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KARLSRUHER REIHE TECHNOLOGIE
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MILAD RAJABI

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Karlsruher Reihe Technologie und Management im Baubetrieb
Karlsruher Institut für Technologie (KIT)
Institut für Technologie und Management im Baubetrieb

Prof. Dr.-Ing. Dipl.-Kfm. Shervin Haghsheno (Hrsg.)
Prof. Dr.-Ing. Sascha Gentes (Hrsg.)

Heft 78

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Gamification of telematics data to enhance operators' behaviour for improvement of machine productivity in loading cycles

by
Milad Rajabi

KIT Scientific Publishing

Karlsruher Institut für Technologie
Institut für Technologie und Management im Baubetrieb

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Zur Erlangung des akademischen Grades eines Doktors der Ingenieurwissenschaften (Dr.-Ing.) von der KIT-Fakultät für Bauingenieur-, Geo- und Umweltwissenschaften des Karlsruher Instituts für Technologie (KIT) genehmigte Dissertation

von Milad Rajabi, M.Sc.

Tag der mündlichen Prüfung: 20. März 2023
Referent: Prof. Dr.-Ing. Dipl.-kfm. Shervin Haghsheno
Korreferent: Prof. Dr.-Ing. Sascha Gentes

Impressum

KIT Scientific Publishing

Karlsruher Institut für Technologie (KIT)
KIT Scientific Publishing
Straße am Forum 2
D-76131 Karlsruhe

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www.ksp.kit.edu

Print on Demand 2023 – Gedruckt auf FSC-zertifiziertem Papier

ISSN 2363-8222
ISBN 978-3-7315-1301-8
DOI 10.5445/KSP/1000158525

"Believe you can, and you are halfway there"

- Theodore Roosevelt

Acknowledgements

I would like to express my deepest appreciation to my supervisor Prof. Dr.-Ing. Dipl.-Kfm. Shervin Haghsheno, who provided me with the opportunity to conclude my PhD studies at Institute of Technology and Management in construction (KIT), for his invaluable feedback and patience.

I am also very grateful to my defence committee, Prof. Dr.-Ing. Sascha Gentes (my second supervisor), Prof. Dr.-Ing. Marcus Geimer and Prof. Dr.-Ing Kunibert Lennerts who their insightful feedback led my work to a higher level. This endeavour would not have been possible without priceless feedback I was provided by Dr.-Ing. Heinrich Schlick, therefore, I would like to extend my sincere thanks to him, and all my ex-colleagues and students at TMB as well.

Many thanks should also go to RIB Software SE who financed my research, and especially to Mr. Michael Sauer, Mr. Wolfgang Müller and Mr. Holger Fomm who provided me the opportunity to take part in this engaging project. Moreover, I would like to acknowledge Mr. Martin Biesinger and Mr. Mamadou Ly for their amazing support during my research work. Beside RIB Software SE, I would like to thank Willemen group as well as Pusch Bau GmbH which provided me the access to their sites to collect data for my research project.

Last but not least, I could not have undertaken this journey without unconditional support of my parents and especially my lovely wife. Sara, you provided me your unlimited support while you were fighting for your own health. Words cannot express my gratitude to you…. my love, keep fighting and do not forget, we grow old together.

Abstract

Construction industry is suffering from low productivity rate in various projects such as excavation. Although this issue is discussed in literature and several approaches are proposed to address it, productivity rate is still low in construction industry compared to other domains like manufacturing.

Three core components directly affect the overall productivity in construction sector, i.e. labour productivity, raw material productivity, and machine or equipment productivity.

With a focus on construction machinery, three factors influence productivity at excavation sites; i.e. 1) machine-based productivity and its configuration, 2) site layout and environmental conditions, and 3) operators' behaviour. Operators' competence and motivation represent two key parameters that affect their behaviour.

On one side, gamification has attracted a growing area of interest both in literature and practice, seeking to place a layer of entertainment and pleasure to the top of serious activities (with a focus on improving the applicant's motivation and behaviour). On the other side, telematics systems are utilized to collect operational data of the machine, and calculate its productivity rate. Telematics data are presented to operators (via a built-in screen available in the cabin of the machine) to provide real-time feedback about machine performance. In addition, these data can support machine owners to perceive operators' behaviour on a real-time basis. To conclude, telematics systems are providing real-time data which can be a great input into gamification.

A guideline is proposed in this dissertation that helps gamification designers to develop more transparent gamification models. This guideline is utilized to introduce a gamification model that gamifies telematics data with a focus on enhancing operators' behaviour (machine productivity) in loading and transferring activities. The model was implemented at two sites (one recycling and one mining site) and could encourage operators (who were operating wheel-loaders and dump-trucks) to prevent redundant activities like texting, phoning, and even eating while operating the machine. Subsequently, it enhanced overall machine productivity up to 37% during the site observation.

To summarize, a gamified platform in which different operators from different organizations can share their achievements, or can get scored and ranked in a leader-board will potentially lead to a more proper operators' behaviour at work and subsequently can improve overall productivity rate at construction sites.

Kurzfassung

Das Baugewerbe leidet unter einer niedrigen Produktivitätsrate bei verschiedenen Bauvorhaben, z. B. bei Aushubarbeiten. Obwohl dieses Problem in der Literatur thematisiert und verschiedene Lösungsansätze entwickelt wurden, ist die Produktivitätsrate im Baugewerbe im Vergleich zu anderen Branchen, wie beispielsweise dem verarbeitenden Gewerbe, nach wie vor teils gering.

Drei Kernkomponenten wirken sich direkt auf die Gesamtproduktivität im Bausektor aus: die Arbeitskräfteproduktivität, die Rohstoffproduktivität und die Produktivität der Arbeitsmaschinen bzw. der Ausrüstung.

Mit Schwerpunkt auf Baumaschinen beeinflussen drei Faktoren die Produktivität auf Aushubbaustellen: 1) die maschinenbasierte Produktivität inklusive ihrer Konfiguration, 2) die Gestaltung der Baustelle sowie die Umgebungsbedingungen und 3) das Verhalten der Maschinenführer. Die Kompetenz und Motivation der Maschinenführer sind dabei zwei elementare Schlüsselparameter, die das Verhalten und die damit verbundene Produktivität bestimmen.

In Literatur und Praxisanwendungen findet einerseits die sogenannte Gamification immer größeres Interesse im Rahmen der Personal(weiter) Entwicklung. Hierbei wird angestrebt, anspruchsvollen Aktivitäten eine Ebene der Unterhaltung und des Vergnügens hinzuzufügen, als Treiber für Motivationssteigerung und kontinuierlicher Verhaltensverbesserung des Anwenders. Auf der anderen Seite kommen Telematiksysteme zum Einsatz, um Betriebsdaten der Maschine zu sammeln und ihre Produktivität zu berechnen. Die Telematikdaten werden dem Bediener (z.B. über einen in der Kabine der Maschine eingebauten Bildschirm) angezeigt, um ihm ein Echtzeit-Feedback über die Maschinenleistung zu geben. Darüber hinaus können diese

Daten den Maschinenbesitzern helfen, das Verhalten der Bediener in Echtzeit zu erkennen und Verbesserungspotentiale zu identifizieren. Schlussfolgernd liefern Telematiksysteme Echtzeitdaten, die wiederum einen großen Beitrag zur Gamification und damit Personalentwicklung auch bei Maschinenführern leisten können.

In der vorliegenden Dissertation wird ein Leitfaden vorgeschlagen, der Gamification-Designern hilft, transparentere Gamification-Modelle zu entwickeln. Dieser Leitfaden wird verwendet, um ein Gamification-Modell einzuführen, das Telematikdaten mit dem Schwerpunkt auf der Verbesserung des Verhaltens der Bediener (Maschinenproduktivität) bei Lade- und Umladevorgängen gamifiziert. Das Modell wurde an zwei Standorten implementiert (einem Recycling- und einem Bergbau-Standort) und konnte Maschinenführer (die Radlader und Kipper bedienten) durch spielerisches Belohnungssystem ermutigen, unproduktive Aktivitäten wie das Schreiben und Lesen von Kurznachrichten (z.B. SMS), Telefonieren und sogar Essen während der Bedienung der Maschine zu vermeiden. In der Folge konnte die Gesamtproduktivität dieser Maschinen während der Beobachtung um bis zu 37% gesteigert werden.

Zusammenfassend lässt sich feststellen, dass eine spielerische Plattform, auf der verschiedene Bediener aus verschiedenen Organisationen ihre Leistungen austauschen oder in einer Rangliste bewertet werden können, potenziell zu einem korrekteren Verhalten der Bediener bei der Arbeit führen und somit die Gesamtproduktivität auf den Baustellen verbessern kann.

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List of Abbreviations

RFID	Radio-Frequency Identification
DSR	Design Science Research
JPL	Jet Propulsion Laboratory
IoT	Internet of Things
OEM	Original Equipment Manufacturer
TSP	Telematics System Providers
IT	Information Technology
IN	In-vehicle Networking
GIS	Geographic Information System
WCI	Wireless Communication Infrastructure
MHI	Machine-Human Interfaces
CAN	Controller Area Network
D2B	Domestic Digital Bus
LIN	Local Interconnect Network
MOST	Media Oriented System Transport
CU	Controlling Units
GNSS	Global Navigation Satellite System

GPS	Global Positioning System
CGIS	Canadian Geographic Information System
MTSO	Mobile Telephone Switching Office
GEO	Geostationary Orbit
LEO	Low-Earth Orbit
TNOS	Telematics Network Operation System
TSU	Telematics Service Units
MQ	Message Queue
HCI	Human-Computer Interaction
UI	User Interface
ASCE	American Society of Civil Engineering
ITS	Intelligent Transportation Systems
AACN	Advanced Automatic Collision Notification
V2V	Vehicle-to-Vehicle
V2I	Vehicle-to-Infrastructure
V2X	Vehicle-to-Everything
IoV	Internet of vehicles
WIM	Weight-in-Motion
OIT	Organismic Integration Theory

SDT	Self-Determination Theory
VR	Virtual Reality
CV	Connected Vehicles
VM	Virtual Management
GDP	Gamification Design Principles
CSDT	Centre for Self-Determination Theory
min	Minutes
s	Seconds
t	Tons

1 Introduction

Gamification represents an approach to foster applicants' motivation in serious contexts (jobs) with a target on improving human behaviour. Although it is utilized in various domains such as education, health, crowdsourcing, software development, etc., and even though a great number of positive results is achieved (Koivisto and Hamari 2019), the gamification applications are limited in construction industry. This study seeks to evaluate how gamification can improve productivity rate in construction sector, with a great focus on enhancing machine productivity (loader or excavator) in loading/unloading and transportation at excavation sites.

