

## 연료전지 차량의 전기 안전성 규제안 작성 방법론

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## Rulemaking Process of Electrical Safety Regulation for Fuel Cell Vehicles

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### ABSTRACT

본 논문에서는 전기자동차의 고전압 시스템의 안전성을 확보하기 위한 법규 규제안 생성 방법을 제시하였다. 법규가 기술적으로 모든 영역을 빠뜨리지 않고 정의하고 있는지를 파악하기 위한 방법으로 법규분포분석법(Regulation Distribution Analysis Method)과 법규완전도분석법(Regulation Completeness Analysis Method)을 제시하였다.

자동차 설계와 생산에 있어서 법규/규제는 중요한 이슈가 되고 있다. 원칙적으로 법규는 자동차 승객과 환경을 보호하는 목적으로 생성되고, 이윤 추구 중심의 시장에서 놓칠 수 있는 기술적 항목들을 규제할 수 있도록 한다. 매연 배출 정도, 매연 모니터링 시스템, 전기 안전성과 같은 항목이 그 예이며, 향후 연료전지자동차 양산을 앞두고는 고전압 안전성과 관련된 규제 또한 필요하게 될 것으로 파악된다. 그러나 규제 항목에서 미정의된 부분이 있는지를 확인하는 체계적인 방법이 없어 본 논문에서는 기술적인 파라미터를 중심으로 규제항목을 검토하는 방법론을 제시하였다.

**KEY WORDS** : Electrical safety(전기 안전성), Fuel cell vehicles(연료 전지차), FMVSS 305, Safety regulation(안전 법규), Regulation distribution analysis method(법규분포분석법), Regulation completeness analysis method(법규완전도분석법)

### 1. Introduction

Compliance to regulations becomes an important issue while designing and manufacturing vehicles. Vehicle related regulations are generated in order to assure the safety of passengers and pedestrians,

and to keep environment from pollutions, which could not be guaranteed in cost driven market. Most of the electronic system characteristics in vehicles are affected by regulations such as emission of the engines, accuracy of the monitoring systems, brightness and angle of the lightings.

In this paper, we are proposing Regulation Dis-

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tribution Analysis Method (RDAM) and Regulation Completeness Analysis Method (RCAM) for checking and revising regulation items during rule-making process.

In RDAM, we proposed how to check the coverage area of regulation items and whether they cover the whole area that needs to be considered. In RCAM, we proposed how to check the completeness of a regulation item using set concept. We introduced these two methodologies with examples to ensure their applicability to existing regulations for electrical vehicle safety such as FMVSS 305<sup>1)</sup>, R101<sup>2)</sup>, A1003).

Researches on hydrogen related safety regulation were conducted for hydrogen generation facility<sup>4)</sup> or hydrogen station<sup>5)</sup>. While their work focused on analyzing and proposing a criteria for a specific safety situation, our work focuses on checking regulation items whether they covers all possible safety related situations.

Figure 1 shows proposing rule making concept. Draft regulation items are brainstormed by multiple individuals and collected in a regulation item pool. Then, the items are reviewed and analyzed by Regulation Distribution Analysis Method (RDAM) and Regulation Completeness Analysis Method

(RCAM). Missing areas and conditions are found during these process and new regulation items derived that can compensate the missing area and conditions. Derived new regulation items are added to the regulation item pool.

This research was conducted while we were generating safety rules for high-voltage system in Fuel Cell Vehicles. We found the necessity to find methodologies to brainstorm, check, and revise regulation items that covers all possible safety situations.

Proposed methods can be applied to other rule making process and will be highly effective if the system in interest can be characterized and decomposed logically and quantitatively.

