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Technological Collaborations in Iran's Automobile Industry Product Development Process through an Open Design Platform

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Purpose: This research was conducted to design a mathematical model of technological collaborations network in automotive research and development and to explain the relationships between various components of the network.
Methodology: A case study was conducted in Iranian automotive industry. With the mixed method approach in the first stage the Delphi technique was conducted and the opinions of 8 managers and experts in the automotive field were received and the framework of the technological collaborations network was compiled. In the second stage, fuzzy cognitive map technique was used to determine the model parameters, and network modeling method was used to develop the model.
Findings: According to the research findings, the technological collaborations network in automotive research and development includes three groups of developers, parts manufacturers and automakers.
Conclusion: Relationships between various members were formed as intra-group and inter-group in terms of cost and value, and according to the optimal model, these relationships lead to the formation of a common platform with minimum cost and maximum value for automotive research and development.

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1. Introduction

More than 2.5% of world GDP has been spent on research and development. This figure shows the global level average and it is obvious that this amount varies in terms of the ratio of countries' development. If we consider only developed countries, this ratio will increase up to 4% (Trade & industry development, 2018). Considering the world's gross domestic product in 2015 (107.5 trillion dollars), research and development expenses have allocated about 2.7 trillion dollars to themselves in this year, which again, if we consider only the average of developed countries, this figure will increase more surprisingly (OECD, 2017). In the statistics announced on March 21, 2018, among the leading companies in the field of research and development, Volkswagen Company still has the highest research and development expenses (KPMG, 2018). In this respect, Iran has 28th rank among other countries that focus on the fields of aerospace, nuclear energy, medical equipment and stem cells (Global R&D Funding Forecast, 2020).

The increasing costs of research and development have led to convergence among various companies in related fields. Globalization and networking are one of the facilitators that have helped the formation of technological partnerships / collaborations in the automotive industry. In the contemporary era, these collaborations are mostly done in areas that determine the future trends of businesses, such as connected cars, making cars electric or autonomous vehicles (Li, and Gao, 2018). In recent years, innovations are performed mostly in a new way. Businesses have gradually turned from closed systems to open innovations and collaboration invitation (Chesbrough, 2006). A report from the Standish Group Research Institute shows that using open source software models leads to save about 60 billion dollars annually for consumers.

So far, numerous studies have been conducted regarding open innovation and open source software (Bresnahan, & Greenstein, 1999; Harhoff, *et al.*, 2003; Waguespack, & Fleming, 2009; Raasch, and Herstatt, 2011, West, *et al.*, 2014; Enkel, *et al.*, 2009; Ehls, 2014; Yuanwen, 2009), but less research has been done in the field of open source hardware. In particular, this concept has received less attention in the automotive industry and in the field of automotive research and development. This research faced the problem and practical gap that various ideas were not used in automotive design and the costs of research and development are high and it is entirely the responsibility of the automotive manufacturer. Accordingly, while using open innovation and creating a common hardware platform in automotive design (Chesbrough, 2006), in addition to using numerous ideas, research and development costs can also be divided. Open source hardware systems can reduce research and development costs and also develop a new product by focusing on providing a common platform. The automotive platform can be considered as an open source hardware (Groll, *et al.*, 2010). By providing its own platform, the automaker can save research and development costs of other automotive components and parts. From this platform, according to the needs of developers, numerous versions of the product can be defined and marketed (Ivanov, *et al.*, 2017). As a rule, like any complex system, innumerable ideas can be specified for product definition. Automakers need a guiding model and pattern to use this gift and justify investment costs. A model based on which existing concepts can be identified, and complex relationships between various structures can be explained.

Although the pivotal role of open innovation is not hidden for anyone, limited attention has been paid to the use of this gift in automotive research and development in the country's automotive industry. This limitation is due to the absence of a specific approach and model to describe the concepts and explain the relationship of technological collaborations based on the formation of a common hardware platform in automotive design and to show its impact on the overall performance of research and development. Considering the importance of the formation of a common hardware platform in realizing the goals of research and development of automobile manufacturing organizations, this research first and foremost seeks to answer the question that if automobile manufacturing companies want to form a common hardware platform in designing a new automotive based on open innovation which pattern (model) they should follow and what strategies they should compile and follow. In the second stage, the researcher seeks to answer the question that basically what are the variables and parameters for the creation of a hardware platform based on technological collaborations and what are the optimal amounts of these variables in automotive research and development.

