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BASIC BIODEGRADATION METHODS OF MATERIALS

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Keywords: biodegradation, methods, testing, properties of material.
Abstract: Biodegradable materials and their applications are now a widespread topic of scientific activities and publications, mainly due to their ever-expanding possibilities for use in biomedical fields. Advances in the study and evaluation of materials often require different methods to determine the properties and consequences of degradation, whether changes in structure, mass changes, morphological changes or differences in the mechanical properties of the material before and after degradation. The aim of this work is to summarize the available and used methods, as well as to compare the information obtained for the design of a suitable method. The procedures are described on the basis of studies that have addressed the issue of biodegradation of materials using in vitro methods.

1 Introduction

Degradation of materials in different environments, depending on their use, is generally a frequently observed phenomenon in a wide range of disciplines, not excluding biomedical engineering. In the case of degradation assessment in a simulated human environment, it is possible to speak of a phenomenon called biodegradation.

Materials are generally prone to degradation to some extent due to various factors. In general, there are three basic categories of material degradation - physical, chemical and biological. Physical refers to the effect of force, heat, or radiation. Degradation of chemical origin refers to the destructive reactions between a material and the substances that come into contact with it. Biological degradation involves all interactions between living organisms or microorganisms and materials [1,2].

In industrial practice, degradation is a negative rather than a positive phenomenon, mainly due to changes in the structure of materials, which results in undesirable changes in the properties of materials. This can lead to reduced safety, reduced operational efficiency, but also economic problems. Degradation is therefore understood to mean processes of mostly continuous and irreversible deterioration of material properties. However, there are industries (eg ecology or bioengineering) where degradation may be desirable, in the form of biodegradable materials. Biodegradability and compostability are types of material degradation in specific environments [2].

Degradation mechanisms are closely related to chemical structures, molecular weights, the presence of microorganisms and environmental conditions. The protection of materials can be achieved to some extent by surface engineering and control of the physical, chemical and biological environment so that the surfaces of the materials are as inert as possible [3].

1.1 Mechanisms of material damage

Degradation can be initiated by external influences such as heat, humidity, chemicals, exposure to UV radiation, mold or bacteria and is promoted by mechanical stress. There are many ways in which degradation can occur. One of the most common ways is wear, for example, when material is constantly rubbing against another material. A form of degradation that affects many types of polymers is degradation caused by ultraviolet light, which affects the internal bonds of polymers. Chemical degradation is another process that can make the material less useful over time (e.g., exposing steel to hydrochloric acid).

Degradation processes often coexist in combined forms, such as corrosive wear or the occurrence of stress cracks due to the environment, where at least two degradants are involved in the degradation. While in the case of one degradant it would be a subthreshold level of damage, in combination the material fails. The most common mechanisms of damage are corrosion, wear and fatigue of the material [2,3].

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1.2 Principles of biodegradation

Biodegradability of materials is nowadays a very desirable process, especially with regard to the environment, but also in the case of other fields such as. medicine, where such materials have enormous potential. Some microorganisms have a naturally occurring ability to degrade, transform, or accumulate vast amounts of compounds, including hydrocarbons, polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), pharmaceuticals, radionuclides, and metals [4].

Thus, biodegradation is generally a process of decomposition of a substance by living microbial organisms. Microorganisms are one of the most adaptable biological species in the world and there is a huge amount that can contribute to degradation in different conditions. These organisms are secreted by enzymes, which break down the substance into smaller compounds by metabolic and enzymatic processes [5].

A very important factor for biodegradation is the presence or absence of oxygen. Based on this, it may be aerobic or anaerobic biodegradation [6].

The process of biodegradation can occur in different environments, which has a great influence on the course and rate of degradation. Biodegradation in marine, freshwater, soil and composting conditions is most often assessed. The behavior of materials in different conditions is different, but all environments are suitable for certain microorganisms [7].

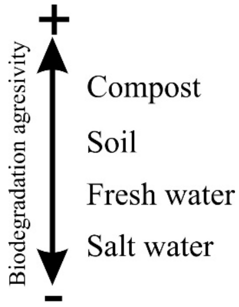

Figure 1Agresivity of biodegradation depending on environment

It is thus a systematic and complete mechanical, physical and chemical change in which the material is broken down by biotic microorganisms such as bacteria, fungi or yeast, supported by abiotic ecosystem factors such as climate and environmental conditions (i.e. acidity, humidity, temperature etc.) [3].

1.3 Biodegradation methods

Historically, biodegradation test methods were first developed for chemicals in wastewater, with the first protocols published by the OECD (Organization for Economic Cooperation and Development) in 1981. Later, biodegradation methods for other environments and also for other materials were described. In addition to the OECD, similar procedures have been published by ISO (International Standards), ASTM (American Standards), EN (European Standards), JIS (Japanese Standards) and various other national standards organizations [8,9].

In nature, biodegradation is influenced by several environmental factors and is mainly caused by enzymes produced by microorganisms, but other mechanisms may also be involved. However, during testing, conditions should be kept as constant as possible to ensure repeatability of results. It is therefore important to choose the most appropriate testing method [10].

In general, biodegradation can be assessed by two basic methods:

• *in vivo* - a method of evaluating the behavior of a biological system in its natural environment,

• *in vitro* - in experimental biology, these are methods that are performed using components isolated from their usual biological environment.

In vitro or in vivo degradation of a substance can be characterized as:

a) a primary change in the chemical structure of the substance that leads to the loss of specific properties of the substance,

(b) environmentally friendly; biodegradation to such an extent that the undesirable properties of the compound are eliminated,

c) final complete decomposition of the compound; either fully oxidized or reduced single molecules such as carbon dioxide / methane, nitrate / ammonium and water [11].

1.4 Comparison of in vitro and in vivo methods

The *in vitro* study is performed in a controlled environment, such as a test tube or petri dish. In vivo is the Latin term for "live". It refers to tests, experiments, and procedures that researchers perform on a living organism (person, laboratory animal, or plant).

While in vivo methods are usually time consuming, *in vitro* methods are fast and cost-effective methods that provide a necessary and useful complement to in vivo studies in materials testing. *In vitro* testing is a straightforward research methodology that allows more detailed analyzes and biological effects to be performed on a larger number of *in vitro* subjects than they would in animal or human experiments [12].

2 Biodegradation testing

Currently, regulations require that biodegradability claims be based on aerobic biodegradability, which usually measures oxygen consumption, CO2 production and the state of inorganic carbon intermediates. For the aerobic environment, biodegradability is measured on the basis of CO2 analysis. For an anaerobic environment, a parameter is used, which is the amount of Dissolved Organic Carbon (DOC) [13].

There are tests simulating different conditions (aquatic, terrestrial, biological conditions of the human body), based on static, semi-continuous or continuous principles, operated under aerobic or anaerobic conditions. In any of these tests, the following important factors affect biodegradation [3,11]:

• the concentration of test material, which should be high enough for the analytical methods chosen, but low enough for toxic substances or if actual environmental concentrations are to be simulated;

• physico-chemical properties of tested substances (solubility, volatility, ...)

• composition and concentration of inorganic nutrients in the test medium;

• the presence or absence of other degradable substances in the same medium for cometabolic processes;

• conditions and properties of test systems, such as volume and shape of test vessels, open or closed bottles, temperature, method of mixing or shaking, and oxygen supply;

• test duration.

In Figure 2 it can be seen the available test methods used for each degradation condition. In general, they can be divided into laboratory, simulation and field tests.

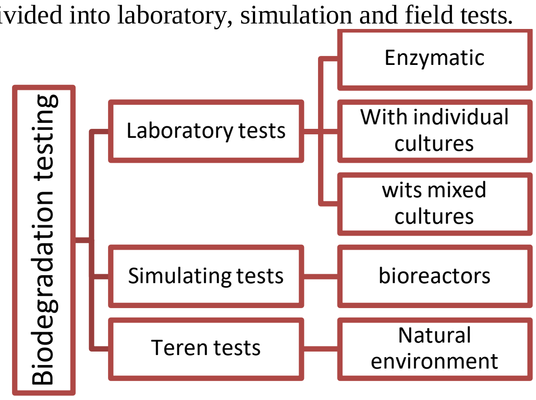

Figure 2Methodsof biodegradation testing

Laboratory tests are a suitable analytical tool for the assessment of biodegradation, while providing a synthetically generated environment with defined conditions and their results are best reproducible. Simulation tests are performed in special bioreactors that provide complex and well-defined environmental conditions. Field tests are the most appropriate choice in terms of relevance, as the material degrades directly under the natural conditions of its use, but due to the variability of environmental conditions, in most cases it is not possible to verify the results of these tests by repeated studies [14].

2.1 Factors influencing biodegradation

The basic biotic factor is the metabolic capacity of microorganisms. The rate of degradation often depends on the concentration of the substance and the number of organisms capable of metabolizing the substance [15].

Another important factor is nutrients and oxygen. Microorganisms need macronutrients and micronutrients to synthesize cellular components. In order to avoid uncontrollable microbial growth, it is necessary that sufficient nutrients and oxygen are available in a usable form and in the right proportions [3,7].

Parameters such as humidity, temperature, pH, presence resp. the absence of oxygen and the supply of the nutrients already mentioned therefore have a significant effect on the microbial degradation of the materials and must be taken into account in determining the degradation [7].

2.2 Biodegradation assessment parameters

Biodegradation is associated with several processes such as oxygen consumption, carbon dioxide formation, chemical surface change or physical losses, which are observable in the sample. There are 2 key aspects to biodegradation testing:

1. degradation parameters: weight loss, molecular weight decrease, dimensional change, deterioration of mechanical properties and analysis of surface chemistry.
2. biodegradability.

Different types of analysis methods are used for evaluation, depending on the type of parameter being assessed. Frequently used methods in the first stages of degradation are X-ray photoelectron spectroscopy (XPS), scanning electron microscopy (SEM) or infrared spectroscopy (IRS), which are used to assess surface changes [12].

In the later stages of degradation, other parameters such as weight loss, changes in molecular weight, temperature or mechanical properties are evaluated on the basis of mass analysis. The assessment of biodegradability is determined by measuring the conversion of carbon to carbon dioxide (and methane in the case of anaerobic conditions) [16].

2.2.1 Chemical development

The basic process in aerobic biodegradation is the oxidation of carbon-based organic substances, which leads to the conversion of carbon to carbon dioxide. A certain amount of carbon may remain present in the sample as residual carbon [17].

Respirometry or the Sturm test are most often used to evaluate chemical development. In principle, these are very similar tests, with the difference that while the Sturm test accurately measures carbon dioxide production and biodegradation is determined as $C \rightarrow CO_2$ conversion, in the case of respirometric tests, O_2 consumption is measured instead of CO_2 production [5,14].

2.2.2 Weight

Mass loss is the most basic and widespread consequence and indicator of degradation. Weight loss measurement is a common method for detecting the biodegradation of various insoluble materials.

For example, Shrivastava et al. used weight loss as one way to detect the biodegradation of wool by two species of fungi, with weight losses of 58% and 22% for individual fungal cultures after 4 weeks of incubation.

Typically, the analysis of this property is performed by means of an experimental measurement, which consists of collecting mass data at different times (before, during and after the degradation process). Before each weighing, the sample must be decontaminated (using distilled or deionized water) and dried. The material can be dehumidified in three ways [18]:

- Mechanically (centrifugation, pressing, ...)
- By the action of heat (dryers)
- Physico-chemical.

2.2.3 Morphology

Biodegradation leads to a significant change in the surface structure of the material. Its process leads to continuous disruption of the sample surface, which results in the formation of cracks, microcracks and other defects, as well as changes in the dimensions of the sample [19].

Prior to analysis, the sample is usually cleaned or otherwise adjusted for microscopy. Different materials require different sample preparation procedures (grinding, polishing, etching, etc.). In the case of electron microscopy, the sample must be thoroughly dried to prevent deterioration. The samples are dehydrated by immersion in acetone. The sample is then poured into synthetic resin, cured by polymerization and post-treated (trimming, grinding) [20].

Table 1Mechanical properties and methods of testing

Mechanical property	Method of testing
Elasticity / plasticity	Compression, tensile tests, twist and bend
Stiffness, static load behavior	
Creep of the material	Creep test
Hardness	Brinell, Rockwell, Vickers exams
Toughness	Impact tests
Fatigue behavior	Wöhler fatigue test

2.2.4 Mechanical properties

One of the other consequences of biodegradation is a reduction in mechanical properties due to the disruption of the crystalline structures of the material. Mechanical properties belong to the quantitative parameters of degradation assessment, and the basis is the observation and assessment of the behavior of the material under external mechanical stress. Standardized tests are used for testing, which ensure uniform procedures for mutual comparison of material properties [20,21].

The tests cover a wide range of materials, using common test methods such as bending tests, tensile and compression tests, wear tests, fatigue tests, etc. The choice of method depends on the property of the sample under consideration.

2.2.5 Surface chemistry

The final design of materials depends, among other properties, to a large extent on their surface microstructure and behavior. In this respect, surfaces play an important role in many technological processes such as catalysis, corrosion and adhesions, these processes depending on the chemical composition of the interface [18,22].

The study of surfaces and surface phenomena at the atomic or molecular level is therefore an essential scientific field. Surface chemical analysis is a term covering a range of analytical techniques used to determine the elements and molecules present in the outer layers of solid samples.

The most commonly used techniques are Fourier Transform Infrared (FTIR) spectroscopy, X-ray photoelectron spectroscopy (XPS), secondary ion mass spectrometry (SIMS) and contact angle measurement [23].

3 Design of *in vitro* degradation methods for materials

Given the similarity of the methodological procedures included in the study review, this part of the work is rather a summary of the possibilities within the methods that can be used in the assessment of *in vitro* degradation of materials. Some procedures such as corrosion ratings are specific only for metallic materials. In Figure 3 we can see a schematic of the methodological procedure that followed all the studies presented in this work.

