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RESEARCH PAPER

Technology Development Envelope Approach for The Adoption of Future Powertrain Technologies: A Case Study on Ford Otosan Roadmapping Model

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Abstract: Industry, government, and academia have started to adopt the technology roadmapping concept to setup their technology strategy, identify gaps and opportunities in their R&D activities. Automotive industry, facing fierce competition with continuous technological breakthroughs and improvements, should have roadmaps with respect to their company objectives that have flexible features so that organizations can reassess and adjust their roadmaps in a timely manner according to the impacts of the changes. This study focuses on future powertrain systems with the aim of defining the most probable implementation roadmap for the different alternatives to improve powertrain efficiency.

Key Words: systems engineering; powertrain; technology assessment; technology forecasting; technology planning; Turkey

1 Introduction

Energy consumption in the developing world has grown far more rapidly over the last twenty years. According to World Energy Outlook (WEO) 2007, with the emerging giants such as India and China, if governments around the world stick with current policies the world's energy needs would be well over 50% higher in 2030 than today. China and India together account for 45% of the increase in demand in this [1]. Global oil demand, which continues to form the largest component of total energy demand, is expected to show a similar increasing pattern. Growing demand will be overwhelmingly (84%) met by fossil fuels, while greenhouse gas emissions will rise by 57%, with the United States, China, India, and Russia contributing two-thirds of the increase. Because of dependence on fossil fuels, the ever-increasing energy demand will eventually lead to a change in world's oil supplies. In 1956, Peak oil theory was created stating that in time, the maximum rate of global petroleum extraction will be reached, after which the rate of production enters terminal decline[2]. The logistic model, now called Hubbert peak theory, and its variants have been shown to be descriptive with reasonable accuracy of the peak and decline of production from oil wells, fields, regions, and countries[3].

Some observers believe the high dependence of most modern industrial transport, agricultural and industrial systems on the relative low cost and high availability of oil will cause the post-peak production decline and possible severe increases in the price of oil to have negative implications for the global economy. Wide use of fossil fuels in internal combustion engines also causes air pollution and risks human health, because of emitting pollutants. Air pollutants like CO, NO_X, et al. can be toxic and pose a threat at even very low levels. In addition, greenhouse gases released into the atmosphere directly affects global warming. The regulations of European Union on motor vehicle emissions force car manufacturers to develop new technologies reducing undesired vehicle emissions. Moreover, market competition due depleting fossil fuel resources, forces car manufacturers search for ways of improving engine efficiency or adopting new technologies while staying within the limits stipulated by the legislated standards. Current studies indicate that radiative forcing by greenhouse gases is the primary cause of global warming[4,5]. According to these studies, the greenhouse effect, which is the

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warming produced as greenhouse gases trap heat, plays a key role in regulating Earth's temperature. CO_2 production from increased industrial activity and other human activities such as cement production and tropical deforestation have increased the CO_2 concentrations in the atmosphere[6]. In general, increases in developing-country energy demand have been underpinned by growth in population, in economic activity and in per capita incomes; and underlying the growth in economic output has been rapid expansion in industrial activity. Combined with the increasing rates of urbanization evident throughout the developing world, these factors have led to sharp increase in the demand for motorized transport. In most countries, the growth in energy demand has outpaced that of GDP, leading to increase in aggregate energy intensities. Automotive industry is going through difficult times, as radical changes are expected in order to overcome above problems. Therefore, it is very important for a company to review their positions and form a strategy to decide how to act on future necessities.

The purpose of this paper is to carry out a roadmapping methodology for automotive industry, with respect to future powertrain systems. This methodology will create a roadmap for the case study company and any other similar company, and due to its flexible nature, it has a chance to be reviewed and changed continuously and quickly. As a result, several future powertrain technologies will be evaluated, and their technological value with respect to several criteria and factors will be calculated.

2 Literature review

In order for companies to face fierce competitive problems, it is highly important to depend on technology management and planning[7]. For many organizations, technological planning is an ongoing function of management. Nevertheless, whether planning is done as a routine or on a project basis, technological forecasting is required[8]. Phaal et al.[9] describe technology roadmapping as a needs-driven technology planning process to help, identify, select, and develop technology alternatives to satisfy a set of product needs. Factors that contribute to successful technology roadmapping are listed by Daim and Oliver[10]. Factors that are particularly important for successful roadmapping include a clearly articulated business need, the desire to develop effective business processes, having the right people involved and commitment from senior management. To summarize, there is a wide range of research available on technology forecasting and roadmapping as well as many industrial roadmaps[11-21]. Furthermore, most forecasting and assessment methods, such as Delphi, are investigated thoroughly[22–24]. However, there are only a limited number of studies concentrating on combining Delphi forecasting method and technology roadmapping for technologic forecasting.

Furthermore, in most of the studies, technology forecasting is usually focused on existing technologies and not on emerging technologies[25–27]. According to Walsh[28], it should be noted that it is rather difficult to gather information on emerging technologies, especially when both quantitative and qualitative measures must be included in the study. Therefore, another approach is required to conduct a roadmap.

