Enhancing Circular Economy Using Expert Systems

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Abstract. An important measure of the success of the expert system's implementation is its users' acceptance. An expert system doesn't have to provide very good conclusions when its use is very complex and time-consuming both in learning and in use. From the user's point of view, it is important that working with the system is easy and easy to understand. It is appropriate for the system to be able to correct the most common user errors. It is necessary to note that expert systems can also be used for training new experts when workers are familiarized with evaluating input data and the possible conclusions that may result from them with the help of the explanatory mechanism of the system. We cannot get complete information to solve most problems. It remains only to fill in the information data gaps while considering the possibility of error. During processing, the effects of stored knowledge and probabilities are combined. In the post, the main problem was the determined amount of tyres provided to each driver for the race. The work deals with t collecting and processing data on the climate, the type of circuit and the subsequent use of this data in motorsport to reduce the number of tyres provided for the benefit of expert systems.

Keywords: Monitoring · Industry · Expert Systems · IoT · Tyres

1 Introduction

The tyre is a critical component of the automobile. Understanding and predicting its behaviour is one of the main keys to performance [1]. A motorsport tyre is designed to absorb and transmit energy in large quantities. The tire is light, strong, and, like every car component, works at the performance limits [2]. The modern tyre generates side loads in corners higher than at any other stage in the sport's history [1, 2].

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It carries enormous traction and braking loads and absorbs an extreme amount of radiant heat from carbon/carbon brake material systems. As part of the design, the tire generally has an operating duty cycle of 120–150 km. A motorsport tire has a relatively complicated structure, ensuring it can withstand a very high load in operation. The technologies used in its design and production are very advanced [3]. Each tire, including those used in motorsports, has its specific construction. The bottom part is called the bead, the reinforcing part of the tire that rests on the steel rim [3]. It is used for anchoring and ensures safe seating of the tyre on edge. Its core is formed by the heel cable, which is located in the heel. Its main function is strengthening and also ensures the tightness of the connection to the rim and the transmission of longitudinal forces [4]. The entire inner side of the tire is made up of a rubber layer, the main task of which is to prevent air from escaping from the inside of the tire, or in tubeless tyres it fulfils the role of the inner tube, as in the case of motorsport tyres. It is made mainly of butyl rubber compounds, which prevent the pressure from leaking from the tyres and ensure its optimal level [4, 5]. The sidewall is an integral part of every tire. It is the transitional part between the frame and the tread. The role of the bumper is to stabilize the track and increase the tyre's impact resistance. There are at least three buffer layers in each tire. Nowadays, they are mostly made of steel or other solid material. At the very top of the tire is the tread [6]. This part of the tire is in contact with the track all the time, which means that the secret of success and failure is hidden in this part of the tire. The tread compound varies with each type, but the properties of each compound determine how quickly the tire heats up and wears. The thickness also varies according to the type of hardness, but in general, a worn tire is about half a centimeter [7, 8].

1.1 The Circular Economy of Selected Materials in the Motorsport

The key property of tyres is grip - adhesion. It is the ability of two, mostly different materials to adhere to each other [8]. In the case of tyres and asphalt on the road, we can talk about dispersion adhesion, otherwise known as Van der Waals force, which works on the intermolecular attraction at the contact surfaces in the pores of the materials. On one side, there is a partially positive charge, and on the other, partially negative [4, 8]. During operation, the F1 tyre continuously absorbs and transfers kinetic, radiant and mechanical energy through the tire sidewall to the tread platform and vice versa. The tire is constantly heating, cooling, expanding and contracting [9]. When analyzing an F1 tire from a structural point of view, it is important to recognize that the structure is a composite matrix of different materials, the structural fibres and the binders that hold them together. The softest tyres from the SOFT series are among the fastest tyres in the world [10]. They are created for quick starts or, since they are the smallest compound, they can develop the best tap at the beginning. However, it is not due to adhesion. In this case, it is the temperature that is decisive. The softest tyres warm up the fastest, often after three or five laps, depending on where the race is held and the air and road temperatures, but they warm up on every circuit by the tenth lap. The tire has its ideal performance when it is heated to 90 °C−110 °C A driver can last a maximum of 30 laps on these tyres, but in most cases, the pit stop usually takes place between the 20th and 25th lap. Tyres have ideal performance between the tenth and fifteenth lap. If the tire overheats or is overloaded, of course, it loses its long-term properties, and with soft tyres it can be up to two seconds of power loss per lap, as they are adapted for a short period. So the maximum time is only 35–35 min.