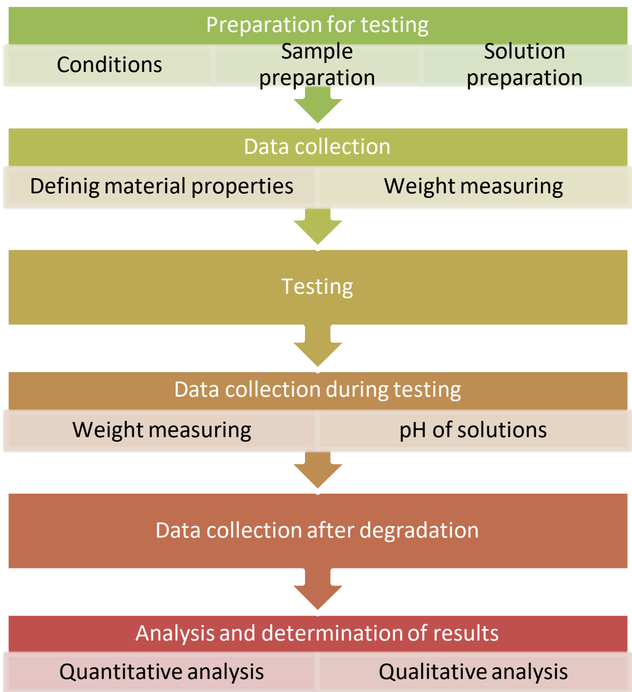

Figure 3process of testing

3.1 Choice of test method

In all the studies described in this work, agreement was found in the choice of test method. The research was based on testing by immersing samples in solution, ie on the so-called immersion test, which is a suitable method for determining biodegradation in simulated human fluid. It is also one of the most widely used methods for assessing metal corrosion.

The principle of the test is to place (immerse) the sample in a suitably selected medium for a fixed period of time, which may be interrupted in order to obtain the necessary data (eg weighing or changing the solution). Samples are weighed before, during and after testing. During testing, it is necessary to monitor and correct the pH value and also maintain the selected temperature, within the deviation.

According to the ASTM Manual for Laboratory Submersible Corrosion Testing of Metals, a versatile device should be used, most often consisting of a suitably sized flask (500-5000 ml), a reflux condenser with an atmospheric seal, an atomizing or aerating atomizer, a thermometer vessel and a temperature control device, heating equipment and sample support system. However, the equipment selected in this way is explicitly characterized for corrosion assessment.

3.2 Test conditions

The basic parameters that need to be determined in the biodegradation test are the temperature, the degradation medium with a suitable pH, as well as the duration of the test. Testing conditions vary for different materials and their uses and may vary from research to research. However, in order to obtain relevant results, it is important to maintain the input conditions throughout the process within tolerable deviations.

3.2.1 Test duration

The total duration of testing is very different compared to the studies, ranging from a few days, weeks to months. Some studies may take a year or more. The testing time chosen may depend on the potential use of the material. E.g. Bone defects usually heal much longer, so degradation behaviour should be monitored over a much longer period of time.

3.2.2 Temperature and pH value

In general, the test solution and in particular the pH have a significant effect on the outcome of the degradation experiments. A key issue for biodegradation is the simulation of physiological conditions occurring in living organisms. For this reason, the most frequently chosen pH is 7.4 and the temperature is 37 ° C (± 1 ° C), which was uniformly chosen in each of the studies. Thus, it can be argued that the most suitable values for biodegradation testing, independent of the material tested, are pH 7.4 and a temperature of 37 ° C.

3.2.3 Degradation medium

The required pH can be achieved with several solutions. Graph 3 shows that the most commonly used medium is the PBS solution used in a total of four experiments. The second is SBF, but it was used in only two studies (Zn alloy and glass-ceramics). In addition to these solutions, however, it is possible to use e.g. also Hanks' solution (HBSS), which has been used in other studies (but these are not specified). According to an overview of solutions used in the degradation of metallic materials by Di Mei et. Al. the use of complex saline solutions as a degradation medium for the Mg corrosion test for biomedical use is not completely reliable. Although PBS solutions provide a more complicated test environment such as NaCl solution, they lack several important inorganic ions (eg Ca 2+, carbonates or phosphates), which have a significant effect on Mg corrosion.

3.2.4 Data collecting

Data collection took place a total of three times during each test in each of the studies, before, during, and after degradation. The first measurement was performed on the initial characteristics of the material in terms of weight, mechanical properties and surface evaluation. The last measurement (i.e. after degradation) is in principle identical to the first measurement and is necessary to compare the results obtained. Data measurement during the test was focused only on data collection and pH control of the degradation medium.

Weighing is an integral part of degradation assessment and is one of the main parameters of the degree of degradation. It takes place throughout the process at various time intervals. However, weighing should be preceded by drying of the samples due to the absorption of the samples by the solution during the immersion time. However, not all studies report the drying process as part of the procedure.

Various methods were used to analyse the data obtained in the studies. The most commonly used (in all studies) was the SEM method, for surface evaluation. FTIR analysis is also relatively numerous, it was omitted only in the studies of metallic materials, while in them the analysis used by optical microscopy was the only one used. In addition to the conventional methods mentioned, other methods such as BEI, SEC or XRD were used in the studies.

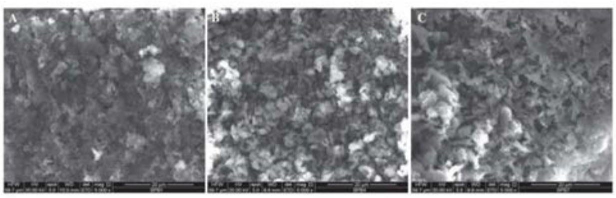

Figure 4 SEM analysis of polymer surface after 1, 4 and 7 weeks of in vitro degradation [18]

4 Conclusions

Today, there are a relatively large number of different methods for evaluating the effects of biodegradation processes affecting a material. These are most often in vivo or *in vitro* methods, which provide a wealth of information about the behaviour of the material directly in a living organism or in a solution of simulated human fluid. However, the procedures and methods chosen for biodegradation testing often differ, which can be confusing when selecting test methods for research in this area.

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WORKERS FLOW AND ON-TIME COMPLETION OF CONSTRUCTION PROJECTS

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Keywords: workers-stages assignment, maximum flow problem, construction planning.
Abstract: The construction sector is one of the most important economic activities since it is responsible for planning, designing, and developing the infrastructure that social development requires, such as roads, schools, and hospitals. Thus, the late completion of construction projects may harm social welfare. Construction companies have problems coping with completion times since they simultaneously manage multiple infrastructure projects that differ in the number of workers they need and the possibility of having projects whose development overlaps. So, companies split their projects into development stages to simplify the management of construction projects, which require an efficient allocation of workers to cope with the stages' activities. This paper analyzes the distribution of workers among development stages to cope with the projects' completion times. Noticing that not all workers should participate in the same development stage of a single project, the previous problem casts similarities with the maximum flow problem. We follow this modeling approach to determine the number of workers participating at each development stage when a company simultaneously manages more than one construction project. Later, we apply the previous model for a company that operates 11 projects and has 24 workers; the maximum workers' flow model sets the number of workers that each development stage needs for the on-time completion of the 11 projects by considering three different scenarios, concerning the overlapping of development stages.

1 Introduction

Due to the high costs associated with construction projects, sponsorship-based tenders are common for increasing the competitiveness and efficiency within the sector in the realization of infrastructure projects [1], in order to avoid a crisis management [2]. Sponsorship-based tenders are competition systems that assign projects to those companies that offer low construction costs at a reasonable completion time. In other words, these assignment mechanisms pretend to reduce projects' costs while parallelly coping with completion times. Although tenders have succeeded in lowering costs [3], the on-time completion of these projects remains a challenge since companies simultaneously manage several projects with different features.

For the on-time completion of each project, construction companies split their projects into development stages, when they manage different projects at the same time. However, the complexity of this strategy increases as stages overlap with other projects' stages because each phase requires a different number of workers. For example, the initial stages tend to be more labor-intensive than the last stages, which implies that the initial stage needs more workers than the last stages. Hence, construction companies characterize by having permanent and eventual workers during the completion of a project [4]. Even more, the empirical evidence points out that late completion times are caused by an inadequate allocation of workers among stages when companies are in charge of several projects [5].

In this paper, we analyze the previous allocation problem for the case of a construction firm that manages 11 projects with different completion times. The company splits them into development stages, and each requires a different quantity of workers. Since projects' stages develop similar activities, workers can 'flow' from one project to another whenever a stage requires them. So, the previous problem casts similarities with the maximum flow problem of Ford and Fulkerson [6]. In other words, our modeling approach considers that workers move on a bipartite network whose nodes represent stages and projects; and arrows go from stages to projects. So, arrows indicate the stages that a project needs for its on-time completion. Moreover, the arrow's weight is the maximum number of required workers at some stage.

Typically, the maximum flow problem determines the maximum amount of some resource from a source node to a destination node, satisfying capacity constraints. For example, Karshenas and Haber propose a piecewise linear objective function to minimize the total project cost through the maximum flow problem [7]. However, Gorham [8] demonstrates that this approach can assign training personnel in the U.S. Air Force at a lower cost. In recent years, Gorham's ideas have been applied to industries like textile [9], automotive [10], aeronautics [11], and manufacturing [12] to optimize human resources.

Our paper is closely related to the previous literature. Specifically, we apply Gorham's ideas for the construction industry, one of the most important sectors within a country since it generates and maintains the infrastructure that other industries use [13]. So, we analyze three different scenarios that consider different starting and ending stages by considering data from a construction enterprise that simultaneously manages several projects. In other words, our assignment procedure is flexible enough to deal with problematic situations that are either beyond control and often lead to delays. In comparison, the traditional approach of planning and controlling projects tends to fail mainly because of too much precise control, which curtails creativity from playing a crucial role in construction [14].

2 Methodology

The allocation of temporary workers among development stages for projects' on-time completion casts similarities with a maximum flow problem. As we mentioned before, a worker may 'flow' from project to project whenever their skills are needed at a particular stage. However, if the construction company is in charge of several projects, it needs to allocate such workers to cope with the completion times of all its projects. We model the workers' flow by considering a network $\boldsymbol{N} = (\boldsymbol{X}, \boldsymbol{A})$, where $\boldsymbol{X}$ is the set of nodes and $\boldsymbol{A}$ is the set of arrows.

We assume that $\boldsymbol{N}$ is a bipartite network, i.e., $\boldsymbol{X}$ is partitioned into two sets, a set of nodes that represent periods, $\boldsymbol{S} = \mathbf{1}, \mathbf{2}, \ldots, \boldsymbol{n}$, and a set of nodes that represent projects, $\boldsymbol{P} = \boldsymbol{p_1}, \boldsymbol{p_2}, \ldots, \boldsymbol{p_m}$. A generic period is denoted by $\boldsymbol{i}$, while a generic project is denoted by $\boldsymbol{p_j}$ or $\boldsymbol{p}$. So, an arrow $\boldsymbol{ip}$ is an arc from some stage $\boldsymbol{i}$ in $\boldsymbol{S}$ to some project $\boldsymbol{p}$ in $\boldsymbol{P}$. Since $\boldsymbol{N}$ is bipartite, there are no arrows from $\boldsymbol{S}$ to $\boldsymbol{S}$, or from $\boldsymbol{P}$ to $\boldsymbol{P}$. We consider that $\boldsymbol{S}$ is a well-ordered set concerning time development, i.e., the company starts construction activities in period 1, and ends its operations during period $\boldsymbol{n}$.

Assumption 1. $\boldsymbol{\Gamma}^-(\boldsymbol{p}) = \{\boldsymbol{i} \in \boldsymbol{S} | \boldsymbol{ip} \in \boldsymbol{A}\}$ is the set of all periods in which the construction company develops activities for completing project $\boldsymbol{p}$.

By Assumption 1, the on-time completion of project p requests $|\boldsymbol{\Gamma}^-(\boldsymbol{p})|$ periods. Even more, note that we can interpret periods in $\boldsymbol{\Gamma}^-(\boldsymbol{p})$ as development stages for project $\boldsymbol{p}$. Since $\boldsymbol{S}$ is a well-ordered set, the initial development stage of $\boldsymbol{p}$ is $\mathbf{min}\{\boldsymbol{\Gamma}^-(\boldsymbol{p})\}$, while the last stage of project $\boldsymbol{p}$ is $\mathbf{max}\{\boldsymbol{\Gamma}^+(\boldsymbol{p})\}$.

To analyze the allocation of workers among projects as a flow problem, we consider the network $\boldsymbol{N} = (\overline{\boldsymbol{X}}, \overline{\boldsymbol{A}})$ such that:

1. $\overline{\boldsymbol{X}} = \{\boldsymbol{s}, \boldsymbol{t}\}$ where $\boldsymbol{s}$ and $\boldsymbol{t}$ are the source and terminal nodes, respectively.
2. $\overline{\boldsymbol{A}} = \boldsymbol{A} \cup \{\boldsymbol{si} | \boldsymbol{i} \in \boldsymbol{S}\} \cup \{\boldsymbol{pt} | \boldsymbol{p} \in \boldsymbol{P}\}$.

A generic arrow in $\overline{\boldsymbol{A}}$ is denoted by $\boldsymbol{\iota\kappa}$.

Quintana [15] points out that each arrow can be considered as a conduit with a capacity that indicates the maximum number of workers that can flow through it. The capacity of an arrow $\boldsymbol{\iota\kappa}$ is a non-negative constant $\boldsymbol{q}(\boldsymbol{\iota\kappa})$, while the flow $\boldsymbol{f}(\boldsymbol{\iota\kappa})$ is a non-negative function $\boldsymbol{f}$ from $\overline{\boldsymbol{A}}$ to $\boldsymbol{R}_+$. Due to the construction company has constraints for hiring additional workers, the flow does not exceed the capacity, i.e., $\boldsymbol{f}(\boldsymbol{\iota\kappa}) \leq \boldsymbol{q}(\boldsymbol{\iota\kappa})$, for all $\boldsymbol{\iota\kappa} \in \overline{\boldsymbol{A}}$. The source and terminal nodes are artificial nodes that allow us to establish the following features concerning the total number of workers and completion times:

1. All workers can flow from $\boldsymbol{s}$ to any vertex $\boldsymbol{i} \in \boldsymbol{X}$. We assume that the total number of workers in the company is $\boldsymbol{K}$, i.e., $\boldsymbol{q}(\boldsymbol{si}) = \boldsymbol{K}$ for all $\boldsymbol{i} \in \boldsymbol{X}$.
2. Weights $\boldsymbol{q}(\boldsymbol{pt})$ indicates the number of workers each project needs for on-time completion.