1.1 Research objectives and motivation

Construction industry is suffering from low productivity rate. Although various approaches are already proposed to address this issue, productivity rate in construction industry is still low compared to other domains like manufacturing. Three components affect the productivity rate at construction sites; i.e. 1) labour productivity, 2) raw material productivity, and 3) machine productivity. (Bock 2015; Linner 2013)

Moreover, complex, and large construction projects require various heavy equipment to ensure safe and efficient operations. The increased requirements for large projects have caused an increase in the use of construction machinery. As a general finding, the construction machinery employed at a site account for approximately 15-30% of the total project cost. Therefore, any enhancement in machine productivity may increases the overall benefit of the project. (Jagushte 2017)

Three primary parameters can directly enhance the overall productivity of a machine and decrease its costs; i.e. 1) specification of the machine such as the machine base productivity rate or the machine configuration, 2) specification of working environment such as site layout or weather condition, and 3) operators' behaviour (Frank et al. 2013). Operators' behaviour is highlighted as an important factor which can affect machine productivity by 80% (Frank et al. 2013). This thesis has sought to enhance overall machine productivity via improving operators' behaviour at construction sites.

It is vital to detect various movements of the machine to understand the operator's behaviour. Three approaches are highlighted to recognize different activities of one equipment; i.e. 1) using sensors and technologies such as accelerometers, gyroscopes, and RFID, 2) computer vision-based solutions to extract information by processing images and videos, and 3) analysing the audio signals generated by the machines. Although all three approaches have their own benefits, the limitation of each method means that equipment managers still are suffering from lack of an appropriate solution to address equipment activity recognition problems. (Cheng et al. 2017; Rezazadeh Azar 2013)

Telematics is an interdisciplinary field employed in different domains such as vehicle tracking, fleet management, car sharing, and insurance, which is offering a promising solution to this problem. It can collect machine operational data, recognize machine activities, and finally perceive operators' behaviour on a real-time basis.

The digital data gathered via telematics platforms can get gamified to motivate operators to enhance their behaviour. This trend is called *gamification* which is a growing research area both in theory and practice. Gamification seeks to add a layer of entertainment and pleasure to the top of serious activities (jobs) with a focus on enhancing human behaviour (Sailer et al. 2017).

To sum up, as Figure 1.1 presents, the author is motivated to gamify the telematics data (digitalized data) and evaluate how gamification can affect operators' behaviour with a focus on enhancing overall machine productivity at construction sites.

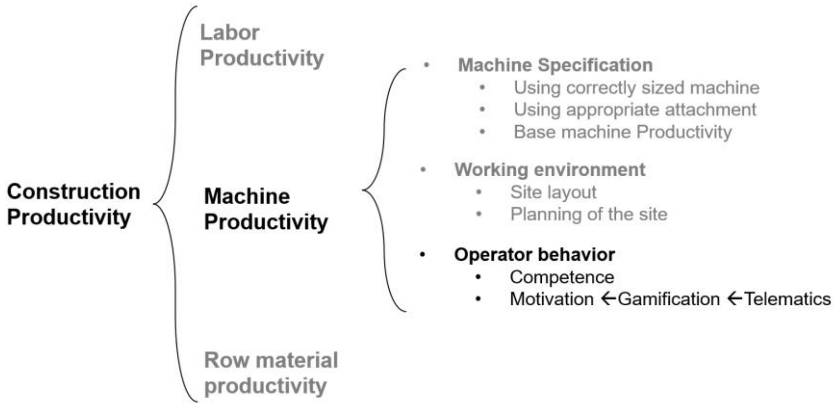

Figure 1.1: The project objective

1.2 State of research

Construction industry is suffering from low productivity rate. Various potential solutions such as automation, lean construction, etc. are discussed in the literature to address this issue. Although a great number of positive results are achieved, but productivity rate is still low in construction compared to other domains like manufacturing. (Bock 2015; Linner 2013)

The impact of labours' motivation on productivity (at construction sites) is investigated to address this issue. As a general finding, labours' productivity is increased substantially when they are better motivated. In other words, a better motivation both in quantity (motivation level) and quality (motivation type) can enhance labours' overall productivity at construction sites. (Aakanksha and Ashish 2015; Johari and Jha 2020)

Gamification is an approach to foster applicants' motivation substantially. It is not an unfamiliar concept and has been utilized by centuries to change applicants' behaviour. However, it has become popular in the literature as well as in practice only during the last decade. (Reiners and Wood 2015; Seaborn and Fels 2015). For instance, Scopus database contains more than 6,200 gamification relevant publications so that 3,744 studies (almost 60%) were published after 2016.[1]

Figure 1.2 presents the distribution of gamification studies in diverse domains. As the figure shows, almost 47% of studies are utilizing gamification for education and learning purposes (Koivisto and Hamari 2019). Focusing on construction industry, gamification applications are very limited. Other than education and training purposes (Bükrü et al. 2020), the application of gamification (at construction sites) is mainly limited to better involve operational teams in the weekly meetings[2] (Neto et al. 2014).

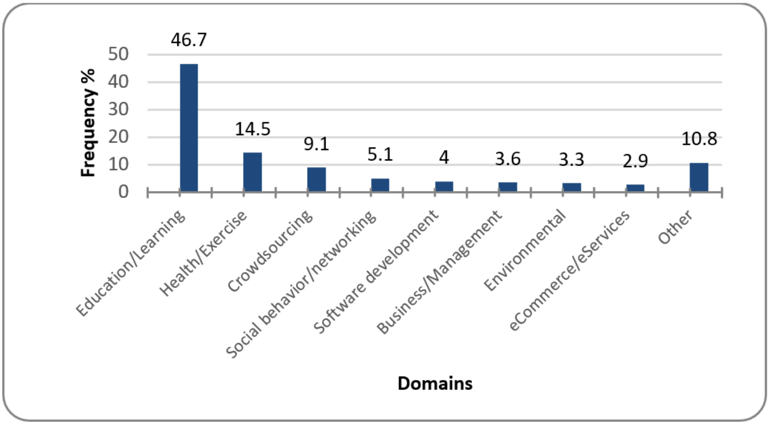

Figure 1.2: Frequency of gamification studies in various domains (Koivisto and Hamari 2019)

[1] Read chapter 3.2.

[2] That are scheduled according to the "last planner" approach

To conclude, applications of gamification at construction sites are limited in terms of 1) enhancing quality of education, and 2) better communications between operational teams[1]. Considering the positive results achieved from gamification projects in other domains, this study seeks to expand gamification applications at construction sites and utilize it to improve overall construction productivity rate.

Data collection is a primary step in gamification; in which applicants' behavioural data are gathered and gamified. The manual data collection techniques are inefficient and waste 30-50% of the supervisor's time. In addition, they account for about 2% of entire efforts at construction sites. Furthermore, manual data collection methods need extra communications between project site and project back office and normally are prone to error. (Rezazadeh Azar 2013; Cheok et al. 2000)

Therefore, automated data collection methods have been introduced and utilized recently at construction sites to address these issues. Both motion and physiological sensors (e.g., skin-temperature sensors, heart-rate sensors, etc.) are utilized in the literature to identify five applications of sensing technologies at construction sites; i.e. 1) avoiding musculoskeletal disorders, 2) preventing falls, 3) evaluating fatigue, 4) analysing hazard-recognition abilities, and 5) tracking mental status. These sensing technologies can capture a great amount of data which can be utilized in future research works to introduce proper gamification models (Bükrü et al. 2020; Ahn et al. 2019).

In terms of construction machineries, various approaches are studied to collect machine operational data and recognize machine activities. GPS devices are employed to send the geographical information of earthmoving machines to the project back-office at regular time intervals. Employing logic algorithms of the controlling systems along with the geographical information can help to evaluate machine activities. In general, the GPS-based activity recognition has one main limitation to distinguish productive activities from unproductive ones. (Rezazadeh Azar 2013; Navon et al. 2004)

RFID (as another tracking system) can record the entrance and exit time of the construction machinery to each zone. Time differences between entrance and exit represent the duration of machine activities. Although the RFID can recognize the general cycle time, it is not capable to identify detailed activities or the engine operation hours. (Montaser and Moselhi 2012; Rezazadeh Azar 2013)

Furthermore, computer-based visions were evaluated to recognize equipment activities as well. Zou has focused on an image-processing-based method for automatic quantification of idle times of excavators (Zou and Kim 2007), and Gong introduced an action recognition approach using visual learning techniques (Gong et al. 2011). Despite good results achieved, it is not viable to cover the whole site by cameras and the result is sensitive to moving backgrounds, illumination conditions, and occlusions. To address that issue, Cheng has evaluated audio signals which still is very sensitive to the background noises at construction sites. (Cheng et al. 2017)

Although all mentioned techniques have their own benefits, none of them independently can solve construction equipment activity recognition problems. Consequently, telematics systems is studied and utilized in this dissertation to collect machine operational data and perceive operators' behaviour.

1.3 Research questions

The aim of this study is to gamify telematics data with the purpose of improving operator's behaviour. Therefore, it is essential to evaluate telematics systems, and document the state of the art telematics in the construction industry. Moreover, it is necessary to perceive which machine data can get captured, and what kind of applicants' behavioural information can get collected via telematics platforms. Thus, following research questions are introduced.

- Which kind of data/information is collected by telematics?
- What is the state of the art telematics in the construction sector?

Furthermore, it is essential to discover how gamification works in order to develop a successful gamification model. Moreover, the state of the art gamification at construction sites should be reviewed to realize most recent applications of gamification. Therefore, below research questions are defined as well.

- What is gamification and how does it work?
- What is the state of the art gamification at construction sites?

Finally, a gamified model has to get developed which collects and gamifies telematics data. Moreover, the model has to get implemented at construction sites to evaluate its highlights and challenges. Accordingly, below questions are identified to be addressed in this dissertation.

- How one can develop a gamification model?
- How can gamification enhance machine productivity?

1.4 Research methodology

This thesis consists of three parts. Telematics and its applications are discussed in the first part. The second part is devoted to discuss gamification and review its applications in the construction sector. Finally, a gamified model is introduced in the last part in order to gamify telematics data and evaluate how much it can enhance machine productivity in loading/unloading cycles.

1.4.1 The first working package

A literature review is done (chapter 2) to evaluate the state of the research telematics in construction. The search query "Telematics OR GPS OR IoT" was utilized to hit all publications that have terms "telematics", "IoT", or "GPS" in their title and were published after 2009 in ASCE library. This search could hit 187 records including 114 proceedings papers, 68 journal papers, and 1 book. All hits are reviewed, and applications of telematics in the construction sector (discussed in the literature) are documented.

In addition, the author visited various construction equipment manufacturers (e.g. Volvo, Caterpillar, Komatsu, John Deere, Hitachi and Liebherr) in Bauma 2019 and discussed the most recent applications of telematics with their experts to evaluate the state of the art telematics in construction sector. Moreover, the term *"telematics in construction projects"* was googled[3] and all results in the first five pages were reviewed. Altogether, 52 web pages were read and various telematics applications in construction projects were documented.

