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Sustainable Electrical Innovation: A Systemic Approach to Innovation Management in the Automotive Supply Chain

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Abstract:

Purpose: *The primary objective of this article was to define an innovation management system comprising the following subsystems: A subsystem for managing internal innovation maturity, a subsystem for overseeing the processes of acquiring product innovations from suppliers, a subsystem for managing the innovation maturity of suppliers within the supply chain and networks of collaborating companies and a subsystem for measuring and managing innovation performance.*
Design/Methodology/Approach: *This study aimed to review the key elements that make up innovation management subsystems through a comprehensive literature review. The research focused on comparing innovation management practices employed by three automotive companies producing electric drive systems in Poland. This comparative analysis facilitated the development of a comprehensive model for a network and supply chain innovation management system. The proposed research tools can also be utilized to evaluate the maturity of innovation management in collaborative environments. Furthermore, these tools can serve as a resource for R&D managers, helping them enhance existing systems by integrating missing elements.*
Findings: *The examined corporations implement innovation management models among suppliers. They do this systematically, and their efforts improve innovation growth. However, their actions cannot be called systemic. The results of the three-case study (three automotive concerns (producing electro-components in Poland) showed that Toyota is the closest to building an integrated innovation management system.*
Practical Implications: *This study aimed to develop a systemic innovation management model for the automotive industry's supply chain and evaluate its feasibility in business practice. This objective was partially achieved, as the research focused solely on assessing the implementation of the model within car manufacturers. Companies collaborating within the supply chain, such as suppliers and customers, were not examined. Consequently, only two subsystems were verified: the subsystem for managing internal innovation maturity and the subsystem for managing the innovation maturity of suppliers within the supply chain.*
Originality value: *The article shows a new systemic management of innovations in the supply chain. It is an interesting case study of three international companies that are leaders in patenting product and process innovations.*

Keywords: *Supply chain management, innovation management, open innovation (OI) model.*

JEL codes: *O31, O32, L62, Q55, M11.*
Paper type: *Case study.*

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1. Introduction

The study examined four innovation management models: the Global Company/Leader Supply Chain Innovation Maturity Model, the Model for Managing Product Innovation Acquisition from Suppliers, the Supplier Innovation Maturity Management Model, and the Innovation Growth Management Model.

The findings of this research form the foundation for building a systemic innovation management model. The primary objective is to develop a comprehensive innovation management framework for the automotive industry's supply chain. This paper compares the current innovation practices of selected global automotive companies.

The comparative analysis of innovation activities led to the development of a reference model for innovation management. The results from the Toyota supply chain study—recognized as the most advanced in implementing a systemic innovation management model—support the hypothesis that "the application of a systemic innovation management model leads to innovation growth."

Grounded in the theoretical foundations of resource-based and network approaches in management, the proposed systemic innovation management model has practical application potential. It contributes to management science in two key ways:

- Advancing the concept of innovation management toward a systemic innovation management model.
- Providing a framework for measuring innovation growth within collaborating companies.

2. Literature Review

A critical literature analysis identified a cognitive gap from a theoretical, methodological and empirical perspective. The review of the research publications shows that many researchers focus on business modelling to enhance corporate innovation (Chesbrough, 2006; Chesbrough, 2010; Brzóska, 2009). And few researchers have built business models for supply chain innovation management (Rexhepi *et al.*, 2019; Stawiarska, 2019). Several authors present innovation management models for implementation in networks of cooperating companies in so-called clusters (Knop, 2013). The indicated researchers refer to them as open innovation (OI) models (West and Bogers, 2014; Chesbrough, 2006; Laursen and Salter 2006; Dahlander and Wallin 2006; Dahlander and Gann 2010). Several researchers propose such models for the automotive industry (Afuah, 2014).

Delving into resource theory, network theory and academic achievements in knowledge management, numerous theoretical considerations have been identified for assessing the innovation growth of firms (Kumar *et al.*, 2020). Few studies indicate how to measure the leader's innovation growth as a result of cooperation (Al-Khatib, 2022; Tanasi *et al.,* 2021). Selected studies provide evidence of the improved quality of goods developed in cooperation (Syla and Rexhepi, 2017; Campanella *et al.,* 2017). Leydesdorff and Ivanova (2016), studied the automotive industry innovation supplier relationship management systems. There is a lack of research into the impact of supplier relationship management on supply chain leader innovation growth.

Literature reviews suggest that effective management of developing innovation-driven relationships with suppliers may be a future component of a systemic model for managing supply chain innovation. Various authors studying the management of relationships supporting innovation inspired the preparation of a tool to assess relational activities (Bratianu *et al.*, 2022).

Internal and external factors influencing supply chain leader innovation have been identified (Robertso 2022). Attempts to assess them have also been identified (Campanella *et al.,* 2017). From a methodological perspective, a cognitive gap was identified regarding methods for determining the factors influencing supply chain leader innovation. No taxonomic methods have been identified in the literature to assess the impact factors on supply chain leader innovation growth.

When looking for ways to measure innovation growth in the context of inter-organisational collaboration, the method measuring the maturity of an organisation to work in an open model – the Smart Grid Maturity Model (SGMM) – was identified in the literature (Stawiarska *et al.,* 2021). A regular self-assessment of leader maturity and an assessment of supplier innovation maturity for IO work could be a future component of a systemic supply chain innovation management model. The SGMM inspired the preparation of tools to assess the innovation maturity of the supply chain leader and supplier companies.

In the search for methods to measure innovation growth in inter-organisational cooperation, methods to measure innovation processes and assess the impact of these processes on the innovation growth of individual companies have been identified in the literature (Mageto, 2021). These approaches advocate systematic evaluation of innovation processes (https://www.statista.com; Un and Kazuhiro, 2015) and also cover the automotive industry (Homfeldt *et al.,* 2017; Wilden *et al.,* 2016). Miller *et al.* (2022) recommends measuring added value in the innovation process: economic, environmental and market.

Previously, the evaluation of collaborative innovation processes was dominated by subjectivity based on surveys (Munim *et al.,* 2023; Nellippallil *et al.,* 2019). And nowadays, the evaluation uses key performance indicators (KPIs) calculated based on automatically acquired and computer-processed data (Nascimento and Cessa, 2019; Chandriah and Raghavendra, 2019). Munin's survey technique inspired the development of another model that can be a component of a systemic supply chain innovation management model. In addition, the survey technique inspired the preparation of tools to assess collaborative innovation processes.

Taxonomic methods for evaluating innovation management were noted in the literature. Researchers tested them in selected single companies. Innovation growth was assessed using innovation growth indicators (Noh, 2015) such as CAPEX, the number of innovations and patents, R&D expenditure. And qualitative assessments involved using survey techniques. The cited studies inspired the development of another model (a component of the new systemic innovation management model).

The proposed innovation growth management model would measure the innovation growth of the supply chain leader. This model is based on the two-dimensional concept of measuring innovation growth proposed by Ryan (Ryan, 2010). It introduces the notion of innovation growth (interchangeably referred to as innovativeness).

Ryan defines innovation growth as improvements in the quantity and quality of innovative ideas and the efficiency and effectiveness of innovation processes. Ryan believes that the listed parameters can be examined independently and interdependently. The formula for innovation growth is given below.