Research Theoretical Foundations and History

The question that has not yet been answered in the field of technology strategy is whether a company should have a closed and internal organization approach to the issue of innovation and seek all the options related to product development within itself or, on the contrary, should leave its technology open and receive related elements and subsets from other actors. Scholars who have addressed this question have considered the two basic issues of utilization and the appropriateness of the resulting value that a balance should be made between them (Geyer, *et al.*, 2012; West, *et al.,* 2014; Herstatt, & Ehls, 2015; Levine, & Prietula, 2014; Balka, *et al.*, 2014; Levine, & Prietula; 2014). For example, some have mentioned the issue that by reducing the risk of retaining the supplier, openness strengthens the acceptance and nutrition of the effects of network and the creation of value in the network (Balka, *et al.*, 2010; Pearce, 2017). However, opening a technology will often lead to the loss of intellectual property rights, make the imitation of other developers and competitors possible, and consequently that desired value from the technology development will be divided; so investment incentives in cases that the expected value is low are overshadowed (Almirall, and Casadesus-Masanel, 2010). Perhaps the basic point hidden in open innovation is that not all smart people work for us (Enkel, 2009), and the openness of technology provides this possibility that developers can use each other's capabilities and facilities.

Technological partnerships are not a new concept; they have already had other forms of collaborations that companies have had with each other (Wu, 2012); the various forms that these collaborations have been observable in a variety of legal forms, cases such as strategic coalitions in the field of research and development, joint research and development projects, and so on. What is important about technological partnerships is the structure of collaboration in this category of partnerships, which is important according to the definitions mentioned earlier (Levine, and Prietula, 2014). Technological partnership has been defined as an inter-firm effort to achieve common benefits in the process of sharing information and resources (Salisu, & Bakar, 2018) and this is due to the elimination or reduction of technological problems that the company cannot remove them alone. Partnership therefore involves collaboration with each other through a variety of partners and based on a specific goal through shared effort and available resources (Jimenez-Jimenez, et al., 2019). Partnerships are considered as one of the most important strategies related to capacity increase (Levine, and Prietula, 2014). Although participation is generally considered as a process that takes place between more than two individuals/ organizations/ institutions, it also has weaknesses within itself and in the operational process. A participatory process means presence in relationships that focus on the positive aspects of human nature in order for working activity to be fruitful (Ostrowski, *et al.*, 2020). Although the process of various and dynamic working groups is often mentioned in business and management texts, the human aspect of working with each other should be emphasized.

Open design provides a framework for sharing hardware design information and other physical objects. This design has different consequences such as aesthetics, usability, production, quality, etc (West, and O'mahony, 2008). In order to examine the openness of software and hardware parts with exact details, Balka et al. (2014) have extended the framework proposed by West and Amahni (2008) for cases beyond software. While the authors distinguish between transparency and accessibility, we add reproducibility as a third form of openness (Balka, *et al.*, 2014). Transparency refers to the quantity and quality of information that is freely provided to developers. The information that in this area can be, for example, software source code or hardware scripts and design files (Jimenez-Jimenez, *et al.*, 2019). Accessibility indicates the possibility of active participation of community members in product development. The findings show that the components have been designed in an open design in a detailed level. Some parts are designed completely closed, while some others are open (Balka, *et al.*, 2010). The degree of openness between software and hardware parts varies considerably, meaning that software is more transparent, more accessible, and reproducible than hardware. Open source

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hardware is a set of design principles and legal cases that are not merely limited to the specific type of a product. Thus, this term can be generalized to a set of products such as automotive, chair, computers, robots or even homes (Pearce, 2017). As any open source software, the source codes related to the open source hardware, plans, working programs, design logic, computer-aided design files can be modified or upgraded for the general public under the conditions of franchise. Users of this category of open source hardware can take the necessary measures to upgrade or improve the codes contained in the related hardware by reading and manipulating related technical knowledge resources (Balka, *et al*., 2014).