1.4.2 The second working package

literature is reviewed to discuss the concept of motivation, to evaluate how gamification works, and to document the state of the research gamification in construction sector. Table 1.1 illustrates the search queries utilized in ASCE as well as Scopus libraries to hit gamification-related publications in construction sector.

Altogether, 44 publications are reviewed and applications of gamification in construction are documented. Furthermore, the Design Science Research (DSR) approach is employed to introduce a comprehensive guideline for developing new gamification models. The guideline can assist gamification designers to develop their gamification model more transparent.

[3] The search was performed on 09.11.2020.

Table 1.1: The search queries to hit gamification publications

	Query
ASCE	Gamif*
Scopus	TITLE-ABS-KEY (gamif* AND "construction industry") OR TITLE-ABS-KEY (gamif* AND "construction domain") OR TITLE-ABS-KEY (gamif* AND "construction sector") OR TITLE-ABS-KEY (gamif* AND "excavation") OR TITLE-ABS-KEY (gamif* AND "civil engineering") OR TITLE-ABS-KEY (gamif* AND "construction machinery") OR TITLE-ABS-KEY (gamif* AND "construction equipment") OR TITLE-ABS-KEY (gamif* AND "BIM") OR TITLE-ABS-KEY (gamif* AND "Telematics")

1.4.3 The third working package

The third working package is conducted to develop a gamification model (based on the guideline introduced in the second part) in order to gamify telematics data and encourage operators to improve their behaviour with a focus on enhancing overall productivity rate of the machine.[4]

The model is implemented at two (one recycling and one mining) sites in order to analyse how machine productivity is improved by the model. Read chapter 6.1 to learn about key findings and contributions.

[4] Section 4.1

2 Telematics

The term “*telematics”* is the translated version of the French word “telematigue” and is initiated by combining the words “Télécommunications” and “Informatique”. Although the word “*telematics*” was introduced first by Simon Nora and Alain Minc in 1978 in a report to the French government (Goel 2008), its orientation goes back to the early 1960s when a team from the Jet Propulsion Laboratory (JPL) and Stanford University utilized radio links between the earth and a spacecraft to investigate the Mars more precisely (Yunck et al. 1999).

Telematics has been defined in the literature as “*the use of computers to receive, store, and distribute information over a telecommunications system*” (Zhao 2002). Its applications call attention to the collection of raw data, processing, and subsequently, producing meaningful information which is delivered to end-users via telecommunication infrastructures (Goel 2008; Cho et al. 2006). In other words, telematics platforms are like an intelligent computer in a vehicle or a construction equipment which announces nearly every information like vehicle location, fuel consumption, idling time, etc. (Craig 2018).

Telematics is an area of research which is underneath the concept of Internet of Things (IoT). IoT refers to the whole theory of connecting every object to the internet infrastructure (e.g. connecting all cars together); however, telematics focuses on the data collection, processing, and transmission to the other parties. Assuming that telematics is referring to a broad range of objects, vehicle telematics is a sub-section of it which generally focuses on collecting data from various types of vehicles or construction machineries and transferring them to other external parties. (Wahlstrom et al. 2017)

The Original Equipment Manufacturer (OEM) and the third-party Telematics System Providers (TSP) are known as the two primary sources that provide vehicle telematics services. (Said et al. 2016)

Smart phones with all their built-in sensors are absorbing a great amount of attention as a device to collect, process and transfer data to other parties. Generally, smart phones are becoming a popular device in vehicle telematics because of three reasons: 1) Having a great number of built-in sensors such as accelerometer, gyroscope, and magnetic to collect a variety of data; 2) The ability to process the collected data via their built-in processors as well as various mobile applications to produce meaningful information; and 3) Providing efficient solutions for data transmission (wireless) and social interaction. (Wahlstrom et al. 2017)

To sum up, Figure 2.1 presents the full picture of the IoT, telematics, Vehicle telematics, and smartphone-based telematics.

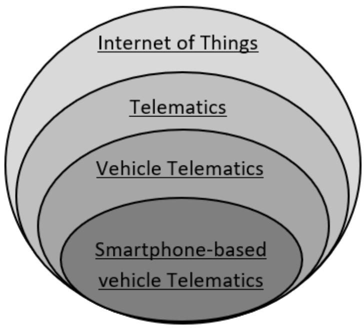

Figure 2.1: The full picture of IoT and telematics (Wahlstrom et al. 2017)

Continuous evolving of the Information Technology (IT) and smart phones have provided numerous opportunities to introduce and utilize telematics applications (or in a broader context, the IoT) in different sectors such as automotive, insurance, construction, mining, education, etc. with a rising tendency (Xu et al. 2014). These opportunities either have been discussed in different scientific publications or even have been realized directly by various telematics service providers and delivered to the market for use in different industries. Therefore, it is necessary to review the literature and the market (the telematics industry) separately in order to provide a comprehensive picture of different applications of telematics systems. Thus, the state of the research telematics in construction is reviewed in section 2.2; and section 2.3 is devoted to reviewing the state of the art telematics in practice (focusing on construction sector).

2.1 Telematics components

Figure 2.2 presents a simplified telematics system that includes four main components and performs four main tasks; i.e. 1) data gathering, 2) data transmission, 3) data processing and archiving; and finally, 4) information dissemination and use.

Ordinarily, modern vehicles have an ‘In-vehicle Networking’ (IN) system provided by OEM which gathers vehicle raw data such as speed, acceleration, deceleration, etc. In addition to the IN system, separate sensors can be installed on vehicles[1] to collect the raw data of the vehicle and prepare them for later transmission. As shown in Figure 2.2, smartphones can be also employed to gather the raw data of the vehicle. Furthermore, position tracking systems as well as Geographic Information System (GIS) are other sources for data collection in a telematics system. Read section 2.1.1 to learn more about various data collection methods in telematics platforms. (Said et al. 2016; Monnot and Williams 2011)

The collected data must be transferred to the data process and archive pools for further analysis and evaluation purposes. As shown by Figure 2.2, Wireless Communication Infrastructure (WCI) available in a telematics platform trans-

[1] provided by various Telematics System Provider (TSP)

fers data from a vehicle (or smart phone) to the processing server and later to end-users. (Said et al. 2016; Monnot and Williams 2011)

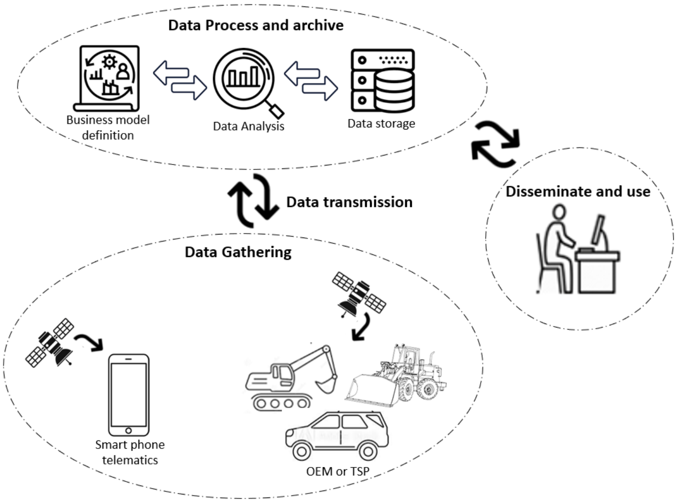

Figure 2.2: A simplified telematics system

Moreover, a telematics system processes the raw data and produces meaningful information based on various business models. The initial data analysis can be partly done directly by the IN system or by another independent device such as smart phones. More advanced data computation and processing is done in the data process and archive pools, before distributing the information among end-users. Finally, the meaningful information is provided to end-users via suitable Machine-Human Interfaces (MHI). (Said et al. 2016; Monnot and Williams 2011)

2.1.1 Data collection

The emergence of innovative technologies has provided various mechanisms and opportunities to collect data in a telematics system. Normally, new and modern vehicles have an IN system such as CAN-bus which is employed to gather and transfer data cross different components in a vehicle. If the vehicle does not have any telematics system provided by the OEM, external sensors can be installed on various components in the vehicle to gather its raw data. The collected data are transferred to the processing pools provided by the TSPs to analyse the raw data and produce meaningful information. Furthermore, additional information such as location and environmental-related data can be collected using other external technologies such as position tracking systems and GIS in a telematics platform. On top of all, smartphones have absorbed a tremendous amount of attention in the literature as a device to collect various data from a vehicle, an operator and even the surrounding environment. Some of the most important approaches to collect data are discussed in the following in detail.

- **In-vehicle networking (IN) system**

New and modern vehicles have better safety and are more comfortable compared to their older versions. In addition, there are more requests to decrease vehicle emission and its fuel consumption continuously. This trend has increased the complexity involved in the vehicle and, therefore, demands a proper data collection and a suitable data exchange approach among different components in the machine.

To address above mentioned requirements, there are different IN systems for collecting and transferring data between various components in a machine. These IN systems vary based on their implementation cost, triggering method, protocol mechanism, reliability, safety mechanisms, and data transferring rate (Cho et al. 2006; Fugiglando et al. 2019). Although the Controller Area Network (CAN) is the most common IN system utilized in vehicles and construction equipment, in the following, a brief introduction about other IN systems is provided first, and then the CAN is discussed in detail.