## 2. Regulation Distribution Analysis Method (Rdam)

The basic idea of RDAM is to distribute every regulation item into a distribution graph and search areas where regulation items are not filled. Figure 2 shows the concept of RDAM. Items in the regulation item pool are distributed into distribution graph. The distribution graph is composed of two axes which are selected during the analysis process. The density of the distributions is analyzed and empty or low density areas are marked. If the marked areas do not have proper reasons,

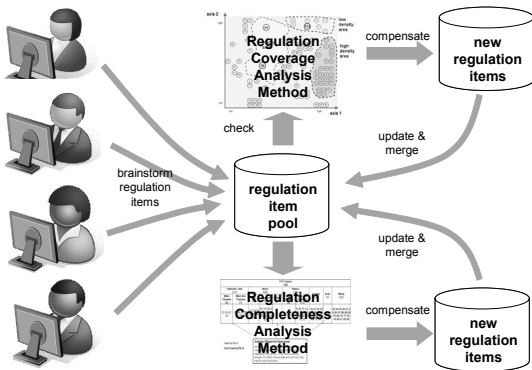


Fig. 1 Proposed rule making concept

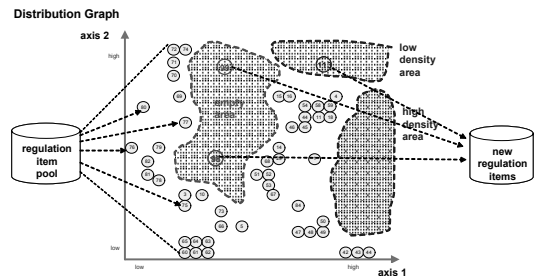


Fig. 2 Concept of regulation distribution analysis method

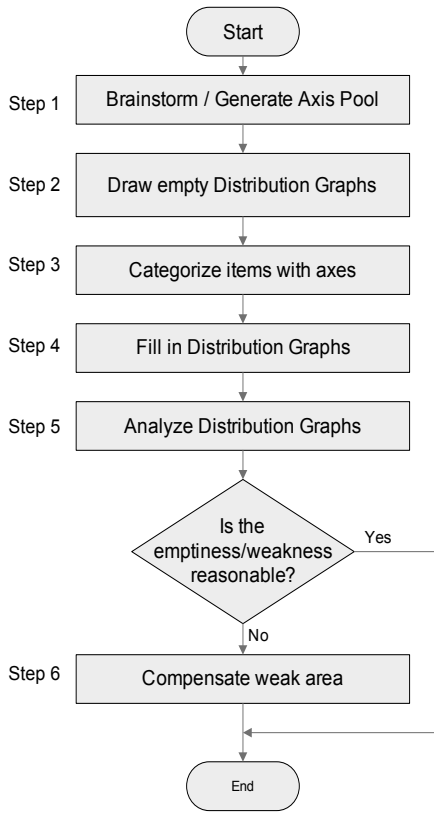


Fig. 3 Procedure for regulation distribution analysis method

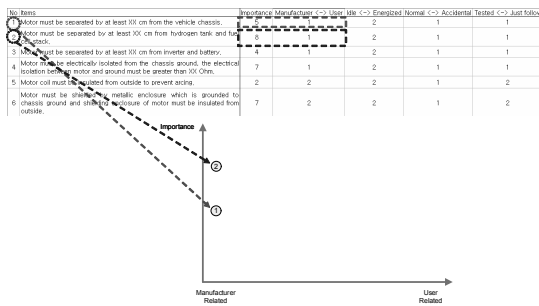


Fig. 4 Process of filling regulation items into distribution graph

additional regulation item are generated in those areas and filled into the regulation item pool.

The procedure for RDAM is described in Fig 3. First step is to brainstorm and generate the axes for analysis. Example of axes can be speed

of vehicle, electric current, relevance to driver, and development stages.

Second step is to draw empty distribution graphs. An empty distribution graph can be drawn by choosing two axes generated in the first step and drawing a two dimensional plane.

Third step is to categorize regulation items for each axis for the distribution graph. If we have chosen vehicle speed as the axis, we can categorize the regulation items according to the speed of the vehicle.

Fourth step is to fill the Distribution Graphs with categorized regulation items. By this step we can visualize the distribution of regulation items.

Fifth step is to analyze distribution graph and find weak areas. Some areas in the distribution graph might be empty and we can find the reason for the empty area. If an empty area has proper reason, we can ignore that area. Otherwise that empty area needs to be filled up with additional regulation items.

Sixth step is to compensate the weak area found in fifth step. The empty or low density area can be filled up with additional regulation items deducted from existing regulation items.

Explanation for each step is given in detail with examples in the following three sections.