Innovation growth = (quantity + quality of ideas) + (efficiency and effectiveness of innovations proces)

Ultimately, four research models were built to complete the concept of a systemic innovation management model. The cognitive gap from an empirical perspective was filled by testing the four research models in three global automotive companies. As a result, the research models were empirically.

Model testing at three global automotive companies has already shown that even incomplete implementation contributes to the innovation growth of the supply chain leader. The research presented in this article shows that Toyota has implemented the most comprehensive innovation management model (close to a systemic innovation management model).

As a result, Toyota demonstrated the highest innovation growth compared to the other global corporations studied. It stems from implementing various IT solutions for innovation processes (Naboru and Takehito, 2022; Hernández-Rojas *et al.*, 2017; Castedo, 2018; Blanco-Novoa *et al.*, 2018; Fernández-Caramés and Fraga-Lamas, 2018; Piller and West 2006).

However, the literature and research show that even global innovation leaders do not have systemic, inter-organisational innovation management models (Leydesdorff and Ivanova, 2016). Research on Toyota’s innovation management activities suggests that it is closest to inter-organisational systemic solutions (Leydesdorff and Ivanova, 2016).

This research also confirms Toyota's advancement in systemic solutions supporting innovation. In addition, a number of researchers believe that innovation growth should be systematically monitored using qualitative and quantitative measures (Stawiarska *et al.*, 2021; Afuah, 2014). Following the guidance of these researchers, tools were prepared for qualitative and quantitative assessment of leader innovation growth (used for the presented research).

3. Research Methodology

This work aims to develop a systemic innovation management model for the supply chain in the automotive industry.

The primary research objective is to empirically verify the usefulness of several component models that, after adjustments, can be implemented into innovation management practice and will contribute to the innovation growth of global automotive companies and their suppliers.

Methodological goals:

- developing a research model along with a research tool for self-estin the ability to create innovation in collaboration (leader innovation maturity assessment model),
- developing a model analysing the process of acquiring product innovations along with a research tool (model for managing product innovation acquisition from suppliers),
- developing a model along with a research tool for assessing skills related to innovation development in collaboration (model for assessing innovation maturity of supplier and potential supplier),
- developing a research/supervision model for leader innovation efficiency (innovation growth management model),
- developing a systemic innovation management model in the supply chain and network.

Empirical goals:

- testing models in selected automotive supply chains,
- identifying the differences in the innovation-supporting),
- introducing the concept of a systemic innovation management model.

To achieve these goals, it was necessary to prepare a research methodology involving the following stages: literature analysis; research gap identification; initial (praxeological) research; conceptualisation of components models; formulation of research hypotheses, preparation of research tools and data gathering; relevant research; data analysis; formulation of research conclusions and acceptance of the hypotheses (or their rejection and creation of a new research model); expansion of the theory with the research on management models; formulation of practical recommendations for the studied companies/chain links and supply networks; research limitations; identification of future research directions.

The empirical research tested the correctness of the main hypothesis: "Application of the systemic innovation management model will result in the innovation growth of global automotive companies (supply chain leaders)".

To establish the relationship between particular innovation management models and the innovation efficiency of supply chain leaders, the following hypotheses were verified:

- *H1: The implementation of the innovation maturity management model by global companies increases their innovativeness as supply chain leaders (measured by the number of patents obtained);*
- *H2: Continuous development of the model for managing innovation processes implemented in cooperation with suppliers (management effectiveness measured by the implementation time of the innovation process and the number of risks emerging in this process) increases the innovativeness of the supply chain leader (measured by the number of patents obtained in cooperation);*
- *H3: Continuous development of the innovation maturity management model of external suppliers increases the innovation of the supply chain leader (measured by the number of patents created in cooperation).*

The hypotheses were tested. This paper uses various research methods corresponding to subsequent research stages. The methods are grouped according to the tested models. Details related to the research methodology are presented in Table 1.

Table 1. *Research methodology*

Innovation management model	**Research methodology**			**Research entities**	**Sample size**
	Critical literature analysis	**Qualitative methods**	**Quantitative methods**		
Innovation maturity model/ supply chain leader	•	SGMM Individual in-depth interviews survey questionnaire 1	Measured by the own number of patents	VW, Toyota, FCA/ Stellantis production of electric drives in Poland	3
Model analysing product innovation acquisition /Innovation	•	Individual in-depth interviews Survey survey questionnaire 2	Measured by the effectiveness and efficiency of innovations	VW, Toyota, FCA/ Stellantis production of electric drives in Poland	3

proces					
Model assessing innovation maturity of supplier and potential supplier	•	SGMM Individual in-depth interviews Survey survey questionnaire 3	Measured by the number of patents obtained in cooperation	VW, Toyota, FCA/ Stellantis production of electric drives in Poland	3

Source: *Own study*

Research was carried out on three global automotive corporations developing electric drive systems in Poland. The three hypotheses were confirmed by qualitative and quantitative research, proving that the implementation of particular innovation management models influences the innovation growth of supply chain leaders. Hypothesis 4 was confirmed by qualitative and quantitative research (interviews with managers). Quantitative secondary data were analysed statistically.

4. Results

4.1 Analysis of the Innovative Activities of Supply Chain Leaders

The following Tables provide a comparative analysis of activities indicative of innovation management by the three supply chain leaders: Toyota, Volkswagen and Stellantis (FCA+PSA). A comparison of innovation-supporting activities of the three global companies was based on data concerning their R&D expenditures and the number of patents.

Hypothesis 1: The implementation of the innovation maturity management model by global companies increases their innovativeness as supply chain leaders (measured by the number of patents obtained).

The following Tables show the respondents' answers, which provide a picture of the innovation activities of the studied global companies (**Source:** Own study based on primary and secondary data).

Does your company have an innovation strategy in place?

Toyota	Volkswagen	FCA/ Stellantis
Yes	Yes	Yes

If so, are there separate actions for the purchasing department in this strategy?

Toyota	Volkswagen	FCA/ Stellantis
Yes	Yes	Yes

Do first-tier suppliers have an innovation management policy?

Toyota	Volkswagen	FCA/ Stellantis
Yes	Yes	Yes

Do second-tier suppliers have an innovation management policy?

Toyota	Volkswagen	FCA/ Stellantis

Yes	Yes	Yes

What percentage of innovative solutions does the company:

	T	V	F/S
develop in-house (R&D) and then outsource to suppliers	61%	55%	53%
get from suppliers through the purchase/licensing of an off-the-shelf solution	34%	41%	43%
acquire through collaborative design with suppliers /an open innovation model	5%	4%	4%
	100%	100%	100 %

Does this percentage pattern hold in relation to previous years?

Toyota	Volkswagen	FCA/ Stellantis
No	No	No/ Stellantis

- increases in favour of

Toyota	Volkswagen	FCA/ Stellantis
No	No	No

- increases in favour of

Toyota	Volkswagen	FCA/ Stellantis
No	Yes	Yes

- increases in favour of

Toyota	Volkswagen	FCA/ Stellantis
Yes	No	No

- Do these changes impact innovation growth?

