Industrial Business: The Impact of Digital Transformation on Automotive Organizations. *Proceedings of the 36th International Conference on Information Systems (ICIS)*, Fort Worth, TX.

Quine, W. V. (1952). The problem of simplifying truth functions. *The American Mathematical Monthly*, 59(8), 521–531.

Ragin, C. C. (2008). Redesigning social inquiry: Fuzzy sets and beyond. Chicago: University of Chicago Press.

Ragin, C. C., & Fiss, P. (2008). Net effects analysis versus configurational analysis: An empirical demonstration. In C. C. Ragin (Ed.). Redesigning Social Inquiry: Fuzzy sets and beyond (pp. 190–212). Chicago, IL: University of Chicago Press.

Ragin, C. C., & Davey, S. (2017). fs/QCA [*computer programme*], version [3.0]. Irvine, CA: University of California.

Riasanow, Tobias & Galic, Gabriela & Böhm, Markus, 2017. Digital Transformation in the Automotive Industry: Towards a Generic Value Network. Conference: European Conference on Information Systems (ECIS), Vol,25. Guimaraes, Portugal.

Rihoux B. (2007). Qualitative Comparative Analysis (QCA) and related techniques: Recent advances and challenges. In Pickel S, Pickel G, Lauth H-J and Jahn D, eds. Methoden der Vergleichenden Politik- und Sozialwissenschaft. Neue

Rubio, F., & Llopis-Albert, C. (2019). Viability of using wind turbines for electricity generation in electric vehicles. *Multidisciplinary Journal for Education, Social and Technological Sciences 6(1)*, 115-126. https://doi.org/10.4995/muse.2019.11743.

Rubio, F., Llopis-Albert, C., Valero, F., & Besa, A.J., (2019). Sustainability and optimization in the automotive sector for adaptation to government vehicle pollutant emission regulations. *Journal of Business Research*. https://doi.org/10.1016/j.jbusres.2019.10.050.

Schneider, C. Q., & Wagemann, C. (2012). Set-theoretic methods for the social sciences: A guide to qualitative comparative analysis. Cambridge University Press.

Simonji-Elias, M., M. Collyer, M. Johnston, L. Lichtenfeld, J. Lund and J. Staiger (2014). *KPMG's Global Automotive Executive Survey 2014*. KPMG International, KPMG International.

CCOO, (2018). Situación y perspectivas en el sector del automóvil. Medidas ambientales, digitalización y automatización de la industria. Confederación Sindical de Comisiones Obreras. Área de Estrategias Sectoriales: https://industria.ccoo.es/9ddeee3ef0745110d18ae92f9a4bc706000060.pdf

Wells, P., Wang, X., Wang, L., Liu, H., Orsato, R. (2020). More friends than foes? The impact of automobility-as-a-service on the incumbent automotive industry. Technological Forecasting and Social Change 154, 119975. https://doi.org/10.1016/j.techfore.2020.119975.

Winkelhake, U., 2019, Challenges in the Digital Transformation of the Automotive Industry. ATZ Worldw 121, 36–4, doi:10.1007/s38311-019-0074-7

World Economic Forum, 2016, Digital Transformation of Industries Automotive Industry.

Yoo, Y., O. Henfridsson and K. Lyytinen (2010). Research Commentary: The New Organizing Logic of Digital Innovation: An Agenda for Information Systems Research. Information Systems Research 21(4): 724-735.

Table 1
Description of the outcome and conditions considered in the fsQCA, which will provide a combination of factors leading to the actors' satisfaction when tackling the digital transformation in the automotive industry.

Factors or antecedent conditions (C)	**Subfactors**
Management, legal & financial issues (C1)	C1.1: Feasibility of implementing the digital transformation: investment costs in equipment, software and Research, Development and Innovation departments, acquisition and installation, short implementation time of measures C1.2: Improved productivity and maximization of performance C1.3: Adaptability to changes in order to achieve flexible manufacturing systems (e.g. to address possible fluctuations in demand and failures in the production line, restriction of machines, number of workers, number of shifts, need to manufacture different products or provide services, etc. C1.4: Other costs such as payback periods, depreciation, workers' dismissals and digitalization training, social and reputational costs, maintenance C1.5: Digital sources in the car buying and marketing processes C1.6: Social equity, fairness, transparency, consensus, accessibility to all social strata C1.7: Greater profits, productivity and competitiveness C1.8: Quality of products / services C1.9: Profit margin of products / services, annual savings C1.10: Implementation will not lead to layoffs. C1.11: Job creation C1.12: Legal framework
Technical issues (C2)	C2.1: Accessibility, connectivity and simplicity C2.2: Autonomous driving C2.3: Connected supply chain and manufacturing C2.4: Guarantee safety, security and privacy C2.5: User-friendliness, difficulty in handling new technologies C2.6: Capabilities and skills for implementing the digitalization transformation
Electric vehicles (C3)	C3.1: Autonomy (driving range) C3.2: Battery recharge times C3.3: Vehicle purchase price C3.4: Number of recharge points C3.5: Repair and maintenance C3.6: Energy cost and efficiency C3.7: Tax incentives C3.8: Specific parking areas
Environmental regulations (C4)	C4.1: Targets of Greenhouse Gas Emissions (GHE) C4.2: Use of renewable energy sources and sustainability policies C4.3: Restrictive standards defining acceptable limits for exhaust emissions of new fuel vehicles C4.4: Deadline to achieve a complete fleet of electric vehicles C4.5: Worldwide climate change agreements repercussions
New services / business (C5)	C5.1: Mobility as a Service (MaaS) and servitization C5.2: Shared driving and vehicle ownership C5.3: Big data and analytics and cloud C5.4: Real-time services C5.5: Users' choice and support C5.6: Possibility of personalization C5.7: Prompt availability 24/7, deliverability C5.8: Digitalization of public transportation services C5.9: Peer to peer (P2P) lending or service platforms
Output	Actors' satisfaction

Table 2
Analysis of necessary conditions. The symbol (~) indicates the absence of the outcome/condition.

Conditions (C) tested	Consistency	Coverage
C1	0.5351	0.8396
C2	0.7405	0.7313
C3	0.8477	0.5765
C4	0.4605	0.3958
C5	0.8650	0.7104
~C1	0.6999	0.6037
~C2	0.6468	0.6350
~C3	0.6385	0.5828
~C4	0.5025	0.8715
~C5	0.5320	0.5409

Table 3
Analysis of sufficient conditions for actors' satisfaction.

	Configuration number								
Conditions (C)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
C1	●	●	○	●	○		●	●	○
C2	●	●	●	○	●	○		○	●
C3	○	●	●		○	●	●	○	●
C4		●		●	●	●	○	●	●
C5	●	○	●	●	●	○	●	●	●
Raw coverage	0.1002	0.3423	0.211	0.0709	0.0507	0.2167	0.1466	0.2363	0.1227
Unique coverage	0.0855	0.0156	0.0038	0.058	0.0666	0.0738	0.0254	0.0399	0.0244
Consistency	0.8543	1.0000	0.8731	0.9172	0.8087	0.8957	0.9506	0.8871	0.8851
Solution coverage					0.6587				
Solution consistency					0.8654				

Note: 1. Black circles (●) indicate the presence of a condition, white circles (○) denote its absence, and blank cells represent ambiguous conditions.