Domestic Digital Bus (D2B)

The Domestic Digital Bus (D2B) was first developed by Philips Consumer Electronics in 1988 and published in 1991. The D2B was first designed for home machines but later in 2002, it was modified to be used in vehicles as well. The D2B has the advantages of low cost as well as no signal quality loss. (Cho et al. 2006)

Bluetooth

Although Bluetooth was introduced originally as a replacement for wire connections between computers, cell phones, and other personal digital assistants, it has been evaluated to be modified for transferring data inside vehicles as well. Bluetooth has the advantage of low cost and low required power. (Cho et al. 2006)

Local Interconnect Network (LIN)

The Local Interconnect Network (LIN) is another IN system, which was introduced by five car manufactures, a semiconductor supplier, and one tool vendor in 1999. (Cho et al. 2006)

Media Oriented System Transport (MOST)

The Media Oriented System Transport (MOST) was introduced by Daimler, Becker, BMW, and Oasis in 1997. Although the D2B is a separate IN system and has been further developed independently, the MOST is known as a successor of the D2B. The MOST has the advantages of flexibility, low implementation cost, and wide application range. (Cho et al. 2006)

Controller Area Network (CAN)

CAN was announced in the 1980s by Robert Bosch to provide a low-cost and standardized approach for transferring messages inside a controlled system. The CAN is a serial bus communication protocol which introduces a standard for efficient and secure communication (without having a complex wiring system) between the Controlling Units (CU) in a vehicle or equipment. (Fugiglando et al. 2019; Johansson et al. 2005)

The CUs are introduced in the early 1970s and are defined as a device which combines the equipment controlling systems with its monitoring and location tracking sensors and potentially provides real-time (location and operation) data from the vehicle, the driver, and the surrounding environment. A modern vehicle may have up to hundreds of CUs which gather data from different components in the machine. For instance, an airbag CU obtains data from crash sensors to protect the operator in the case of accident, or a door lock CU obtains data when the lock/unlock button is pushed to lock/unlock the door. To sum up, as shown in Figure 2.3, imagine a vehicle or equipment as a human body, the CAN is the nervous system which facilitates communications between all nodes (CUs) and transfers data to the transponder unit without a wiring system. Then, the transponder unit sends the data to the data processing and archiving pools using the wireless communication infrastructure. (Fugiglando et al. 2019; Hallac et al. 2016; Wan et al. 2009; Li et al. 2009)

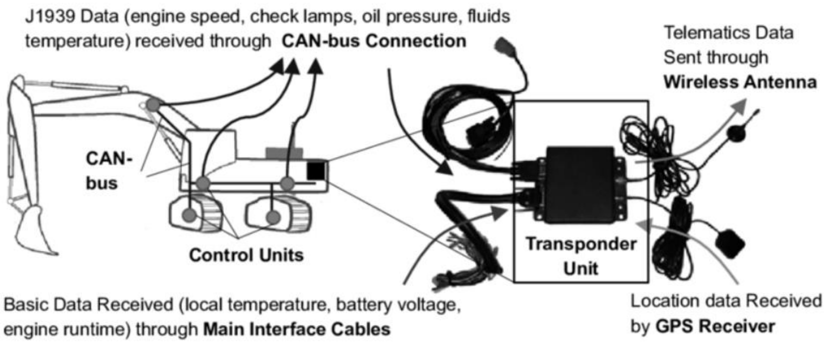

Figure 2.3: CAN-bus overview (Said and Nicoletti 2015)

Although transponder unit collects a great amount of data as well as messages (e.g. engine speed, oil pressure, etc.) via the CAN bus, there are still some data (e.g. battery voltage) which are transferred by main interface cables. Moreover, the transponder unit gets the location-related data directly via a built-in GPS receiver (Figure 2.3). Nowadays, many car manufactures, such as Mercedes-Benz, Fiat, BMW, Volvo, Volkswagen, and Renault, use the CAN to transfer different data inside their vehicles. For instance, Mercedes-Benz has been using the CAN in their cars since 1992. (Johansson et al. 2005)

- **Position tracking systems**

Vehicle tracking is one of the primary applications of telematics platforms. Basically, the knowledge of the vehicle location is crucial in developing other concepts such as connected vehicles, Internet of vehicles, and autonomous navigation. There are various methods and techniques to determine and track location of a vehicle. Among all, satellite positioning, dead reckoning technique, and signpost systems can be highlighted. (Goel 2008)

<u>Satellite positioning</u>

A Global Navigation Satellite System (GNSS) is a satellite service which allows to determine the exact location of a vehicle or other mobile receivers. Different GNSSs have been introduced, among which, the Unites States' Global Positioning System (GPS) is more known worldwide. The GLONASS (a satellite navigation system developed in Russia), the IRNSS (developed in India), the Galileo (developed in European Union), the BDS (developed in China) and the QZSS (developed in Japan) are some other available GNSSs. (Goel 2008)

GPS (as the most popular GNSS) is comprised of minimum 24 active satellites which orbit the earth two times per day at the height of approximately 20,200km above the sea level. These satellites are orbiting the earth in such the way that each location on the earth surface is covered by minimum 4 satellites all the times in order to calculate the latitude, the longitude, the altitude, and the time zone of the area where the vehicle is detected. GPS is widely used today for different purposes, including agriculture, aviation, environment, marine, public safety and disaster relief, rail, space, map, navigation, etc. (Steiner et al. 2017; GPS.gov 2020)

Due to various obstacles such as high rise building and tunnels, a vehicle or mobile receiver cannot consistently receive signals from the satellite. Therefore, satellite positioning systems are used in conjunction with other techniques such as “dead reckoning” to provide a high availability of positioning services continuously. (Goel 2008)

Dead reckoning

The position of a vehicle can continuously be tracked by gathering the course, the speed, the distance, and the time of a trip. Such information can be collected by analysing the wheel circumference and odometers. Therefore, if the vehicle position become known once, its current position can continuously be determined. This approach for determining a vehicle position is called “dead reckoning”. (Goel 2008)

The main advantage of the dead reckoning is its fully autonomous position detection; however, its major disadvantage is cumulative errors that may occur during the vehicle position determination processes. Thus, the dead reckoning technique needs a periodic position correction to eliminate the accumulated errors. To sum up, the dead reckoning technique in conjunction with a satellite positioning system can determine the location of vehicles very accurate continuously. (Goel 2008)

Signpost systems

The signpost system is a position determination method which utilizes the roadside beacons. It collects the locational information of a vehicle when the vehicle is crossing a signpost. The main issue with the signpost system is its expensive infrastructure cost in broader areas. (Goel 2008)

- **Geographic Information System (GIS)**

GIS is a business information management system developed to store, retrieve, and analyse the spatial and geographic data. This system merges various geographical information into a single model where all data are georeferenced. (Goel 2008; Maliene et al. 2011)

The history of GIS goes back to 1832 when a first GIS-like application was developed by Charles Picquet. Following it, an innovative concept of GIS was introduced in early 1960s when a group of researchers in Washington University developed a quantitative basis of geographical data analysis by the use of computer technologies. Furthermore, the term "*Geographic Information System (GIS)*" was introduced first in 1966 when the Canadian Geographic Information System (CGIS) was released. (Goel 2008; Maliene et al. 2011)

GIS is employed in different domains such as urban planning, real state, military, logistics applications, environmental protection purposes, construction, and transport engineering. Focusing on transport engineering, GIS is a preliminary data source in the telematics platforms and provides fundamental transport- and environment-related data. To cite an example, geocoding is one of the applications of GIS in vehicle telematics. It does the assignment of address information (e.g. country, city, street, and house number) to the geographic coordinates (e.g. longitude and Latitude), which are used as the base in vehicle telematics in order to calculate the shortest distance and fastest travel time between two locations A and B. In addition, map matching is another application of GIS in telematics which matches the gathered estimated location of the vehicle with the corresponding location in a digital map. Thus, the vehicle location can be presented in a digital map. (Goel 2008; Maliene et al. 2011)

- **Smart phones**

The emergence of smartphones has provided various opportunities to collect data (e.g. traffic, vehicle, environment, and drivers' behaviour data). This data can be analysed via installed software applications (apps) and produce meaningful information. The produced information (or even raw data) can be transferred to other external computation servers (via built-in wireless communication infrastructures) and be processed in more details according to numerous business models. Figure 2.4 presents the information flow when the data is collected via smartphones. (Wahlstrom et al. 2017; Engelbrecht et al. 2015)

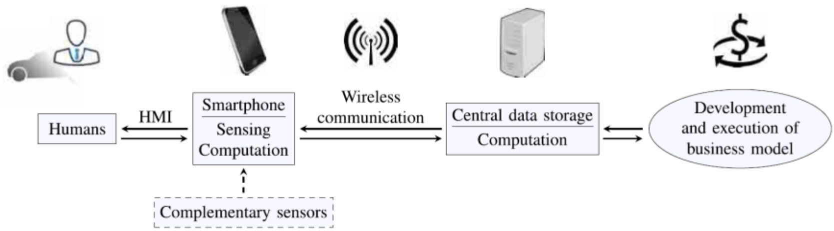

Figure 2.4: Process diagram in smart-phones telematics (Wahlstrom et al. 2017)

There are different data collection sensors and approaches utilized in smartphones to gather data. Exteroceptive and proprioceptive sensors (e.g. microphones, magnetometer, Wi-Fi, Bluetooth, camera, accelerometers, etc.) gather various types of data directly from the surrounding area. In addition, smartphones can be connected to the internet and collect various data (e.g. weather conditions) on the internet. Moreover, smartphones can become in synced with the CAN-bus system of the vehicle and gather various operational and safety data directly from the CAN-bus. To sum up, smartphones are utilized to collect following information. (Wahlstrom et al. 2017; Engelbrecht et al. 2015)

Traffic information

Smartphones can determine the vehicle's location and detect various events, including car braking, acceleration, or honk. These data can be processed in order to produce meaningful information such as road congestion. Moreover, smartphone cameras can be used to detect other vehicles and accordingly estimate the traffic condition or the waiting time in a traffic jam. Furthermore, smartphones can be utilized for car sharing purposes.

Vehicle information

Smartphones can become in synced with the CAN-bus system of the vehicle via Bluetooth. This allows smartphones to connect different CUs in a vehicle and gather various data. In addition, smartphones themselves can collect different data of a vehicle via their built-in sensors such as accelerometer, gyroscope, GPS etc.

Environmental information

Smartphones can collect weather conditions data via their built-in sensors or even on the internet. In addition, they can be utilized as a tool to detect road anomalies like potholes and warn other drivers.

Drivers' behaviour information

Smartphones are evaluated in the literature to perceive operators' behaviour. To cite an example, aggressive driving style (e.g. drunk driving) can be detected by smartphones. This can support insurance companies to first evaluate the risk of accident for each driver separately, and then adjusts their fees accordingly. In addition, cameras in smartphones can be used to evaluate drivers' facial expressions and accordingly detect their fatigue. Moreover, smartphones were studied in terms of providing drivers with some feedbacks (e.g. eco-driving tips) to improve their behaviour with the purpose of reducing fuel consumption. Finally, smartphones can detect any event of phone usage while driving, which is considered as one important case of accident nowadays.

2.1.2 Data transmission

Wireless Communication Infrastructure (WCI) is an essential component for exchanging information in a telematics application. The data (or processed information) is transferred to the external data processing (or storage) servers via WCI in a telematics application. WCI provides long-distance (as well as short distance) communications which were initially established with the emergence of telegraph in 1838 by Samuel Morse. Later, radio communications were introduced by Marconi in 1895 which make information transmissions easier, quicker, and with a better quality over a larger distance. There are different wireless communication techniques available in the market, each of which has its own design, advantages, and disadvantages. Although wireless communication techniques have been improved significantly, there are still some challenges to be addressed in order to enable future wireless applications. Some of the most important wireless communication techniques are described below. (Goel 2008; Agrawal and Zeng 2011; Goldsmith 2005)

Trunked radio

Trunked radio is a technique which provides different communication channels for different agents. In this technique, each agent (user group) needs to select an empty channel before starting his/her communication with others. This technique has the advantage of being easy to be used and being cheap; on the other hand, its disadvantage is that user groups need to wait to get an empty channel to start their communication (one channel cannot be used by different user groups at the same time). Although the trunked radio communication technique is used normally by security and safety organizations (e.g. fire department and police), other organizations such as commercial fleet management companies can additionally use it to transfer their data, information, and messages to other parties.