Toyota	Volkswagen	FCA/ Stellantis
Yes	Yes	Yes

Is the company sourcing any modules/sub-modules/components for the internal combustion engine?

Toyota	Volkswagen	FCA/ Stellantis
Yes	No	No

If so:

Is the company trying to increase the number of first-tier suppliers collaborating in R&D on the internal combustion engine?

Toyota	Volkswagen	FCA/ Stellantis
No/In future, yes	No	No

Is the company trying to increase the number of second-tier suppliers collaborating in R&D on the internal combustion engine?

Toyota	Volkswagen	FCA/ Stellantis
No/In future, yes	No	No

Does the company manage R&D contracts with second-tier suppliers?

Toyota	Volkswagen	FCA/ Stellantis
No	No	No

In R&D activities with suppliers, does the company use the processes developed?

Toyota	Volkswagen	FCA/ Stellantis
Yes	Yes	Yes

Does the company manage the risk of purchasing innovative solutions?

Toyota	Volkswagen	FCA/ Stellantis

Yes	Yes	Yes

Based on which criteria does the company segment (group) the suppliers with whom it develops R&D projects?

Toyota	Volkswagen	FCA/ Stellantis
Technology, evaluation of the implementation of previous projects	Technology, evaluation of the implementation of previous projects	Technology, evaluation of the implementation of previous projects

Based on which criteria does the company segment (group) the suppliers with whom it wants to develop R&D projects in the future?

Toyota	Volkswagen	FCA/ Stellantis
Technology, affiliation to Keiretsu groups	Technology, references, personal contacts	Technology

Is controlling implemented for the awarded categories of suppliers with whom the company develops R&D projects?

Controlling organisational unit (purchasing and/or R&D department)																								Controlling	Level of
Active suppliers												Inactive suppliers												Area of control activities	
Drive			Electrical equipment			Undercarriage			Car body			Drive			Electrical equipment			Undercarriage			Car body				
Toyota	VW	FCA/S	Toyota	VW	FCA/S	Toyota	VW	FCA/S	Toyota	VW	FCA/S	Toyota	VW	FCA/S	Toyota	VW	FCA/S	Toyota	VW	FCA/S	Toyota	VW	FCA/S		
✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓													Market analysis	
✓	✓	✓	✓	✓	✓																			Strategy	
✓	✓	✓	✓	✓	✓																			Innovation strategy	
✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓													Supplier/ contract management	
																								Preferences of sub-processes	
✓	✓	✓	✓	✓	✓																			Risk management in shared processes	
✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Negotiations	

Does the company use an ICT tool, business intelligence, e.g. K-Monitor, for: grouping suppliers?

Toyota	Volkswagen	FCA/ Stellantis
No	No	No

- strategic control of suppliers?

Toyota	Volkswagen	FCA/ Stellantis
No	No	No

- operational control of suppliers?

Toyota	Volkswagen	FCA/ Stellantis
Yes	Yes	Yes

What are the specific criteria for evaluating a supplier with whom the company is developing/intending to develop innovative component designs?

Toyota	Volkswagen	FCA/ Stellantis
Project development costs, project implementation costs, production costs, IATF 16949, ability to work/respect the Toyota Production System	Project development costs, project implementation costs, production costs, IATF 16949	Project development costs, project implementation costs, production costs, IATF 16949, respecting the FCA's corporate social responsibility

Are these criteria:

- formulated/written down?

Toyota	Volkswagen	FCA/ Stellantis
Yes	Yes	Yes

- presented to suppliers?

Toyota	Volkswagen	FCA/ Stellantis
Yes	Yes	Yes

- measured?

Toyota	Volkswagen	FCA/ Stellantis
Only IATF 16949	Only IATF 16949	Only IATF 16949

Does the company use the managerial tools listed below in its relations with suppliers?

Management tools	Use		
Company	T	V	F/S
Individual meetings with suppliers	✓	✓	✓
Participation in dedicated discussion forums	✓	✓	✓
Requests for information and technical dialogues	✓	✓	✓
Standard in communication with suppliers, e.g. developed RFI process	✓	✓	✓
Dedicated teams to solve problems arising in cooperation with suppliers	✓	✓	✓
Supplier assessments as part of development programmes and identification of potential improvements	✓		

Secondment of staff to the supplier to exchange knowledge	✓		
Admission of seconded staff from the supplier to share knowledge	✓		
Cyclical meetings of inter-organisational working groups	✓		
Cooperation and exchange of experience not only with suppliers but also with subcontractors			
Innovation days organised to communicate development and innovation needs to suppliers	✓	✓	✓
Learning trips/ Learning journeys		✓	
Strengthening of inter-organisational personal links between R&D and purchasing employees	✓		
Finding commonalities between supplier companies and combining them for innovation development	✓		
Continuous training or education and incentives for innovative suppliers	✓		
Innovation audit as a routine activity/identifying specific resources and processes dedicated to the relationship/ asking the supplier for a self-assessment	✓		
Monitoring of relations dedicated to the development of innovative projects	✓		
Supplier portfolio management and relationship termination mechanisms			
Appointment of "Innovation Champions"	✓	✓	✓
Hiring an innovation champion			
Computer vision of the project to which talent is recruited			
Formal mechanisms for managing investment in open innovation	✓	✓	✓
Building trust between employees of cooperating companies and education in the area of relational competence	✓		
Analysis of purchasing practices, audit of purchasing reports	✓	✓	✓
Innovative competitions		✓	✓
Use of creativity and inventive thinking tools developed using the theory of inventive problem solving (TRIZ) in cooperation with suppliers			
Use of quality function deployment (QFD) tools in cooperation with suppliers			
Use of failure mode and effects analysis (FMEA) tools in cooperation with suppliers	✓	✓	✓
Use of "procurement engineering" in cooperation with suppliers to improve product performance to meet changing customer expectations			
Use of "reverse engineering" in cooperation with suppliers to study the product and design an equivalent	✓	✓	

Source: *Own study based on primary data.*

What are the company's distinctive stimulators (including communication) for developing innovation with suppliers?

Respondents unanimously agreed that the most significant stimulator for the development of innovation collaboration is the supplier's implementation of IATF 16949. Key changes related to the introduction of this standard and facilitating innovation collaboration are:

- corporate responsibility and related requirements,
- high-level management structure (previously introduced in ISO 9001),
- clarification of requirements dedicated to sub-suppliers and the development of a pathway for them,
- risk and capability management (FMEA),
- APQC methodology as a planning tool for product and process design and development,

- detailing the requirements for internal audits and the competence of auditors.

Other innovation drivers in cooperation with suppliers included:

- the desire to reduce material costs resulting from the implementation of the global company recommendations,
- high mutual trust and relationship quality,
- management commitment to innovation,
- willingness to share knowledge,
- alignment of organisational cultures.

What are the company's distinctive barriers (including communication) and risks to developing innovation in cooperation with suppliers?

The risks mentioned included:

- lack of design experience in the early stages of innovation development,
- financial constraints that make it difficult to „subsidise innovation development",
- formalised, multi-level decision-making on both sides of the relationship,
- lack of risk management and risk sharing procedures,
- lack of a system for sharing the savings/profits generated on both sides of the relationship,
- business processes and procedures are not oriented towards standardisation and comparability of offers.