In researches related to product development, the word platform was first used to introduce a new generation of a product or a family of product. In a research, Wheelwright and Clark (1992) used the word platform to describe a new product that meets the needs of a group of customers (and is being designed) through easy modification in derivatives by adding, replacing or deleting features (Bonvoisin, et al., 2017). In the second wave of researches related to platform, technology strategists have defined the platform as a valuable starting point in controlling the industry. Platforms competition has been identified as an important force at the industry level that can be effective in the success or failure of companies and the development of a new product. Brosnahan and Greenstein (1999) presented a theory to explain the evolutionary structure of the computer industry (Bresnahan, and Greenstein, 1999). In this theory, the competition structure focuses around a small number of superior (leading) platforms, and this issue leads to the intensification of competition in a specific segment of the market. Finally, industrial economists have used the word platform to describe products, services, companies, or institutions that are the mediator of the exchange of operations between two and a group of agents (Gawer, 2009).

Holle *et al*. presented the technological partnerships development model in automotive research and development (Holle, et al., 2011). In this model, various actors such as developers, automakers and third party stakeholders play a role in creating an open platform of automotive (Chesbrough, 2003). In this research, an automotive platform has been formed to create integration between the network and the internal components of the automotive with external modules and networks. In another Research (Wheelwright, and Clark, 1992) the term of "platform" is to describe a new product (being designed) that meets the needs of a group of customers by easily changing derivatives by adding, replacing or deleting features. In the second wave of researches related to platform, technology strategists have defined the platform as a valuable starting point in controlling the industry. Platforms competition has been identified as an important force at the industry level (Gawer, 2009) that can be effective in the success or failure of companies and the development of a new product.

2. Methodology

In this research, using the mixed research method in the first stage to compile a conceptual framework from the Delphi approach and in the second stage in order to determine the amounts of the model parameters, the multiple case study method, and also to design the network model of technological collaborations, the mathematical modeling method were used. In order to identify the dimensions and components of the technological collaborations model, the opinions of 8 experts using the Delphi technique were used. In order to determine the amounts of model parameters (value and cost) using fuzzy cognitive map, 35 managers of Saipa Automobile Manufacturing Group were interviewed. In the first step, the respondents' opinions regarding the relationship between various parts of the model in terms of innovation value were examined, and in the second step, their opinions regarding the cost of creating innovation between various parts of the automotive research and development network were received. After receiving the weights matrix of 35 respondents, the cumulative weights matrix was prepared and regarded as the basis for multiple case study calculations. In this research, the components of the model were compared with each other from two aspects; firstly, in terms of "value created in the network" and secondly in terms of "cost and time of achieving innovation results". Separate weights matrices were prepared for each of these aspects and the initial amounts

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were determined as input parameters of the model. The weight of each arc indicated the effect of one concept on the other concept in terms of value added or cost increase ratio, which was defined as follows:
Node: Components or parts of the technological collaborations network in automotive research and development,
Arc: The weight of each relationship in the network in terms of the value of innovation or the cost of creating innovation. One of the most powerful alternatives for the time that nodes in a network are not of the same type is to use multilayer networks. A multilayer network (Newman, 2018) has been consisted of a collection of layers, each with a separate network that has its own connections. In order to develop the mathematical model of technological collaborations based on hardware platform in the automotive research and development, the method of mathematical modeling based on multilayer networks was used. The mentioned mathematical model was formed of three separate network layers connected with each other by the arcs defined above. In the first layer, there are developers that also have connections between themselves. In the same way, in the second and third layers, there are parts manufacturers and automakers. In order to adjust the amounts of value and determine the optimal combination of relationships in the network, in addition to value, innovation costs were also considered and the model with two objective functions of value maximization and costs minimization was considered. Collections, variables and parameters of the model have been summarized as follows:

