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FUZZY LOGIC IN AUTOMOTIVE ENGINEERING

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Abstract
Nowadays, automotive industry gains more and more importance due to the innovative technology use in design and manufacturing. This branch consists of several manufacturer and supplier companies. The aim of each car manufacturer company is to provide the perfect driving experience for the customers. Fuzzy logic aids to design quality products for increasing the comfort of drivers. In our study, we present a variety of automotive applications, which use fuzzy logic.

1 Introduction

Nowadays, automotive industry is a major factor in global industry (despite that manufacturer face issues concerning environmental safety). It consists of numerous different manufacturer companies: car manufacturers and their supplier chain. We refer to car manufacturers as those companies which final assemble the cars themselves. As nowadays cars are complex (mostly because of the amount of electrical components) car manufacturer companies are using suppliers and sub-suppliers for production. In Chapter 2 we introduce the main features of the automotive sector (automotive production groups, amount of produced vehicles, revenue of manufacturers, revenue of automotive supplier chain). With this introduction, our aim is to point the volume of the automotive production which is the driving power of automotive innovation. (These innovations include the usage of fuzzy logic as well.) In Chapter 3 we present fuzzy logic in general (with the introduction of fuzzy-set theory and measure of fuzziness). As our aim is to introduce Fuzzy logic in connection with automotive industry, we take the examples of application in Chapter 4.

2 Automotive industry

In Chapter 2, our aim is to present the importance and volume of automotive industry. (As this branch is innovative and quickly changing, there is an increasing need for technological novelties. These innovations improve driving experience and safety- this is the aim of fuzzy logic control applications present in Chapter 4.)

Automotive market consists of and is dominated by 14 major companies, which are the following:

- Ford (brands: Ford, The Lincoln Motor Company);
- Daimler (brands: Mercedes-Benz, Smart);
- Toyota (brands: Toyota, Daihatsu, Lexus);
- Nissan (brands: Nissan, Infiniti, Datsun, Mitsubishi Motors): in connection with Nissan it is important to point its role in spreading ABS with fuzzy logic controllers;
- Renault (brands: Renault, Dacia, Alpine, Samsung, Lada, Venucia);
- PSA (brands: Vauxhall, Peugeot, DS Automobiles, Citroën);
- Volkswagen (brands: Volkswagen, Seat ,Skoda, Bugatti, Bentley, AUDI, Lamborghini,

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Porsche);
- GM (brands: Chevrolet, Cadillac, Wuling Motors, GMC, Buick, Baojun, Holden);
- FCA (brands: Chrysler -Jeep, RAM, Dodge-, Fiat -Maserati, Lancia, Alfa Romeo-);
- TATA (brands: TATA Motors, Land-Rover, Jaguar);
- Honda (brands: Honda, Acura);
- BMW Group (brands: BMW, Mini, Rolls-Royce);
- Geely (brands: Volvo, Geely, Proton, LOTUS, Lynk&Co., The London Taxi Company);
- Hyundai (brands: Hyundai, KIA, GENESIS) [18].

This connection between manufacturers and brands can be seen on Figure 1 [18].

Figure 1. Most important automotive manufacturer companies [18]

These 14 most important automotive manufacturer companies make most of the worldwide automobile production, according to Figure 2 [12].

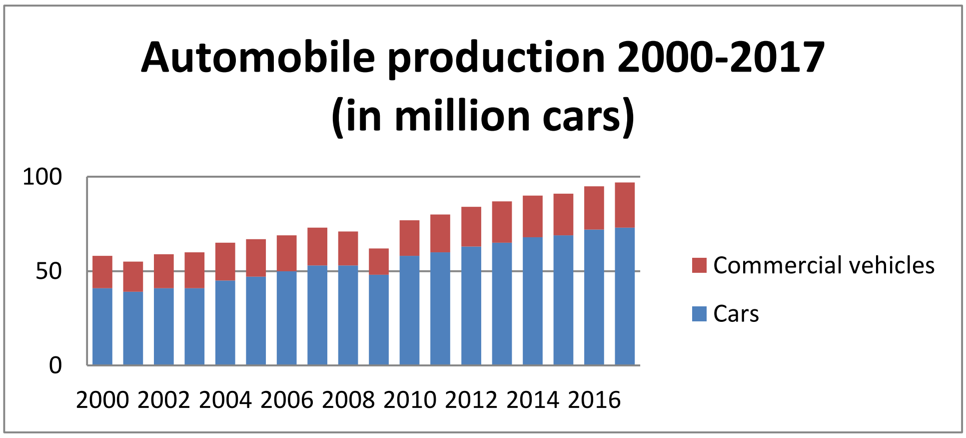

Figure 2. Automobile production from 2000 to 2017 [12]