Given the previous constraints, the workers-projects allocation problem is to find the maximum flow of workers that each project's stage needs for on-time completion. Below, we present the mathematical model that summarizes the previous problem.

$$\boldsymbol{Max\, z} = \boldsymbol{x_{ts}} \tag{1}$$

subject to

$$\sum_{\boldsymbol{\kappa}:\, \boldsymbol{\iota\kappa} \in \overline{A}} \boldsymbol{f}(\boldsymbol{\iota\kappa}) - \sum_{\boldsymbol{\kappa}:\, \boldsymbol{\kappa\iota} \in \overline{A}} \boldsymbol{f}(\boldsymbol{\kappa\iota}) = \begin{cases} \boldsymbol{x_{ts}}, & \textbf{if } \boldsymbol{\iota} = \boldsymbol{s} \\ \mathbf{0}, & \textbf{if } \boldsymbol{\iota} = \boldsymbol{\kappa} \\ -\boldsymbol{x_{ts}}, & \textbf{if } \boldsymbol{\iota} = \boldsymbol{t} \end{cases} \tag{2}$$

$$\mathbf{0} \leq \boldsymbol{f}(\boldsymbol{\iota\kappa}) \leq \boldsymbol{q}(\boldsymbol{\iota\kappa}) \tag{3}$$

Expression (1) establishes the objective function of our problem, i.e., to maximize the number of workers that should flow from the source node to the terminal node. Expression (2) illustrates flow constraints related to the total number of workers that flow through the network $\overline{\boldsymbol{N}}$. Specifically, the number of workers that depart from the source node must equal the number of workers that arrive in the terminal node. At the same time, flow's conservation is satisfied in middle nodes, which means a flow equal to zero. In other words, the number of workers that start working in a project's stage is the same that leaves the project. Finally, the worker's flow in an arrow must not exceed the maximum capacity of such an arrow, expression (3) requires.

3 Data description

The construction company that we analyse is in charge of eleven projects, which the company got from participating in public sponsorship-based tenders. All projects have the same completion time, 45 days, and the company splits all projects into three development stages of 15 days. Moreover, the company has a total labour force of 24 workers, and each development stage needs at most 14 workers.

Table 1 Data of the construction company

Workers	Projects	Project completion time (in days)	Stage duration (in days)	Work year (in days)
24	11	45	15	360

Despite the construction company's efforts to cope with the on-time completion of its projects, it struggles to reach this goal. More than 14 workers are assigned to some developmental stages, according to historical data. At the same time, some projects start their development many periods after the company gets it because there are no available workers. In other words, projects' construction does not initiate because the company's assignment mechanism does not allow the ow of workers from projects, where they are not necessary, to new projects. We apply the maximum ow problem explained in the previous section to deal with this problem.

4 Results and discussion

This section solves the maximum flow problem described in Section 2 by considering the company's features summarized in Table 1. Since the maximum flow problem is a linear programming model, we use the LINGO 11 software to compute its solutions. Below, we present and explain the model's code.

MODEL:
SETS:
We first set the variables of the maximum flow model. So, we establish the total number of nodes and arrows describing the network under workers from one development stage to another. The cardinality of the nodes set is n = 37 because we have 11 projects, 24 development phases, and the initial and terminal nodes.

NODES / 1. . . *n* /:
Before specifying the arrows set, it is essential to remember that the maximum ow problem unfolds on a network whose nodes play different roles. Hence, nodes represent development stages and projects, but we also include a source and a sink, nodes one and n, to describe the problem as a linear programming model. Consequently, the arrows' set includes arrows from the source node to all stages, while all projects should be connected with the sink node. It is worth recalling that arrows from stages to projects depend on the period where the company gets the project. So, all projects may start and finish during the same development stages, or the initial stage may overlap with the last stage of particular projects. In the following subsections, we present networks that illustrate the company's current scenario and other possibilities.

ARROWS (NODES, NODES):
ENDSETS:
The objective is to maximize the flow of workers that go from the sink node to the source node.

MAX: FLOW (N,1)
Now, we describe the problem's constraints. First, we set the capacity constraints

@FOR(ARCOS(I,J):FLUJO(I,J)<=CAPACIDAD(I,J)):
Later, we establish the flow conservation constraints

@FOR(NODOS(I):@SUM(ARCOS(J,I):FLUJO(J,I)) =@SUM(ARCOS(I,J):FLUJO(I,J))):
Finally, the data that our model needs summarize arrows capacities.

DATA: *For each arrow, we need to specify its capacity, i.e., the maximum number of workers that can flow through them. Note that arrows with nodes not in $\{s,t\}$ have a maximum capacity of 14, while arrows from the source node to stages have a capacity of 24 workers. Also, arrows from projects to the sink node have a capacity constraint of 14 because it represents the maximum number of workers needed to complete a project in 45 days.*

CAPACITY:
ENDDATA:
END:
In the following subsections, we discuss three possible scenarios. The first one is the construction company's situation at the moment of our study; such a scenario considers that the company needs to plan the year to initialize and terminate a project because it has already gotten the 11 projects. The other two examples show the flexibility of our modeling approach by specifying the stages where projects arrive and should finish. The complete codes for each scenario are shown in the Appendices.

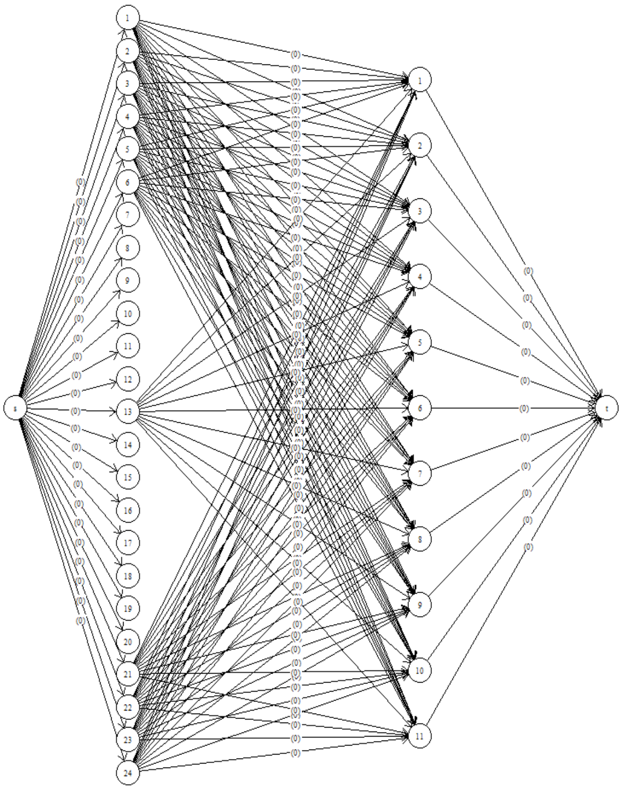
4.1 Scenario 1 (the current situation)

Nowadays, the construction company is in charge of 11 projects whose arrival was characterized by the lack of planning from the company's managers. Since the company needs to complete each task by using its workers for 45 days, we assume that the company can carry out and complete any project at any period. So, in the network where workers ow, the set of arrows whose initial or final nodes are not in $\{s,t\}$ is:

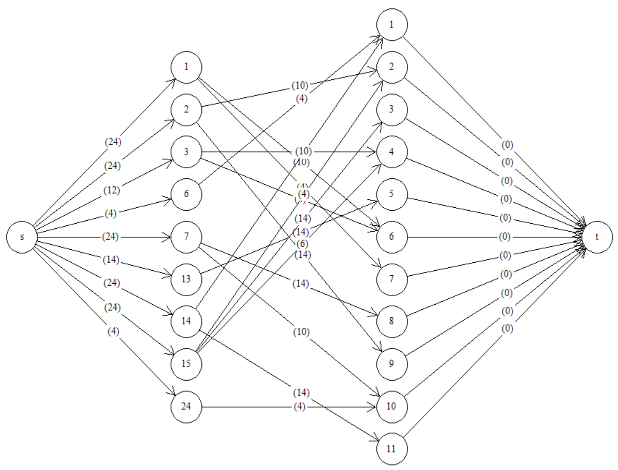
$$A = S \times P \quad (4)$$

that is to say, for all $\iota \in S$ and $p \in P$, there exists an arrow ιp in $\bar{A}$.

In other words, the previous scenario is represented by a complete bipartite network when we only consider nodes in S and P. Figure 1a illustrates the network that serves the case where the company is not sure of the initial and final stages of its eleven projects. We use the LINGO software to solve the maximum ow problem represented in Figure 1a. The results show that the company can complete each project in two stages. Table 2 indicates the initial and final stages and the number of workers that the company needs to cope with completion dates.



(a) Network



(b) Results

Figure 1 Scenario 1: Any project can start and terminate at any period

In other words, the projects' features allow the company to cope with completion times in a year. When the company does not have specific delivery stages, it is possible to allocate the necessary workers to complete a project in only one stage. Figure 1b illustrates this solution.

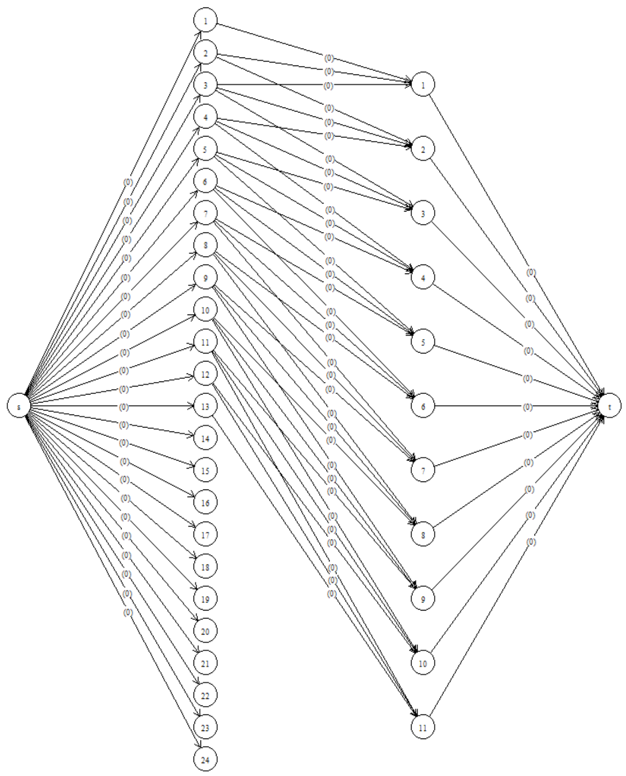
Table 2 Allocation of workers by initial and final stages

Project	Initial Stage	Number of workers	Final Stage	Number of workers
1	6	4	14	10
2	2	10	15	4
3	15	14		
4	3	8	15	6
5	5	14		
6	1	10	3	4
7	1	14		
8	7	14		
9	2	14		
10	7	10	24	4
11	14	14		

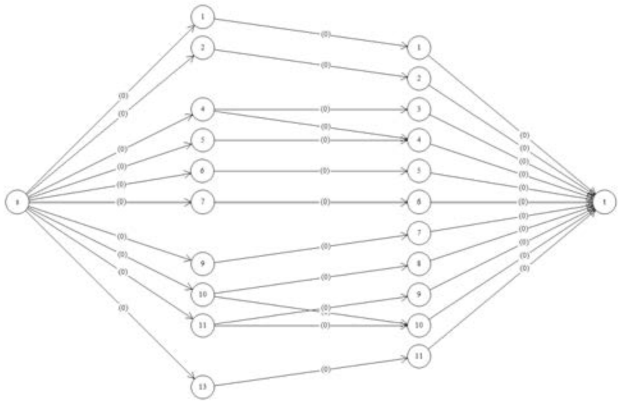
4.2 Scenario 2

Although the previous analysis allows the company to plan the number of active workers at each project during a year, it is common that the initial and final stages of different projects overlap. Our second scenario analysis is based on the previous observation.

Hence, we consider that the construction company carries out a new project halfway through completing a project; that is to say, the company starts a new project in the second development stage of a previous project. Also, we consider the existence of a tight completion time. For example, we have that project 2 starts during period 2, which implies that it should finish at period 4. Figure 2 illustrates this scenario.



(a) Network



(b) Results

Figure 2 Scenario 2: Projects begin in the intermediate stage of a previous project

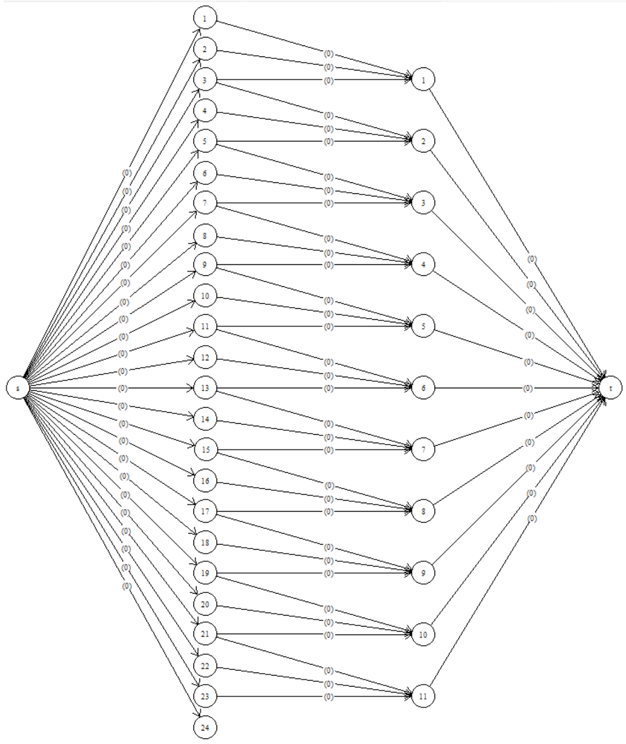
As before, we use LINGO to solve the maximum ow problem by considering the network in Figure 2a. Table 3 summarizes the number of workers that need to work on each project during a particular stage. As before, we observe that no project is completed in three stages; even more, it is possible to complete a project by assigning 14 workers in only one development stage.