## 2.1 Generate Axis pool & Categorize Regulation Items

Brainstorming axis is an important to step to ensure full coverage of inspection area. The axes found in the step forms the basis of the following steps. Every characteristic of the system in interested needs to be considered during this process.

After brainstorming all possible axes in the form of an axis pool, every regulation item can be assigned a value for each axis. Figure 4 shows an excel file where the regulation items on the

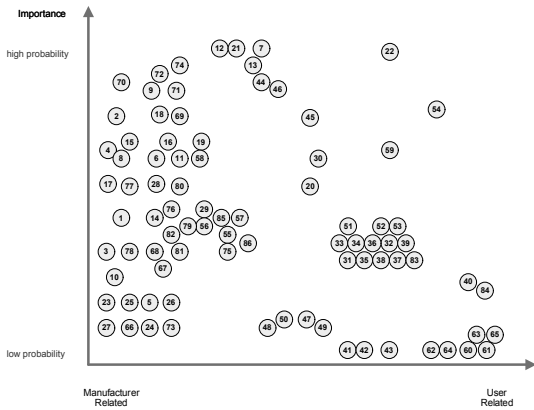


Fig. 5 Distributed regulation items

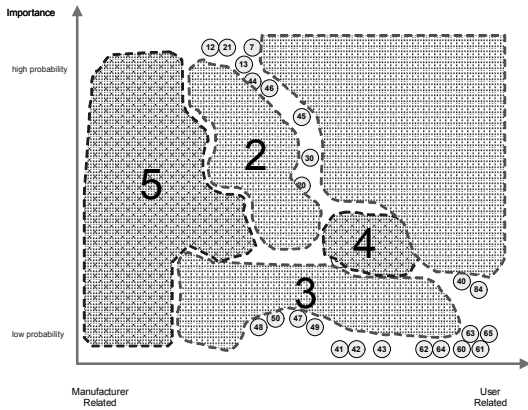


Fig. 6 Analyzed distribution graph

row are assigned with values for each axis on the column.

We can generate empty distribution graph combining two axes out of the axis pool. The axes are chosen in a way that every area in the distribution graph can have a significant meaning. For example, if the axes were chosen to be vehicle load and electric current, then regulation items related to low vehicle load and low electric current, high vehicle load and low electric current, low vehicle load and high electric current, high vehicle load and high electric current should have signifi-

cant meaning from which the distribution regulation item can be checked.

## 2.2 Draw Distribution Graph

Figure 4 shows the process of filling regulation items into the distribution graph. The regulation items in the Excel file are already assigned with values for each axis and empty distribution graphs are generated by combining two axes.

Numbers are assigned to every regulation item and assigned numbers are put into distribution graph with positions determined by the value of each axis. For example, as depicted in Figure 4, regulation item “High voltage cores must be separated by at least XX mm from chassis ground” is assigned with number 1, and has value 5 for Y-axis representing possibility of accidental situation when violated, and value 1 for X-axis representing relativity of manufacturer or user (smaller number represent more relation to manufacture). This regulation item is put to position (1, 5) in the distribution graph with number 1. Figure 5 shows the distribution graph filled up with all regulation items.

## 2.3 Compensate Weak Area

After filling the distribution graph, analysis is performed to derive significant meaning. High density area where many regulation items exist, low density area where small number of regulation items exist, and empty area where no regulation item exists can be identified.

Figure 6 shows an example of the analyzed distribution graph. We can identify area 2 and area 3 as empty, area 1 as low density, and area 4 and area 5 as high density. If the reason for the emptiness of weak area (low density and empty area) can not be explained, the area needs to be