As it can be seen on Figure 2, there is an increasing trend of growth in the number of produced cars since the beginning of the 21th century (there was one significant regression due to the financial crisis in 2008). In 2000 approximately 60 million cars were produced (ca. 40 million personal cars, and 20 million commercial vehicles). In 2017 almost 100 million cars were produced (ca. 75 million personal cars, and 25 million commercial vehicles). The approx. 30 million growth in 17 years is a result of personal car production increase; the proportion of commercial vehicle production volume is stagnant [12].

The revenue of automotive industry is outstanding, as Figure 3 shows according to 2017 data [12].

- Nissan Motor's revenue was 107 billion U.S.dollars;
- BMW Group earned 111 billion U.S.dollars;
- SAIC Motor earned 128 billion U.S.dollars;
- FCA earned 132 billion U.S.dollars;
- Honda Motor earned 138 billion U.S.dollars;
- Ford Motor earned 156 billion U.S. dollars;
- General Motors earned 157 billion U.S. dollars;
- Daimler earned 185 billion U.S. dollars;
- Volkswagen earned 260 billion U.S. dollars;
- Toyota Motor's revenue was 265 billion U.S.dollars [12].

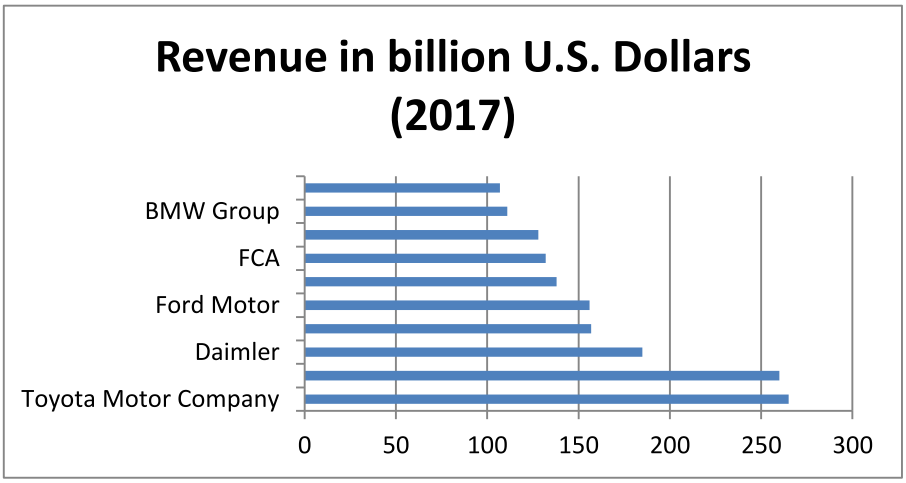

Figure 3. Revenue of leading automotive manufacturers in 2017 [12]

When it comes to automotive suppliers, the revenue is outstanding as well, as we have summarized in Table 1 [4]:

- Robert Bosch GmbH's revenue was 47.5 billion U.S. dollars;
- Denso Corporation earned 40.7 billion U.S. dollars;
- Magna International Inc. earned 38.9 billion U.S. dollars;
- Continental AG earned 35.9 billion U.S. dollars;
- ZF Friedrichshafen AG earned 34.4 billion U.S. dollars;
- Aisin Seiki Co. earned 33.8 billion U.S. dollars;
- Hyundai Mobis earned 24.9 billion U.S. dollars;
- Lear Corp. earned 20.4 billion U.S. dollars;
- Valeo SA earned 19.3 billion U.S. dollars;
- Faurecia earned 19.1 billion U.S. dollars [4].