Table 3 Allocation of workers by considering the second scenario

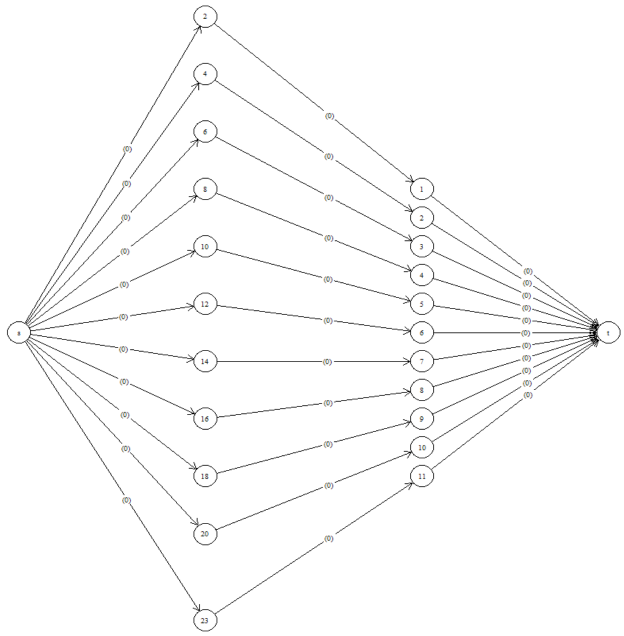
Project	Initial Stage	Number of workers	Final Stage	Number of workers
1	1	14		
2	2	14	15	4
3	4	14		
4	4	4	5	10
5	6	14		
6	7	14	3	4
7	9	14		
8	10	14		
9	11	14		
10	10	4	11	10
11	13	14		

4.3 Scenario 3

In the third scenario, we assume the company does not start a new project in the middle of a previous project. This means that the company accepts a new project in the last development stage of a given project, see Figure 3a.



(a) Network



(b) Results

Figure 3 Scenario 3: Initial and final stages overlap

Using the LINGO software, we observe the company can assign the maximum number of workers in only one stage. Table 4 presents the stage under which each project is completed, while Figure 3 illustrates this result.

Table 4 Allocation of workers by initial and final stages

Project	Initial Stage	Number of workers
1	2	14
2	4	14
3	6	14
4	8	14
5	10	14
6	12	14
7	14	14
8	16	14
9	18	14
10	20	14
11	13	14

5 Conclusions

In this paper, we analyse the number of workers that development stages need for the on-time completion of simultaneous construction projects. Since development stages may overlap, companies need to distribute workers across them. Graphically, we represent the previous problem through a bilateral directed network that links development stages with projects. We assume that stages nodes are ordered; consequently, the arrows that arrive at each project summarize the time the company can spend on a project. So, in this manner, we capture the projects' completion times. Moreover, we weight each arrow by considering the maximum number of workers participating in the stage node where the arrow departs. Consequently, the maximum flow problem determines the number of workers each stage needs to cope with projects' completion times.

To exemplify our model, we consider a company that manages 11 projects and only has 24 workers. We use LINGO to determine the distribution of workers in the development stages of each project. Our results indicate that the company has enough staff to carry out the 11 projects over a year. In addition, we compare different scenarios where the projects differ in their initial and final stages. So, the modelling approach allows us to compare the distribution of workers when overlapping development stages change; that is to say, the maximum flow model is flexible enough to analyse different scenarios, which is useful for planning the acceptance of new projects that may overlap with the previous ones.

The optimal solution provides a workers' allocation that avoids idle times; such a solution demonstrates that the company does not need to hire additional workers to cope with completion times. This result prevails when considering different structures concerning the dates when projects start or finish.

Although our modeling approach is flexible enough to analyze different structures concerning the possibility that development stages may overlap, the maximum flow problem we analyze ignores uncertain phenomena that may impact project development. For example, we implicitly assume that the workforce does not change during a year, which is not always true. So, our model does not consider that the total number of workers at each stage may vary. Also, projects' completion may change by exogenous factors like natural disasters or economic crises. This means that the directed network may suffer random modifications. In future works, we pretend to extend our analysis by considering exogenous factors that introduce uncertainty to the number of workers or the network's structure.

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BRIDGE SCOUR AND ROAD POTHOLES HAZARDS ASSOCIATED WITH THE TRANSPORT SYSTEM AND THEIR DETECTION METHODS

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Keywords: transportation infrastructure, national economies, Bridges and roads, scour, potholes.
Abstract: The Transport is among the most significant human activities on the planet. Better transportation allows for more trading and a wider distribution of people. Transportation infrastructure like bridges and roads significantly influences the environment and is the primary energy drainer, making transportation sustainability a key concern. This paper also analyses current bridge scour and road potholes detection equipment and methodologies and their effect on the transport system. In scouring regards, a particular emphasis on those uses the structure's complex reaction to suggest the presence and severity of the scouring phenomena affecting the structure. A Sensitivity Analysis of a newly introduced monitoring system is also assumed. This report examines the similarities and differentials between the bridges scour detection methods and potholes methods. Our key aim is to minimize human effort in identifying road potholes and bridge scouring by using a quick, easy-to-use, cost-effective process, resulting in fewer injuries and economic savings. On the other hand, many initiatives have been taken to create a technology that can instantly identify and detect potholes, leading to improved survey reliability and pavement quality through prior inspection and prompt intervention.

1 Introduction

Scour can generally be defined as sediment corrosion around an obstacle in the flow field's direction. Scour can significantly break down structures such as bridges, spillways, and weirs when their foundations have been undermined. Scour around bridge foundations is classified into three types. First, long-term aggradation and degradation cause elevation and supplementary variations in the river's shape over a very long period due to geomorphic modifications. Second, contraction scour happens due to flow restriction for natural reasons or the presence of any obstacle such as river embankments or contraction caused by a bridge opening. Third, local scour around the bridge foundations happens when bridge abutments and piers choke the flow in the rivers' main channel and valley (Figure 1) (Chang, 1988).

Several recent bridge structure failures have resulted from local bridges scouring nearby piers. Furthermore, they concentrated on understanding the causes of pier scour causes and developed new methods for protecting bridges against scour effects. Over three decades, 1,000 bridges collapsed, 60% due to hydraulic failures, including bridge scooping, in the United States (Lagasse and Richardson, 2001). They reported that the local scour along bridge foundations was caused by river flooding, which is thought to be the chief cause of the bridge disaster. Furthermore, bridge failure results in the deaths of many people and economic damage due to the cost of rebuilding and reconstruction. For instance, in 1987, Scholarie Creek Bridge collapsed in New York (USA), killing around ten people. In 1989, a part of the U.S. 51 Bridge was demolished into the Hatchie River close to Covington, the U.S., resulting in eight deaths. The collapse in California in 1995 of the Interstate 5 bridges over Arroyo Pasajero resulted in seven people's murders. The reports of these disasters show that the local scour is the chief reason for their collapses. In addition to the human life lost, the bridge collapses cost approximately millions of dollars as indirect payments to refurbish and replace bridge structures per year and the indirect expenditure for the disruption of transportation services. The Federal Highways Administration 1978 reported a concentrated study of bridge failure in the U.S., proving that bridges and highways collapsed due to severe floods between (1964 and 1972) and cost about $100 million. In New Zealand, the scour consumed $36 million per year. The bridge's collapse resulting from the scour is a common incidence, and millions of dollars are expended each year to repair or rebuild bridges affected by the water scour.

Roads offer a vital contribution to global prosperity and deliver significant social benefits. They are of critical importance to making a nation grow and develop. Roads are connecting more areas and promoting economic and social growth. Road connection is among the essential public properties for these purposes. However, due to constant loading and weathering on the roads, a pothole can be caused, severely affecting human life. A pothole is defined as a scouring in the road's surface, frequently asphalt pavement, and traffic removes these broken portions of the pavement surface. This action causes the water in the soil structure under the pavement surface and the highest traffic moving over the pavement's affected part (Figure 2). The flowing water at the beginning deteriorates the underlying soil structure, and as a consequence of traffic, fatigue led to the break of the soft supported road surface in the exaggerated area. Transport vehicles started excavating, resulting in a road break, the pavement, and the underlying layer of land (Rioja, 2003). Most potholes appear during the wet or rainy season. However, potholes are not unusual to grow and deteriorate during the dry season due to road activity and temporary wet conditions from localized irrigation, ponding, and water seepage. The bad reinstatement of trenches excavated by bituminous roads usually leads to potholes. Potholes could be accompanied by extreme cracking and breakage or distortion of the pothole's surface, indicating a deeper cause of the potholes' formation. Water intrusion into surficial cracks in the road pavement and erosion of only the pavement's surface and upper structural layers are more likely to be the source of minor deformation in the pothole area. The distress should be present as a bowl-shaped hole with minimum plan dimensions of 6 inches to be called a pothole. The low gravity potholes are less than 1-inch, moderate gravity is between 1 and 2 inches, and the high-gravity potholes are more than 2 inches wide. Furthermore, A pothole has three characteristics that differentiate it from any entity on the street from an outer appeal. At first, the potholes are more profound than the surrounding field. Second, the pothole outline is roughly like an ellipse to a circle seen from the driver's viewpoint. Third, the surrounding area's composition around the potholes is more delicate than the texture within the pothole itself, thicker and grainier. Potholes may have arisen when snow and icefall, and the water flows under cracks formed due to road corrosion. As a result, freezing temperatures at night freeze the water, and the pavement below it grows. Consequently, cold night temperatures and water become ice, forcing the pavement to grow beneath. The traffic continues to pound on the expanding segment; thus, a low divot happens below, breaking down the pavement and forming a pothole (Koch et al., (2011).Kornél Almássy, C.E.O. of B.K.K. Public Roads reported that the number of potholes on Budapest's roads had risen dramatically due to the rapid temperature fluctuations. Due to current weather conditions, more than four hundred potholes have developed, and repair staff is working three shifts to developing the consistency of the Budapest road network. The weather in Budapest is affecting the city's road system. The main challenge is not the cold weather only, but the unexpected rise and fall of the temperature. One day, it was less than 10-15 degrees and another 15 degrees, damaging the capital's road network, with hundreds of potholes reported daily. Inspectors continually check the roads, and if they come across a large pothole, they would cover it with bagged asphalt. Potholes can grow up to several feet across but usually just a few inches in diameter. Harm tires, wheels, and car suspensions will likely occur if they become high enough. In addition, serious road crashes can occur directly, particularly at higher vehicle speeds. Potholes can be the product of four major causes: Insufficient pavement thickness to sustain traffic through freezing/dew cycles without localized failures, failures in service trenches and castings (maintenance hole and drain casings), insufficient drainage, and Pavement flaws and gaps left not sustained and opened to allow moisture and to damage the structural reliability of the road surface.

The Hungarian Statistics office, where the last study was conducted in 2017, found that about half of the road conditions in Hungary (about 54%) are wrong. Forty percent of the prominent and 60 percent of the secondary network are in a terrible state. The condition is currently the worst in Komárom-Esztergom County, where 73% of local roads are poorly paved. In the Nógrád and Győr-Moson-Sopron, 69 %-70 % of roads are only in the fair and bearable condition in Pest County. Potholes are caused mainly by excessive rain when the water reaches the road by its tears, freezes, and bursts the asphalt. In 2018, -about 1,600 claims of poor road conditions arrived at the Hungarian Road Authorisation. Out of 1,600 reports, roughly 640 were confirmed and spent a total of 43 million HUF on repairing (Kátyúhelyzet: pocsék állapotban vannak az útjaink | Világgazdaság, 2021).The Automobile Association of the United States reported an annual loss of $4 billion in 16 million vehicles, including tire puncture, twisting, and suspension injury. There is a greater risk to the economy due to potholes, which includes risks associated with road users and businesses in the form of a higher rate of incidents and potential payments for insurance rates. Driving on potholed roads increases consumer prices as it accelerates vehicle degradation and depreciation. In addition, it raises the level of much-needed repairs and extra fuel consumption. The industry has suffered annual losses in Nigeria due to vehicles' poor roads. They calculated a loss of over a million dollars per year, in addition to the other economic damages associated with poor highways, such as air pollution, traffic delays, armed robbery, and frequent deaths (Ericksson et al. 2008).

Figure 1 the pier scours at the eastern Yuriage Bridge Kayen

Figure 2 The potholes on the road surface (tirereview.com, 2021)

2 Scour monitoring using instrumentations

Monitoring concepts for structural structures have been through a steady growth phase over the last decade. As a result, they play a role in designing new and emerging architectures. Traditional instrumentation used for tracking and measuring scour and their characteristics is discussed in this chapter based on literature analysis of sensors and instrumentation technologies used to monitor scour at particular site conditions. This chapter briefly reviews selecting the more often used scour detection and measuring techniques. Then, the instruments used are divided into portable and integrated or fixed instrumentation methods. Portable instrumentation methods include Physical probing, fathometers (Sonar), and Geophysical information, while fixed or integrated instrumentation methods include buried sensors, sonar, and similar devices.

2.1 Portable instrumentations

Portable scour samples have been taken using several instruments. In particular, there are three approaches for creating a portable scour measurement and diving probing. Fathometers are the second kind of meter (Sonar) and Geophysical data.