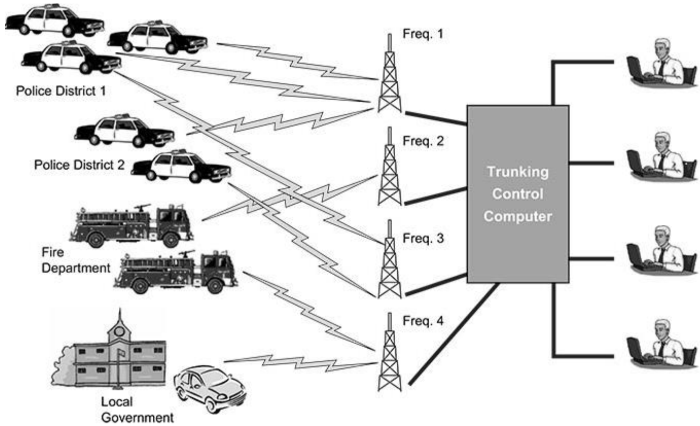

Figure 2.5: Trunked radio communication system (Faruk et al. 2018)

Figure 2.5 presents a big picture of trunked radio communication technique where each user group can connect to an empty channel to transfer their data or message. (Goel 2008)

<u>Cellular communication</u>

Due to presence of physical objects (e.g. buildings), environmental factors and even the shape of the earth, electromagnetic waves cannot travel long distance. This issue has been addressed in the cellular communication technique which provides bidirectional communications with even an international coverage. In a cellular network, geographical areas are divided into different hexagonal cells. Each cell has its own cell tower (base station) which collects the magnetic waves produced in the cell. The collected waves are transferred to other base stations (in other cells) via the base transceiver and fibre cables. Generally, a base station in the cellular communication system can cover a limited number of users. Therefore, in dense urban areas, the geographical area is divided into narrower cells, each of which has its own base station (Figure 2.6). (Goldsmith 2005)

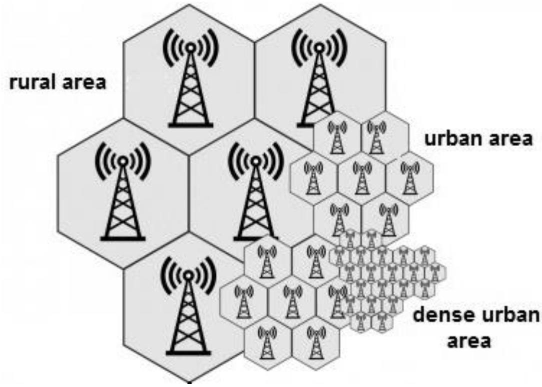

Figure 2.6: Cellular communication system (Tnuda 2020)

The Mobile Telephone Switching Office (MTSO) is used in the cellular communication networks to find the target cell tower which receives the message and to control the handoffs when a mobile agent is travelling between different cells. Read Goldsmith's work to learn more about cellular communication systems. (Goldsmith 2005)

Satellite communication

The data and information in a telematics platform can be transferred via communication satellites as well. There are two types of communication satellites acquirable (according to their orbit) to transfer information: The Geostationary Orbit (GEO) satellites and the Low-Earth Orbit (LEO) satellites. (Goel 2008)

GEO satellites are moving with the same speed as the speed of the earth and therefore, they are stationary in proportion to each specific point on the earth's surface. These satellites orbit in the height of around 35,700km above sea level and, therefore, (because of such enormous distance) each of them can cover around 34% of the earth's surface. As shown in Figure 2.7, four GEO satellites can cover the whole earth's surface. (Goel 2008)

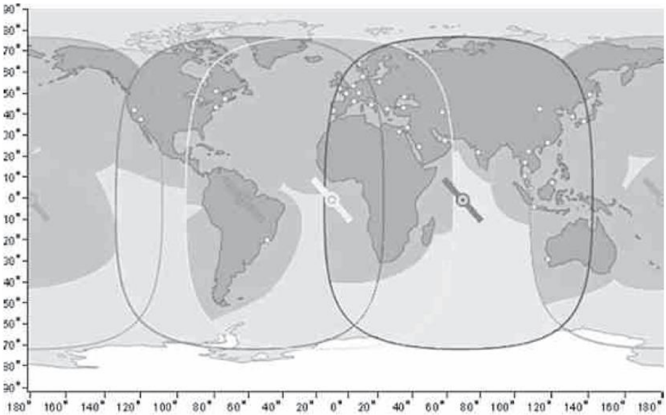

Figure 2.7: Coverage of GEO satellites (Goel 2008)

On the other hand, LEO satellites are located closer to the earth's surface and therefore require smaller transmitters. In addition, due to their height, each of these satellites covers less surface of the earth than the GEO satellites do and therefore more satellites are required to cover the whole earth's surface. (Goel 2008)

2.1.3 Data processing and archiving

It is a challenge to process and analyse big data (considering their huge volume) using traditional approaches. Some frameworks and infrastructures have been introduced to address this issue. Four key requirements for these frameworks are proposed in the literature; i.e. 1) scalability, 2) robustness, 3) real-time processing, and finally 4) data sharing. (Haroun et al. 2017; Fuchs 2002)

Scalability

The Telematics Network Operation System (TNOS) or any other infrastructure for processing the raw data should present good performance to deal with all the big data collected from various sources (vehicles).

Robustness

Errors can occur due to numerous reasons while processing the raw data. The recovery time should be minimum (and without any data loss) in TNOS when an error is eliminated.

Real-time Processing

The data should be processed and analysed in a short time. In addition, both on-line[2] as well as off-line[3] data processing should be available to cover all the expected business models.

Data sharing

TNOS should provide the possibility to exchange the information with a third-party application and control the access rights (what information can be exchanged with which third-party application and in which level).

Figure 2.8 presents the architecture of TNOS which is utilized to analyse, process, and store the telematics data by the PSA group. As shown in Figure 2.8, the infrastructure has following layers: (Haroun et al. 2017; Fuchs 2002)

[2] Immediate data process and share

[3] Data process and archive for a later usage

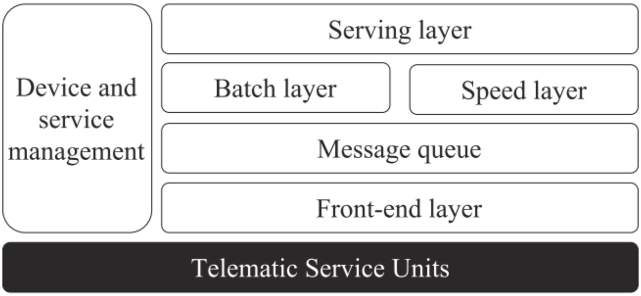

Figure 2.8: PSA group's TNOS architecture (Haroun et al. 2017)

Telematics service units

The Telematics Service Units (TSUs) are used to capture and transfer the telematics data to the "data processing" infrastructure within the PSA group. The data collection and transmission methods in a telematics platform are already discussed in more details in subsections 2.1.1 and 2.1.2.

Device and service management layer

All the management functions are centralized in the "device and service management" layer. This layer has all the information and web services to connect the infrastructure. (Haroun et al. 2017; Fuchs 2002)

Front-end layer

This layer is used to decode and ingest the data received from TSU. In general, the Front-end layer receives the messages from TSU, transforms them into Message Queue (MQ) messages, and forwards them to MQ layer. (Haroun et al. 2017; Fuchs 2002)

Message queue

MQ layer acts as a memory or disc which stores the raw data till the receiver retrieves them. This provides a continuous data feed for the processing layers (speed and batch layers). Put differently, the sender and the receiver do not interact directly, but messages are kept in MQ layer until the receiver requests them. MQ is utilized to provide an asynchronous and secured communication between the sender and the receiver. (Haroun et al. 2017; Fuchs 2002)

Speed layer

The speed layer processes and analyses the data on time and is the most important component in TNOS. In addition, this layer prepares the raw data to be stored in the batch layer for later analysis. Furthermore, the data are anonymized in the speed layer in order to meet the contract requirements about access rights. (Haroun et al. 2017; Fuchs 2002)

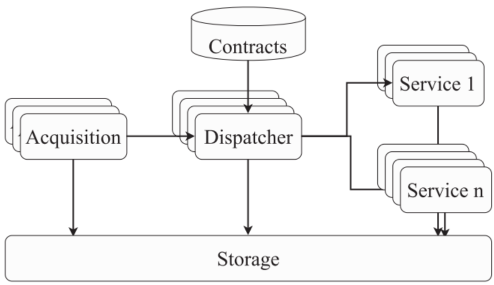

Figure 2.9: Functional architecture of speed layer (Haroun et al. 2017)

Batch layer

The batch layer provides two main functionalities; i.e. 1) the batch processing and, 2) the storage. On one hand, this layer can accumulate the data received from the speed layer, and on the other hand, it can analyse the historical data. (Haroun et al. 2017; Fuchs 2002)

Serving layer

The analysed data in the speed and batch layers are served to the external users via the serving layer. The access policies (e.g. who can access to what data) are controlled in this layer. (Haroun et al. 2017; Fuchs 2002)

2.1.4 Dissemination and use

Telematics systems collect and process data in order to produce meaningful information. This information is disseminated to end-users via various Human-Computer Interaction (HCI) methods. HCI is defined as inspecting the interactions between humans and computers and was formally founded in 1982 in the first conference on *human factors in computing systems*. (Booth 2014; Lazar et al. 2017)

The User Interface (UI) is a tool for HCI and is employed in telematic systems to provide users with real-time telematics information and allows them to communicate with the vehicle or equipment. UI translates the telematics information to the human-understandable language. Focusing on vehicle telematics, two main objectives should be considered while designing UI. (Said et al. 2016; Wahlstrom et al. 2017)

1) UI should be efficient and applicable to different devices

Various devices are utilized by end-users to get telematics data. Normally, vehicle owners use laptops to get information; however, operators may use mobile phones or tablets with various screen sizes. To sum up, UI should be efficient and suit different devices (various screen sizes).

2) UI should not result in operators’ distraction

Many of fatal and serious injury crashes are results of the operator distractions due to using their smartphones while operating the machine or vehicle. Therefore, it is important to avoid operator distractions while having operator-UI interactions. There are four aspects of operator distractions identified in the literature; i.e. 1) cognitive distraction, 2) visual distraction, 3) auditory distraction, and 4) manual distraction. (Wahlstrom et al. 2017; Watkins et al. 2011)

2.2 State of the research telematics in construction

Telematics systems have been discussed widely in the literature with a focus on all their technical aspects as well as their various applications. For instance, 1,735 research studies which have the term “telematics” in their title, in their abstract or as a keyword have been published since 2010 only in Scopus database.[4]

Furthermore, the same number of studies have being published approximately in Scopus database each year since 2010, indicating the similar popularity of telematics among scholars during the last decade. Read Figure 2.10 to learn how many telematics-related studies have been published in Scopus database (yearly) since 2010.[4]

Just as the overall trend discussed above, the construction sector is not an exception and telematics has attracted scholars’ attention in the construction. In this chapter, the author studies state of the research telematics in construction industry.