Phall[29] states that current roadmaps on automotive industry focus on general aspects of the future technologies and reflect an overall evaluation. During the constitution of a product or an industry roadmap, the work is carried out either by colleagues within a company or external technology developers across industries. However, as Gerdsri[30] discussed, it is highly important to form a link between both external and internal technology developers and researchers. Roadmaps are stationary by nature and need to be re-constructed each time a change is required. However, it is highly important for a company to keep the roadmap dynamic and ready to change accordingly. Therefore, it is crucial to “keep the roadmap alive”, as Gerdsri[31] defines in another study.

It also should be noted that even though almost every transport industry player has already constituted their roadmaps, a flexible and dynamic roadmap created by technology developer and technology implementer experts on emerging powertrain technologies has never been studied before. All these roadmapping gaps require a more flexible approach that can evaluate emerging technologies by gathering data from both technology developers and technology implementers.

3 Research methodology

TDE is a new concept and methodology for identifying the optimum path in developing technology strategies and combining them with business strategies and/or policy decisions[30–32].

TDE helps companies to identify emerging technologies, evaluate the value of those technologies with respect to the organization’s objective. As Gerdsri describes, the connection of technologies from one period to the next results the technology development path, containing technologies with the highest value in each period is considered as TDE[31]. Once the best path is identified, it can be used to structure the technology elements in a roadmap, making it more flexible and alive.

The TDE framework is structured by obtaining strategic information on the development of technologies and then using this information to evaluate the value of each technology based on the impacts of its characteristics on the organization’s objective in each period. A technology development envelope is formed by connecting technologies that have the highest value in each period throughout the specified period.

The methodology involves forecasting, identification, assessment, evaluation and selection of emerging technologies. In order to develop a methodology to build a TDE, a research objective should be selected by fulfilling five research goals.

The development of a TDE is designed to be completed through six model development steps: technology forecasting, technology characterization, technology assessment, technology evaluation, hierarchical modeling and formation of technology development envelope[31]. The flow of information to the model and within the model is shown in Table 1.

Table 1 Summarizing each step to achieve research objective [31]

Research objective		
Step 1:	Technology Forecasting	Develop a forecasting model using Delphi for identifying the trend of emerging technologies
Step 2:	Technology Characterization	Identify criteria and technological factors satisfying a company's objective
Step 3:	Technology Assessment	Assess emerging technologies based on the measures of effectiveness
Step 4:	Hierarchical Modeling	Develop a hierarchical model to determine the relative impact of measures of effectiveness on a company's objective
Step 5:	Technology Evaluation	Evaluate the impact of emerging technologies on a company's objective by using the semi-absolute value
Step 6:	Formation of TDE	Construct the technology development envelope and technology development paths

In this study, expert opinions were obtained from separate expert panels; such as universities (Istanbul Technical University, Sakarya University, Boğaziçi University, et al.), a research center (TUBITAK) and industry (Ford Otosan, Ford Motor Company, et al.).

4 Application of the model

For the purpose of illustration, the proposed model is applied to the strategic evaluation of emerging powertrain technologies. The outcomes of technology value will indicate which technology of the case study company, Ford Otosan in this case, should consider for R&D investment in developing new vehicles.

Ford Otosan, established at the end of 1950s, is one of the most innovative research-intensive companies and the sales leader in Turkey. Within a short time, Ford Otosan has joined the ranks of Ford of Europe top production plants, with strong international reputations. Today, Ford Otosan has the technology and the know-how to design a complete vehicle for the domestic and international markets.

Ford Otosan Product Department was formed in 1961, as of today can develop almost a complete vehicle in house. Engineers utilize the state of art engineering tools to develop parts and systems, simulate crash tests or cooling performance and have gained extensive knowledge and experience from countless hours and kilometers of engine and vehicle testing. Engineering resources include Design Studio (concept development, digital modeling, A-class surfacing, clay generation & modeling, rapid prototyping, color & harmony analysis, craftsmanship, design aid manufacturing) 6 Test Cells (with TUV & TSE accreditation capable of measuring performance, emissions, T/C Matching and Turbo Transient Response), Material Lab (to support material characterization, failure root cause and micro structure analysis), Vehicle Performance Measuring Equipments (to measure speed, acceleration, brake performance, fuel consumption and noise & vibration), Fatigue Test Rigs (with programmable 6 hydraulic cylinders and SINCOTEC Resonance Frequency Fatigue Rig Test Rig), Durability Rig Test Laboratory (to support key life tests). As of April 2009, the number of engineers working in Product Development has reached 596. The PD has 12 PhD and 474 MSc. and BSc. degree level engineers who are internationally recognized in their area of expertise. 110 technicians and supporting workers form the competitive employee body of the company.

R&D department of Ford Otosan, established in 2002, is known to be the leading structure of “pre-competitive level actions” in Turkey, leads most of the vital projects with universities, research centers and other companies, and plays a key role in driving forward the whole process to reach the results compatible with the truly integrated European approach. R&D Department is the first automotive industry partner that has involved in a project funded by FP6 program of EC (GREEN Integrated Project). Turkey's first fuel cell package has been designed and developed with and consortium led by Ford Otosan. In the first quarter of 2006, Ford Otosan designed and produced its first hybrid vehicle, FOHEV (Ford Otosan Hybrid Electric Vehicle) again working with universities and research centers in Turkey.

A state of the art plant, carefully initiated product development projects, projects being worthy of funding from Turkish government as well as European Commission, exceptional human resources – all these components enable Ford Otosan to thrive as a dynamic and innovative institution of high level design and development.