2.1.1 Diving probing and sound rods

Diving is a basic scour screening system in which a trained bridge inspector conducts a manual inspection of the bridge underwater. This system will capture scour data from various sites, and the water clarity does not affect the data collection process. However, the downside of this approach is that it can be costly, making it more ideal for worst-case cases. It also has a strong potential for risk. Furthermore, owing to the subjectivity of the regulators, the data produced from such visual inspections may have a high degree of uncertainty (Zheng, 2013). A sound rod is used for the bridge inspector to manually test a bridge by placing a rod or weight on the Streambed to determine the sediment depth. The bottom of the shaft must be low to prevent it from contacting the Streambed due to its weight and friction created by rushing water. When the riverbed is sand, sounding rods travel through it, decreasing accuracy. Diving probing offers several benefits, including that it is not affected by air entrainment or high sediment levels and may be employed in rapid, shallow water. The main flaw in this methodology is the inaccuracy of the data samples acquired and the potential hazards involved. Furthermore, this strategy is pricey and lacks the potential for automated alerts.

2.1.2 Fathometers

For portable scour measures, fathometers or acoustically depth sounders are typically utilized. Hydrographical assessment fathometers and fish locators of precision survey grade are also utilized. While measurements are performed from the bridge, transducers are attached to a pole, thumb, tethered buoy, or boom. Tethered float platforms include kneeboards and pontoon-style floats. The floating volume seems crucial for stability in fast-moving, whirling water. A bridge inspection vehicle may also deploy both floating and non-floating structures. This is exceptionally effective whenever the bridge is considerably above the river. For example, bridges taller than 15 m are ordinarily unreachable from the bridge surface unless this procedure is applied. Mueller and Landers developed an articulated arm for positioning a sonar transducer in 2000. The trailer-mounted equipment could work on highway bridge lengths up to 15 meters high. Based on the angle and distance between the teaser and the transducer, an onboard computer calculated the transducer's orientation around a given point on the bridge deck. The researchers also illustrate a manned boat as a scour measuring platform, requiring a safe distance between the bridge and the launch facilities. During floods, however, the river level may reach or submerge the low chord of the bridge, and watercraft ramps may be flooded. A fathometer is often used for depth measurements, while position detectors are usually GPS devices. The benefit of GPS above traditional land-based vulnerability screening is that it eliminates the necessity for control stations to have line-of-sight. The GPS can be used in the dark and bad weather, making it particularly valuable for flood monitoring. The disadvantage of GPS is that it can be utilized in areas with overhead barriers, such as trees or bridge decks. GPS readings of the structure's surface have proved correct without walking beneath the bridge.

2.1.3 Geophysical data

Geophysical instruments use wave spread and recurrence data to detect the interfaces between different resources with different physical qualities. The distinction between acoustic and geophysical procedures is that geophysical techniques can detect semi-detail, but acoustic can only identify the water-soil contact, not the sediment layer. The primary differences between geophysical approaches are the delivered signals and the tangible asset alterations that create reflections. Lower-frequency acoustic waves are used in seismic instruments, similar to sonar (2-16 kHz). Seismic waves can be propagated by air bubbles and huge silt concentrations, just as sonar can (Yankielun and Zabilansky, 1999) (Figure 3). The best use of the geophysical technique is to determine scouring depth in increasing the water zones during a flood at lower flow conditions. These challenges have become minimized as more advanced, low-cost GPR devices with digital data dispensing capability have been identified. However, GPR can be limited by cost and difficulties, as well as the necessity for borehole data and trustworthy bridge influences the development to recalibrate and understand the results.

2.2 Fixed instrumentations

Instruments installed in the bridge's vicinity or in the bridge construction itself, usually at piers and abutments, to record data to alert concerned staff when the scour depth becomes extreme are known as fixed instrumentation approaches known as embedded instrumentation scour monitoring. The device is mounted at pre-determined bridge locations to track and measure scour. Sonar-based sensors, sounding rods, magnetic sliding lapels, tilt-meters, and float-out instruments are among the most popular embedded instrumentation tracking methods (Lagasse and Richardson, 2001). The type of fixed scour monitoring device that is used is determined by the information that is required. Fixed scour measurement and tracking tools can be categorized into many groups.

2.2.1 Sonar-based sensors

Which are permanent devices typically mounted on the bridge pier. Sonar emits pulse waves and processes the portable trip time from the riverbed to assess scouring depth. Both scour and accumulation of sediments can be measured using sonar sensors. The only drawback of sonar as a scour measurement instrument is that its measurements are influenced by heavy sediment and turbulent flow in the sea. In addition, high-end sonars with a large depth capacity and high resolution can be costly (Fisher et al., 2013).

2.2.2 Electrical conductivity devices

This type of device uses fluctuations in the electrical conductivity of various media to identify the orientation of the water-sediment contact. They use the principle of determining the electrical connection between two probes to do their work. The potential to draw current changes as the substance between the probes changes. This occurrence could demonstrate the prevalence and severity of the scour.

2.2.3 Magnetic sliding collars methods

Magnetic sliding collars are another helpful method used for scouring identification. This instrument consists of a thick necklace placed on a magnetic pole. The rod is pushed into the stream's bed, and the collar lies on the stream's bed. When the sand is swept away from the stream bed during the scour, the collar slips down the magnetic rod, and the depth falls. The base station senses this difference in the collar height used to deduce the scour. It is a straightforward measure, and the water's consistency does not influence its reading. While this method is very useful in calculating scour depth, the main downside is that its sensors can only be used once and cannot measure sediment deposition (Fisher et al., 2013).

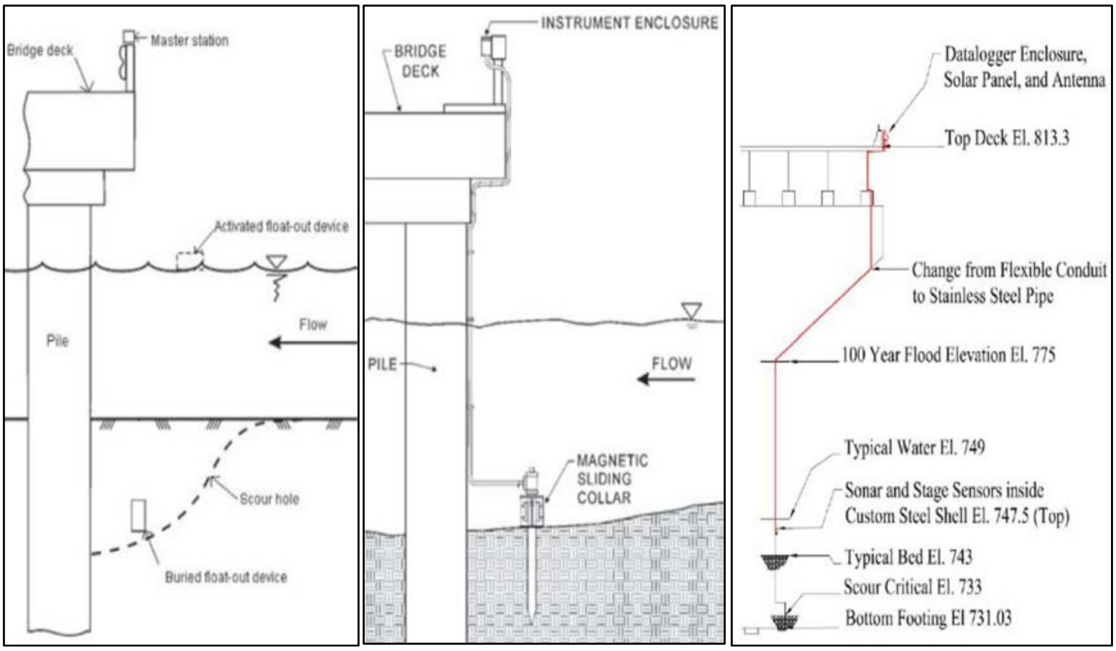

Figure 3. Fixed devices (a) sonar, (b) magnetic collars, (c) float-out devices, modified from (Zabilansky, 1997)

2.2.7 Vibration-based method

This approach uses the principle of calculating the actual occurrence of the rod fixed in the Streambed. To monitor scouring depth, the opposite relationship between essential frequency and the sensor of the rod length is applied. It uses structural vibration sensors, such as accelerometers or fiber-optic (FBG) devices, as the scour sensor's dynamic sensing feature (Figure 4). However, this approach is yet to be thoroughly tested. It is continuing research, and studies are being carried out (Lagasse and Frederick, 2007).

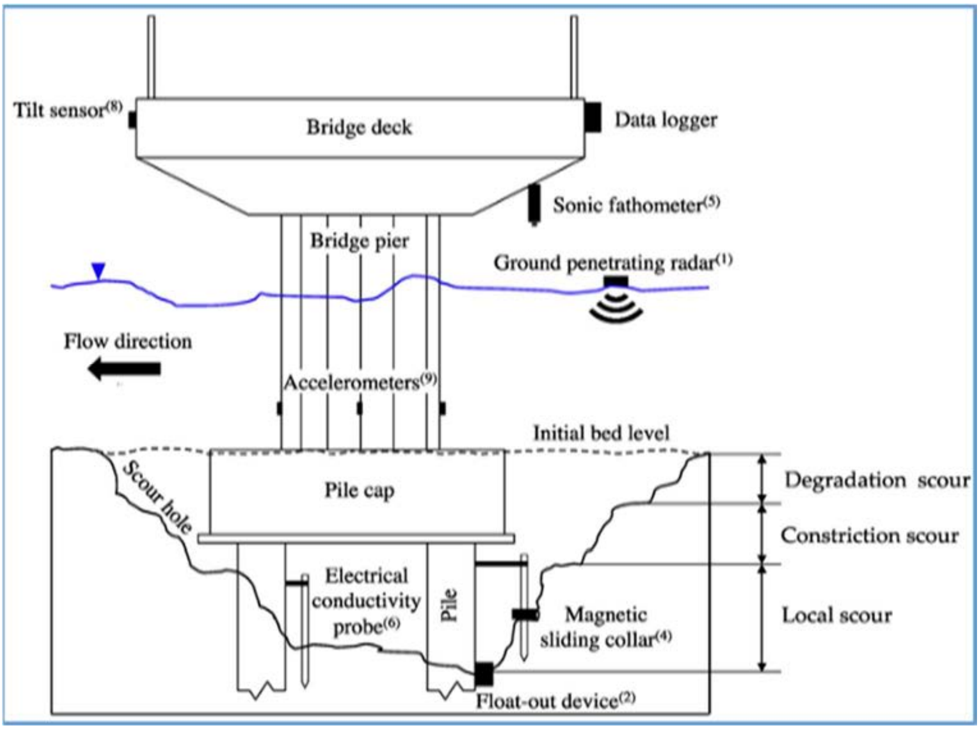

Figure 4 Bridge scours detection methods (Maroni et al., 2020)

3 The approaches for the road potholes monitoring

3.1 Two-dimensional Image-Based Approaches

It is a technique for automatically detecting holes in the asphalt. Using the suggested method, the image is initially segmented into faulty and non-defective parts. The geometric properties of the defective field are then used to estimate the theoretical form of the pothole. Following that, the surface of the prospective region is separated and correlated with the texture of the neighboring non-defective region. For example, if the composition of the defect zone is denser and blurrier than the neighboring regions, the area of interest is classified as a pothole (Koch and Brilakis, 2011).

Buza et al. (2013) proposed an innovative vision-based unsupervised technique that would not require expensive infrastructure, additional processing, or training. Their technique uses image analysis and spectral clustering to find and estimate potholes. Image classification, contour separation using spectroscopic grouping, and detection and removal are the 3 phases in the suggested model. The technique was evaluated using 50 pothole photos from website image collection and MATLAB. The surface area was estimated to be around 81% correct. As a result, this technique will offer a preliminary estimate for surface repair and rehabilitation. Matlab was used with the Image Processing Toolbox to test the suggested technique. Images were altered from video formats acquired using a wireless router robotic truck prototype outfitted with only an H.P. Premier Image stabilization Camera mounted at roughly 2 ft. hundred twenty images were gathered, with 50 used for training and research. With 82 percent specificity and 86 percent recall, the overall accuracy was 86 percent.

3.2 Methods of three-dimensional Laser Scanner

It works by producing exact digital photographs of existing structures using reflected laser pulses. Actual 3D point cloud points with their heights were gathered during scanning and recovered using a grid-based processing approach concentrating on essential distress characteristics (Chang et al., 2005). Experiments show that pothole covering and distress coverage can be monitored efficiently and precisely to determine the amount of significant material required.

They used elevated 3d cross-scanning techniques with an invisible (I.R.) laser line projector and a virtual camera to build a low-cost real-time inspection approach that distinguishes bothersome features such as rutting, gunshot, and potholes. In the calibration process, a multifunctional coplanar device is applied to increase the system precision to enable the use and distribution of further feature points throughout the camera field of view Potholes can be detected in real-time using laser scanning equipment. However, the cost of laser scanning technology remains high at the vehicle level (Li et al., 2009).

3.3 Methods of Stereo Visualization

An extensive survey of the pavement state using the stereo visual software for a feasibility report. In that way, the asphalt surface is protected by two optical cameras. The first move is an analysis of 2D pictures from both cameras for any cracks to be seen and classified. The findings of two image providers of the same asphalt are then integrated to measure missed damages during one analysis, allowing for better precision. Geometric modeling with lateral and longitudinal profiles is frequently used to set three-dimensional surface models using a pair of photographs taken within the same paving surface. To gather 3D characteristics from specific 2D pairs of photographs on the same pavement surface, procedures should be completed, including camera calibration, correction distortion, aligning stereo dots, template matching, and characteristic reports (Wang, 2004).

The stereo vision technique replicates the base of the 3D pavement with a pair of pictures. In two couples, four cameras were used to capture surface pavement photographs around a 4-meter extensive floor (an individual couple of images covers 200 cm of the road). The approach included four stages: measurement, distortion correction, correspondence, and 3D reconstruction. DHDV (Digital Highway Data Vehicle), an experimental tool advanced by the University of Arkansas, a multi-system road condition investigation, provided preliminary findings on the viability of stereovision for pavement photography. However, in 3D reconstruction, the resolution can only be achieved in a static environment of 2mm and a dynamic motion environment of more than 5mm. Therefore, stereo vision strategies are proposed to calculate pavement status with a stereo-visual device connected to a car to record road network conditions. This method delivers a brief overview of the suggested solution. The road segment was measured as field trials along a local road of 650 m in length. The author found that the proposed stereo viewing system could assess Poland's road network conditions (Hou et al., 2007).