3. Findings

Collections

First Layer - i: Developers collection ($1i =$, ..., I) -- m: Developers $m \subseteq i$
Second Layer – j: Parts manufacturers Collection ($1j =$, ..., J) -- k: Parts manufacturers $k \subseteq j$
Third Layer – h: Automaker

Variables

First Layer -z_{im} : The binary variable that takes 1 value if connection from developer i to developer m is made, otherwise it takes 0 value.
Second Layer 2-: z'_{jk} : The binary variable that takes 1 value if connection from parts manufacturer j to parts manufacturer k is made, otherwise it takes 0 value.
Between the first and second layers - : x_{ij} : The binary variable that takes 1 value if connection from developer i to parts manufacturer j is made, otherwise it takes 0 value.
Between the second and third layers$-y_{jh}$: The binary variable that takes 1 value if the connection from parts manufacturer j to automaker h is made, otherwise it takes 0 value.

Parameters

First Layer:
V_{im} : The value created in relation from the developer i to the developer m.
C_{im}: The cost created in relation from the developer i to the developer m.
Second Layer:
V'_{jk} : The value created in relation from the parts manufacturer j to the parts manufacturer k.
C'_{jk} : The cost created in relation from the parts manufacturer j to the parts manufacturer k.
Between the first and second layers:
VV_{ij} : The value created in relation from the developer i to the parts manufacturer j.
CC_{ij} : Cost created in relation from the developer i to the parts manufacturer j.
Between the second and third layers:

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VV'_{jh} : The value created in relation from the parts manufacturer j to the automaker h.
CC'_{jh}: The cost created in relation from the parts manufacturer j to the automaker h.

Mathematical Model

$$Max\ Z = \sum_i \sum_m z_{im} * V_{im} + \sum_j \sum_k z'_{jk} * V'_{jk} + \sum_i \sum_j x_{ij} * VV_{ij} + \sum_j \sum_h y_{jh} * VV'_{jh} \tag{1}$$

$$Min\ Z = \sum_i \sum_m z_{im} * C_{im} + \sum_j \sum_k z'_{jk} * C'_{jk} + \sum_i \sum_j x_{ij} * CC_{ij} + \sum_j \sum_h y_{jh} * CC'_{jh} \tag{2}$$

$$s.t \tag{3}$$

$$\sum_i x_{ij} \geq 1 \ \forall j \tag{4}$$

$$\sum_j \sum_h y_{jh} \geq \left[\frac{J}{2}\right] \tag{5}$$

$$y_{jh} \leq x_{ij} \ \forall i, j, h \tag{6}$$

$$x_{ij} \leq z_{im} \ \forall i, j, m \tag{7}$$

$$\sum_k z'_{jk} \geq 1 \ \forall j \ (j \neq k) \tag{8}$$

$$y_{jh} \leq z'_{jk} \ \forall j, h, k \tag{9}$$

$$\sum_j \sum_k z'_{jk} \geq J \tag{10}$$

$$\sum_i \sum_m z_{im} \geq I \tag{11}$$

$$z_{im}, z'_{jk}, y_{jh}, x_{ij} \in \{0,1\} \tag{12}$$

Equation (1) expresses the first objective function; it is with the goal of maximizing the sum of values, that these values include costs reduction and innovation increase. Equation (2) expresses the second objective function, with the aim of minimizing the sum of costs. Constraint (3) indicates that there is at least one relation between developers and parts manufacturers. Constraint (4) states that there is at least one relation between parts manufacturers and automakers. Constraint (5) states that until a relation is not formed between developers and parts manufacturers; no relation will be formed between parts manufacturers and automakers. Constraint (6) states that until there is no relation between developers; there will be no relation between developers and parts manufacturers. Constraint (7) states that for each developer, there is at least one relation with other developers. Constraint (8) indicates that until no relation is established between parts manufacturers, parts manufacturers cannot establish relation with automakers. Constraint (9) states that the minimum number of relations between parts manufacturers is equal to the number of collection of parts manufacturers. Constraint (10) indicates that the minimum number of relations between developers is equal to the number of collection of developers.