As an OEM, Ford Otosan foresees its future in well-developed investments in R&D, therefore requires a dependable, applicable, practical and yet flexible roadmap.

There are many roadmaps, international, national and industry wise, with respect to future vehicle technologies. Furthermore, different technologies were assessed with respect to their efficiencies and some performance features[33-38]. However, most of the studies do not acquire any methodologies to assess these technologies and only list specific attributions of those. Several studies that assess advanced powertrain technologies with a specific methodology only include main specifications such as efficiency, fuel consumption, exhaust and CO_2 emissions, but do not have a more detailed review of other features.

The next sections detail the results of the application. The initial plans of the application including the questionnaires can be found in [39].

4.1 Technology forecasting

In order to shape the powertrain technologies, a Delphi questionnaire is prepared and allocated to separate expert panels. The first group of experts represents the university side of the research as they focus on powertrain development and technological gaps. The second group is a panel of research center experts, focusing on advanced technologies and control strategies. Third group represents the industry that involves in powertrain development and production. After receiving first round of reviews, the panels were united to be separated once again in two panels. First panel represents an industry-wide group of experts, who involve in the development of future vehicle technologies. This panel is formed in a way that experts' biases in the outcomes of emerging technologies and differences in their ideas across industry, academic, and government background are well balanced. Second panel consisted of members from the company and partners. Therefore, after two rounds of Delphi study, a list of seven technologies was listed as Table 2.

Table 2 List of future vehicle technologies

T1:	Diesel engine + CVT + Common Rail 3rd Gen (1800 bar) + TC + SCR + DPF
T2:	GDI engine + Downsizing + VVT + VCR + TC
T3:	Diesel HCCI + VCR + VVT + EGR
T4:	Hydrogen ICE + Liquid H2 storage (cyrogenic) + VVT + TC
T5:	Diesel engine + Li-ion battery + Starter/charger motor + Electric motor
T6:	PEM Fuel Cell + Li-ion battery + Electric motor + Compressed hydrogen storage

The surveys point out that gasoline and diesel ICEs will still be dominant; however, their market share will be diminished due to increasing shares of hybrids and hydrogen vehicles. Today, the greatest challenge that ICEs are facing is considered the limitation of further development. In the upcoming decades, diminishing resources and environmental issues will be the number one challenge against their improvements. Experts believe that SCR together with LNT will be used in the future for the reduction of exhaust emissions. In addition, further increase in injection pressure for next generations of Common Rail is expected. Combustion chamber optimization may show some promising progress in the coming few years, however, most of the experts underlined that it has reached its boundaries.

With respect to hybrids and fuel cells, system components are the biggest challenges. They are open for further technological development and must overcome cost, weight, complexity and control issues. Nevertheless, hydrogen infrastructure and on-board hydrogen storage units will require further development.

In addition to the questionnaire, experts also provided their estimates on the technological metrics indicating the future development progress of each technology along twenty-two factors.

4.2 Technology characterization

The objective of the company is defined as "to achieve technological competitiveness with respect to powertrain systems", with which the second round-second panel experts agreed on. In accordance with the pre-defined technologies, a table was created to categorize them according to design criteria and technological factors associated with each criterion. Seven criteria and factors associated with each criterion along with their limiting values on the measure of effectiveness were finalized.

4.3 Technology assessment

In this step, emerging technologies are assessed based on the measures of effectiveness. The experts are asked to provide the values of the measures of effectiveness of each emerging technology with which they are familiar according to the technological factors.

Experts were asked to provide estimates for the technologies of their expertise indicating the future development of the technology using the factors that were sent to them as a "Powertrain Technology Evaluation" document, taking a Euro 4 level, 1,9 Gasoline Engine Light Commercial Vehicle as reference. Reference values and the evaluation of an expert are given in Table 3. Experts used the reference values and were asked to fill out the form in accordance with them.

4.4 Hierarchical modeling

A generalized hierarchical model can be constructed with a four-level hierarchy: objective, criteria, factors, and technologies. This model represents the hierarchical structure in which the relative contributions of technologies to the objective are calculated by determining the priorities of the criteria, the relative importance of factors on each criterion, and the relative impact of technologies on each factor.

However, this approach poses two disadvantages. First, the judgment quantification approach becomes very difficult when the number of technologies increases. Second, the whole series of comparative judgments need to be repeatedly quantified every time a new technology is added to the list.

To overcome these difficulties, a composite index called "technology value" is developed to quantify the impact of each technology on the objective based on the semi-absolute values instead of the relative values.

With the new approach of quantifying the technology value, the generalized model has to be transformed to an operational model by replacing the technologies with their measures of effectiveness as shown in Fig. 1. Set of measures of effectiveness (metrics) is defined for each technological factor so that the performance and physical characteristics of emerging technologies could be directly evaluated. The impact relationships of measures of effectiveness associated with each factor are determined through the quantification of judgments for the desirability of each measure of effectiveness.