Tyres one degree harder, but still relatively soft [11]. As Formula 1 requires one change of tyres during each race, MEDIUM tyres are often used as a second (or first) complementary compound to a harder or softer compound. The advantage is that they still heat up to the ideal operating temperature, 105 °C−135 °C. They can do it by the fifteenth round at the most. Opo wear sometimes occurs around 30–35 laps on warmer circuits, even earlier, but the tyres can last 40 laps. Again, the tread, the surface of the tire that is in contact with the road, constantly rubs and rubs, but MEDIUM tyres resist wear visibly better than SOFT tyres, which are visible even to the naked eye of the viewer on some circuits. The composition of this compound is adapted to suit most laps. Tyres last 55–65 min [11, 12]. The hardest and most consistent mixture can last even 70 min without any major problems (HARD). Of course, the performance is not always the same this time either. The tire is difficult to heat up. It often reaches its ideal temperature window, 110 °C−140 °C, only in the twentieth lap. At first glance, it may look like a big complication, but the tyres last almost 50 laps, so if the team chooses the right strategy, all the other teams will gradually change the tyres, and the Formula with these tyres can get a few rungs progressively ahead. The wear-in occurs around the fortieth lap, so the tire is in ideal performance for at least twenty laps [13, 14]. But what can be a problem if it is used at the wrong time or on the bad lap, during the warm-up, the competitor can lose a lot of time and positions that are difficult to catch up. Also, during the introduction, the rider must be careful when cornering and braking, as the tyres tend to slide.

Intermediates are a very interesting type of tyre. We do not know more species or types divided according to hardness or other properties. One single species with amazing properties. Their use is in moments when it is drizzling, light rain is falling on the track, or it is after rain, and the way is not yet dry, or even if there are only wet areas on it. SLICK tyres do not handle driving on water, aquaplaning occurs immediately after entering a wet place, and the car slides uncontrollably since there are no grooves on the tyres [8, 15]. Therefore, Intermediate tyres are used for these situations, with symmetrical grooves adapted to drain water. One tire can drain 30 L of water in 1 s at a speed of 300 km/h. The wear of the tyres is manifested primarily by the fact that the grooved part of the tread changes almost to a SLICK tyre. That is, if the track is completely dry after rain and the tyres already have grooves, they can function on a dry track as SLICK tyres for several laps. However, it is not advantageous in the long run, as they are slower than them.

Interestingly, the pit stop rule does not apply to these tyres [6, 16]. It means that if it rains during the entire race or if the race is shortened, for this reason, it is not necessary to replace the tyres, and they can be stripped down to the canvas, which is located under the tread. Tyres for heavy rain, as the name implies (FULL WET) [15, 17]. The deep asymmetric grooves of each tyre ensure that one tyre can drain up to 85 L of water in 1 s at a speed of 300 km/h. It may seem like an unimaginable amount, but in reality, it looks like a huge spray of water is created behind the Formula, which makes it impossible for the following rider to see. It is where the real riding prowess and anticipation of each rider's situation will be shown. It's really dangerous, so these tyres are rarely used, except when it starts raining during the race and looks like a short rain.

If it rains before the start, there is a high probability that the start will be postponed, the race will be cancelled completely, or several laps will be driven behind the Safety Car [17]. In general, the greatest risk of tire wear arises from so-called over braking. It is mostly the driver's fault, paid for by the loss of positions. The problem occurs during right-angled and sharp-angled turns and overtaking manoeuvres [12, 15]. The driver tries to brake as late as possible before the corner and to add gas as soon as possible. Still, if the driver attempts to overtake, does not estimate the distance and force, and starts braking too hard, a place is created on the tire where the materials under the tread are often visible. It's called a flat spot, and for the driver who made this mistake, it means that if it's on a large surface or deep, he has to head to the pits and change the tyres. It's not always necessary, but the tire will still lose a significant portion of its performance [17].

