Digital transformation of bicycle rental maintenance process

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Abstract. The payback of urban cycling has received considerable attention in many countries. One of the reasons for the loss of bicycle rental companies is the cost of maintaining rental bicycle transport caused by vandalism and poor bicycle handling. The article describes a fuzzy inference system, which, based on information obtained from an accelerometer installed on a bicycle, allows making a forecast about its technical condition. Each bike is assigned a rating, in accordance with bicycle rental maintenance process should be carried out. This rating is also used when cyclist choose a bicycle at the rental station. At the same time, a bicycle with an unsatisfactory technical condition is not issued to a cyclist. A conceptual model of digital transformation of a company providing bicycle rental services is presented.

1. Introduction
Bicycle is a fairly safe kind of transportation. The number of road accidents in Russia involving cyclists is relatively small, for example, in 2018 – about 5265 accidents, in which 360 people were died.

Bicycle is popular in both rural and urban areas. Bicycle rental helps urban residents to change vehicles to environmentally friendly and healthy bicycle. However, the development of cycling in the cities is hampered by several problems:

- Insufficiently clear and convenient service for consumers;
- Slow development of bicycle lanes and bicycle stations;
- Vandalism, or poor bicycle handling.

The problem of vandalism hinders the further development of bicycle rental services in the Russian Federation and cannot be solved only through the use of known methods, such as the installation of tracking cameras, which is due to the relatively high cost and difficult operating conditions.

The consequences of vandalism are: the risk of serious injuries as a result of the operation of a faulty bicycle, reducing the popularity of bicycle rental services among consumers, followed by an increase in losses of the rental companies.

Thus, the need to increase the attractiveness of bicycle rental sets the task of creating methods and means of monitoring the technical condition of rental bicycle.

The above considerations allow us to determine the way in which it is possible to increase the competitiveness of the bicycle rental – digital transformation of the bicycle rental maintenance process. The implementation of such elements of the Industry 4.0 as IoT, Big Data creates opportunities to solve a number of problems of bicycle rental, increasing the competitiveness of this
service, to minimize the risks that may arise during operation by monitoring the technical condition of rental bicycles [1…5].

One of the features of customer service is that the customer usually has the opportunity to choose a bicycle at the bicycle station. Feature of modern bicycle rental – the use of mobile technology, the smartphone software interface allows you to choose a bicycle but there isn’t information about its technical condition.

The purpose of the digital transformation of the bicycle rental service is to reduce the probability of getting a faulty bicycle to the consumer, thereby reducing the losses of the enterprise by increasing the popularity of this service among consumers.

2. Digital transformation of bicycle rental maintenance process

For successful digitalization of the service, it is necessary to use sensors and microcontrollers on board the rental bicycles, which collect and process information about various situations arising during the driving of the rental bicycle: falls, collisions, drifts, etc.

Bicycles used in bicycle rental are often equipped with an on-board computer, which can be supplemented with an electronic accelerometer [6].

Any bicycle as technical system consists of several subsystems:

- Braking system: pedals, chain drive, hand brake, foot brake;
- Control system: steering wheel, steering column;
- Comfort system: seat, shock absorbers, frame;
- Bicycle lighting system: reflectors, headlight, generator.

Identification and assessment of possible risks to the consumer associated with unsatisfying technical condition of the Bicycle rental is given in tables 1-4. The standard method of FMEA-analysis was used to assess possible risks [7].

| Table 1. FMEA-analysis of bicycle braking system. |
|--------------------------------------------------|
| Type of potential defect                  | Potential failure effects | Severity | Potential Causes | Occurrence | Current Controls | Detection | RPN |
| Consumer has difficulty moving or braking a bicycle | 1 Injury up to death | 10 | 1 Failure of braking system elements | 3 | Visually | 5 | 150 |
|                                          | 2 Reduced efficiency of the braking system | 7 | 2 Contamination of braking system elements | 4 | Visually | 3 | 84 |

| Table 2. FMEA-analysis of bicycle control system. |
|--------------------------------------------------|
| Type of potential defect                  | Potential failure effects | Severity | Potential Causes | Occurrence | Current Controls | Detection | RPN |


| Type of potential defect | Potential failure effects | Severity | Potential Causes | Occurrence | Current Controls | Detection | RPN |
|--------------------------|---------------------------|----------|-----------------|------------|------------------|-----------|-----|
| Consumer has difficulty driving | Injury up to death | 10 | Damage steering elements | 5 | Visually | 5 | 250 |
| | Reduced efficiency of steering | 7 | Contamination or lack of lubrication in the elements of the control system | 6 | Visually Organoleptic | 3 | 126 |

**Table 3. FMEA-analysis of bicycle comfort system.**

| Type of potential defect | Potential failure effects | Severity | Potential Causes | Occurrence | Current Controls | Detection | RPN |
|--------------------------|---------------------------|----------|-----------------|------------|------------------|-----------|-----|
| Consumer experiencing discomfort when driving on a bicycle | Getting a cyclist injury | 8 | Damage or theft of seat, frame, wheel | 2 | Visually | 1 | 16 |
| | Reduced comfort system efficiency | 7 | Failure of the bicycle adjustment system | 2 | Visually | 2 | 28 |
| | Increased vibration while driving | 5 | Wheel rim curved | 4 | Organoleptic | 5 | 100 |

**Table 4. FMEA-analysis of bicycle lighting system.**

| Type of potential defect | Potential failure effects | Severity | Potential Causes | Occurrence | Current Controls | Detection | RPN |
|--------------------------|---------------------------|----------|-----------------|------------|------------------|-----------|-----|
| Bicycle is poorly visible on the road at the dark | Serious injuries of a cyclist, up to death when a bicycle collides with another vehicle | 10 | Loss / theft of light reflectors or electrical equipment | 4 | Visually | 7 | 280 |
| | Getting a cyclist injury when a bicycle collides with an obstacle | 10 | Damage or contamination of light reflectors or electrical equipment | 4 | Visually | 5 | 200 |
| | | 10 | Failure of a bicycle's electrical equipment | 3 | Visually | 8 | 240 |
The highest risk is the risk of collision of transport with a bicycle in conditions of poor visibility, which can lead to serious injuries up to death.