The method of stereo vision requires a high level of computational effort to rebuild asphalt surfaces by comparing feature points between two points of view. Besides, all cameras are correctly positioned, and where there is a vehicle movement vibration, the cameras can be misaligned and impair the accuracy of the result. Therefore, it is impossible to implement them in a real-time setting.

3.4 The radar of Kinect

Using a Kinect sensor (or radar) and USB high-speed camera, a low-cost radar device detects and analyzes potholes. The project was in its early phases at the time of this report. There have recently used low-cost Kinect radar to take pavement depth images and the quantity of an estimated pothole volume. The Kinect sensor extracted a pavement depth picture from the concrete and asphalt roads. Meshes have been created to enhance the depiction of potholes. Detailed analysis of the pothole region, the estimated pothole volume was measured using the trapezoidal area-depth curve test employing a pavement image analysis (Moazzam et al., 201).

4 Discussion

Poor road and bridge conditions and an inadequate transportation infrastructure impede the flow of products and people in metropolitan areas. Inadequate infrastructure may also be a deterrent to both domestic and international investors in our metropolitan regions. Productivity constraints at the city level, such as infrastructural limitations, impacted the productivity of enterprises and families, affecting the economy's aggregate productivity. Transportation development's economic relevance is linked to improved society's welfare through proper social, political, and economic conditions. Quantitative and qualitative gains in human capital, such as income and education levels, and physical capital, such as utilities, transportation, and telecommunications, are predicted.

One of the severe challenges in evaluating adequate roadway repair and refurbishment techniques is accurately identifying potholes. Physically recognizing and testing procedures are expensive and timewasting. As a result, several investigations have been made to implement technologies that can quickly identify and recognize potholes, increasing survey reliability and pavement quality by allowing for early detection and intervention. First, existing pothole detection approaches are examined and evaluated, with the most common vibration-based, 3D renovation, and perception systems. Although perception methods are much less costly than 3D laser scanning methods, because of the fuzzy signal created by pollution, it can be hard to diagnose a pothole because they observe by evaluating the acquired picture and video data. As a result, to improve the current pothole identification approach and consistently discover a pothole, a pothole identification system based on diverse 2D pictures is necessary.

Traditional Scour detection equipment is typically expensive to install and operate and is frequently destroyed by debris during floods. Data processing from this equipment can be time-consuming and difficult. The structural dynamic behavior is frequently used in research to identify and identify the level of scour around buildings. The research offers the door for non-intrusive condition monitoring and intermediate maintenance to diagnose and track scour progression. Easy installation above the waterline and inexpensive maintenance are two advantages of dynamic measurements versus traditional scour computation instrumentation. Frequency shifts will assess the stiffness distortion and, ultimately, the influence on the structure of interest of the stiffness effect. The instruments of the Streambed often neglect this factor since the global influence of scour cannot be detected until a high number of instruments are used nearby scour critical points. There is already much space for improvement in complex measuring methods. Some of the challenges associated with these approaches include the large amount of acceleration data needed to collect helpful knowledge, the high power necessities for data achievement systems, and other effects.

5 Conclusion and recommendations

Transportation of goods and services to people is made more accessible by adequate road infrastructure, which is the development wheel. Good roads make it easier to carry products and services and deliver them on schedule. They can also help with agricultural production and high-quality health care. Aside from that, excellent roads reduce the loss of human life, commodities, and property, provide a convenient and comfortable transit route, and function as a recreational avenue. In addition, good roads minimize the cost of transportation upkeep, fuel, and operation. The methods are presented in scouring, and potholes detection is costly in monetary costs and requires more human resources. Therefore, instead of investing so much money on new gadgets, sensors already integrated into our smartphones can be used. A primary mobile phone, which anybody can use, can identify potholes on the lane; regarding the bridge monitoring, it can connect the smartphone to sensors fixed in the bridge structure, which can function for a long time and give an alarm during the flood period. Our key aim is to minimize human effort in identifying potholes and bridge scouring by using a quick, easy-to-use, cost-effective process resulting in minor injuries. On the contrary, primarily underwater instruments are used by standard methods to detect bridge distance profiles that can also be detected using instrument deployments and services. Additionally, the advancement of these fixed and portable scouring measurement devices, GPS, remotely operated ships, instrumented vehicles, and knowledge of the need to calculate and monitor bridge spacing have greatly enhanced the scour database, methods for forecasting spacing depths, bridge scouring, and bridge protection. Recently, the theory of vibration-based harm sensing has been investigated to address particular challenges by examining the natural bridge or bridge frequency spectrum.

Finally, there are some similarities in monitoring bridge scour and road potholes, such as sonar, sensors, and vibration-based methods, which can significantly depend on them. However, there is still a problem with some of these methods to monitor the scour and potholes' depths, and places need to examine again.

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INFLUENCE OF COMPUTER GAMES ON HUMAN PHYSIOLOGICAL FUNCTIONS

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Keywords: video games, physiological functions, blood pressure, heart rate.
Abstract: Video games are popular leisure activity for all ages and therefore it is needed to examine their psychological and physiological effects. The aim of the presented paper is to point out possible changes in physiological functions due to playing computer games and to present them in a pilot study. Part of the work is the categorization of video games and a systematic overview of studies aimed at examining and confirming or refute their connection. The purpose of this pilot study is to measure blood pressure and human heart rate while playing different video games and to evaluate possible changes in the game. The methodology of the experiment includes demographic data, measured values during the monitoring of individual subjects and the measuring means used.

1 Introduction

A popular leisure activity for many people is playing video games. For gamers, gaming can be seen as a fun distraction or a hobby, and their popularity continues to grow. According to various surveys, it is clear that despite the rapid development of gaming consoles, many people prefer to play games on personal computers. The increasing prevalence of video game play among people has led to research into their potential positive or negative psycho-physiological effects. Research suggests that depending on the content of the game, gambling can affect physical and mental health [1-4].

The aim of the presented work is to investigate the short-term effects of video games on human physiology in a pilot study. Using the available measurement technology, the cardiovascular parameters of the subjects playing different types of games during a uniform time limit were examined.

1.1 Overview of studies

The measuring devices used in the studies were diverse, with the automatic pressure gauge being the most commonly used. Digital automatic pressure gauges mostly work on so-called oscillometric principle. During the measurement, a cuff is placed on the upper limb, typically on the shoulder or wrist, which is pressurized to a value at which the artery is securely constricted and no blood flows in it. Periodic pressure changes occur as the cuff pressure decreases. Pressure changes are caused by volume pulsation in the arteries [5,6].

These oscillations are transmitted to the measuring device via the cuff pressure, where they are evaluated. Thus, the pressure gauge does not determine the values of systolic and diastolic pressure, but the value of the so-called mean arterial pressure and both limits are calculated by the software of the device [7,8].

An interesting measuring technology was used of "Smart" clothing from Hexoskin® in a study from 2020. It allows remote monitoring of health in real time and display data on a smartphone or tablet using the Bluetooth function. Smart clothing was developed for personal experiments and was also used by health researchers to study physiology of elite and professional athletes to optimize their physical health. Hexoskin® incorporates physiological sensors into intelligent textile materials to monitor ECG, heart rate, heart rate variability, respiratory rate, respiratory volume and other activity measurements such as step counting and energy expenditure. This technology may be suitable for this type of experiment, as it allows continuous measurement without disturbing the player while playing [9,10].

In a horror video game study, they used a Biopac technique to measure electrodermal activity, heart rate and respiratory rate. Biopac provides a complete combination of hardware and software with a range of electrodes, cables, transducers and stimulus options for the secure collection of physiological signal data. BIOPAC supports a wide range of experimental protocols - from simple to complex - and are designed to enable researchers with different levels of experience to acquire, analyze and interpret scientific data [11].

In a 2018 experiment, they used a "Runner cardio watch" from TomTom to measure their heart rate. This watch has two heart rate measurement options, with a built-in optical sensor directly in the watch or via an external sensor mounted on the chest. The heart rate is measured by LED light that penetrates the surface of the skin and the wall of blood vessels. The sensor is located on the wrist and captures the changing reflections of light that change with the blood flow. Due to their size and location, they provide comfort when playing video games and data is imported directly into the smart device [12].

A 12-lead ECG was used in a study to examine the cardiovascular side effects of video games in boys aged from 7 to 10 years. The device senses the electrical potentials that the heart muscle generates during its operation and thus also records the heart rate. However, the connected limb and thoracic leads could interfere with the player during play and it is also not appropriate to measure as the subject moves, as the electrical potentials of the skeletal muscle may be recorded [12].

2 Methodology

The chosen technology was an automatic blood pressure monitor, which was also the most widely used technology for measuring cardiovascular values in the presented studies.

Four subjects aged from 22 to 29 years (three men and one woman) were asked to complete the questionnaire with basic information. Subjects answered questions about age, gender, game preferences, gaming experience, and health.

When asked how skilled subjects are in playing video games, the first and second subject stated very well skilled and the third subject stated not very skilled. The first and second subject stated that they were considered to be players and the third and fourth subject to be considered casual players.

2.1 Subjects monitoring before the experiment

An overview of the average values of blood pressure and heart rate in subjects during the day is important for the final comparison. These values can be used to compare video game values with activities other than exercise or relaxation. The subject's blood pressure and heart rate were measured for three days and the values recorded were attributed to the respective activity. Ten measurements were made per day, the first measurement being the morning after waking up and the last before going to bed. Fluctuations in values could be caused by work during the day, physical activity or exercise. The first three subjects have a sedentary job and work most of the time at the computer. The fourth subject works manually.

Table 1 Questions and answers of subjects

Questions	***Subject no. 1***	***Subject no. 2***	***Subject no. 3***	***Subject no. 4***
Age	29	26	22	29
Gender	*man*	*man*	*woman*	*man*
Do you consider yourself a regular / occasional player or a "non-player"?	*Regular player*	*Regular player*	*Casual player*	*Casual player*
How long have you been playing games on a regular basis?	*17 years*	*13 years*	-	-
How many hours a week do you play regular games?	*More than 20 hours*	*More than 3 hours*	-	-
What are your game preferences?	*Action RPG*	*Action RPG*	*Simulations*	*Horror*
Are you treating some chronic diseases?	*no*	*no*	*no*	*no*

2.2 Factors influencing measurement

Participants were introduced to the rules for measuring blood pressure and heart rate correctly using an automatic sphygmomanometer. During the monitoring, the participants measured the blood pressure by themselves and recorded the values, which were later processed. For the objectivity of the measurement, participants were asked not to smoke, consume alcohol / caffeine and eat just before the measurement and the experiment itself.

2.3 Measuring equipment

A digital Omron Class M3 (Figure 1) shoulder cuff blood pressure monitor was used to measure blood pressure and heart rate.

Figure 1 Omron M3 digital automatic pressure monitor

The device has several functions such as motion detection during measurement, detection of arrhythmia and irregular pulses, control of a correctly fitted cuff and memory for two users. The manufacturers state a pulse measurement accuracy of 5% and a pressure measurement accuracy of ± 3 mmHg. The measuring range provides at a blood pressure from 0 to 299 mmHg and at a heart rate from 40 to 180 beats / min.

2.4 Game environment

In order to compare the different effects of several genres of video games, three popular genres were selected, namely action RPG, survival horror game and FPS game. The hypothesis is that in more intense or exciting games, there will be a difference in blood pressure and heart rate before play than during and after play. The games were selected on the basis that the players did not have experience with specific games. This could affect the results as players may react differently to the game than when they play it for the first time. However, when choosing an existing game, there is no control over the design of the game, which can be limiting in terms of the various non-life passages. Therefore, before playing, it was necessary to set specific storyline "missions" that the games offer and the player was directly exposed to the story. In the horror game, it was necessary for the player to empathize with the story and to evoke the atmosphere and a feeling of fear, it was necessary to complete the whole story with the introductory trailers.

For the survival horror game, a game from 2017 called "Resident evil 7: Biohazard" was selected. The game called "Call of Duty: World War II" from 2017 was chosen as the FPS game. From the action RPG, the game called "Fallout 4" was chosen, which takes place in a post-apocalyptic world. According to "The Entertainment Software Rating Board", video games have a rating of M ("Mature"), ie suitable for people aged 18 and over, and according to PEGI, games are suitable for at least 18 years old players.

2.5 Difficulty of the games

At the beginning of each game, the subjects chose the difficulty of the game according to their playing experience. Video games usually offer the player three to four options to choose from, and the system of rules or the number of challenges may change depending on this choice.

2.6 The course of the experiment

The experiment was run one player at a time, who was familiar with the rules. After completing the questionnaire, they sat in front of the computer on which the selected video game was prepared and set up. After five minutes of sitting and resting, their blood pressure and heart rate were measured. These values were recorded and subsequently the players were acquainted with the genre of the game, the name and the principle of control of the game.

Interfering elements were removed as much as possible during play and measurement. As the game began, a stopwatch was set up every ten minutes to measure physiological functions. Since the playing time per game was 60 minutes, more frequent measurements could mean that the player would not be able to concentrate on the game and this would be counterproductive. After ten minutes, the game was paused and the pressure gauge cuff was put on. The measurement started and the values were recorded. Simultaneously with the game, the game was recorded using the "recording" function, which is available in the game panel of the Windows 10 operating system. By this way, it was possible to later describe the game situation before the measurement during the game. During more action passages, it would be possible to realistically compare the values with the values of calmer passages for each game and each subject. These recordings were saved automatically when the recording was stopped. At the end of the game period, the video game was paused and the last reading during the game was immediately measured. In the end, the player remained still for five minutes, then he was measured for the last time and the values were recorded as values after the game.

There was a slight twilight in the room where the measurement was made, as this factor can also affect the intensity of the gaming experience. Subjects played games during different parts of the day, ie. in the morning (8:00 - 12:00), in the afternoon (12:00 - 17:00) or in the evening (17:00 - 00: 00). For this fact, it was appropriate to compare the values from the game time and from monitoring in the same part of the day.