Data Analysis

The components of the technological collaborations model or parts of the automotive research and development network were formed based on the research literature and were confirmed in the form of an initial framework according to the opinions of experts with Delphi technique. In the first round, a questionnaire was sent to 8 managers and experts in the automotive industry and they were asked to review the importance of each component in different parts of the model and express their opinion. In this step, the mean and median of the components of the model were 3, so it can be said that consensus has been reached in most cases, but in order to obtain better results, the second round was also implemented. In the second round, in addition to the list of final indicators, average opinions were also sent to the experts of the previous stage, and finally they were asked to modify their opinion if necessary. In the second round, most of the opinions tended towards the middle of the opinions and the average of all opinions was higher than 4. According to the results, it can be said that the group of experts had a consensus regarding the various

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components of the technological cooperation model.
In addition to value, innovation costs were also considered to adjust the amounts of value and to determine the optimal combination of relations in the network. In this case, the model was converted to a dual-purpose mathematical model with optimal values. Since the amounts of value and cost are different, certainly the amount of all variables will not become 1, and for creating the balance between value and cost, some variables will appear with the amount of 0. For doing it, value and cost parameters that were determined in the previous step using multiple case study were used. Considering that two objective functions are considered in this model and it is not possible to solve the model with more than one objective function simultaneously, so the weighting approach is used to convert the objective functions into one objective function. For this purpose, the weights of w_1 and w_2 are assigned to each of the objective functions, as follows. Due to the fact that values are more important than costs in the model, we assign more weight to the objective function related to values (W1 = 0.6, W2 = 0.4).

$$Max\ Z = w_1(\sum_i \sum_m z_{im} * V_{im} + \sum_j \sum_k z'_{jk} * V'_{jk} + \sum_i \sum_j x_{ij} * VV_{ij} + \sum_j \sum_h y_{jh} * VV'_{jh}) \\ -w_2(\sum_i \sum_m z_{im} * C_{im} + \sum_j \sum_k z'_{jk} * C'_{jk} + \sum_i \sum_j x_{ij} * CC_{ij} + \sum_j \sum_h y_{jh} * CC'_{jh}) \quad 12$$

$$w_1 + w_2 = 1 \quad 13$$

To solve the model, cost and value parameters were obtained according to the output of the previous stage weights matrix (multiple case study). General Algebraic Modeling System (Gams) software was used to analyze the data. The optimal amount of the first objective function (total value of collection) is 32 and the optimal amount of the second objective function (total cost of collection) is 29. These amounts show that in order to create an innovation in the network, using the optimal relations of this model, 32 units of value can be created, while the cost of its formation is 29 units.
The outputs of model that show the optimal relationships between components of research and development's network are presented in Tables 1 to 5.

Table1. Values of x_{ij}

	PT	PTI	CH	HVAC	INT	BOD	EXT	OCC
MC	1	1	1	0	0	1	1	0
ELC	1	1	0	1	0	1	1	1
ELCR	1	1	0	1	0	1	1	1
POL	1	1	0	1	1	1	0	0

The relations between developers and aggregators are defined as table 1 where is the 1 value in the edge of Xij show the connection between them.

Table2. Values of y_{jh}

	PLT
PT	1
PTI	1
CH	0
HVAC	0
INT	0
BOD	1

[DOI: 10.52547/ijes.3.4.190]

EXT	1
OCC	0

The relations between aggregators and automakers are defined as table 2 where is the 1 value in the edge of Yjh show the connection between them.

Table3. Values of z_{im}

	MC	ELC	ELCR	POL
MC	1	1	1	1
ELC	1	1	1	1
ELCR	1	1	1	1
POL	1	1	1	1

The relations between developers are defined as table 3 where is the 1 value in the edge of xij show the connection between them.