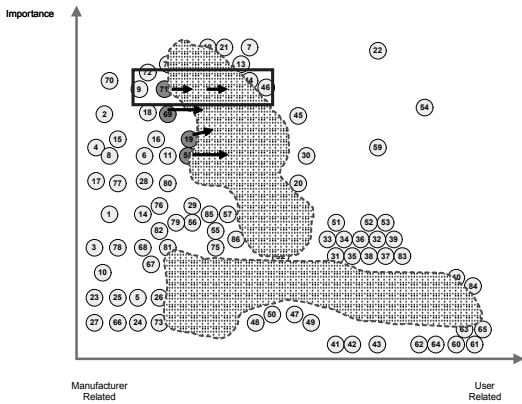


Fig. 7 Example of generating new regulation items on the distribution graph

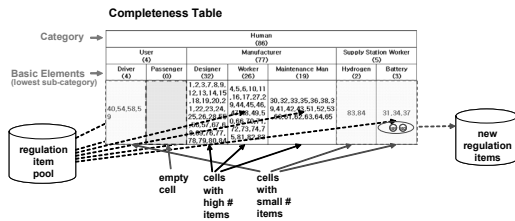


Fig. 8 Concept of regulation completeness analysis method

filled with proper regulation items.

Compensating weak area in the distribution graph can be done by inferring new regulation items from adjacent regulation items. For example, in figure 7, regulation items 95 and 99 are inferred from regulation item 71. Regulation item 71 means “Battery should be designed to work normally (Voltage maintains at xx V - xx V, Energy xx W - xx W, temperature under xx C) longer than xx hours)” By inferring regulation items which is more related to user, new regulation item can be generated located to the left side the original regulation item.

Examples can be item 95 with “Every battery should be diagnosed before released to market. Battery should work normally as specified in regulation item 71.” This regulation is more related

to user because it is related to the market rather than the manufacturing site for design process. Another example can be item 99 with “10 Year warranty should be guaranteed by manufacturer to the customer. Any case when the normal work condition of item 71 is not satisfied, battery should be replaced free of charge.” which is more related to user because this regulation is related to warranty or after market.

Applying the approaches and procedures proposed in RDAM can generate more complete regulation whose items are covering all possible situations.

### 3. Regulation Completeness Analysis Method

Figure 8 shows the concept of RCAM. Each item in the regulation pool is distributed into completeness table to verify the completeness of the regulation. Completeness table is made for every category which is related to system in interest. For each category, subsets are divided into tree structure in a way that in each level the subsets become mutually exclusive and complete (exhaustive). By grouping regulation items to each subset, we can see which subset is weak or empty and needs to be filled with additional regulations.

Figure 9 shows proposed procedure for RCAM. First step is to brainstorm and generate categories which are going to be divided into subsets. The categories can be selected from given set or newly brainstormed from existing regulations. Second step is to draw empty Completeness Table. Each category is divided into complete subsets at this step. Third step is to categorize regulation times according to subsets for each category. Forth step is to fill the completeness table with regulation items. Fifth step to find empty or weak subset and analyze whether emptiness or weakness

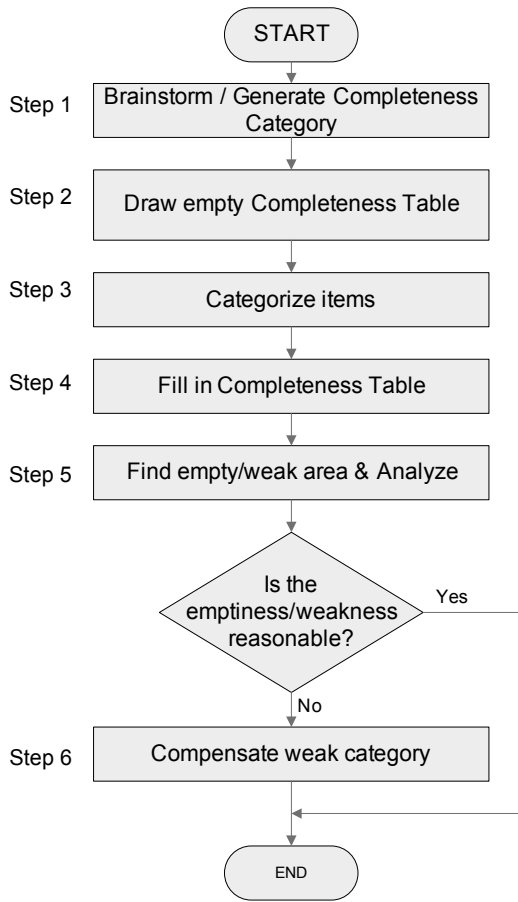


Fig. 9 Procedure for regulation completeness analysis method

	Human						
	User		Manufacturer			Supply Station Worker	
	Driver	Passenger	Designer	Worker	Maintenance Man	Hydrogen	Battery
40			1, 2, 3, 7, 8, 9, 12, 13, 14, 15, 18, 19, 20, 2, 1, 22, 23, 24, 25, 26, 28	4, 5, 6, 10, 11, 16, 17, 27, 2, 9,	30, 32, 33, 35, 36, 38, 3, 9, 41		31, 34, 37