Table 2 Average values during gaming compared to the average values from the monitoring of the first subject

Game	***Subject no. 1***	***Subject no. 2***	***Subject no. 3***	***Subject no. 4***
FPS game	*afternoon*	*evening*	*morning*	*evening*
Horror game	*afternoon*	*evening*	*morning*	*evening*
Action RPG	*afternoon*	*afternoon*	*morning*	*evening*

3 Evaluation of results and discussion

The measurement results reflect the current situation at the time of the measurement and are influenced by the current situation. Therefore, it is important to record the course of the game in order to associate an action in the game, e.g. distance / near combat with a change in blood pressure or heart rate.

3.1 Summary of the measured data of the first subject

In Figure 2 is a graphical representation of the measured values of systolic pressure (SP), diastolic pressure (DP) and heart rate (HR) of the first subject. In the legend, the games are marked in order, the so-called FPS game (G1), survival horror game (G2) and action RPG (G3).

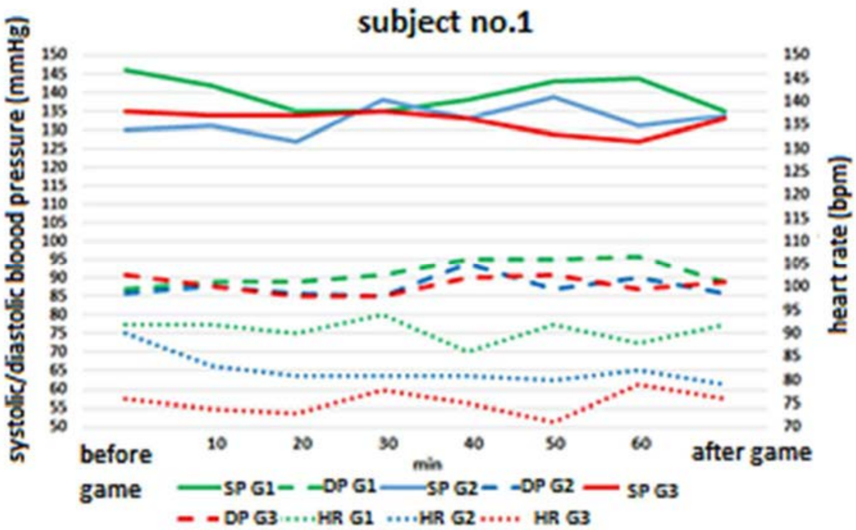

Figure 2 Graphical representation of the measured data of the first subject

As a consequence of these measured data, it is clear that the systolic blood pressure of the first subject fluctuated maximally during FPS play, while the diastolic blood pressure fluctuated minimally. The data were measured differently during the horror game, when the diastolic pressure and the mild systolic pressure fluctuated maximally. The heart rate was relatively stable during the horror game. Playing an action RPG caused the slightest fluctuation in the first subject's cardiovascular values.

During the FPS game, the average blood pressure and heart rate were significantly higher compared to the average rest value. At the same time, the average values during the playing of the FPS game are also higher compared to the average value during the workload.

Playing a horror game caused only a negligible difference in systolic blood pressure compared to the average rest value. The average diastolic pressure and heart rate during the horror game were significantly higher compared to the average rest value. The value of the average systolic pressure during the workload is slightly lower than the value of the systolic pressure during the horror game. There is no significant difference in the values of diastolic pressure and heart rate during horror play compared to the values during workload.

During the action RPG, the average values differ significantly compared to the values during the rest only in diastolic pressure, which was significantly higher during the game. During the action RPG game, the average systolic blood pressure values were significantly lower than the average values during the workload. The average value of diastolic pressure during play does not differ significantly from the value during workload.

Table 3 Average values during gaming compared to the average values from the monitoring of the first subject

Subject no. 1	**Systolic blood pressure *mmHg***		**Diastolic blood pressure *mmHg***		**Pulse *bpm***	
While playing (FPS game) average	*140*		*93*		*90*	
Highest and lowest value	*144*	*134*	*96*	*89*	*94*	*86*
While playing (Horror game) average	*133*		*88*		*81*	
Highest and lowest value	*139*	*127*	*94*	*85*	*83*	*80*
While playing (Action RPG game) average	*132*		*88*		*75*	
Highest and lowest value	*139*	*127*	*91*	*85*	*79*	*71*
Average value during workload	*136*		*86*		*80*	
Average value during rest	*132*		*81*		*77*	

3.2 Summary of the measured data of the second subject

In Figure 3 is a graphical representation of the measured values of systolic pressure, diastolic pressure and heart rate of the second subject. In the legend, the games are marked in order, the so-called FPS game, survival horror game and action RPG.

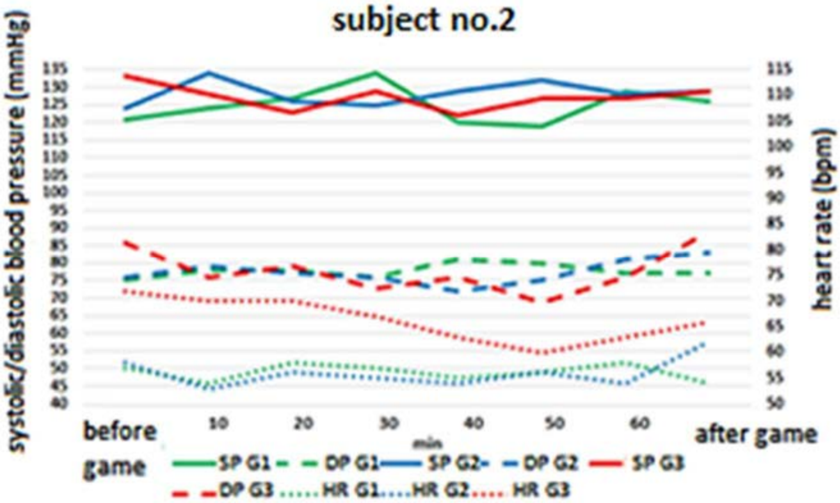

Figure 3 Graphical representation of the measured data of the second subject

As a result of playing the FPS game, the maximum fluctuation of systolic pressure was recorded, while the diastolic pressure and heart rate were stabilized. As a result of playing the horror game, a slight fluctuation in blood pressure and minimal fluctuations in heart rate were found. The systolic pressure during the action RPG was relatively stable. Playing an action RPG was affected by fluctuations in diastolic blood pressure and a decrease in the other person's heart rate.

Table 4 Average values during gaming compared to the average values from the monitoring of the second subject

Subject no. 2	**Systolic blood pressure *mmHg***		**Diastolic blood pressure *mmHg***		**Pulse *bpm***	
While playing (FPS game) average	*126*		*78*		*56*	
Highest and lowest value	*134*	*119*	*81*	*76*	*58*	*54*
While playing (Horror game) average	*129*		*77*		*55*	
Highest and lowest value	*134*	*125*	*81*	*72*	*56*	*53*
While playing (Action RPG game) average	*126*		*75*		*66*	
Highest and lowest value	*129*	*122*	*79*	*69*	*60*	*70*
Average value during workload	*127*		*78*		*67*	
Average value during rest	*118*		*64*		*64*	

During the FPS game, the average systolic and diastolic pressures were significantly higher compared to the average rest value. At the same time, the average values of blood pressure during playing the FPS game are identical compared to the average value during the workload. The heart rate during FPS play is lower compared to the average value during rest and workload.

Playing a horror game caused only a negligible difference in systolic blood pressure compared to the average rest value. The average diastolic pressure and heart rate during the horror game were significantly higher compared to the average rest value. The value of the average systolic pressure during the workload is slightly lower than the value of the systolic pressure during the horror game. There is no significant difference in the values of diastolic pressure and heart rate during horror gameplay compared to the values during workload.

During the action RPG, the average values differ significantly compared to the values during the rest only in diastolic pressure, which was significantly higher during the game. During the action RPG, the average systolic blood pressure values were significantly lower than the average values during the workload. The average value of diastolic pressure during play does not differ significantly from the value during workload.

3.3 Summary of the measured data of the third subject

In Figure. 4 is a graphical representation of the measured values of systolic blood pressure, diastolic blood pressure and heart rate of a third subject. In the legend, the games are marked in order, the so-called FPS game (H1), survival horror game (H2) and action RPG game (H3).

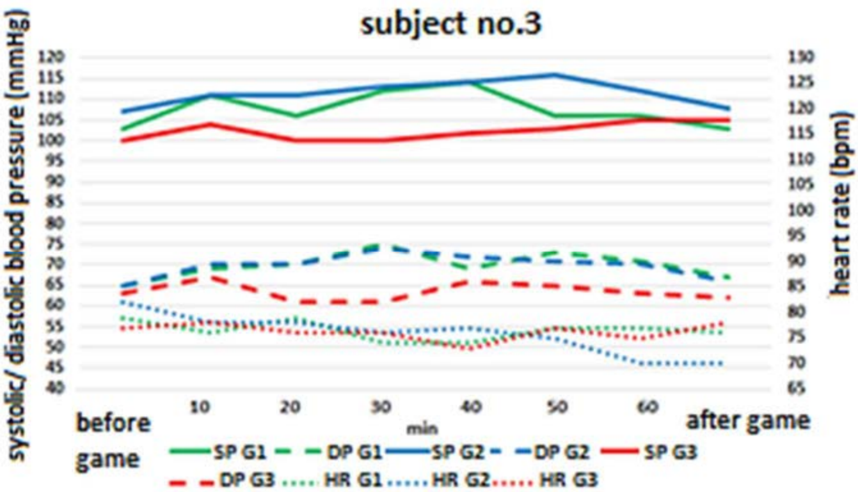

Figure 4 1 Graphic representation of measured data of a third subject

Increased systolic pressure when comparing values before and after playing was recorded only when playing an action RPG by 5 mmHg. After playing the FPS game, the subject had the same systolic pressure as before the game. After playing the horror game, there was no significant difference in systolic pressure before and after playing. There was no significant difference in diastolic pressure values before and after playing in any of the measurements. The heart rate after playing a horror game dropped by up to 12 beats compared to a lot before playing. In other games, there was no significant difference before and after playing in heart rate values.

Table 5 Average values during gaming compared to average values from third subject monitoring

Subject no. 3	**Systolic blood pressure** *mmHg*		**Diastolic blood pressure** *mmHg*		**Pulse** *bpm*	
While playing (FPS game) average	*109*		*71*		*76*	
Highest and lowest value	*114*	*106*	*75*	*69*	*79*	*74*
While playing (Horror game) average	*113*		*71*		*76*	
Highest and lowest value	*116*	*111*	*74*	*70*	*78*	*75*
While playing (Action RPG game) average	*102*		*64*		*76*	
Highest and lowest value	*105*	*100*	*67*	*61*	*78*	*73*
Average value during workload	*115*		*69*		*70*	
Average value during rest	*108*		*67*		*64*	

During the FPS game, the average diastolic pressure and heart rate were higher compared to the average rest value. The difference in average systolic pressure during FPS play is negligible compared to the rest value. At the same time, the heart rate during playing the FPS game was also higher compared to the average value during the workload. During play, the average systolic pressure was lower than during workload. There is no significant difference in the values of diastolic pressure during the horror game compared to the values during the workload. The average heart rate during FPS play is significantly lower than the value during workload.

Playing a horror game caused an increase in systolic blood pressure compared to the average rest value. The average diastolic pressure and heart rate during the horror game were significantly higher compared to the average rest value. The value of the average systolic pressure during the horror game was slightly lower than the average value during the workload. There is no significant difference in the values of diastolic pressure during the horror game compared to the values during the workload.

The subject's blood pressure was even lower than his average resting value while playing the action RPG. The heart rate was significantly higher during play. During the action RPG game, the average systolic blood pressure was significantly lower than the average during workload. The average heart rate during play is significantly lower than the value during workload.

As a result of playing the FPS game, the maximum fluctuation of systolic pressure was recorded, while the diastolic pressure and heart rate were stabilized. As a result of playing the horror game, a slight fluctuation in blood pressure and minimal fluctuations in heart rate were found. The systolic pressure during the action RPG game was relatively stable. Playing an action RPG game was affected by fluctuations in diastolic blood pressure and a decrease in the heart rate of a third subject.

3.4 Summary of measured data of the fourth subject

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In Figure 5 is a graphical representation of the measured values of systolic pressure, diastolic pressure and heart rate of a fourth subject. In the legend, the games are marked in order, the so-called FPS game, survival horror game and action RPG game.

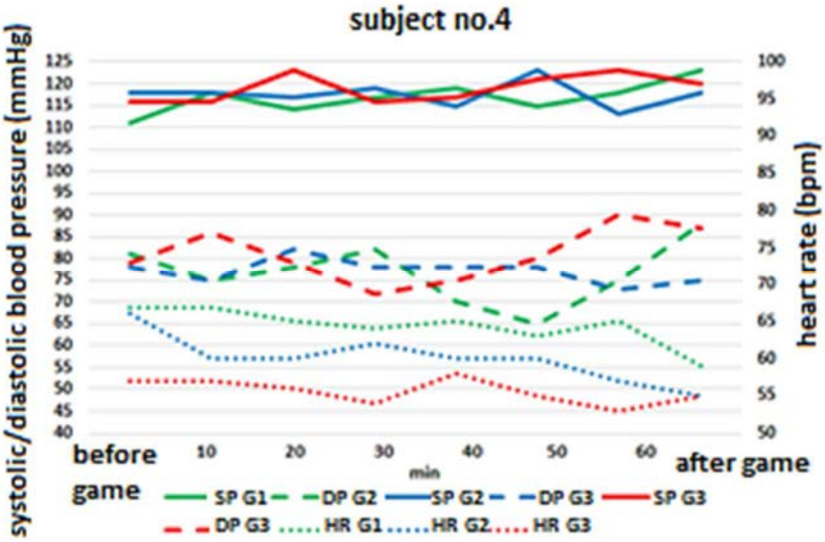

Figure 5 Graphical representation of the measured data of the fourth subject

As a consequence of these measured data, it is clear that the systolic blood pressure of the fourth subject fluctuated maximally during the horror game, while the diastolic pressure fluctuated minimally. The data were measured differently during the action RPG game, when the maximum diastolic pressure and mild systolic pressure fluctuated. The heart rate was relatively stable while playing the action FPS game. Playing the FPS game caused the slightest fluctuation in the fourth subject's cardiovascular values.