Global companies implement measures to support innovation management among suppliers. For example, they have appointed innovation champions and managers, use a set of managerial methods and tools to manage innovation, model and implement innovation sourcing processes, monitor processes using ITC and manage risks of these R&D processes.

Toyota is the leader in innovation management implementations in the open model (as shown above). The data in Tables 2 and 3 indicate that Toyota spent comparable amounts to Volkswagen on R&D but obtained a much greater number of patents. The above findings support detailed H1.

Thanks to these analyses, global companies can identify measures to be implemented in innovation management to support innovation growth. Self-assessment (on a five-point scale) of companies belonging to the surveyed global companies – engine manufacturers in the area of supplier relationship management

Level 1	✓	✓	✓
Complete database of suppliers	✓	✓	✓
Supplier segmentation	✓	✓	✓

Supplier qualification criteria	✓	✓	✓
Level 2	✓	✓	✓
Supplier assessment for collaboration risks	✓	✓	✓
Cooperation evaluation for quality and internal customer satisfaction	✓	✓	✓
Supplier management strategies	✓	✓	✓
Periodic audits of suppliers	✓	✓	✓
Level 3	✓	✓	✓
Ongoing monitoring of cooperation	✓	✓	✓
Monitoring of compliance with Service Level Agreements (SLAs)	✓	✓	✓
Supplier development programmes	✓	✓	✓
Level 4	✓	✓	✓
Cooperation with suppliers generates measurable added value for the organisation (measured KPIs)	✓	✓	✓
Management of strategic suppliers involves Board Members	✓	✓	✓
Cooperation with suppliers to develop innovative solutions	✓	✓	✓

Source: *Own study based on primary data.*

The next table shows a self-assessment of the innovation maturity of engine manufacturers to work in an open innovation model. The engine manufacturers were asked if the following statements were close to the truth in their companies (1 – strongly disagree, 5 – strongly agree). Respondents from Toyota, Volkswagen and FCA answered as follows:

Self-assessment of innovation maturity of global companies (produce electric drive systems in Poland) for cooperation in the open innovation model.

We apply supplier innovation management	1	2	3	4	5
We periodically monitor internal causes of potential inefficiencies in purchasing processes				**V F**	**T**
We periodically monitor external causes of potential inefficiencies in purchasing processes			**F**	**V**	**T**
We measure the value generated by purchases, e.g. impact of purchases on sales performance, operating expenses by purchasing category					**T V F**
We periodically observe the market trends among purchasing organisations and consider their applicability to our organisation		**T F**	**V**		
We periodically monitor external suppliers (not currently affiliated with our organisation) to acquire their innovative solutions through purchase/licensing		**T**	**F**		**V**
We periodically monitor external suppliers (not currently affiliated with our organisation) to develop innovation projects with them		**T V F**			
We fear the complexity of buying innovations and prefer to co-develop them in cooperation with the supplier	**T V F**				
Our structures allow us to quickly and agilely implement changes in new solution development projects with suppliers; we implement an open-book policy	**T V F**				

We audit our company and analyse the Strategy, Management and Regulatory (SMR) domain to be more open to external innovations		**T**	**V F**		
We audit our company and analyse the Organisation and Structure (OS) domain to be more open to external innovations	**T V F**				
We audit our company and analyse the Grid Operations (GO) domain to be more open to external innovations	**T V F**				
We audit our company and analyse the Work and Asset Management (WAM) domain to be more open to external innovations	**T V F**				
We audit our company and analyse the Technology (TECH) domain to be more open to external innovations	**T V F**				
We audit our company and analyse the Customer (CUST) domain to be more open to external innovations	**T V F**				
We audit our company and analyse the Value Chain Integration (VCI) opportunities to be more open to external innovations	**T V F**				
We audit our company and analyse the Societal and Environmental (SE) domain to be more open to external innovations	**T V F**				
We apply risk management to innovation projects implemented with suppliers		**T**	**V F**		

In addition, the studied companies were asked if developing R&D cooperation in an open model with suppliers increases the number of innovative solutions implemented. Their responses are shown in the table below.

Toyota	Volkswagen	FCA/ Stellantis
Yes	No answer	Yes

The information presented confirms that automotive supply chain leaders examine their innovation maturity to work in an open model using various methods. Assessments and expert opinions result in the slow implementation of the open innovation concept in global companies. Innovation management systems for suppliers are lacking everywhere.

Toyota has the most mature innovation management model, which moves it towards open collaboration with suppliers. The study of Toyota's maturity to working in an open model to the number of patents obtained in cooperation with suppliers (see Table 2) also confirms the validity of H1.

4.2 Analysis of the Innovative Activity of Supply Chain Leaders in the Automotive Industry

This section presents the research results that confirm H2, i.e., Implementation of a model for managing product innovation acquisition from suppliers increases innovation (measured by the effectiveness and efficiency of innovations).

The comparison of managing product innovation acquisition from suppliers was made for a selected strategic component, i.e., the electric drive systems (all three global companies manufacture such an component, but they organise the processes and sub-processes of developing this innovative component differently.

The comparative analysis of the sub-processes of sourcing innovative solutions from suppliers is presented in the tables below. Below is a comparison of the innovation processes of three manufacturers.

Supply chains for the production of the latest engine	T	V	F/S
In-house/outsourced design	Created in cooperation	Created in cooperation	Own design

Source: *Own study based on primary data.*

Standardisation innovation sub-processes is necessary for implementing the open innovation model. IT tools, employees, and external organisations involved in the flow of information and knowledge between cooperators play an important role in the standardisation of sub-processes. Sub-processes used by global corporations to obtain innovative solutions from outside were identified and an attempt was made to evaluate them.

Process steps	Product	OEM	Company designing engine	Company suppliers
PDP 1	Determination of the scope ("workload") of cooperators	✓	✓	-
PDP 2	Determination of the moment of involvement of cooperators	✓	✓	-
PDP 3	Coordination of development activities between the supplier and the company	✓	✓	✓
PDP 4	Coordination of development activities among various tier-one providers	✓	✓	✓
PDP 5	Coordination of development activities between first- and second-tier suppliers	✓	-	✓
PDP 6	Joint manufacturing of the prototype	✓	✓	✓