Table 3 Powertrain technology evaluation example

Criteria	Factors	Units	Reference Vehicle - 1,9 L. EURO 4 Gasoline Engine		DIESEL ENGINE + CVT +COMMON RAIL (1800 BAR) + TC + SCR + DPF		
			2009	Comments	2009-2015	2015-2025	2025--
C1:Cost Effectiveness	F11: Vehicle cost (additional)	$	21.000	A conventional light duty SI vehicle price	7.000	4.000	2.000
	F21: Maintenance cost	% of capital cost	2		5	4	3
C2: Performance	F12: System efficiency	%	14	Well-to-wheel efficiency	15	16	17
	F22: Peak power output	kW	95		100	110	125
	F32: System control technologies	5 pt scale	E		G	VG	E
	F42: Power density	kW/l	75		75	78	80
	F52: Additional weight	kg	1.400	A conventional light duty vehicle weight	50	20	10
	F62: Durability	km	100.000	Euro 4 stage	100.000	160.000	200.000
C3: Emissions	F13: NOx	g/km	0,1	N_1, Class II, Euro 4 stage	0,22	0,15	0,05
	F23: PM	g/km	0	N_1, Class II, Euro 4 stage (not available)	0,005	0,005	0,003
	F33: HC	g/km	0,13	N_1, Class II, Euro 4 stage	0,003	0,002	0,001
	F43: CO	g/km	1,81	N_1, Class II, Euro 4 stage	0,63	0,55	0,4
C4: Fuel Consumption	F14: Fuel consumption	l/100 km	10	An average light duty vehicle fuel consumption	9	7,5	6
	F24: CO_2 emissions	gCO_2/km	263	An average light duty vehicle CO_2 emissions	238	198	159
C5: Fuel Specifications	F15: Fuel availability	5 pt scale	E	Fuel is available everywhere for every vehicle	E	E	VG
	F25: Fuel infrastructure cost	billion $	0	No further infrastructure is required	0	0	0
	F35: Energy density by mass	MJ/kg	43	Regular gasoline	42	42	42
C6: System Evaluation	F16: Materials availability	5 pt scale	E		E	E	E
	F26: Components availability	5 pt scale	E		VG	E	E
	F36: Technology dev. state	5 pt scale	A		VG	G	P
	F46: Regulations/legal framework	5 pt scale	E		E	E	E
	F56: Complexity	5 pt scale	VG		G	VG	E
	F66: System safety	5 pt scale	G		VG	E	E
C7: Market	F17: Availability of vehicles	5 pt scale	E		A	VG	E
	F27: Sales volume	%	45	Sales of gasoline vehicles were %45 of total LCVs	2	4	10

4.5 Mathematical modeling

(1) Measurement 1- Criteria Evaluation

This step shows the determination of [w_k], the relative priority of criteria (k) with respect to objective. The values representing comparative judgment on each pair of criteria were obtained from each expert to determine the relative priority of the seven criteria, according to Equation (1) below:

$$\sum_{k=1}^{K} w_k = 1.0 \text{, where } w_k > 0 \qquad (1)$$

(2) Measurement 2 - Factors Evaluation

This step shows the determination of [$f_{j_k,k}$], the relative impact of factors (f_k) associated with each criterion (k), in accordance with the Equation (2) below:

$$\sum_{j_k=1}^{J_k} f_{j_k,k} = 1.0 \quad \text{where, } f_{j_k,k} > 0 \qquad (2)$$

The values representing comparative judgments on the set of factors associated with each criterion were obtained from all the experts. The relative importance of the factors with respect to the criterion, which they are associated with, was calculated by following the same approach as Measurement 1 above.

(3) Measurement 3 – Relative Desirability of Measures of Effectiveness

This step shows the determination of [$V(m_{j_k,k})$], the relative desirability of measures of effectiveness (metrics) under each combination of factor [j_k] and criterion [k]. Resent his/her judgment on the relative desirability of each measure of effectiveness as a ratio of the desirability of the "best" limiting metric. The mean values were calculated among the relative values given by each expert to represent the group decision. As a result, 25 desirability curves were developed.

Figure 2 shows some examples of desirability curves developed for vehicle cost, maintenance cost, system efficiency and peak power output.

(4) Measurement 4 – Mapping Metrics

This step includes the mapping of technological metrics [$t_{n,j_k,k}$] to the desirability values [$V(t_{n,j_k,k})$] using the relative desirability value of measures of effectiveness [$V(m_{j_k,k})$] resulting from Measurement 3 as presented in Table 4.

(5) Measurement 5 – Quantification of Technology Value

The technology value is calculated through matrix computations among the criteria priorities (Measurement 1), the relative importance of factors on each criterion (Measurement 2), and the desirability value of technologies for each factor (Measurement 4), by applying Equation 1.