Fig. 10 Process of filling regulation items into completeness table

is reasonable. If they are not reasonable, new regulation items need to be brainstormed and added in the sixth step.

### 3.1 Generate Completeness Category and Draw Completeness Table

Completeness Table is generated by filling the subset cell with regulation items. Before filling the cells, each regulation item needs to be assigned with sequential numbers and categorized to certain subset as the excel file in figure 10. Then each subset of completeness table can be filled up with assigned numbers of regulation items.

For example, as regulation item 40 is categorized to user in human category, the number 40 is put to the cell below the user category. As regulation item 41 is categorized as maintenance man, the number 41 is put below the maintenance man category.

Similar procedure can be repeated for all regulation items and the completeness table will be filled up. With the filled up completeness table, analysis can be performed to find weak subsets.

### 3.2 Analyze Completeness Table and Compensate Weak Subset

After filling the completeness table, analysis can be performed to find out the whether the regulation is complete in the given category. Any subcategory which does not have any or few regulation items needs to be explained with proper reason. Otherwise additional regulation items need to be generated.

Figure 11 shows an example of the filled in completeness table. We can identify the subcategories of driver, passage, and supply station worker need to be explained or filled in. For passenger subcategory, it can be left empty because there is little chance that passengers can access to high voltage systems of electrical vehicles. However for the driver and supply station worker subcategories, there are few regulation items and more regulation items need to be added.

Human (86)						
User (4)		Manufacturer (77)			Supply Station Worker (5)	
Driver (4)	Passenger (0)	Designer (32)	Worker (26)	Maintenance Man (19)	Hydrogen (2)	Battery (3)
40,54,58,59		1,2,3,7,8,9,12,13,14,15,18,19,20,21,22,23,24,25,26,28,55,56,57,67,68,69,76,77,78,79,80,84	4,5,6,10,11,16,17,27,29,44,45,46,47,48,49,50,66,70,71,72,73,74,75,81,82,83	30,32,33,35,36,38,39,41,42,43,51,52,53,60,61,62,63,64,65	83,84	31,34,37

**No need to add more items**

Passenger does not need to follow any regulation

**More Items need to be added**

Hydrogen and battery supply station workers need more regulations to prevent FCV high voltage accidents

Fig. 11 Process Of Filling Regulation Items Into Completeness Table

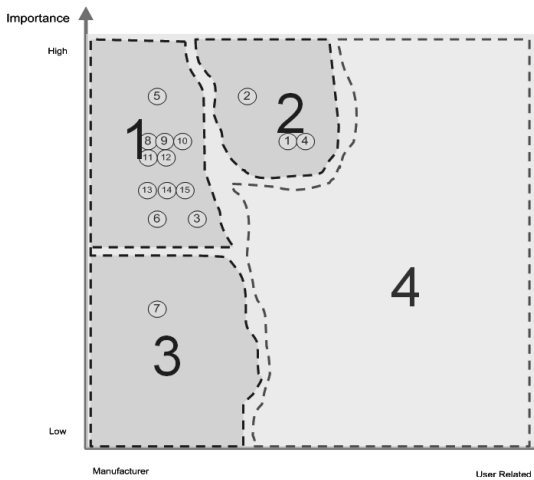


Fig. 12 Distribution Graph Of Fmvss 305

### 4. Application to Fmvss 305

The purpose of the analysis methods proposed in this paper is to generate and check safety regulations for high voltage system Fuel Cell Vehicles (FCVs). Currently regulations related to FCVs electrical safety are FMVSS1) (Federal Motor Vehicle Safety Standard) 305 from National Highway Traffic Safety Administration (NHTSA) of United States, EN ECE R1012) from European Commission (EC), Amendment A1013) from Japan Transport Administration.