[4] Search was done on 6th October 2020 in Scopus database. Following search query was used: “TITLE-ABS-KEY(Telematics) AND PUBYEAR > 2009.”

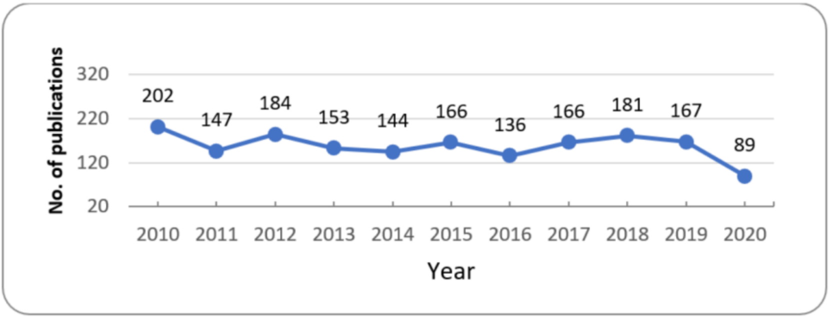

Figure 2.10: Number of telematics studies in Scopus database [4]

Three characteristics are identified for a comprehensive “literature review”; i.e. 1) the target publications should clearly be defined in advance, and as many as possible related studies should be hit and reviewed. Otherwise, the “literature review” will not be comprehensive. 2) The search approach and the employed search query to hit the related publications should be transparent and clearly defined. 3) The search approach should be reproducible and hits same as well as new publications in a later try. (Gusenbauer and Haddaway 2020)

The focus in this session is on construction sector. Therefore, the target publications are limited to the studies which have discussed and evaluated telematics in construction projects. The American Society of Civil Engineering (ASCE) has a library which includes publications from various scientific sources (books, journals, etc.) focusing on construction and transportation engineering. Thus, this library is chosen to hit the relevant research studies.[5]

The main challenge is to look for an appropriate search query to hit most of the “telematics”-related studies available in ASCE library. Moreover, due to

[5] Although other databases (e.g. Scopus) include more telematics-related publications, they are mainly focusing on technical aspects of telematics or its applications in other domains (rather than construction), which is not the focus of this study.

the rapid development observed in the IT sector during the last decade, the search query should target the latest publications. Considering all the aspects, (in the first try) the term “telematics” was utilized to hit all the publications in ASCE library that had the term “telematics” in their title and have been published after 2009. This search query could hit only 4 records. Thus, the search query was enhanced to “Telematics OR IoT” to hit all the publications that have these two terms in their titles. This modified search query could hit in total only 28 publications.[6]

In the next try, the term “GPS” was included to the search query because GPS is a sub-service from telematics platforms and is popular among researchers. Therefore, the search query “Telematics OR GPS OR IoT” was finally employed to hit all the publications that had “telematics”, “IoT”, or “GPS” in their titles and have been published after 2009. This search query hit 187 records, including 114 proceeding papers, 68 journal papers, and 1 book. The other 4 hits were discussion or editorial documents and, therefore, were excluded from further analysis.[6]

The titles and abstracts of all 183 publications were scanned and the irrelevant hits (publications related to survey engineering, aerospace, hydraulic science, and other publication that were discussing telematics from a technical point of view) were excluded. Finally, 106 publications from ASCE library were reviewed and the (potential) applications of telematics were categorized into four main groups; i.e. 1) vehicle monitoring applications, 2) operator identification and behaviour recognition, 3) safety and productivity enhancement, and finally 4) other general applications.[7]

[6] Search was done at “https://ascelibrary.org/search/advanced“ on 24.10.2020

[7] 1 book, 29 journal papers and 76 proceeding papers. In the following, some other publications from their bibliographies were included in the review as well.

2.2.1 Vehicle monitoring applications

Telematics systems are employed to collect vehicle location and its operational data e.g., idle time, actual machine hours, fuel consumption. This data can be utilized for various use-cases. For instance, the location of a vehicle can be tracked and be shown on a map. This allows machine owners to visualize all their vehicles in a unique map (Said et al. 2016). In addition, telematics has been employed for geofencing purposes as well, so machine owners can define a set of boundaries (e.g. construction site) where the vehicle is allowed to operate. Subsequently, when the machine gets out of the defined boundaries, the machine owner is informed automatically. (Said et al. 2016)

Furthermore, one other study has focused on telematics (GPS data) to analyse the distribution of taxis and public transportation services in the cities by tracking location of buses and taxies (Zhang and He 2011). More than that, telematics, RFID, and in general, IoT have been evaluated in the literature to introduce an intelligent taxi and cargo distribution system which tracks location of public vehicles continuously and helps to get a better distribution of public services across the cities (Gao and Tang 2011).

Telematics has absorbed a great amount of attention to be utilized for navigation as well as traffic density detection purposes. For instance, an alternative framework to enhance navigation and guiding systems from a navigation “based on the shortest path algorithms” to the one “based on the real-time traffic flow” is proposed. Furthermore, telematics and smartphones are utilized in other study to reconstruct traffic density in a given area or to evaluate traffic speed on highways. In addition, telematics has been utilized widely to better predict the remaining trip length both for public and private vehicles. (Ren and Kong 2011; Herrera et al. 2010)

To sum up, most hits found in ASCE library are proposing telematics applications to develop intelligent and integrated transportation systems in order to support location detection and traffic (or transport) management applications. Read Table 6.1 available in the appendix to find 47 publications which are discussing applications of telematics in an intelligent and integrated transportation system.

In addition to the location tracking and traffic engineering applications, telematics has been employed to collect the vehicle operational data, and accordingly, monitor its situation. To cite an example, Dhall has utilized telematics and IoT to introduce a predictive maintenance approach to recognize minor issues in the vehicle before they turn into bigger problems where more expensive repair and downtime period might be required (Dhall and Solanki 2017). Moreover, Siegel has used telematics services (smartphone accelerometer and GPS data) to calculate the wheel rotational frequencies and therefore, to determine vehicle tire pressure (Siegel et al. 2016). Furthermore, other studies have evaluated telematics to measure the fuel consumption rate or to analyse the real-time carbon emissions from vehicles and construction machineries (Mao et al. 2018). To sum up, telematics can provide intelligent decision-support capabilities which can support the machine owner or machine manufactures in various use-cases in terms of maximizing the machine utilization and minimizing its costs.

2.2.2 Operator identification and behaviour recognition

Operator identification is in interest of various firms such as insurance and car rental companies. It is even an exciting feature for vehicle owners as well. Therefore, telematics services are used to 1) identify operators; and 2) recognize their behaviour while operating the machine. For example, Jafarnejad has proposed a mechanism for utilizing telematics (signals received from CAN-Bus) in order to identify the operator (Jafarnejad et al. 2017; Wang et al. 2017), and Wakita has proposed a driver identification approach which is based on the driver's behaviour signals, such as the vehicle velocity, distance from the vehicle in front, and his use of accelerator or brake pedals (Wakita et al. 2005). One step further, telematics and smartphones (built-in sensors in smartphones) are broadly employed to recognize the operator's driving style and aggressive behaviour (or harsh driving) and evaluate the subsequent risks. (Xing et al. 2017; van Ly et al.; Lin et al. 2014; Hong et al. 2014)

In addition, telematics systems are evaluated to recognize the specific condition of drivers, such as their fatigue (or vigilance), inebriation, and distraction while driving. For instance, Dai has proposed a system which detects and alerts drunk driving using mobile phones (Dai et al. 2009), and Zhang has suggested an eye state recognition method to detect the driver's fatigue (Zhang et al. 2017). Moreover, Xing has employed telematics to predict driver's braking intention, which can help to improve the emergency braking system of the machine (Xing et al. 2017).

One step further, Vaiana has introduced a mobile application which evaluates how safe is the operator's behaviour and accordingly alerts the operator to correct his/her driving style (Vaiana et al. 2013) . Moreover, Castignani has introduced a driver profiling and scoring application which can detect events, such as over-speeding, and score the driver accordingly (Castignani et al. 2015).

In addition to vehicles, telematics can be utilized to track the employees' movements at job. For instance, to solve complex business problems, Platonov has discussed one application of telematics in terms of tracking the employees' location indoor as well as outdoor (Platonov et al.).

2.2.3 Safety and productivity enhancement

A great number of examples are proposed to utilize telematics for safety purposes in construction as well as in transportation engineering. Focusing on the construction sector, telematics can help site managers to monitor the health of structures or to observe the geo-hazards. For example, Bao has introduced an approach to monitor any deformation in structures using GPS units (Bao et al. 2018). Moreover, Kaloop has conducted a case study to monitor deformation of a bridge using GPS data (Kaloop et al. 2015) , and

Song has proposed a GPS monitoring technique to monitor deformations in tunnels (Song et al. 2013). To sum up, telematics technologies have been employed in the literature to propose innovative solutions for monitoring deformations in bridges, high rise buildings, dams, tunnels, towers, and chimneys.

Moreover, telematics can improve safety at construction sites. For instance, construction workers and operators can get informed (via telematics platforms) when they get close to a dangerous construction machinery or a hazardous area. Yeo has evaluated the effectiveness of IoT techniques in site accident prevention (Yeo et al. 2020), and Du has suggested to integrate GPS, GIS and BIM in order to introduce early warning and risk management systems at construction sites (Du et al.). These systems can monitor the risk of accident among construction machineries (cranes, drilling machines, loaders, etc.), or the collision risk between construction machineries and neighbouring buildings.

In addition, telematics can support construction managers to track the materials or equipment at a huge site or keep them informed when a material (or equipment) has reached or has left the construction site. This can decrease the theft rate at construction sites and improve their safety. (Pradhananga and Teizer 2012, 2013)

Telematics and specifically smartphones are also employed in driver-assistance systems to improve the road and traffic safety. For example, Corti has proposed a centralized platform (including some safety algorithms) which uses telematics systems to detect potentially dangerous situations and alerts drivers by forwarding messages on their smartphones (Corti et al. 2012). On other hand, Zhang discussed the complexity of telematics applications which alone can negatively affect the situational awareness. Therefore, he proposed to analyse the operator’s condition using telematics systems and provide only the needed information to the driver while driving. This will reduce the in-vehicle complexity and improve the operator’s situational awareness (Zhang 2017). Furthermore, telematics has been employed in safety research projects as well. For instance, Jun has utilized the telematics data to study speed patterns between crash-involved and crash-not-involved drivers (Jun et al. 2011).