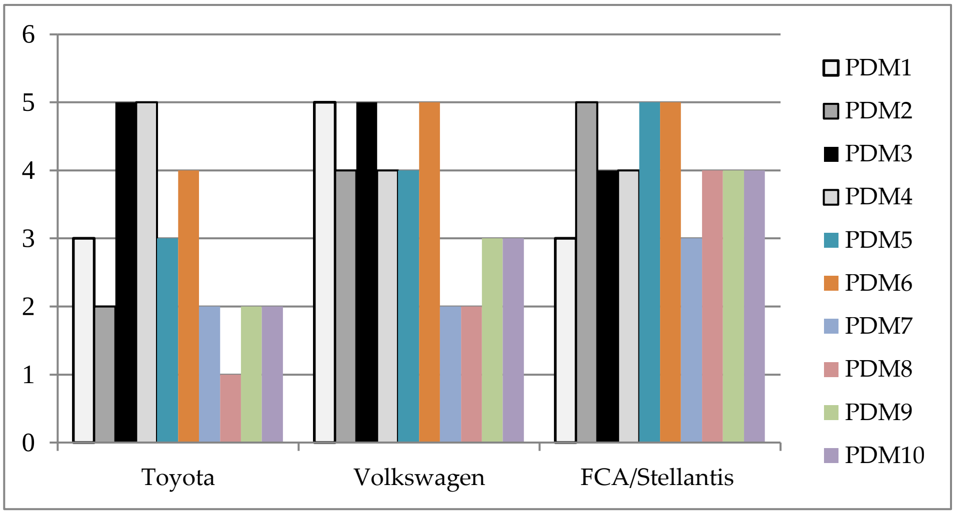
PDP 7	Provision of information on new components and technologies under development or already available from the supplier	✓	-	✓
PDP 8	Identification of additional and alternative sub-suppliers (parts or technologies) that can result in a higher-quality final product	✓	-	-
PDP 9	Implementing the solution and evaluation in terms of production capacity, lead time, quality and cost	✓	✓	✓
PDP 10	Promotion of standardisation and simplification of designs and parts	✓	✓	✓

Figure 1 shows the differences in the implementation of the innovation process (abbreviation PDP Product Development Process) (here: the development of electrical components created in cooperation with design companies and suppliers.

The time taken to complete the innovation subprocess (abbreviation PDP Process Product Development) was assessed (five-point scale).

The five-stage self-assessment is a weighted average of the self-assessment duration of the process, timeliness of implementation and labor intensity of the process (i.e., time spent in hours on the implementation of activities carried out in cooperation).

Figure 1. *Assessment of the lead time of the PDP process of electric componet*



Source: *Own elaboration based on primary data.*

Respondents evaluated risks during the electric component development PDPprocess on a scale of 1 to 5 (where "-" means no risk, 1 – risk occurred very rarely, 5 – risk occurred very often). The table below shows the evaluation results.

The average score for risks during the PDP sub-process

Type of risk assessed	Average score		
Company	T	V	F/S
Transfer of supplier engineering tasks back to the group	2	3	2
Doubts about the correct choice of supplier/lack of full internal commitment	2	2	2
Doubts/protracted discussions on contract prices under the project	1	3	3
Problems with the communication interface with the supplier	3	2	1
Transfer of testing tasks back to the group	1	1	1
Hidden contract specifications (specifications do not match the supplier's business profile)	-	1	1
Transcription of tasks to second-tier suppliers	-	-	-
Unexpected/unwanted divestments, acquisitions or mergers between cooperating partners	-	-	1
Change of first-tier suppliers during the project	1	1	1
Risk of non-availability of machinery	1	1	1
Numerous changes in the composition of project teams	-	1	0
Language barriers/cultural differences	3	2	1
Limited access to the supplier's product and technology knowledge maps	3	3	3
No future projects/risk of non-continuation	-	-	-
The supplier is not able to keep the same people on the project team	-	-	-
Discussions on incompatible CAD/data management systems	2	3	4
The company rejects the second-tier supplier selected by the first-tier supplier	-	-	2
Scheduled times and deadlines for providing information exceeded in project discussions	5	5	5
Unclear and restrictive specifications	5	5	5
Incomplete access to critical project information	2	3	3
Discussion of guarantee costs	2	1	3
Total score	33	37	39

Source: *Own study based on primary data.*

There were discrepancies in the responses about risk management in PDP sub-processes. Respondents answered as shown in the table below:

Type of risk assessed	Average score		
Company	T	V	F/S
Transfer of supplier engineering tasks back to the group	2	3	2
Doubts about the correct choice of supplier/lack of full internal commitment	2	2	2
Doubts/protracted discussions on contract prices under the project	1	3	3
Problems with the communication interface with the supplier	3	2	1
Transfer of testing tasks back to the group	1	1	1
Hidden contract specifications (specifications do not match the supplier's business profile)	-	1	1
Transcription of tasks to second-tier suppliers	-	-	-
Unexpected/unwanted divestments, acquisitions or mergers between cooperating partners	-	-	1

Change of first-tier suppliers during the project	1	1	1
Risk of non-availability of machinery	1	1	1
Numerous changes in the composition of project teams	-	1	0
Language barriers/cultural differences	3	2	1
Limited access to the supplier's product and technology knowledge maps	3	3	3
No future projects/risk of non-continuation	-	-	-
The supplier is not able to keep the same people on the project team	-	-	-
Discussions on incompatible CAD/data management systems	2	3	4
The company rejects the second-tier supplier selected by the first-tier supplier	-	-	2
Scheduled times and deadlines for providing information exceeded in project discussions	5	5	5
Unclear and restrictive specifications	5	5	5
Incomplete access to critical project information	2	3	3
Discussion of guarantee costs	2	1	3
Total score	33	37	39

Source: *Own study based on primary data.*

The above analyses confirm that automotive supply chain leaders have standard processes for developing innovation. Toyota has the best results in all the analyses processes presented. The above process comparisons confirm H2: Continuous development of the model for managing innovation processes implemented in cooperation with suppliers (management effectiveness measured by the implementation time of the innovation process and the number of risks emerging in this process) increases the innovativeness of the supply chain leader (measured by the number of patents obtained in cooperation).

Thanks to these analyses, global companies can identify measures to be implemented in innovation management to support innovation growth.

4.3 Analysis of the Innovative Activity of Supply Chain Leaders in the Automotive Industry

Shaping the innovation maturity of suppliers should be included in the strategy of the chain leader's activities. A systematic assessment of the innovation maturity of suppliers will facilitate the preparation/modification of supplier relationship management policies towards the open innovation model.

The study assumes that the supply chain leader is co-responsible for innovation management. Using the Smart Grid Maturity Model, the leader can assess the innovation maturity of cooperators and prepare measures to improve their R&D cooperation competence.

The proposed comprehensive method is a multidimensional set of precise instruments for measuring and assessing the maturity of activities carried out in cooperation. The SGMM lists six levels of maturity assessment of activities carried out in eight organisation domains. An example grid for assessing innovation maturity is shown in the table below.

Example of innovation maturity grid in the open innovation model

Level								
5								
4								
3						X		
2			X	X	X			
1	X	X					X	X
	SMR	OS	GO	WAM	TECH	CUST	VCI	SE

Source: *(Stawiarska, et al.2021) (Rudkowsk, 2014) and*

http://www.sei.cmu.edu/library/assets/brochures/sgmm-1010.pdf

The eight organisation domains on a six-point scale are:[2]

1. Strategy, Management and Regulatory (SMR),
2. Organisation and Structure (OS),
3. Grid Operations (GO),
4. Work and Asset Management (WAM),
5. Technology (TECH),
6. Customer (CUST),
7. Value Chain Integration (VCI),
8. Societal and Environmental (SE).

Using the analytic hierarchy process (AHP), the domains most relevant to cooperation in IO with first-tier and next-tier suppliers and inactive suppliers were selected based on the Smart Grid Maturity Model.

Using the juxtaposition of AHP with the strategic scorecard method found in component weights were assigned to the eight organisation domains (Rudkowski, 2014).