However, there is no electrical safety regulation

explicitly for Fuel Cell Vehicles and generation is under process by Electrical Safety (ELSA) group of Working Party on Passive Safety (GRSP). We applied our methodologies to FMVSS 305 regulation to check its applicability and we could get results of the weak area where new regulation items need to be generated.

### 4.1 Results from Regulation Distribution Analysis Method

The axes used for RDAM were protection level, relation from machine to human, electrical current, severity caused by accident, relation from manufacturer to user, and running state of the vehicle.

We generated 5 distribution graphs combining the axes and distributed 15 regulation items extracted from FMVSS 305. Figure 12 shows one of the distribution graphs relating severity and relation from manufacture to user. As it can be seen from the graph, most of the items were concentrated on manufacture state and little were related to user.

Other distribution graphs include protection level vs relationship to human, electrical current level vs relationship to human, vehicle running state vs relationship to user, electrical current vs relationship to user.

After analysis, we could conclude that there were little regulations related to user. Example of possible candidates to compensate user related regulation items can be “Ignition Key which connects high voltage systems should be not operated when the high voltage systems (battery, inverter, motor part) are opened for repairing services”. Other conclusions include absence of differentiating current levels in the components and vehicle speeds.

Human (15)						
User (0)		Manufacturer (15)			Supply Station Worker (0)	
Driver (0)	Passenger (0)	Designer (6)	Worker (9)	Maintenance Man (0)	Hydrogen (0)	Battery (0)
		1,3,6,13,14,15	2,4,5,7,8,9,10,11,12			

Fig. 13 Completeness table: Human category

FCV System (15)					
Hydrogen Tank (0)	Motor (0)	Battery (13)	Inverter (0)	Chassis (0)	General (2)
		1,2,3,4,5,8,9,10,11,12,13,14,15			6,7

Fig. 14 Completeness table: FCV system category

Electrical Problem Protection (15)						
EMC (0)		Insulation (0)		Shock Protection (15)		
Wiring (0)	Device (0)	Vehicle (0)	Human (0)	Design Stage (0)	Operation Stage (1)	Accidental Condition (15)
					Normal Condition (0)	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15

Fig. 15 Completeness table: Electrical protection category

Vehicle State (15)		
Parking (0)	Idleness (0)	Driving (15)
		1,2,3,4,5,6,7,8,9,10,11,12,13,14,15

Fig. 16 Completeness table: Vehicle state category

## 4.2 Results from Regulation Completeness Analysis Method

The categories used for RCAM were human (manufacture, passenger, maintenance related personnel, etc), vehicle state (parking state, driving state), and fuel cell vehicle high voltage system (batter, motor, inverter, etc). For each category we derived completeness table as shown from figure 13 to figure 16.

Results of the completeness analysis were similar as Regulation Distribution Analysis Method.

Regulation related to driver, maintenance repairers, and supply station workers were few or missing compared to designer or worker. The regulations were not differentiating the vehicle state such as parking, idle, driving, charging which can miss dangerous situation occurred by specific action to the car. Most of the regulations were dealing only with fuel cell battery system. Regulations items for fuel tank, motor, inverter were missing in the regulation.

## 5. Conclusion

In this paper we proposed two methodologies to check regulation items. Regulation Distribution Analysis Methodology (RDAM) checks regulation items by distributing the items into distribution graphs which show the density of the regulation items in specific areas. Regulation Completeness Analysis Method (RCAM) distributes regulation items into completeness tables which show the empty part of the regulation using complete subset of specific categories.

The methodologies can be used to generate new regulation during rule making process and revise existing regulation to compensate missing areas. The methodologies check every technical point and user, human related issues. We applied our methodology to FMVSS 305 standard to check the regulation coverage and completeness for electrical safety of fuel cell vehicle.

For generating electrical safety regulation for high voltage system of Fuel Cell Vehicles, additional regulations need to be analyzed with more axis and categories. While applying our methods to FMVSS 305, we could find more regulation items that need to be added.



## Acknowledgement

This research was supported by a grant from program funded by Ministry of Land, Transport and Maritime Affairs of Korean government

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