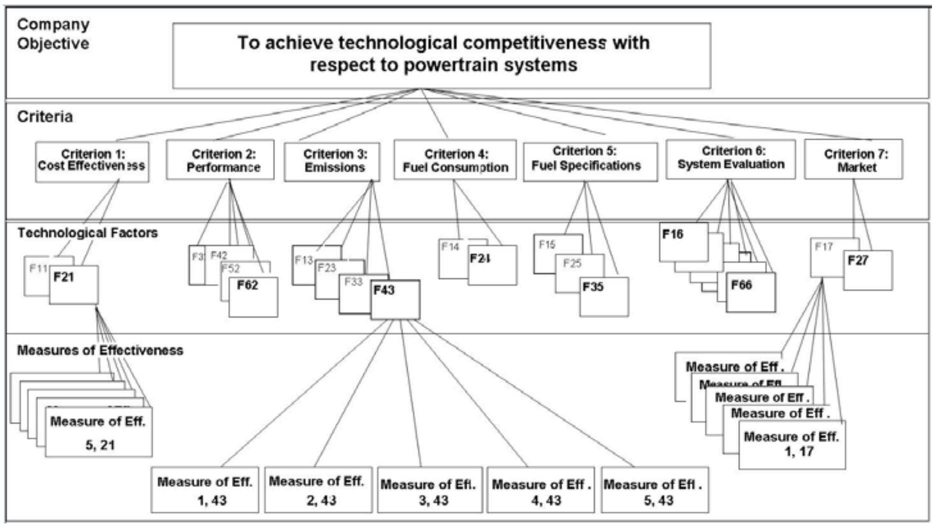

Fig.1 The hierarchical model developed for evaluating technologies

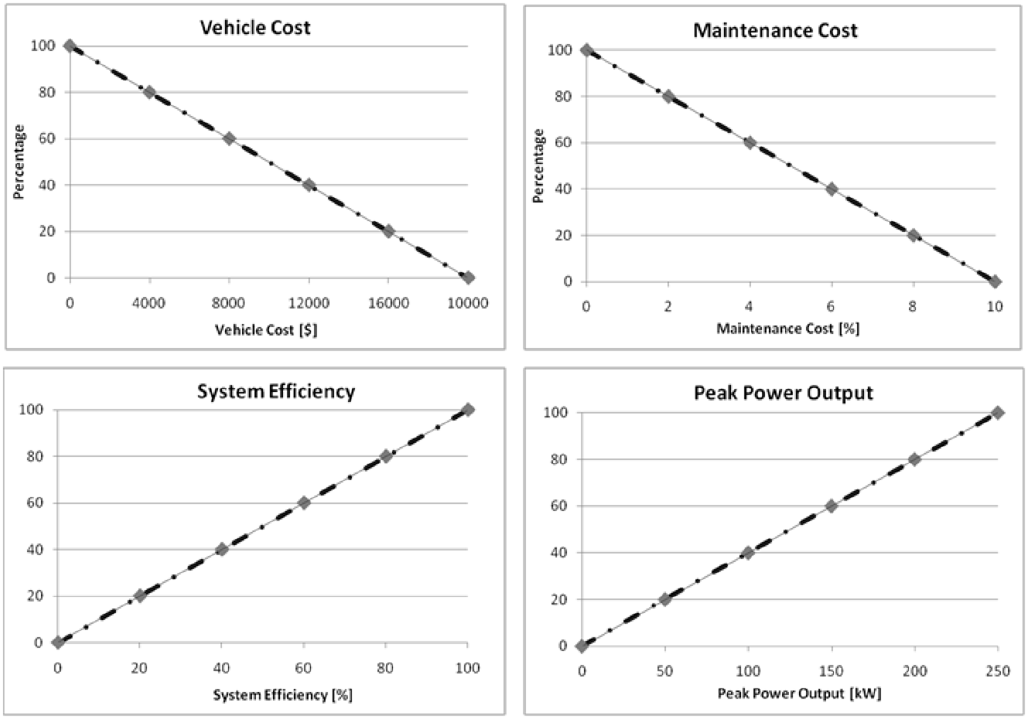

Fig. 2 Desirability curves

Table 5 shows the calculation of the technology value for Technology 1, the future diesel engine system. The table 6 represents all the results derived from all the calculations.

The outcomes are the technology values of emerging technologies according to a company's objective. The ideal technology from a company's point of view would represent the technology value of 100. (Fig. 3)

The path linking technologies that have the highest impact on a company's objective in each time period is called the Technology Development Envelope (TDE). The connection of one technology to the next results in the technology develop path. The path connecting the technology, which has the strongest impact value on the objective, is called the TDE. If the development of technologies follows the TDE, the technological benefits to company from the development would be maximized. Fig. 4 shows alternative paths of technologies for Ford Otosan.