Since the information about the current technical condition of the rental bicycle is ill defined, it is advisable to use fuzzy inference system, when creating a rule base which should use the information on the ratio of priority numbers of the risk (RPN), obtained from results of the FMEA-analysis above (figure 1).

![Figure 1. Inputs and outputs of the Sugeno fuzzy inference system for assessing the technical condition of the Bicycle based on data obtained from the accelerometer of the on-Board computer.](image)

Table 5. Linguistic variables, their ranges and values, types of membership functions and their parameters.

| Name of the linguistic variable | Range of the linguistic variable | Values of a linguistic variable | Type of the membership function in MatLab | Parameters of the membership function in MatLab |
|---------------------------------|---------------------------------|---------------------------------|------------------------------------------|-----------------------------------------------|
| $pMbrake$                       | 0…1                             | Low                             | trapmf                                    | [0.45 -0.05 0.05 0.45]                        |
| $pMcontrol$                     | 0…1                            | Medium                          | trapmf                                    | [0.05 0.45 0.55 0.95]                         |
| $pMcomfort$                     | 0…1                            | High                            | trapmf                                    | [0.55 0.95 1.05 1.45]                         |
| $TechCondition$                 | 0…100%                         | Dangerous                       | constant                                  | 0                                             |
|                                 |                                 | Bad                             | constant                                  | 25                                            |
|                                 |                                 | Normal                          | constant                                  | 50                                            |
|                                 |                                 | Good                            | constant                                  | 75                                            |
|                                 |                                 | Well                            | constant                                  | 100                                           |

Rule base for the created fuzzy inference system is given in table 6.

Table 6. Rule base for fuzzy inference system, shown in figure 1.

| Rule # | If $pMbrake$ is… and $pMcontrol$ is… and $pMcomfort$ is… Then $TechCondition$ is… |
|--------|-------------------------------------------------------------------------------------|
| 1      | low low low                                                                       | Well                              |
| 2      | low low medium                                                                     | Good                              |
| 3      | low low high                                                                       | Normal                            |
| 4      | low medium low                                                                    | Bad                               |
|   | Acceleration | Shock | Corresponding Probability |
|---|--------------|-------|---------------------------|
| 5 | low          | medium | medium                     |
| 6 | low          | medium | high                      |
| 7 | low          | high   | low                       |
| 8 | low          | high   | medium                    |
| 9 | low          | high   | high                      |
| 10| medium       | low    | low                       |
| 11| medium       | low    | medium                    |
| 12| medium       | high   | low                       |
| 13| medium       | medium | low                       |
| 14| medium       | medium | medium                    |
| 15| medium       | high   | low                       |
| 16| medium       | high   | low                       |
| 17| medium       | high   | medium                    |
| 18| medium       | high   | high                      |
| 19| high         | low    | low                       |
| 20| high         | low    | medium                    |
| 21| high         | low    | high                      |
| 22| high         | medium | low                       |
| 23| high         | medium | medium                    |
| 24| high         | medium | high                      |
| 25| high         | high   | low                       |
| 26| high         | high   | medium                    |
| 27| high         | high   | high                      |

The conceptual model of digital transformation of the process of bicycle rental maintenance is shown in figure 2.

**Figure 2.** Conceptual model of digital transformation of the process of bicycle rental maintenance.

During the operation of the bicycle mounted accelerometer records acceleration and shock, their amplitude and number. The more registered accelerations and shocks, the greater their value, the greater the corresponding probability of malfunction in the relevant bicycle subsystems. At the moment of returning the bicycle to the bicycle rental station, this information is transferred to the subsystem of forecasting the technical condition of the bicycle returned from the rental, using a fuzzy inference system (figure 1). Each bicycle, which is currently at the bicycle rental station, on the basis of the forecast is assigned a rating of its technical condition in the range from 0 to 100.
percent, where 0% corresponds to the dangerous technical condition, and 100% – «ideal» technical condition. In the future, depending on this rating, the following two situations are possible:

- The value of the technical condition rating is in the range from 0 to 30 percent – a cyclist can’t get the bicycle because of its possible dangerous condition;
- The value of the fuzzy inference system output is in the range of 31 to 100 percent – a cyclist can offer bicycle, the higher the technical condition rating, the greater the likelihood that its real technical condition is really good or excellent.

From the bicycle rental station, information on the technical condition of parked bicycles is transferred via Internet to the bicycle rental company server, where it is analyzed for the need for maintenance of damaged bicycle, as well as, for example, to find hidden patterns.

3. Conclusion
The implementation of this solution should allow to reduce the losses of bicycle rental companies, as well as to reduce the number of accidents with cyclists caused by the possible unsatisfactory technical condition of the bicycle rental.

The proposed approach is also valid for companies engaged in the rental of boats, scooters, personal electric vehicles.

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