2 Definition of Expert Systems

They are systems that contain certain knowledge or issue a recommendation for a decision based on the entered data [14, 19]. They are artificial intelligence systems with a knowledge base for solving problems. They are called expert systems because they simulate the work of an expert. It is known from the history and origins of artificial intelligence that knowledge is the most important for expert systems [17, 18]. To this day, the information required by expert systems is still entered into computers manually. Although there are known machine learning methods, they cannot exactly imitate the process of human learning and thinking. Despite this, expert systems are already used in common practice today [20]. Figure 1 presents the basic structure of the expert system.

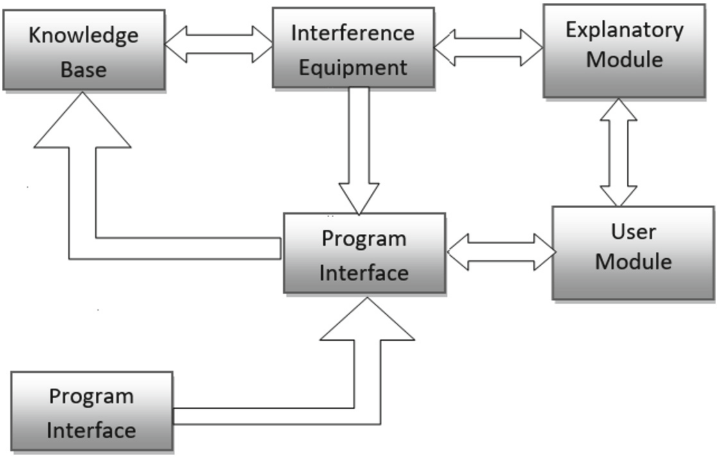

Fig. 1. Expert systems [Authors own processing]

3 Results and Discussion

For the two known types of laps, city and racing, the work focuses on conditions such as the probability of rain and the average temperature when races are held on the given lap [17]. The data needed to create the graphs are collected from statistical data from the past years and the race schedule for 2022. All these data are processed in the following table (Table 1).

Table 1. Climate data on individual circuits [Authors own processing, 2]

State/City	Lap type	Month	Average air temperature [°C]	Average humidity [%]	Rain forecast [%]
Bahrain, Sakhir	Racing	March	22	46,1	0
Saudi Arabia, Jeddah	City	March	26,2	46,7	0
Australia, Melbourne	City	April	22,7	61,4	14
Italy, Imola	Racing	April	14,2	61,6	12
USA, Miami	City	May	26,6	60,5	19
Spain, Barcelona	Racing	May	17,9	63	9
Monaco, Monaco	City	May	18,2	64,2	18
Azerbaijan, Baku	City	June	24,8	60,3	5
Canada, Montreal	City	June	19,2	57,5	28
Great Britain, Silverstone	Racing	July	13,5	65,2	4
Austria, Spielberg	Racing	July	21,6	60	34
France, Le Castellet	Racing	July	24,4	53,9	0
Hungary, Mogyoród	Racing	July	23,1	47,6	2
Belgium, Spa	Racing	August	16,1	69,1	26
Netherland, Zandvoort	Racing	September	14,8	75,8	27
Italy, Monza	Racing	September	19,3	58,4	7

(*continued*)

Table 1. (*continued*)

State/City	Lap type	Month	Average air temperature [°C]	Average humidity [%]	Rain forecast [%]
Russia, Sochi	Racing	September	21	66,5	14
Singapur, Marina Bay	City	October	28,5	72,6	11
Japan, Suzuka	Racing	October	17,6	68,5	23
USA, Austin	Racing	October	21,8	51,8	13
Mexico, Mexico city	Racing	October	16,6	54,1	13
Brazil, Sao paulo,	Racing	November	22,4	62,1	0
United Arab Emirates, Abu Dhabi	Racing	November	26,2	48	1

These data are analyzed together with data on the condition of the asphalt on the circuits, and then the Pirelli team selects the compounds most suitable for each circuit. However, the condition of the asphalt changes every year, or some laps are not used every year, so statistically we cannot determine the nature of the asphalt in advance before carrying out tests before the start of the season [2, 18, 20]. After choosing these three compounds, each team will determine its tire strategy.

The teams also consider other criteria, such as the effect of weather and climate, namely the length of the circuit, the number of laps and the effect of the asphalt on the tyres. Subsequently, the teams determine a strategy, most often chosen from three options. Data on circuits and strategies are processed in the following table (Table 2), where we also see the possible start on tyres in the last column. The table contains statistical data from previous years.