Telematics and smartphones have been used to introduce the Intelligent Transportation Systems (ITS). Among different use-cases of ITS, they can recognize an unauthorized use of a vehicle and then inform the vehicle owner. Moreover, they can detect the occurrence of an accident immediately via the Advanced Automatic Collision Notification (AACN) system and subsequently provide situational awareness for emergency departments. This can obviously minimize the time interval between the accident and when the emergency medical personnel and the firemen reach the scene, resulting in higher survival rates (Thompson et al. 2010; Engelbrecht et al. 2015).

In addition to safety, telematics systems have been employed to improve the productivity of vehicles and construction machineries. Monnot has discussed various data collected by telematics systems. These data on one hand are distributed with the machine manufacture in order to enhance the machine base productivity and the machine safety and, in general, to improve the machine design. On the other hand, these data are processed and delivered (as meaningful feedbacks) to the machine operator in order to improve the operator’s behaviour and enhance overall machine productivity. Moreover, telematics are utilized to improve productivity of various maintenance works as well. (Monnot and Williams 2011; Aslan and Koo 2012; Johanson et al. 2014; Monteiro and Szpytko 2019)

Furthermore, telematics has been utilized to improve the overall productivity rate at construction sites. For instance, Shehata has concluded that telematics platforms can enhance the productivity rate up to 41% and save the operation time by 18% in road construction operations, compared to the same project where no telematics has been employed. (Shehata et al.)

IoT and telematics systems have been used broadly to introduce a new concept of “smart city transportation” which includes various theories such as vehicle-to-vehicle (V2V), Vehicle-to-infrastructure (V2I), vehicle-to-everything (V2X), and Internet of vehicles (IoVs). All these concepts provide different communication models to be used in vehicles and by passengers in various applications. These intelligent transportation systems provide enormous volume of data (big data) which finally can result in safer roads, reduce fuel consumption, and in general improve the overall productivity and efficiency of transport infrastructures. (Dow 2017; Wahlstrom et al. 2017; Arena and Pau 2019; Rathore et al. 2015; Mayer and Siegel 10/26/2015 - 10/28/2015; Haberle et al. 2015; Dhall and Solanki 2017)

Telematics systems are even employed to optimize the charging process of electric vehicles. Ostermann has proposed the concept of a “centralized charging management system” which optimizes the charging schedules, based on the real data received from various electric vehicles via telematics. (Ostermann and Koetter 2016)

Furthermore, telematics systems have been utilized to computerize vehicle routing and scheduling in urban freight transport. This can improve the overall productivity in urban freight transports. (Iwan et al. 2018)

2.2.4 Other applications

Telematics and sensor technologies have enhanced data acquisition capabilities in construction sites and have been employed for various purposes. For example, Ahn has utilized GPS to gather and characterize the travel time distribution in earthmoving operations (Ahn et al. 2015), and Andoh has employed GPS, GIS, and RFID technology to collect the location information and, subsequently, to create a 4D tracking system in order to track dynamics of the construction sites (Andoh et al. 2012).

Furthermore, telematics is supporting engineers at site to better monitor an activity. For example, Cacciola utilized telematics to gather data for the purpose of monitoring and controlling the quality of different soil compaction activities at the construction site (Cacciola et al. 2014) , and John has introduced a monitoring system to follow the early-age compressive strength of the concrete using IoT (John et al. 2020) .

Moreover, telematics has been utilized for navigation purposes in different construction sites. For instance, Tserng has employed GPS to introduce a real time guidance and positioning system which can support pile-driving in marine pier construction projects (Tserng et al. 2013), and Taghaddos has utilized GPS coordinates in the BIM model to facilitate connecting the BIM model with the construction site (Taghaddos and Eslami 2016).

Telematics has been utilized widely for logistics purposes as well. For example, Shen has introduced a modern logistics system based on Integration of GPS, GIS, and RFID technologies in order to improve navigation and monitoring accuracy for logistics purposes (Shen and Sui 2010). Moreover, Zhang has proposed integrated applications of IoT in logistics in order to maximize the service efficiency and quality (Zhang et al. 2012).

Furthermore, telematics platforms are employed to evaluate the vehicle load condition and weight-in-motion (WIM). In addition, telematics data are utilized to control legal uses of transport infrastructures, to protect and maintain the road surface, and finally to assist fleet owners with an efficient vehicle planning. (Venugopal et al. 2019; Grakovski and Pilipovecs 2016, 2017; Luo et al. 2017)

Moreover, telematics systems are investigated by insurance firms, resulting in modern concepts of “usage-based insurance”, “pay-as-you-drive” and “Pay-How-You-Drive” (Troncoso et al. 2011; Husnjak et al. 2015; Ferreira and Minikel 2012; Guillen and Pérez-Marín 2018).

In fact, the information gathered via telematics can help insurance companies to better perceive the operator’s behaviour, his driving style, and the total distance travelled. This can eventually improve the risk management processes within insurance companies (Baecke and Bocca 2017; Paefgen et al. 2014; Denuit et al. 2019; Wahlstrom et al. 2015; Ayuso et al. 2019).

Moreover, telematics services (e.g. GPS) and laser technologies are utilized in order to identify underground utilities correctly before starting a construction project. This can help to increase the efficiency in the construction processes and, subsequently, to reduce the accident and utility interruption risks. (Patel and Chasey 2014)

2.3 State of the art telematics in construction

The state of the research was reviewed in section 2.2 from a theoretical perspective; however, a great number of applications already exist in which telematics has been utilized. Therefore, this section is devoted to reviewing the existing applications on telematics in the construction industry.

With the purpose of providing a comprehensive review, on the one hand, the author visited various construction equipment manufacturers (e.g. Volvo, Caterpillar, Komatsu, John Deere, Hitachi, and Liebherr) in Bauma 2019[8], and discussed the latest applications of telematics with their experts. Moreover, their advertising brochures were scanned, and their telematics solutions were documented.

On the other hand, the term *“telematics in construction projects”* was googled[9] and all the results found in the first five pages were reviewed. Altogether, 52 web pages were evaluated and various telematics applications for construction projects were documented.

To sum up, beside simple location tracking and gathering machine operational data, telematics is utilized in construction projects to enhance machine

[8] https://www.bauma.de/de/

[9] The search was performed on 09.11.2020

productivity and provide operators with some assistance and "in cab coaching" features. Moreover, telematics is employed to better maintain the machine and improve the overall safety at construction sites. Furthermore, telematics is used for some automation as well as digitalization purposes and facilitates renting and invoicing processes for construction machineries. Read following subsections to learn more about applications of telematics in the construction sector.

2.3.1 Productivity and operator assistance features

Telematics platforms are employed widely to improve machine designs and subsequently enhance their base productivity rates. For example, machine manufactures are analysing telematics data to enhance the machine base productivity rates in their next production lines. Furthermore, machine owners are also evaluating telematics information to understand if the machine configuration or size are suitable to the job. (Volvo 2020)

In addition, productivity relevant information such as actual total load in the machine bucket, tons transported per litter of fuel (or per hour), number of cycles done per hour, total fuel consumption, total working hours, percentage of utilization, idle time, cycle time, distance travelled, etc. are collected via telematics systems. This information is directly given to the operator (on a real-time basis) on a built-in screen available in the machine cabin. Moreover, the information can be processed in some coaching apps and also provide real-time guidance to the machine operator. Both approaches can support the operators to better understand how their behaviour affects the machine productivity. (Volvo 2020)

One step further, some challenges and competitions are introduced based on telematics data to motivate and encourage operators to enhance their behaviour continuously. For instance, there is an app which introduces a competition between operators to decrease machine fuel consumption. Each operator has one profile in the app and is given some points according to his performance. (Transpoco 2020b)

Furthermore, the real-time location of other construction machineries (e.g. loaders, excavators, and haulers) can also be presented on the built-in screen available in the machine cabin. This gives the operators an enhanced orientation of the site (especially at sites with limited visibility) and allows them to adjust their timing according to the site traffic conditions. Therefore, the risk of getting blocked (by other large construction machines) decreases, resulting in reducing the machine idle time and subsequently enhancing the machine productivity rate. (Volvo 2020)

Telematics services are utilized to enhance productivity in delivery and logistic works as well. They are employed to track a delivery, communicate with the vehicle driver, propose a better path for the delivery (based on traffic conditions), inform the receiver about the delivery time, and even generate the delivery receipt upon materials reaching the site. In addition, telematics can support logistics companies to detect the closest vehicle to the source of a delivery and utilize it to perform the delivery job. (UK Telematics 2020)

2.3.2 Machine maintenance

Telematics services are employed to better maintain construction equipment and machineries. A massive amount of operational data (e.g. actual hours, oil temperature, engine speed, fuel consumption rate, etc.) is collected from the machine via the telematics platforms. These data are analysed in order to produce meaningful information which can support the machine owners both in preventive and predictive maintenance work. (Volvo 2020)

The preventive maintenance is a set of check-ups scheduled according to the machine usage. It helps to predict, catch, and fix the machine errors before they happen or turn into a more significant problem. The preventive maintenance can minimize the machine downtimes and, therefore, optimize its utilization rate. (Volvo 2020)

In addition to the preventive maintenance, various alerts are generated from the machine via telematics services (based on numerous business models and algorithms) to indicate if an error or a failure (predictive maintenance) occurs. These alerts inform the machine owner about a potential failure which can lead to an expensive maintenance cost and a long downtime period. The all alerts are first documented and then are investigated in the next scheduled check-up appointment. However, in more urgent cases, the alerts inform the operator directly about the failure and a repair or check-up appointment is directly scheduled. There are mainly two types of alerts generated by telematics platforms; i.e. 1) technical alerts, and 2) operator behaviour alerts. (Volvo 2020)

Technical alerts

Construction equipment and machineries are systematically monitored by telematics systems, and their operational data are also gathered by these systems. As described above, (base on various business models) some alerts are generated in the case of any failure in the operational status of the machine. According to the alert priority, the alerts are documented to be investigated in the next check-up appointment or are forwarded to the operator and experts for initiating an immediate action.

Operator behaviour alerts

The machine operational data are gathered and analysed to understand the operator's behaviour as well. In the case of any dangerous or unhealthy behaviour, some alerts (according to various business models and algorithms) are generated by the telematics systems. These alerts inform the operator or the machine owner about how the machine is operating and can encourages the operator to avoid further risky actions which might endanger his safety and the machine health.