Table4. Values of z'_{jk}

	PT	PTI	CH	HVAC	INT	BOD	EXT	OCC
PT	1	1	1	1	1	1	1	1
PTI	1	1	1	1	1	1	1	1
CH	0	0	1	0	1	1	1	0
HVAC	0	1	0	1	1	0	0	1
INT	1	0	0	1	1	1	1	0
BOD	1	1	1	1	1	1	1	1
EXT	1	1	1	1	1	1	1	1
OCC	1	1	0	0	1	1	0	1

The relations between aggregators are defined as table 4 where is the 1 value in the edge of xij show the connection between them.

The relationships are formed at the three levels of the network of developers, parts manufacturers and automakers in such a way that the relationships within the network at the level of developers are two-sided and between the network of developers and the network of parts manufacturers is one-sided. Also, there are one-sided (in black) and two-sided (in blue) relationships between various nodes at the parts manufacturers' network level, while these relationships between the network of parts manufacturers and automakers are one-sided and have been formed only by engine nodes, engine accessories, body and external components.

The optimal model, in addition to showing the optimal relationships and the optimal path in the network, has also specified the optimal amount of cost and value. In addition, each of the paths has a certain amount of cost and value, which shows the optimal amounts of that path.

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In order to investigate the validity of the proposed mathematical model, we examined the three random samples of the mentioned network. These samples have random paths that were selected to compare with the optimal model. The purpose of investigating random models was to show that the optimal model has a significant difference with random models. As the outputs of the three random models showed, the amounts of cost and value had significant difference in all three models with the optimal amounts in the main model.

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Although the value in these three random models has allocated a lower amount in the final objective function than the optimal model, the amounts of cost have significantly been reduced. This comparison firstly showed that the amount of objective function in the optimal model was better than its amount in the random models and secondly the difference between the random samples and the optimal model is considerable and significant.

4. Conclusion

In this research, the technological collaborations network was classified into two general parts including the participants (developers, parts manufacturers and automakers) and concepts / components (mechanical, electrical, electronic, polymer/ chemical, engine, components and spare parts of the engine, chassis, ventilation system, interior decorations and components, body, exterior components, electrical/electronic components and platform). Findings related to the mathematical modeling of automotive research and development technological collaborations network were optimized using two parameters of value and cost in the maximum value and minimum cost states of the model. In addition to the relationships existing between various levels of the network (relationships between networks), relationships within the network that represent the relationship between various actors at each level of the network has also been established. In this model, three various layers of interconnected networks have been defined. Developers, the first layer of the network, parts manufacturers, the second layer of the network, and automakers, the third layer of the network. At the intrnal level of the network, developers have a two-sided relationship with each other. On the other hand, at the same level, parts manufacturers have two-sided and one-sided relationships with some of the nodes existing in their network. Also, relationships are formed at the level between networks, as these relationships can be observed between the networks of developers and parts manufacturers on the one hand and parts manufacturers and automakers on the other.

In the present research, the relationship between developers and automakers has been established through parts manufacturers that does not exist in previous models. Also, the relationships between developers, parts manufacturers and automakers with themselves and other networks based on value and cost were specified in this research. Based on the research findings, the performance of the research and development network (value increase and cost decrease) was optimized in a multi-layered relationship between various stakeholders. In the optimal model, in addition to the various layers of the research and development network, the optimal relationships have also been specified. In order to create value in the network, it is suggested that the role and importance of various actors be determined according to the influence in the whole network. In case of the formation of a partnership based on collaboration in internal networks (developers, parts manufacturers and automakers) based on the optimal model, the maximum value and minimum cost regarding network performance can be expected and considering the main function of the platform, the optimal path can be determined.

Based on the research findings, it can be said that technological collaborations are formed based on the partnership between various actors of the research and development network and has led to the formation of a network with optimal specifications in this research. These results in previous researches also show the importance of participation in research and development. Chesbro and Vanoverbeke (2006) by examining the middle markets (where technologies are important for the company) emphasize the importance of participation in innovation and show that increasing technology development costs and reducing product life cycle time and also instability of closed (innovation) models lead companies towards open innovation; open businesses lead to the creation of more sources for revenues and reduce costs and time through using external resources. In the findings of the research model, maintaining the platform as a whole in the automobile manufacturing and as a component in the research and development network is of particular importance and reflects the final results (value and cost) of the network. In this regard, Chesbro (2003) has shown the creation of value arising from compliance with third parties with particular importance and has considered the

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acquisition and attraction of value vital for the stability of the platform.