The strategies are repeated during the circuits, so all strategy options are listed in the table (Table 3), from which it is subsequently possible to create rules for strategy selection.

Table 2. Circuit parameters and possible tyre strategies [Authors own processing, 2]

State/City	Lap's length [km]	No. Round	Strategy a	Strategy b	Strategy c	Starting tyres
Bahrain, Sakhir	5,412	49	soft-hard-medium	soft-medium-hard	soft-medium-soft	SOFT
Saudi Arabia, Jeddah	6,174	50	medium-hard	medium-hard-medium	soft-hard	MEDIUM
Australia, Melbourne	5,303	58	soft-soft-medium	medium-soft	soft-hard	SOFT
Italy, Imola	4,909	63	medium-soft	soft-hard	medium-hard	MEDIUM
Spain, Barcelona	4,675	66	soft-medium	soft-medium-soft	soft-hard	SOFT
Monaco, Monaco	3,337	78	soft-medium	soft-hard	medium-soft	SOFT
Azerbaijan, Baku	6,003	51	soft-hard	medium-hard	soft-hard-soft	SOFT
Canada, Montreal	4,361	70	medium-hard	soft-hard	soft-medium-medium	SOFT
Great Britain, Silverstone	5,891	52	medium-hard	soft-medium-medium	soft-hard	SOFT
Austria, Spielberg	4,318	71	medium-hard-hard	medium-hard	hard-medium	MEDIUM
France, Le Castellet	5,842	53	medium-hard	hard-medium	hard-soft	HARD
Hungary, Mogyoród	4,381	70	medium-hard	soft-hard-medium	soft-hard	SOFT
Belgium, Spa	7,004	44	medium-hard	soft-hard	soft-medium	SOFT
Netherland, Zandvoort	4,259	72	soft-hard	medium-hard	soft-medium-soft	SOFT
Italy, Monza	5,793	53	medium-soft	soft-medium	medium-hard	MEDIUM
Russia, Sochi	5,848	54	medium-hard	hard-medium	medium-hard-medium	MEDIUM
Singapur, Marina Bay	5,063	61	soft-medium	medium-hard	soft-hard	SOFT
Japan, Suzuka	5,807	53	soft-medium	medium-soft	soft-soft-medium	SOFT
USA, Austin	5,513	56	medium-hard-hard	soft-hard-hard	medium-hard-medium	MEDIUM
Mexico, Mexico city	4,304	71	medium-hard	medium-hard-medium	medium-hard-hard	MEDIUM
Brazil, Sao Paulo,	4,309	71	medium-hard	medium-hard-soft	soft-hard	MEDIUM
United Arab Emirates, Abu Dhabi	5,281	58	medium-hard	soft-hard-medium	medium-hard-medium	MEDIUM

Table 3. Unification and designation of strategies [Authors own processing, 2]

Start probability/tyres	Description	Label
SOFT	soft - hard -medium	S1
	soft - medium	S2
	soft-hard	S3
	soft-medium-soft	S4
	soft-soft-medium	S5
	soft-hard-hard	S6
	soft-medium-hard	S7
	soft-hard-soft	S8
	soft-medium-medium	S9
MEDIUM	medium-soft	M1
	medium-hard-hard	M2
	medium-hard	M3
	medium-hard-medium	M4
	medium-hard-soft	M5
HARD	hard-medium	H1
	hard-soft	H2

3.1 Utilization of Acquired Data Using Expert Systems

By using filtering based on some of the columns in the above tables, it is possible to create a system that can be used to determine the choice of strategy [15, 19]. The parameters are circuit type, season, likely start on tyres, probability of rain and location and are marked as follows:

- Lap type: C – City, R – racing
- Season: SPRING (March, April, May), SUMMER (June, July, August), FALL (September, October, November), WINTER (December, January, February)
- Probable start on tyres: SOFT, MEDIUM, HARD
- Chance of rain: LOW (< = 10%), MEDIUM (11–18%), HIGH (>19%)
- Race venue

From these five criteria, a general notation is created, for example, as follows:

If C and SPRING and SOFT and LOW and PLACE ◊STRATEGY

In this way, it is possible to choose a strategy for each lap, e.g.:

R and SPRING and SOFT and LOW and BAHRAIN ◊S1 or S7 or S4

Subsequently, the team chooses the one that best suits the current situation on the circuit from these three strategies. All three strategies suitable for the race in Bahrain, where the track is 5.4 km long and runs 49 laps, take into account two pit stops because the circuit in Bahrain is treated with anti-sand substances on the track during the competition weekend. However, there is still some sand on the track.