Table 4 Metrics and desirability values estimated for 2009–2015

Criteria	Factors	Units	Technological Metrics						Desirability Values					
			T1	T2	T3	T4	T5	T6	T1	T2	T3	T4	T5	T6
C1: Cost Effectiveness	F11: Vehicle cost (additional)	$	7.000	6.000	19.000	17.000	9.500	39.500	82,50	85,00	52,50	57,50	76,25	1,25
	F21: Maintenance cost	% of capital cost	5	7	9	8	5	6	50,00	30,00	10,00	20,00	46,67	40,00
C2: Performance	F12: System efficiency	%	15	15	45	30	21	22	15,00	15,00	45,00	30,00	20,50	22,00
	F22: Peak power output	kW	125	120	100	120	118	75	50,00	48,00	40,00	48,00	47,00	30,00
	F32: System control technologies	5 pt scale	VG	A	A	G	VG	A	80,00	40,00	40,00	60,00	80,00	40,00
	F42: Power density	kW/l	75	80	80	90	108	69	30,00	32,00	32,00	36,00	43,00	27,60
	F52: Additional weight	kg	50	50	200	210	275	325	90,00	90,00	60,00	58,00	45,00	35,00
	F62: Durability	km	100.000	100.000	80.000	80.000	100.000	125.000	40,00	40,00	32,00	32,00	40,00	50,00
C3: Emissions	F13: NOx	g/km	0,220	0,100	0,290	0,150	0,133	0,000	26,67	66,67	3,33	50,00	55,56	100,00
	F23: PM	g/km	0,005	0,005	0,000	0,005	0,017	0,000	95,00	95,00	100,00	95,00	82,67	100,00
	F33: HC	g/km	0,003	0,130	0,380	0,040	0,035	0,000	99,25	67,50	5,00	90,00	91,17	100,00
	F43: CO	g/km	0,630	1,810	1,100	0,001	0,710	0,000	68,50	9,50	45,00	99,95	64,50	100,00
C4: Fuel Consumption	F14: Fuel consumption	l/100 km	9	9	5	11	5	5	40,00	40,00	70,00	26,67	65,00	68,33
	F24: CO2 emissions	gCO2/km	238	238	140	1	143	0	20,67	20,67	53,33	99,71	52,33	100,00
C5: Fuel Specifications	F15: Fuel availability	5 pt scale	E	E	A	UA	E	UA	100,00	100,00	25,00	0,00	100,00	0,00
	F25: Fuel infrastructure cost	billion $	0	0	0	100	0	10	100,00	100,00	100,00	90,00	100,00	99,00
	F35: Energy density by mass	MJ/kg	42	42	46	120	42	120	28,00	28,00	30,80	80,00	28,00	80,00
C6: System Availability	F16: Materials availability	5 pt scale	E	E	G	VG	G	P	100,00	100,00	60,00	80,00	60,00	20,00
	F26: Components availability	5 pt scale	G	VG	G	A	A	UA	60,00	80,00	60,00	40,00	40,00	0,00
	F36: Technology development state	5 pt scale	VG	VG	VG	E	E	E	80,00	80,00	80,00	100,00	100,00	100,00
	F46: Regulations /incentives	5 pt scale	G	G	E	E	E	E	60,00	60,00	100,00	100,00	100,00	100,00
	F56: Complexity	5 pt scale	G	A	VG	VG	G	UA	60,00	40,00	80,00	80,00	60,00	0,00
	F66: System safety	5 pt scale	VG	VG	VG	VG	VG	A	80,00	80,00	80,00	80,00	80,00	40,00
C7: Market	F17: Availability of vehicles	5 pt scale	A	P	A	P	A	UA	40,00	20,00	40,00	20,00	40,00	0,00
	F27: Sales volume	%	10	3	1	1	5	1	10,00	3,00	0,50	1,00	4,67	0,75

Table 5 Calculation of the technology value of Technology 1 for 2009-2015

Criterion		Factors			Desirability Value	Technology Value
C1: Cost effectiveness	(0,22)	F11	(0,70)	$V(t_{1,11})$	(82,50)	12,71
		F21	(0,30)	$V(t_{1,21})$	(50,00)	3,30
C2: Performance	(0,21)	F12	(0,21)	$V(t_{1,12})$	(15,00)	0,66
		F22	(0,20)	$V(t_{1,22})$	(50,00)	2,10
		F32	(0,12)	$V(t_{1,32})$	(80,00)	2,02
		F42	(0,16)	$V(t_{1,42})$	(30,00)	1,01
		F52	(0,13)	$V(t_{1,52})$	(90,00)	2,46
		F62	(0,18)	$V(t_{1,62})$	(40,00)	1,51
C3: Emissions	(0,14)	F13	(0,32)	$V(t_{1,13})$	(26,67)	1,19
		F23	(0,32)	$V(t_{1,23})$	(95,00)	4,26
		F33	(0,19)	$V(t_{1,33})$	(99,25)	2,64
		F43	(0,17)	$V(t_{1,43})$	(68,50)	1,63
C4: Fuel Consumption	(0,23)	F14	(0,53)	$V(t_{1,14})$	(40,00)	4,88
		F24	(0,47)	$V(t_{1,24})$	(20,67)	2,23
C5: Fuel Specifications	(0,05)	F15	(0,37)	$V(t_{1,15})$	(100,00)	1,85
		F25	(0,45)	$V(t_{1,25})$	(100,00)	2,25
		F35	(0,18)	$V(t_{1,35})$	(28,00)	0,26
C6: System Evaluation	(0,08)	F16	(0,09)	$V(t_{1,16})$	(100,00)	0,72
		F26	(0,26)	$V(t_{1,26})$	(80,00)	1,25
		F36	(0,09)	$V(t_{1,36})$	(80,00)	0,58
		F46	(0,09)	$V(t_{1,46})$	(60,00)	0,43
		F56	(0,15)	$V(t_{1,56})$	(60,00)	0,72
		F66	(0,32)	$V(t_{1,66})$	(80,00)	2,05
C7: Market	(0,07)	F17	(0,59)	$V(t_{1,17})$	(40,00)	1,65
		F27	(0,41)	$V(t_{1,27})$	(10,00)	0,29
						Sum 54,63

Table 6 Technology values for all technologies for each time period

	2009-2015	2015-2025	2025-
T1	54,63	65,33	70,80
T2	51,36	61,75	63,14
T3	48,12	58,21	65,77
T4	53,80	63,31	67,54
T5	59,25	69,14	77,60
T6	48,57	67,22	79,48