Regarding the formation of the communication technology revolution and using it in facilitating the relations of automotive with the outside, open platforms have been formed mainly with the aim of improving the performance of automotive and while integrating software and hardware facilities, makes it possible for the automotive to make connection to the outside world. In the research model, we showed that developers in various electrical and electronic sections have established their relationship with the network of parts manufacturers (various internal, external sections, ventilation, engine and engine accessories, as well as electrical and electronic components) to develop appropriate software and hardware in the automotive platform. On this basis, according to Hirth, Hossfeld, and Tran-Gia (2015), open platforms provide numerous new facilities for automakers to establish a stable, meaningful, and interactive relationship between the automotive and the outside world. Open platforms will therefore be able to provide numerous opportunities for automakers, third parties and users through the personal development of tools and software applications within a framework of simple distribution process through an innovative participatory community (Chesbrough, 2003).

Based on the research findings, technological partnerships to shape the open source hardware platform have been formed in a network of various communities called open community. These communications ultimately manifest themselves in the form of partnership to develop their common platform pack and to determine the optimal path in the network with a specific value and cost. Accordingly, open participation defines a collection of principles and determines the necessary foundations for achieving maximum output of innovation and production. Necessary foundations for it can be defined by observing the samples in the amount of value created, the ratio of performed exchanges and interactions, the reduction of inconsistencies and the amount of exploitation cost from the achievements. As Levine and Peritula (2014) state, when we think about performance, a computational model can be compiled that combines innovation theory that is based on evidence with human beings' collaboration. Accordingly, three elements in the field of performance can be involved; "participatory collaboration", "diversity of needs and a degree of competition in products" and finally "products in a competitive market".

The research findings showed that the performance of the research and development network (value increase and cost decrease) was optimized in a multi-layered relationship between various stakeholders. In the optimal model, in addition to the various layers of the research and development network, the optimal relationships have also been specified. In order to create value in the network, it is suggested that the role and importance of various actors be determined according to their influence in the whole network. If a partnership based on collaboration between internal networks (developers, parts manufacturers and automakers) is formed, according to the optimal model, maximum value and minimum cost regarding network performance can be expected. Regarding the main function of the platform, the optimal path can be selected. In platforms whose main function is to develop the engine and mechanical components of the automotive, the main path follows the following diagram:

Mechanical Developer → Parts Manufacturer of Engine → Platform

Or

Mechanical Developer → Parts Manufacturer of Engine Accessories and Components → Platform

Also, if the desired function of the platform is to develop the automotive connection capability with the outside world, the main path follows the following diagram:

Electronic Developer → Parts Manufacturer of Electrical/ Electronic → Engine/ Engine Accessories and Components → Platform

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Components

In each path, the main nodes act as pivotal components in the network and the main focus of activities will be on these nodes.
In this research, due to the lack of access to real data of research and development performance, value and cost parameters were defined as a whole and their amounts were extracted through expressive data (experts' opinions). It is suggested that in future researches using the real performance data in the research and development network, the proposed research model be used to determine the optimal paths and to define the research and development network in other statistical populations.

Appendix-A. Dimensions/concepts of the technological collaboration network

Participant	Concepts	Abbreviation
Developers	Mechanical	MC_C
		MC_V
	Electrical	ELC_C
		ELC_V
	Electronic	ELCR_C
		ELCR_V
	Polymeric/Chemical	POL_C
		POL_V
Systems Aggregators	Power Train	PT_C
		PT_V
	Power Train Integration	PTI_C
		PTI_V
	Chassis	CH_C
		CH_V
	HVAC & Power Train Cooling	HVAC_C
		HVAC_V
	Interior	INT_C
		INT_V
	Body	BOD_C
		BOD_V
	Exterior	EXT_C
		EXT_V
	Occupant &Vehicle Electrical/Electronic	OCC_C
		OCC_V
OEM	Platform	PLT

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