Another criterion for choosing two pit stops is the difficulty of the track. Rather, it belongs to the technical, not very fast tracks, where tire wear in the turns is medium to high [2,22].

The S1 strategy, i.e. SOFT – HARD – MEDIUM, will be used in case the team wants to use and gain as much as possible at the start. Subsequently, sometimes by the 10th lap, they switch to HARD tyres, on which the rider can consistently last until approximately 35–40. Wheels and change to MEDIUM tyres in the second pit stop. In this case, it can be seen that the times driven on the tyres are short, also because the average air temperature in Bahrain is 22 °C and the road has an even higher temperature, so there is no problem with a long warm-up of the tyres. The S7 strategy, SOFT – MEDIUM – HARD, is different only in the order of the tyres. The S4, SOFT – MEDIUM – SOFT strategy may look unreliable at first glance, and it may seem that these sets will not be able to ride the entire race. Still, suppose the rider is in a position not to engage in aggressive battles and overtaking manoeuvres on the track. In that case, this strategy can ensure a safe and quickly arrive at the destination and get valuable points [2].

Another example can be the circuit in Brazil.

R and AUTUMN and MEDIUM and LOW and BRAZIL ◊C3 or C5 or S3

The Interlagos lap in Sao Paulo is known for its many challenging corners, elevation changes, rough surfaces and minimal room for error. These errors also include changing tyres at the wrong time.

The C3 strategy, MEDIUM–HARD, is effective as it is very consistent, and the track surface requires tyres that do not wear much and quickly. The C5 strategy, MEDIUM–HARD–SOFT, allows the driver to drive a fast lap on soft tyres at the end of the race or make a few more overtaking manoeuvres. The S3 strategy, SOFT–HARD, is probably the most effective, as the rider can secure a quick start and can drive most of the laps on HARD tyres if he can handle these tyres sensibly.

This tyre selection system can be used especially when choosing strategies for new circuits. In 2021, it raced in the Netherlands, in the city of Zandvoort, after several years, which means that strategy had to be chosen again, as the circuit was modified, new asphalt was laid, etc.

In 2022, a lap in the USA, Miami, was added to the calendar. Data that are known about the circuit are listed in the table (Table 4). We can see that the air temperature is quite high, and so is the probability of rain and the average humidity.

Table 4. Characteristics of the lap in the USA – Miami [Auhtors own processing, 2]

Country/City	Lap's type	Month	Lap's lenght [km]	Lap's No	Average air temperature [°C]	Average humidity [%]	Rain forecast [%]
USAMIAMI	City	May	5,41	57	26,6	60,5	19

It is possible to assume that the likely start will be on MEDIUM tyres, as asphalt temperatures can reach over 40 °C, which is disadvantageous for SOFT tyres at the beginning of the race. In some cases, the HARD compound can also be used for the start, but it will not be preferred due to the slow start and the driver may lose valuable positions in the first laps.

4 Conclusion

If it were possible, based on statistics, observation and expert systems, to determine possible tire strategies used on certain circuits, such quantities of tyres would not have to be offered for each driver or team. It would reduce the number of tyres that are absolutely destroyed after every competition weekend. An example can be the circuit in Saudi Arabia, where the probability of rain is 0%, so it is possible to consider light rain and heavy rain tyres unnecessary for this weekend. Of course, nature is unpredictable, so to be sure, it is advisable to leave one set of both types for both riders. Despite this, it is possible to save up to ten sets of tyres, which in total cost 25,200€, which we can save in just one competition weekend [9, 20]. Expert systems have one more important feature. It is an explanatory mechanism that, at any stage of task processing, can provide the user with information about what has already been inferred, what is the current goal of the inference (i.e., an explanation of "why the user was asked for this particular information") and how any of the conclusions of the expert system. The explanation mechanism is used very rarely during the operation of the expert system, but the feeling of its existence usually greatly increases the users' confidence in the system. It has an irreplaceable role in the system's design, modification, control and debugging.

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