Table 1. Revenue of automotive suppliers (2017) [4]

Supplier name	*Revenue (U.S. billion dollars)*
Robert Bosch GmbH	47.5
Denso Corporation	40.7
Magna International Inc.	38.9
Continental AG	35.9
ZF Friedrichshafen AG	34.4
Aisin Seiki Co.	33.8
Hyundai Mobis	24.9
Lear Corp.	20.4
Valeo SA	19.3
Faurecia	19.1

According to Table 1, automotive suppliers produce goods in a wide range; from advanced driver assistance systems to emission control systems [3].

3 Fuzzy-set, measure of fuzziness, fuzzy logic

In our work, we aim to present application examples of fuzzy logic. (Fuzzy logic is for technical problem solving in automotive engineering.) This method aids effective problem solving which is important in this cost-sensitive industry. To introduce fuzzy logic, at first fuzzy-set theory and fuzzy sets has to be identified (as fuzzy-set theory is based on fuzzy-sets).

Fuzzy sets are built from reference sets (universes of discourse), and these reference sets are never fuzzy.

If $U = \{x_1, x_2, \dots, x_n\}$ is the universe of discourse [17], (1)

then a fuzzy set $A \subset U$ is defined as a set of ordered pairs as $\{(x_i, \mu_A(x_i))\}$[17], (2)

where $x_i \in U, \mu_A : U \to [0,1]$ [z], (3)

is the membership function of A and $\mu_A(x) \epsilon [0,1]$ is the degree of membership of x in A. (4)

The fuzzy-set theory was first defined by Lotfi Zadeh (Berkeley professor) in 1965 [12]. In 1972, De Luca and Temini [6] defined the measure of fuzziness d(μ). According to them, measure of fuzziness might have three different conditions. (Measure of fuzziness is an important feature, in connection with fuzzy-set theory.)

1. if the set is non-fuzzy, (the elements belongs to it or not (i.e., μ(x) = 0 or 1 only) [11]

$$d(\mu) = 0 \quad (5)$$

2. d(μ) is maximal for the most fuzzy set [11]

$$\mu(x) = \frac{1}{2} \mathit{for\ every\ x} \quad (6)$$

3. if a set associated with a given function $\mu'(x)$ is uniformly less fuzzy than another set associated with $\mu''(x)$[11]

$$if\ for\ \mu''(x) \geq \frac{1}{2} \to \mu'(x) \geq \mu''(x) \leq \frac{1}{2} \to \mu'(x) \leq \mu''(x), then\ d\mu(x) \leq d(\mu''(x)) \quad (7)$$

Fuzzy-sets can be either discrete or continuous, depending on their universe [16]. In connection with discrete fuzzy-sets, Yager used the definition of distance (d) to define the measure of fuzziness [17] :

$$H_y(q, A) = (d^q(Y, Y^c) - d^q(A, A^c))/d^q(Y, Y^c) \quad (8)$$

where, A: fuzzy-set
Y :arbitrary crisp subset of X,
Y^c :complement of Y (defined by Zadeh).

Fuzzy logic is based on the fuzzy-set theory. Fuzzy logic is different to ‘classic logic’ described by the Boolean algebra. In classic logic, the values can be true {1} or false {0}. In fuzzy logic values can take up any real value [0;1] [12].This means, that instead of being bivalent, fuzzy logic is multivalent. This result that truth is a point of view, not a sharp result and an element belongs to a set with a certain degree [5]. As a part of method development, fuzzy logic has many practical applications: fuzzy control, fuzzy diagnosis, fuzzy data analysis and fuzzy classification [2]. The steps of using fuzzy logic in an application are the following:

1. Input values need to be ‘fuzzified’
2. All applicable rules need to be executed
3. Output functions need to be ‘de-fuzzified’[7]

Fuzzy logic uses human language rules, which are converted to mathematical equivalents. As stated earlier, this simplifies solving of difficult problems. Models using fuzzy logic are fuzzy interference systems. These models use conditional if-then rules. Fuzzy logic models use non-numeric linguistic variables, to define facts and rules. In terms of usage, fuzzy logic is used widely: in artificial intelligence, computer science, medicine, control engineering, decision theory, expert systems, logic, management science, operations research, pattern recognition, robotics and automotive engineering [7]. In Chapter 4, we introduce automotive examples of fuzzy logic usage.