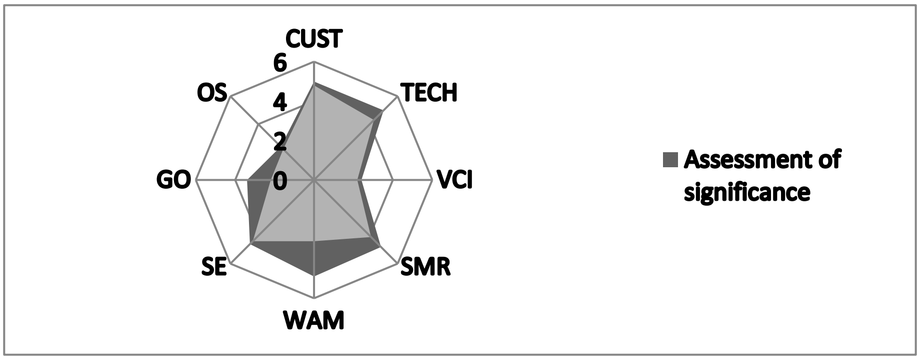
The leader can build the innovation maturity of suppliers in different areas of operation. Assessing the level of innovation maturity and identifying the competency gap, if any, is necessary to improve supplier innovation.

The competence gap of suppliers of the three global automobile companies was examined and shown in the following radar charts.

Respondents/employees of the companies were asked to assess their (electric component) suppliers. The scores were averaged and shown in Figures 2, 3, and 4 below.

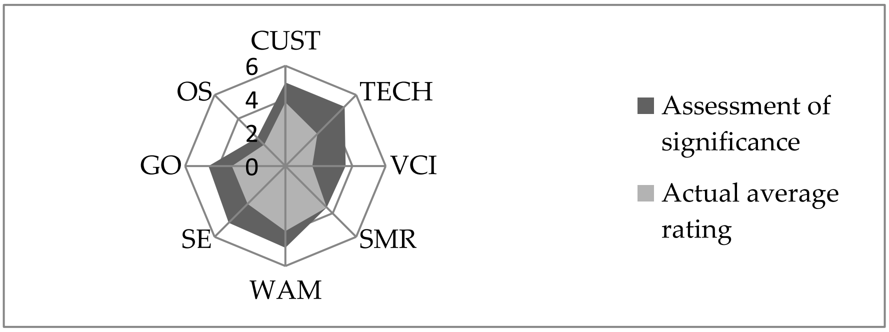
[2]*For domain evaluation criteria and complete domain evaluation, see Stawiarska, 2019*

Figure 2. *Competency gap analysis of Toyota suppliers' innovation maturity*



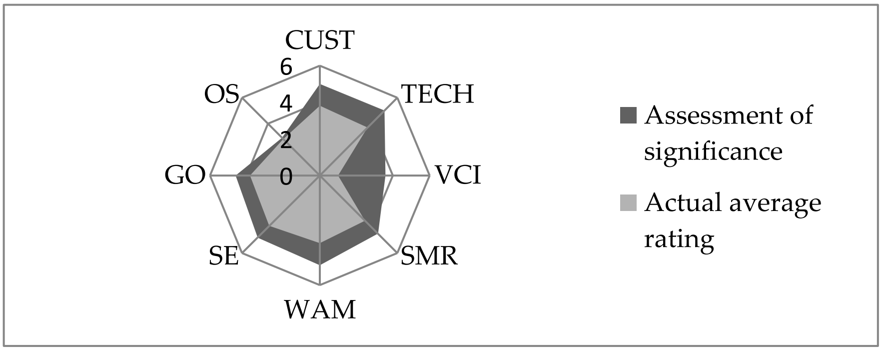
Source: *Own elaboration based on primary research.*

Figure 3. *Competency gap analysis of Volkswagen suppliers' innovation maturity*



Source: *Own elaboration based on primary research.*

Figure 4. *Competency gap analysis of FCA/ Stellantis suppliers' innovation maturity*



Source: *Own elaboration based on primary research.*

The organisation domains listed above play a key role in developing organisations to work in an open innovation model. A high score guarantees the ability to collaborate on innovation. The average scores showed that suppliers have competence gaps in innovation maturity. The radar charts above suggest that Toyota suppliers show the smallest competence gap in maturity to work in an open innovation model.

Perhaps it is the case because Toyota suppliers receive support in developing the eight domains of the SGMM. The above analysis proves H3: Continuous development of the innovation maturity management model of external suppliers increases the innovation of the supply chain leader (measured by the number of patents created in cooperation). Toyota has the highest number of patents obtained in cooperation (Table 2).

Table 2. *Number of patents obtained by the studied corporations*

Number of active patents used by the automotive industry and divided by concern										
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Number of active automotive patents -fossil fuel drive	23000	27500	27000	30000	31000	33000	32000	30000	27500	24800
Number of active automotive patents electric drive	3000	3800	3500	4900	5600	10800	11060	12070	13000	14200
number of active automotive patents - all car drives (additionally hydrogen)	26000	31400	30560	34950	36600	43900	44060	42570	41500	39500
VW	2000	7500	9500	10500	11500	12500	13500	14500	15000 of which 52% electric tim	15080 of which 55% electric tim
Toyota	12500	14845	15347	16983	16427	17876	175,8	18,512	19500 of which 60% electric tim	2050 of which 59% electric tim
FIAT/FCA/Stellantis**	87	98	98	155*	267	321	341	411	629of which 30% electric tim	639 of which 31% electric tim
Number of active patents (obtained in cooperation, i.e. by the concern and the cooperating company/companies)										
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
VW	987	1001	1100	1303	2100	2403	2480	4095	4189	4678
TOYOTA, BYD*	3904	4891	4845	5340	5234	5456	6054	6943	6987	6876
FIAT/FCA/Stellantis**	45	21	45	50	98	102	120	132	140	142

Note: *the data presented in the table are data calculated based on the*
Sources:*https://iri.jrc.ec.europa.eu/scoreboard/2017-eu-industrial-rd-investment-scoreboard#field_data; http://iri.jrc.ec.europa.eu/scoreboard.html; file:///C:/Users/ewast/Downloads/KJBD20001ENN.en.pdf*[3]*;* *https://www.statista.com/statistics/1178549/number-of-patents-owned-by-the-top-automobile-manufacturers/; https://www.lexisnexisip.com/resources/the-green-race-using-patent-data-to-uncover-insights-into-the-future-of-automotive-sustainability/*