Table 5 Average values during gaming compared to the average values from the monitoring of the fourth subject

Subject no. 4	**Systolic blood pressure *mmHg***		**Diastolic blood pressure *mmHg***		**Pulse *bpm***	
While playing (FPS game) average	*117*		*74*		*65*	
Highest and lowest value	*119*	*114*	*82*	*70*	*67*	*63*
While playing (Horror game) average	*118*		*77*		*60*	
Highest and lowest value	*123*	*113*	*82*	*73*	*62*	*57*
While playing (Action RPG game) average	*119*		*81*		*56*	
Highest and lowest value	*123*	*116*	*90*	*72*	*58*	*53*
Average value during workload	*120*		*81*		*74*	
Average value during rest	*113*		*78*		*69*	

During the FPS game, the average blood pressure was higher compared to the average rest value. At the same time, the average values during the playing of the FPS game are also lower compared to the average value during the workload. The average heart rate during FPS play was lower compared to the average value during rest and workload.

The average systolic blood pressure during the horror game was significantly higher compared to the average rest value. Playing a horror game caused only a negligible difference in diastolic pressure compared to the average respite. The value of the average systolic pressure during the workload is slightly higher than the value of the systolic pressure during the horror game. The average diastolic pressure and heart rate were lower during the horror game compared to the average during the workload.

During the action RPG, the average systolic pressure was significantly higher compared to the values during the rest and almost the same compared to the value during the workload. Playing an action RPG, the average systolic blood pressure values were significantly lower than the average values during the workload. The average value of diastolic pressure during the action RPG game is the same as the value during the workload and slightly higher compared to the rest value. The average heart rate during play was lower compared to the average value during rest and workload.

4 Conclusions

A person's physical and mental health is primarily related to his or her lifestyle, which is also affected by the way he or she relaxes. The massive increase in the use of modern technology has caused people to use their free time to relax by playing video games. Examining the effect in both the short and long term is relevant because video games can have a potentially positive as well as a negative impact on human health. These hypotheses are based on research that scientists have been conducting for years, and their opinions differ, as there are many influencing factors, such as the periodicity of video games [3,4].

The aim of the presented work was to investigate the effect of playing video games from the point of view of human physiology in the pilot study by evaluating three cardiovascular parameters. The correlation between the measured values and the game event was found through the available measuring technology and the recording of the game event. Consistent with the results, no risk fluctuations were found and the values recorded were within physiological standards. As this is a pilot study designed to test the functionality and the research process, the results cannot be generalized. The research part of the work was limited by the epidemiological situation in Slovakia.

For a more objective assessment of the measured values during play, it would be necessary to use a device that ensures continuous measurement of the player's cardiovascular values, such as electrocardiography. In this way, it would be possible to record all values and thus eliminate the regular interference of the player during the game. To determine the risk of playing games, research could be focused on chronically ill patients (eg hypertension) under the supervision of a doctor. This method of research and its results can have the benefit of a recommendation for regular players suffering from a chronic illness. An interesting alternative to research would be to measure and monitor people with gambling addiction for several consecutive days, and the results would be averaged. There are different gaming platforms whose resulting effects on the player may vary and could be compared.

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TEMPLATE DESIGN FOR TRANSFEMORAL PROSTHETIC SOCKET DEVELOPMENT

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Keywords: prosthetic socket, template design, CAD/CAM, 3D scanning, additive manufacturing.

Abstract: The presented paper aims to design 3D templates of the sciatic muscle and thigh to simplify and speed up the process of modelling TF (transfemoral) sockets using the CAD/CAM method. A proposal for a general procedure for modelling the proximal part of the TF socket and a thorough description of the proximal part and the types of sockets that are used is presented. Ten individual scans of positives of TF amputated limbs were obtained from which ten mounting ring templates were designed via CAD modelling in the Autodesk Meshmixer software. In the last step a production simulation was generated in PrusaSlicer software for the overall price evaluation.

1 Introduction

The prosthetic socket is a component that secures the prosthesis on the residual limb. Due to the functionality of the prosthesis socket, personalization is necessary, considering individual measurements. Currently, the latest measurement and production methods available in the field of prosthetics and orthotics are increasingly being used [1]. In the design of prosthetic aids, digital data obtained with the help of 3D scanning technology are used, based on which the CAD (Computer Aided Design) modelling of the aid and subsequent CAM (Computer Aided Manufacturing) production are approached. The use of this innovative method prevents the creation of a plaster positive of the residual limb and the conventional production of the socket itself [2]. The introduction of computer-supported tools also reduces the time and costs of the entire development process. These tools make it possible to evaluate different variants of the same product faster and cheaper [3].

Specifically, the transfemoral socket of the lower limb prosthesis is one of the most complex custom-made prosthesis components from a design point of view [4-7].

The process of designing a prosthetic socket can be divided into three levels:

- Preparatory phase of modelling (import of patient data, import of 3D model of the femur, adjustment of the scale of femur circumferences, creation of 3D surface of the socket, optimization of the distal part of the socket)
- Stage of personalized modification of the model (marking important areas of the 3D model of the stump, virtual sculpting of the stump, adjusting measurements)
- Final phase and completion of the geometric model of the socket (modification of the surface of the 3D model of the socket, FEM (Finite Element Method) analysis of the pressures acting on the socket)

Each level of production is personalized, as important adjustments need to be made directly to each individual patient. It is caused by the different shape of the stump. Currently, from a functional point of view, 3 types of transfemoral beds are produced (Figure 1):

- Quadrilateral (transverse oval socket) - using support on the hump of the sciatic bone [8,9].
- Ischial (longitudinal oval socket) - using fixation of the hump of the sciatic bone [10,11].
- Subischial - using fixation by compression of the soft tissue [12-14].

The most complicated part in the design of the socket is the mounting ring, which surrounds the 5-6 cm long proximal part of the thigh. The design is complex due to the curvatures of the surface of the given body segment and the complexity of its 3D scanning. Scans of this area may be unusable depending on the weight and body shape of the subject being scanned. Places and points important for the design of the mounting ring may be indistinct, thus it is not possible to use the CAD/CAM method for its design and production.

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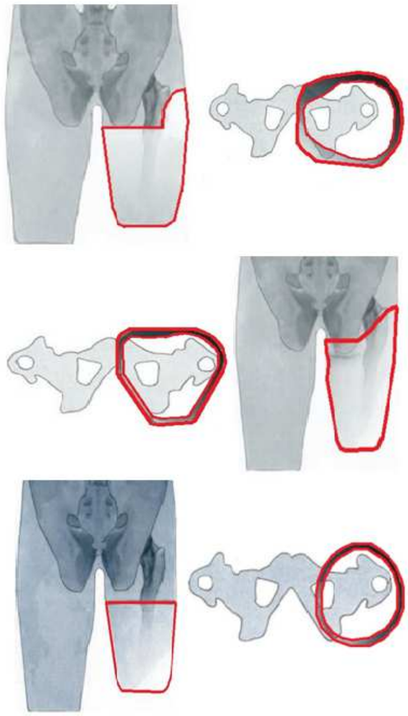

Figure 1 Quadrilateral (top), ischial (middle) and subischial (bottom) transfemoral sockets [9]

For this reason, it is important to design and manufacture mounting ring templates of various shapes and sizes that can be fixed on the subject during scanning to avoid its CAD designing.

2 Methodology

Positive models of transfemoral amputated limbs were obtained using the 3D scanning method using the M4D 3D scanner (Rodin4D, Merignac, France). The result was 10 transfemoral 3D scans of positives in STL (Standard Triangle Language) format. Editing of the obtained 3D models of the positives and the design of the mounting rings were conducted in the CAD software Autodesk Meshmixer (Autodesk, Inc., San Rafael, CA, USA).

Before designing of the ring, itself, it is necessary to modify the model of the 3D scan of the positive on which it will be designed. The first step is to align the model in the software's Cartesian coordinate system so that the frontal, transverse, and sagittal planes of the femur model are identical to those in the software. Subsequently, it is necessary to reduce the number of triangles that make up the surface of the 3D model of the positive. The lower the number of triangles is, the faster the software can work. We perform the reduction as needed. It is necessary to be careful that a too high reduction does not deform the shape of the surface of the model. Next, it is advisable to remove parts of the positive model that are not essential when designing the mounting ring. Thus, a part of the model 5-6 cm distal from the indicated proximal edge of the socket is removed by a transverse incision (Figure 2).

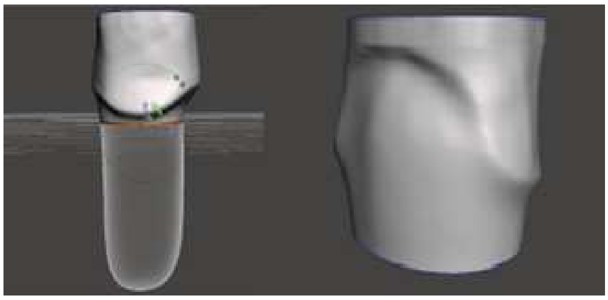

Figure 2 Preparation of the 3D positive model

When designing the ring itself, it is necessary to indicate the area that will represent its inner surface area. This surface is located distal to the proximal edge of the socket. The marked area is then extruded to a height of 5 mm, which results in a 3D model of the mounting ring (Figure 3). In the last step, it is necessary to smooth out the surface of the model and its sharp edges, which may have arisen during the creation of the 3D model.

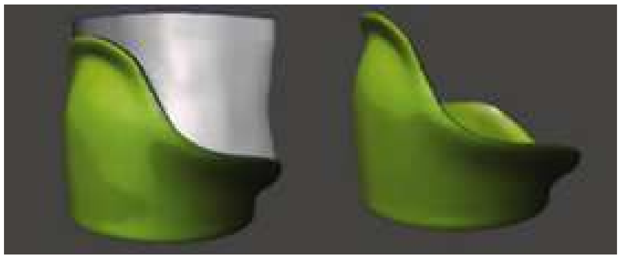

Figure 3 Mounting ring model

3 Results

The result of the modelling is ten templates of the mounting ring of the TF (transfemoral) socket in a digital form, which is ready for CAM production. When making a template, it is important to analyse 3D printing from an economic point of view. The CAM simulation of the production of individual rings was created in PrusaSlicer (Prusa Research a.s., Prague, Czech Republic) software. The low-cost FFF (fused filament fabrication) type 3D printer TRILAB DeltiQ2 (TriLAB, Brno, Czech Republic) with PLA (polylactic acid) and ABS (acrylonitrile butadiene styrene) materials were chosen as the device for model production.

Before printing itself, several parameters need to be considered, namely the time of modelling using CAD software, preparation of the model for 3D printing, printing time and the amount of material consumed. The simulation results are summarized in Table 1.

Table 1 Mounting ring templates production simulation results

Model number	Used PLA materi-al [kg]	Length of production (PLA)	Used ABS materi-al [kg]	Length of producti-

				on (ABS)
1	0.475	1d 18h 55m	0.398	1d 18h 55m 1135
2	0.418	1d 16h 32m	0.350	1d 16h 18m 978
3	0.325	1d 7h 34m	0.273	1d 7h 38m 458
4	0.357	1d 10h 49m	0.300	1d 10h 56m 656
5	0.344	1d 9h 16m	0.292	1d 9h 20m 560
6	0.292	1d 4h 6m	0.245	1d 4h 11m 251
7	0.415	1d 15h 37m	0.274	1d 9h 25m 565
8	0.430	1d 18h 15m	0.361	1d 18h 23m 1103
9	0.342	1d 9h 13m	0.287	1d 9h 21m 561
10	0.433	1d 18h 27m	0.363	1d 18h 25m 1105
Average	**0.383**	**1d 12h 52m**	**0.314**	**1d 12h 17m**

4 Discussion

Meshmixer software allows the user to quickly create models of prosthetic aids and devices using appropriately selected features. Using available programming tools, it is also possible to automate the design workflow [15].

The advantage of this software is its availability, as it is a freely downloadable software that contains several functions and tools that speed up the TF socket modelling process compared to the classic conventional manufacturing method. The software is linked to a 3D printer so that the TF socket can be printed directly after the modelling process is completed. From the point of view of developments in the field of prosthetics and orthotics, this method of modelling and subsequent 3D printing is very advantageous in terms of financial costs, but also the time saved, thanks to which the given TF socket reaches the patient much earlier.

Designing and modelling in this software was timesaving. The design of one template took an average of 20 minutes. From 10 3D positives, which are remarkably similar in shape but different in size, it was not possible to create S, M and L (small, medium, and large) template sizes. A larger sample of 3D positives would need to be used to create standardized sizes. The main advantage of these templates is speeding up and simplifying the 3D scanning process when obtaining a virtual positive of the stump and working on the CAD design of the TF prosthesis socket.

Based on the shape of the stump, the orthopaedic technician selects a suitable template with the required size and then adjusts the proximal part of the stump as needed. The evaluation of the total value of the material had to be determined using the PrusaSlicer software, where the average amount of material used for 3D printing was calculated in the case of PLA and ABS filaments. The output of the calculation was the determination of the total price for the material. It was found that the material price for one template made from PLA material is 12,26 euros and from ABS material 8,79 euros. This means that PLA material is 3,47 euros more expensive than ABS. However, the total price for the template would be higher because it is necessary to consider other production expenses, such as a surcharge for the design, device, preparation for 3D printing, energy consumed during 3D printing and so on.

5 Conclusions

Using the presented procedure, ten mounting rings were designed to simplify and speed up the process of 3D modelling TF sockets using the CAD/CAM method. The goal was to create templates that should be in selected sizes to be used as a template for a professional technician. Based on the shape of the bone, he selects a suitable template with the required size and then adjusts the proximal part as needed.

In the future, it is necessary to obtain a larger sample of 3D positives, so that it is possible to design the average sizes of the mounting ring templates according to them. It would also be appropriate to simulate production on other types of CAM technologies and compare the results with the results of this research.

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