4 Automotive examples for fuzzy logic usage

In the following, we would like to present examples of automotive application of fuzzy logic. In the 21th century, its usage is getting more and more extensive. Examples include: ABS (anti-lock braking system), ASR (anti-slip regulation, or as TCS: Traction Control System), AFS (active front steering), automotive automatic air conditioning systems, automotive energy management systems. These systems improve driving quality, comfort and safety as well [8].

ABS is an important part of automotive electronics. ABS is a safety feature in cars to keep steering control during heavy braking. It helps to prevent wheels from locking up. (Avoiding locking is important, because it negatively influences steering and braking.) ABS systems consist of three parts: wheel speed sensors, hydraulic units and ECU (electronic control unit). The working principle is the following: the ECU receives information from the wheel speed sensors and it directs the hydraulic units to pump the brakes in case of necessity [1]. The principle of ABS can be seen on Figure 4 [13].

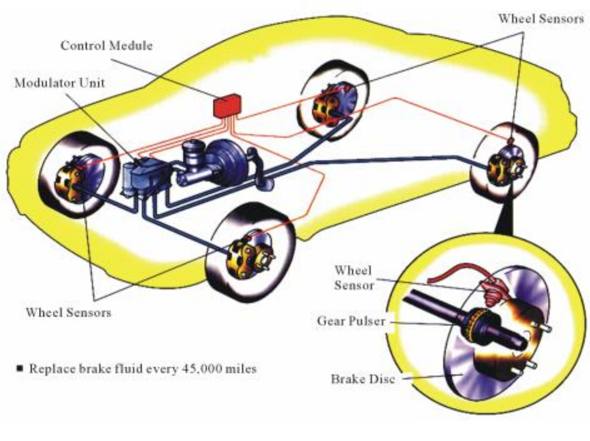

Figure 4. Working principle of ABS [13]

As tests proved, fuzzy logic estimator improves efficiency of ABS. It is especially useful on dry road surfaces. The usage of it is advantageous, because multiple inputs can be used, such as signs of sonar sensor, or stored map information. The interaction between braking systems and road conditions is hard to describe with mathematical models, fuzzy ABS is more effective. Fuzzy ABS systems are already present on the market (Nissan and Mitsubishi sell cars with it) [7].

ASR (anti-slip regulation) is an active vehicle safety feature, and can be considered as a supplement of the existing ABS setup. It uses the same components as mentioned before (wheel speed sensors, hydraulic units and the ECU). Its' importance is shown in case of driving on slippery surfaces (e.g. ice or snow) so that it helps to overcome slip (providing the possible biggest grip for the wheels). In practice Fuzzy-ASR maximize acceleration and deceleration, regardless of road conditions. Its usage is highly advantageous in case of icy road conditions. As it can be seen on Figure 5, traction control is an important feature of driving safety, it helps to prevent accidents caused by sliding [9].

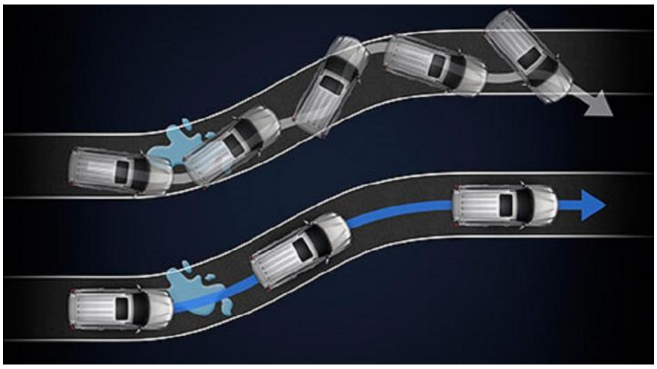

Figure 5. Advantages of ASR usage [9]

5 Conclusions and summary

In our study, our aim was to point out the importance of automotive sector in global economy, the introduction of fuzzy logic and the need for innovative solutions in automotive electronics. As mentioned, ABS and ASR are important safety features for cars. Their effectiveness can be improved with fuzzy logic controllers.

Fuzzy logic provides another way of problem solving as well, which is important in the automotive industry. Our aim is to do further research in terms of the method and exploring it to quality tools (e.g. FMEA: Failure Mode and Effect Analysis).The usage of FMEA is a must for automotive producer companies (according to IATF 16949:2016), mainly this is the reason why its continuous improvement is needed.

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