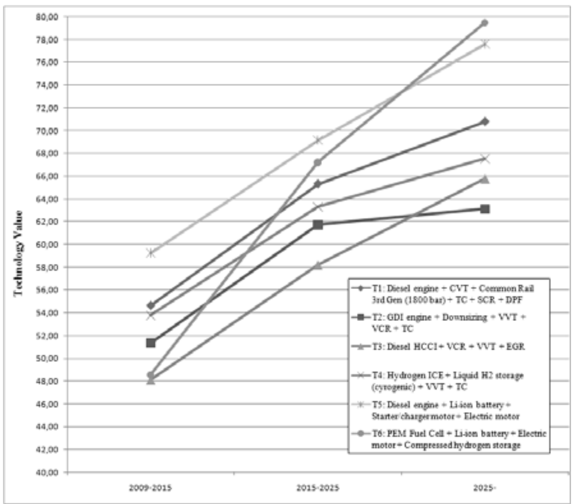

Fig.3 Evaluation of all technologies

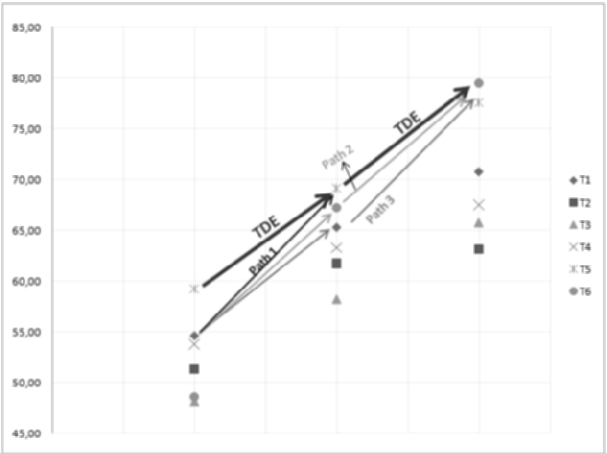

Fig. 4 Formation of TDE for Ford Otosan

A comparison of the technology values of six different technology alternatives indicates that GDI technology will no longer be satisfying the Company's objective. The company should follow paths as summarized in Table 7.

Table 7 The TDE paths to maximize technological benefits

TDE Paths				
T5	➡	T5	➡	T6
T1	➡	T5	➡	T6
T1	➡	T6	➡	T6
T1	➡	T1	➡	T6

5 Conclusions

This study represents a robust quantitative model for evaluating the impact on current and emerging technologies on a company's objective. A methodology, named as "Technology Development Envelope", has been applied to a company, and with respect to its objective, several powertrain technologies are investigated.

Six technologies are selected; two currently dominant technologies, Diesel and Gasoline engines, two in development phase, HCCI and Hydrogen ICE engines and finally two require to overcome some bottlenecks before a large scale market introduction, Battery Hybrid and Fuel Cell.

Seven criteria and 25 factors associated with these criteria are selected to assess these technologies. Each step has been conducted with the imputs from experts, as a requirement of the Delphi method. All the imputs were gathered together and evaluated with respect to the methodology's mathematical model. Each technological metrics were calculated into desirability values and the total of these values constitutes technology values for each technology. Once the technology value is known, then the technology can readily be incorporated into the model and compare with all other available and emerging technologies. The change of the values for each time periods shows the state of development for each technology.

Currently, Battery Hybrid and Diesel technologies are considered to be the closest to be the ideal technologies according to the company's preference. However, in the upcoming decades, Fuel Cell technology makes an impressive progress and becomes the dominant technology after 2025.

References

[1] World Energy Outlook 2007 Edition, 2007 IEA/OECD Publications, Paris.

[2] King H M. Nuclear energy and the fossil fuels drilling and production practice. API, 1956, Retrieved on 2008-04-18.

[3] Brandt A R. Testing hubbert. Energy Policy, 2007, 35(5): 3074–3088.

[4] Oreskes N. Beyond the ivory tower: The scientific consensus on climate change, 2004, 306(5702): 1686 – Science.

[5] http://groups-beta.google.com/group/sci.environment/msg/aa8521b67cd216acb? dmode=source, Retrieved on 2008-11-25.

[6] Solomon S, Qin D, Manning M, et al. IPCC Fourth Assessment Report, Working Group I Report: The Physical Science Basis. 2007, Cambridge Press, New York.

[7] Gaynor G H. Handbook of technology management. 1996 McGraw-Hill, New York.

[8] Anonymous. Co-operative technology roadmapping. 2003, TU Delft, http://www.strategie-vsb.nl/pdf/1.pdf, Retrieved on 2008-05-07.

[9] Phaal R, Farrukh C J P, Probert D R. Characterisation of technology roadmaps: purpose and format, Technology Management for Global Economic Growth, Eds Kocaoglu DF and Anderson TR, 2001, IEEE, Piscataway NJ, 367–374.

[10] Daim T U and Oliver T. Implementing technology roadmap process in the energy services sector: A case study of a government agency. Technological Forecasting and Social Change, 2008, 75(5): 687–720.

[11] Phaal R, Farrukh Clare J P, Probert David R. Technology roadmapping-A planning framework for evolution and revolution, Technological Forecasting and Social Change, Roadmapping: From Sustainable to Disruptive Technologies, January-February 2004,71(1-2): 5–26.