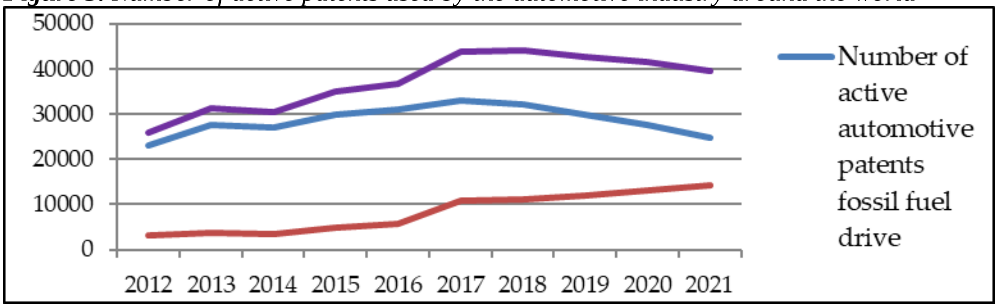
[3]*Bristol Street's innovation study based on data from Google Patents. The company analysed automotive patents filed worldwide for 20 global brands, including Ferrari, Volvo, Porsche, Land Rover, Lamborghini, Subaru, Chevrolet, Toyota, Hyundai, Ford, Honda, Nissan, Volkswagen, BMW, Audi, Mercedes-Benz, Peugeot, Renault, Mazda and Fiat. Analysts collected data from more than 100 major patent offices around the world and, based on this, compared automobile brands in terms of the number of patents filed.*

The companies surveyed have made significant innovations in electric vehicles, including hybrids, plug-in hybrids, fuel cells and all-electric vehicles. Looking at the combined portfolio of the 3 automotive companies surveyed, it can be concluded that most of their patents are related to the Sustainable Development Goals (SDG).

First, SDG No. 9: Industry, Innovation and Infrastructure and SDG 7: Affordable and Clean Energy. Analyzes show that the number of patents for electric vehicles also continues to grow, while the number of patents for fossil fuel vehicles has declined (2016/17). This commitment to sustainable transportation research and development has increased manufacturers' R&D spending. Volkswagen was the carmaker that spent the most on research and development.

In 2022, VW spent over 18.9 billion euros. The manufacturer also recorded high intensity of research and development work, and its expenses constitute approximately 6.8 percent. sales revenues. Figure 5 shows the number of active patents used by the automotive industry around the world (divided into patents used in traditional and electric cars.

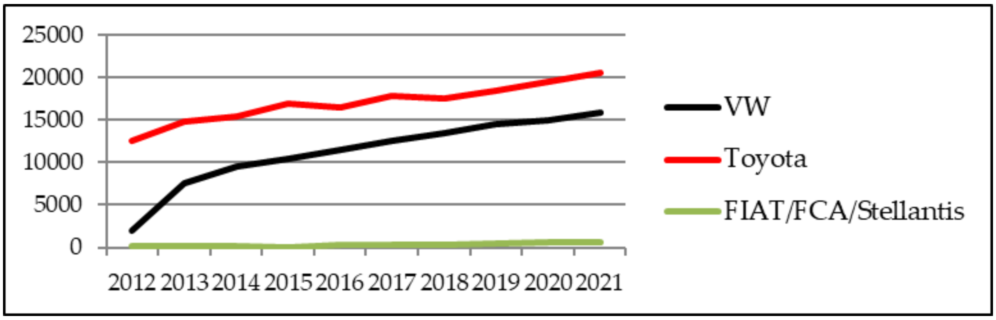
Figure 5. *Number of active patents used by the automotive industry around the world*



Source: *Own study based on data from Table 3.*

Figure 6 shows the number of active patents used by selected companies.

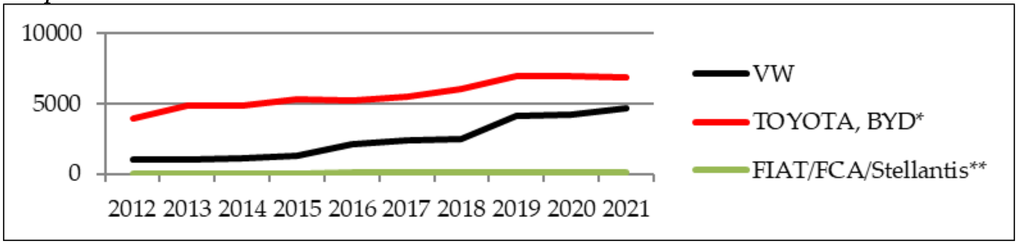
Figure 6. *Number of active patents used by the automotive industry around the world*



Source: *Own study based on data from Table 3.*

Figure 7 shows the number of active patents used by selected companies, developed in cooperation.

Figure 7. *Number of active patents used by selected companies, developed in cooperation*



Source: *Own study based on data from Table 3.*

5. Discussion

Companies need to learn how to source innovation from a variety of internal and external sources using business models (Piller and West, 2014). The literature review indicated an ongoing intensification of conceptualisation, operationalisation, testing and implementation of innovation management models across industries (Afuach, 2014). However, the literature and this research show that even global innovation leaders are not implementing innovation management models that can be called inter-organisational (Leydesdorff and Ivanova, 2016).

Research on Toyota's innovation management activities suggests that the company is closest to inter-organisational systemic solutions (Noboru and Takehito, 2022). Toyota's advancement in systemic solutions supporting innovation is also confirmed in this research. In addition, a number of researchers believe that innovation growth should be systematically monitored using qualitative and quantitative measures (Forslund, 2007; Ryan, 2010). Following the guidance of these researchers, tools were prepared for qualitative and quantitative assessment of leader innovation growth.

Comparing company activities supporting innovation made it possible to indicate the most efficient ones, which increased the innovation growth of chain leaders and their suppliers.

Conversations with experts, which indicated the possibility of integrating models and creating a systemic innovation management model on an IT platform, were also held. Tests and interviews with managers of the studied organisations confirmed giving the green light to developing a systemic innovation management model.

Using information from different sources makes it possible to substantiate the need to create a systemic innovation management model. The collected empirical material (obtained using complex tools) made it possible to propose the integration of the tested models.

Research has shown that managing innovation in an organisation, supplier organisations and innovation processes translates intoinnovation growth of the leader (number of patents obtained). Therefore, the systemic innovation management model may consist of three applied models:

1. Management model of own innovation maturity;
2. Management models innovation proces;
3. Model for managing the supplier innovation maturity.

The practical message of implementing a systematic innovation management model is the innovation growth of supply chain leaders. In addition, the model may find practical use in supply chains of other industries.

5.1 Managerial Implications of the Study

The research produced the analyses from which the following conclusions can be drawn:

- As highlighted during the literature review and research (Chesbrough, 2006; Chesbrough, 2010; Brzóska, 2009; Rexhepi *et al.*, 2019; Knop, 2013), there is a lack of innovation management models that apply to automotive industry supply chains and networks designed following the latest research recommendations. Implemented innovation management models do not take into account the supply chain perspective and other inter-organisational linkages (Rexhepi *et al.*, 2019; Stawiarska, 2019). Most innovation management systems in operation are internally oriented. Their metrics do not extend beyond the corporation or affiliated companies. In addition, they often involve a heavy manual workload to analyse data and evaluate activities (Fajratama *et al.*, 2024).

- The need for a new tool is reported by consulting firms and corporations, which expect it to detect and describe suppliers' innovation competencies in a structured and easy-to-understand way (West and Bogers, 2014; Laursen and Salter, 2006; Dahlander and Wallin, 2006; Dahlander and Gann, 2010; Fajratama *et al.*, 2024). The new tool also identified the missing competencies needed to carry out the innovation process. The new tool assessed potential suppliers' innovation maturity and those from other sectors and disciplines. Only by having a complete picture of the competencies of suppliers and potential suppliers can a global company join forces with suppliers in developing new solutions.