[12] Petrick I J, Echols A E. Technology roadmapping in review: A tool for making sustainable new product development decisions. Technological Forecasting and Social Change. 2004, 71: 81–100.

[13] Phaal R, Farrukh C, Mitchell R, et al. Starting-up roadmapping fast. Research-Technology Management, 2003, 42(2): 52–58.

[14] Phaal R, Shehabuddeen N T M H, Assakul P. Technology roadmapping: Charting the route ahead for UK road transport, IEEE International Engineering Management Conference, 2002. IEMC'02. 2002, 18-20 Aug. 2002, 2: 794–798

[15] Prem H, Srinivasa Raghavan N R. Building a technology roadmap in high performance computing in the Indian context. Proceedings of the Portland International Conference on Management of Engineering and Technology, 2005

[16] Rinne M, Technology roadmaps: Infrastructure for innovation. Technological Forecasting and Social Change. Roadmapping: From Sustainable to Disruptive Technologies, 2004, 71(1-2): 67–80.

[17] Fenwick D, Daim T U, Gerdsri N. Value driven technology Road mapping (VTRM) process integrating decision making and marketing tools: Case of Internet security technologies. Technological Forecasting and Social Change, 2009, 76(8): 1055–1077.

[18] Gerdsri N, Assakul P, Vatananan R S. An activity guideline for technology roadmapping implementation. Technology Analysis & Strategic Management, 2010, 22(2): 229–242.

[19] Gerdsri N, Vatananan R S, Dansamasatid S. Dealing with the dynamics of technology roadmapping implementation: A case study. Technological Forecasting and Social Change, 2009, 76(1): 50–60.

[20] Kostoff R N, Schaller R R. Science and technology roadmaps. IEEE Transaction on Engineering Management, 2001, 48(2): 132–143.

[21] Productive Nanosystems. A Technology Roadmap. DE-AC05-00OR22725, U.S. Department of Energy, 2007.

[22] Skulmoski G J, Hartman F T, Krahn J. The delphi method for graduate research. Journal of Information Technology Education, 2007, 6.

[23] Costa C A. Future of sport management research: A delphi study. Digital Abstracts International, 2000, 61 (11): 4332.

[24] Linstone H, Turloff M. The delphi method: Techniques and applications. London, UK, Addison-Wesley, 1975, http://www.is.njit.edu/pubs/delphibook/, Retrieved on 2008-10-05.

[25] Laughlin D, Roper M. NASA eEducation roadmap: Research challenges in the design of massively multiplayer games for education & training. NASA eEducation, 2007.

[26] Chen D C, Kameoka A, Toyama R. 2005 How Taiwan fabless firms use technology roadmap in product development: A preliminary study. Proceedings of the Portland International Conference on Management of Engineering and Technology, 2005.

[27] Richey J M, Grinnell M. Evolution of roadmapping at Motorola. Research Technology Management, March-April 2004, 47(2): 37–41.

[28] Walsh S T. Roadmapping a disruptive technology: A case study the emerging microsystem and top-down nanosystems industry. Technological Forecasting & Social Change, 2004, 71: 161–185.

[29] Phaal R. Foresight vehicle technology roadmap-technology and research directions for future road vehicles. London: UK Department of Trade and Industry, URN 02/933, version 2, 2004, www.foresightvehicle.org.uk, Retrieved on 2008-08-17.

[30] Gerdsri N. An analytical approach on building a technology development envelope (TDE) for roadmapping of emerging technologies. Technology Management: A Unifying Discipline for Melting Boundaries, Eds Anderson TR, Daim TU, Kocaoglu 2005, DF, IEEE, Piscataway NJ, 123–135.

[31] Gerdsri N, Kocaoglu D F. An analytical approach on building a technology development envelope (TDE) for roadmapping of emerging technologies: A case study of emerging electronic cooling technologies for computer servers. Technology Management for Reshaping the World, Eds Kocaoglu DF and Anderson TR, 2003, IEEE, Piscataway NJ, 380-387.

[32] Gerdsri N, An analytical approach to building a technology development envelope (TDE) for roadmapping of emerging technologies. International Journal of Innovation & Technology Management, 2007, 4, 121–135.

[33] Pischinger S, Lang O, Kemper H. System comparison of hybrid and fuel cell systems to internal combustion engines. SAE Paper 2002-21-0070.

[34] Atkins M J, Koch C R. A well-to-wheel comparison of several powertrain technologies. SAE Paper 2003-01-0081.

[35] An F, Santini D. Assessing tank-to-wheel efficiencies of advanced technology vehicles. SAE Paper 2003-01-0412.

[36] Rousseau A, Sherer P. Comparing apples to apples: Well-to-wheel analysis of current ICE and fuel cell vehicle technologies. SAE Paper 2004-01-1015.

[37] Pischinger, et al. Future of combustion engines. SAE Paper 2006-21-0024.

[38] Eberhardt J J. Fuels of the future for cars and trucks. 2002 Diesel Engine Emissions Reduction (DEER) Workshop, California, San Diego. 2002.

[39] Kockan I, Daim T, Gerdsri N. Roadmapping future powertrain technologies: A case study of ford otosan. International Journal of Technology, Policy and Management, 2010, 10(1–2): 157–184.