- The examined corporations implement innovation management models among suppliers. They do this systematically, and their efforts improve innovation growth. However, their actions cannot be called systemic. Toyota's innovation management among suppliers is closest to a systematic one. Within keiretsu suppliers, Toyota builds a specific organisational culture, using the philosophy of challenge, kaizen, genchi genbutsu, mutual respect, teamwork, Toyota Production System and quality circles. The innovation management system among suppliers implemented by Toyota is a perfect example of the Japanese approach to work. Decisions on product development do not arise suddenly; they are worked out during many meetings, discussions and collective consultations in a group of managers of cooperating companies. Even if Toyota's activities are not directly referred to as a management system, they de facto form an integrated set of principles, procedures and methods oriented to creating, disseminating and using innovation knowledge (Syla and Rexhepi, 2017; Campanella *et al.*, 2017; Leydesdorff and Ivanova, 2016; Bratianu *et al.*, 2022).

- Corporations do not build a culture of innovation among suppliers, do not require creativity or measure suppliers' innovation maturity. They use supplier databases prepared for their use, where they store information on innovations developed by suppliers. Volkswagen has the most advanced tool for monitoring suppliers and their innovations. A supplier can log into VW's website, become an "inactive" supplier and provide information on a proposed innovation (Syla and Rexhepi, 2017; Campanella *et al.*, 2017; Leydesdorff and Ivanova, 2016; Bratianu *et al.*, 2022).

- The case studies reveal apparent difficulties associated with changing the supplier base and reconnecting the resources of new suppliers. Improving existing resource configurations means abandoning the status quo, which is difficult in the automotive industry but necessary. Engaging suppliers and potential suppliers in innovation processes must start with behavioural adjustments to integrate and reap the rewards of new resource configurations (Chesbrough, 2006; Chesbrough, 2010, Leydesdorff and Ivanova, 2016; Fajratama *et al.*, 2024).

- Lack of a clear long-term strategy for managing supplier relationships, defining the long-term path of cooperation and their development.

- Studied global automotive companies, when carrying innovation processes. There is a lack of description of these sub-processes, detailed procedures and ICT systems to support the implementation of sub-processes. In addition, there is no clear long-term strategy for managing relationships with suppliers, defining a long-term path of cooperation and development (Robertso, 2022; Stawiarska, 2021; Fajratama *et al.*, 2024).

- The results from the process analyses show that the current set of indicators has a limited range of what needs to be measured to effectively improve innovation processes. By measuring value-added, these processes could be updated more frequently. Short-term project management, inconsistent outsourcing and the lack of a framework for defining a supplier's contribution to product development cause recurring operational problems (Robertso, 2022; Stawiarska, 2021).

The findings provide evidence that there is still much to be done in terms of systemic innovation management of automotive suppliers (Chesbrough, 2006; Chesbrough, 2010; Brzóska, 2009; Rexhepi *et al.,* 2019; Knop, 2013). The supply chain leader's implementation/use of innovation management models provides an opportunity to integrate them into a systemic innovation management model (Rudkowski, 2014). It has been shown that the single proposed models will already support decision-makers in improving their own, suppliers' and potential suppliers' innovation growth (Stawiarska, 2021).

A systemic innovation management model will enable consistent monitoring of innovation growth indicators and optimisation of investments in research and development carried out in an open model in cooperation with suppliers. Thus, by implementing a systemic innovation management model, an increase in the innovation growth of cooperating automotive companies can be expected (Fajratama *et al.,* 2024). The proposed systemic model is the key to increasing the maturity and innovation growth not only of suppliers but, above all, of automotive companies.

The supplier innovation management model could be implemented in the group's IT system and serve as a tool to support innovation development. The implementation idea was discussed with a specialist from SAP (responsible for cooperation with automotive companies) and found interest and feasibility confirmation. An IT supplier innovation management system could be classified as an integration platform for innovation. It could integrate "active" and "inactive" suppliers. The tool could support the innovation process and consist of different procedural elements.

The first one would serve as a self-assessment of innovation maturity. Equipped with artificial intelligence, the platform would analyse the supplier's innovation maturity declared in the self-assessment and identify competence gaps in the domains subject to self-assessment. At the end of the research periods, the platform could display averages of supplier assessments by group (by row or segment related to a specific technology). It could also find competence gaps in specific domains of the surveyed company, generate action plans for their improvement and indicate incentives.

It seems that corporations remain indifferent towards new ICT tools in supplier relations for innovation development, so they do not invest in modern ICT systems, which delays organisational change in innovation development processes in open models (Afuah, 2014; Ryan, 2010; Fajratama *et al.*, 2024). Educating and promoting the platform will therefore be necessary. However, looking at what is happening in the automotive software supplier market, it is becoming clear that all automotive suppliers will develop innovations based on open-source software in the future.

This is because it has become apparent in the software market that the amount of code needed to develop this vehicle element is too great for any company to develop on its own.

Corporations are now gaining experience with open-source software. With open-source software, more resources (feedback from customers and car users) can be harnessed to develop technologies for mobility services and autonomous driving. So why not make open-source software available to suppliers for inclusion in the race to develop innovative car software?

There will come a time when all automotive innovation will result from collaboration on open-source platforms, but neither corporations nor suppliers can simply wait for this to happen. Their biggest challenge in the 21st century will be managing innovation that crosses all conventional boundaries.

6. Conclusion

Peter Drucker called the automotive industry "an industry of industries". He explained that the average vehicle has more than 30,000 parts, each requiring innovative solutions that cannot be developed in a single company. Therefore, innovation must be open and inter-organisational. Therefore, future success in the automotive industry belongs to those who will create it in cooperation based on a systemic innovation management model.

Based on the research gap identified in the literature, the focus was on developing a systemic innovation management model that holistically supports innovation in the supply chain. The model developed takes into account the trends identified by researchers, i.e. the shift from traditional relationships to an open innovation model. Research into building a systemic innovation management model will be continued.

The primary goal of the research was to empirically verify the usefulness of the research models, which, after adjustments, can be implemented in innovation management practice. This goal was achieved after a lengthy preparation, in which the biggest problem was overcoming the hierarchical path of obtaining approvals for surveys and interviews and arranging appointments. Interviews and surveys were conducted in an atmosphere of friendliness and commitment, but the researcher identified a number of research limitations affecting the usefulness of the models tested.

Problems with data acquisition and analysis for model one. The statements were subjective and not corroborated by quantitative data or internal documents, so the model may appear subjective.

Problems with data acquisition and analysis for model two. The research into verifying model two also experienced difficulties. Innovation processes were examined; however, only the purchasing and R&D departments, which perform selected process activities, joined the process evaluation. Thus, the assessment of sub-processes may have been inaccurate. As a result, the evaluation of processes was reduced to electric components, and the scores were averaged.

Future projects should aim to develop software processing data on the potential of suppliers. AI algorithms will be used to find the best suppliers, identify their resources and simulate efficient and effective innovation processes. The endeavour is important in terms of supplier sustainability and innovation growth of all companies in the supply chain. The fact that there is a growing demand for eco-innovation, as well as the projected possible crisis in this market, remains an important context.

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