Furthermore, telematics platforms can indicate why a failure is happening. Telematics can support experts to reduce the troubleshooting time and therefore, decrease the downtime period, leading to improvement of the overall utilization rate of the machine. (Volvo 2020)

2.3.3 Machine safety

Geofencing and anti-theft features provided by telematics systems has reduced the theft risk at construction sites. In fact, geofencing provides the possibility to set a digital boundary where the machine or equipment is allowed to perform its job. Subsequently, when a machine gets out of the defined boundary, the machine owner or manufacture receives a predefined safety notification or theft alert. Moreover, telematics provides some authorizations on the machine or equipment usage which decrease the theft risk as well. For example, telematics can monitor if the operator has all the certificates to operate the machine or if the machine operates over-time or out of an authorized time frame. In addition to the anti-theft features, telematics systems are employed at construction sites to enhance the operator and others' safety. For example, various "in cab coaching" apps (and features) have been introduced by telematics platforms to recognize occurrences of harsh driving, hard braking, and speeding. Therefore, in the case of danger, the operator is informed via a message on his mobile phone or the built-in screen available in the machine cabin. (UK Telematics 2020; samsara 2020; ConstructionToday 2020; Volvo 2020)

Furthermore, telematics has provided a great infrastructure to connect machines and equipment at the construction site and subsequently, has helped to introduce the concept of "*connected vehicles*". This concept on the one hand can reduce the risk of machine crashes (by generating alert messages or even shouting down the machine engine when the machine is getting very close to another machine), and on the other hand, can support the concept of "*machine automation*" by connecting various machines on a single platform. (ConstructionToday 2020; Forconstructionpros 2020)

2.3.4 Other applications

Digital site documentation is another service made available by telematics platforms. Telematics can log the machine operational status as well as various activities performed by it. In addition, it can recognize and document the amount of work done and distribute a report with a predefined list of recipients. (wirtgen Group 2020)

Furthermore, telematics facilitates the renting, and subsequently the invoicing process for the construction machineries. On the one hand, telematics can present the location of all available machines on a map and propose the most suitable equipment to the renter. On the other hand, it can help the machine owner first to recognize the amount of work done by the machine and then to understand the operational conditions where machine was in use. Therefore, the machine owner can generate his/her invoices automatically and forward them to the renter based on the contract conditions as well as the operational situation of the machine. (Volvo 2020; CSS Electronics 2020; Forconstructionpros 2020)

Warranty claims is one of the challenges between equipment manufacturers and machine owners. In fact, telematics can document how long and in what manner the machine has been operated and therefore can evaluate if the machine warranty can cover the costs of a failure. (Volvo 2020; CSS Electronics 2020; Forconstructionpros 2020)

Moreover, telematics is employed by insurance companies to first evaluate the operator's behaviour and then understand the usage rate of the machine. Thus, insurance companies can adjust their rates for each machine or operator individually. Furthermore, telematics supports insurance companies and safety departments (e.g. police, fire departments, and emergency centres) in recognizing an event of accident and, in the next step, reconstructing the event for further analysis. Focusing on construction sites, telematics can report exact locations of construction machineries and their activities at the time of an accident and therefore, support construction companies in evaluating the basic reasons of an accident and, subsequently, improve the site safety. (Volvo 2020; CSS Electronics 2020; Forconstructionpros 2020)

Fuel level management is another service provided by telematics systems. Normally, larger construction sites have onsite fuel sources; however, for smaller sites, fuels have to be provided from external sources. Telematics data can indicate the fuel level of each machine at the site and therefore, submit fuel request when needed. By identifying the location of the machine, the fuel supplier can deliver the fuel directly to the machine. In general, telematics supports construction managers in implementing the concept of "just-in-time delivery". (Forconstructionpros 2020)

Furthermore, telematics supports project managers with site registration and certificate management purposes. For example, materials and equipment can be recognized and registered by the RFID, sensors, and telematics technology directly when entering the construction sites and, subsequently, the accounting team can be informed accordingly. Focusing on workers, telematics can help to check if a specific worker or operator has a valid license to have presence at the construction site or operate the machine. (Vtec solutions 2020)

Moreover, telematics supports construction companies to submit a more accurate bid in the tendering phase of a project. In fact, telematics can evaluate the machine costs (induced by previous projects) more accurately and therefore support construction companies to submit a more competitive bid. Furthermore, telematics technologies are employed for fuel tax refunds purposes. One step further, telematics and gamification have been proposed to challenge the operators and enhance their behaviour in order to improve the machine performance and decrease the CO2 emissions. (Impacfleet 2020; Transpoco 2020a)

3 Gamification

Over the last few years, video games have become popular worldwide. On average, 64% of the US households own a device that can be utilized to play video games, and 60% of Americans play video games daily. Playing video games is not limited to a specific age or gender group, as 45% of USA gamers are women and the average age of all gamers in the USA is 34. Almost 72% of gamers (in the USA) are above 18 years old and interestingly, 23% of all the USA video game-playing population is more than 50 years old (11% are men and the other 12% are women). From financial perspective, 29.1 billion USD was spent on video games in 2017, indicating 66% growth compared to 2010 in which 17.5 billion USD was paid for video games. Figure 3.1 presents the expenses on video games in a period of 8 years from 2010 to 2017. To conclude, the gaming industry has been a growing sector during the last decade and it is expected to further grow within the next decade. (ESA. 2018)

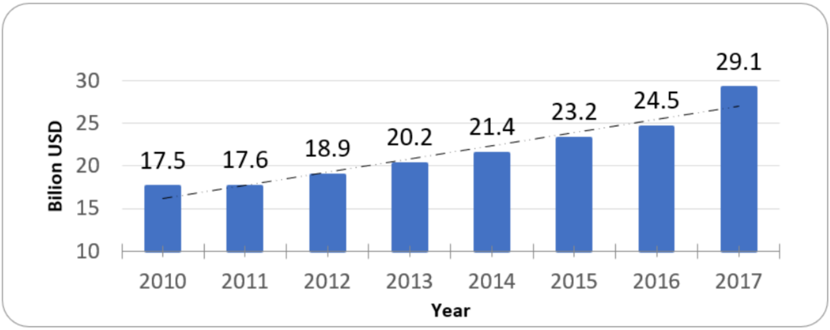

Figure 3.1: Money spent on video games yearly since 2010 (ESA. 2018)

Considering their competitive business environment, a large number of companies and organizations from various industries cannot afford to waste anymore the potential of their resources. Thus, they are continuously looking for innovative solutions to improve their employee's behaviour, motivation, and efficiency in the favour of the general goals of their firms. (Chandrasekar 2011; Çınar et al. 2011)

To address this requirement, researchers have been persuaded to investigate and understand what makes games engaging and have employed its principles in non-game contexts (serious jobs). Even though there is not any universally accepted definition, this trend is called "gamification" which was initially emerged in the early 2000s. (Aldemir et al. 2018; Nacke and Deterding 2017; Mekler et al. 2017; Deterding et al. 2011; Groh 2012; Hamari and Keronen 2017; Robson et al. 2016)

Gamification initially was defined in the literature as *"the use of game design elements in a non-game context"* (Deterding et al. 2011). Other experts claimed that not every use of game design elements in non-game contexts should be called gamification. For instance, although the "progress bar" is a game element, using it in websites and software programs (to indicate the progress) should not be called "gamification", because it is employed only as a feedback tool and has no gaming intention (Sailer et al. 2017; Werbach 2014). After that, other definitions of gamification were proposed, e.g. *"the process of making activities more game-like"* (Werbach 2014), *"the process of making activities in non-game contexts more game-like by the use of game design elements"* (Sailer et al. 2017) or *"an interactive system that aims to motivate and engage end-users through the use of game elements and mechanics"* (Seaborn and Fels 2015). Finally, a more comprehensive definition of gamification was introduced by Koivisto as *"designing information systems to afford similar experiences and motivations as games do, and consequently, attempting to affect user's behaviour"* (Koivisto and Hamari 2019).

Human behaviour and performance are improved when a clear and reasonable target is defined compared to the situation where they are simply requested "to do their best"; i.e. where gamification is considered as an approach to foster users' motivation and engagement via defining a clear target and tracking the progress. (Morschheuser et al. 2018; Jung et al. 2010)

To conclude, gamification attempts to enhance human engagement, motivation, participation, achievement, and satisfaction via adding a layer of entertainment and enjoyment to the top of serious jobs. (Huotari and Hamari 2017; Aldemir et al. 2018; Warmelink et al. 2018)

Gamification is a rapidly growing area of interest both in the literature and practice. For instance, Koivisto reviewed the literature and found the yearly increasing number of gamification publications since 2011 (Koivisto and Hamari 2019). As the literature was reviewed by Koivisto in 2015, the term "TITLE-ABS-KEY (gamification)" was utilized to seek all the publications having term "gamification" in their titles, abstract, or as a keyword in Scopus database. Figure 3.2 illustrates the result of this search query, which proofs the increasing number of gamification-related publications since 2011.[1]

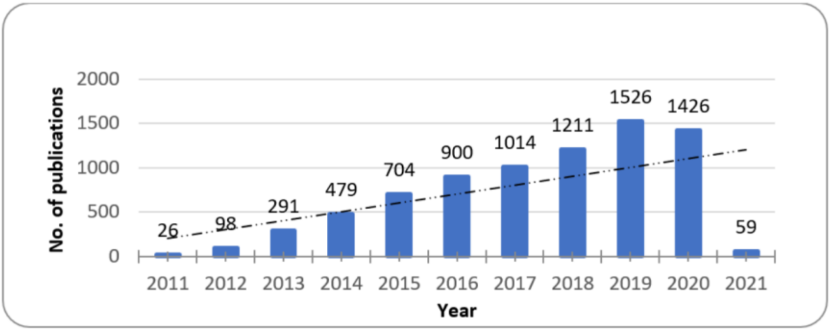

Figure 3.2: Number of gamification studies in Scopus database

Financial figures also prove the rapidly increasing trend for gamification in practice. The global gamification market was valued around 2.17 bn USD in

[1] Search was performed on 03.01.2021

2017; however, it is expected to reach 19.39 bn USD in 2023, indicating nearly 900% growth in 6 years. (Xi and Hamari 2019; Nacke and Deterding 2017)

A great number of gamification projects in different industries are conducted. Although “positive” and “mixed positive” outcomes have been mainly reported, the negative conclusions cannot be ignored. There are two main reasons concluded by the literature for the failure of gamification projects; i.e. 1) as was explained what gamification can do, it also is important to highlight what gamification cannot do. Gamification is an approach that may enhances users’ engagement and motivation; however (in some situations) better motivation or engagement is not enough to solve a core business problem. Therefore, gamification might fail if it is employed in a wrong context. 2) The negative results of gamification can be an outcome of an incompetent gamification design. Refer to section 3.3 to learn more about how to design gamification. (Hamari et al. 2014; Aldemir et al. 2018; Buckley et al. 2017; Zichermann and Cunningham 2011; Seaborn and Fels 2015; Koivisto and Hamari 2019)

This chapter is conducted to 1) provide an overview about how gamification works, 2) evaluate the state of art gamification in construction projects, and 3) introduce a guideline which can support gamification developers to enhance transparency in their design phase.

3.1 How gamification works

Gamification transforms activities into a more game-like variant, where the term “game” does not simply mean “play”. In the literature, the term “game” is defined as *“a system by which players engage in an artificial conflict defined by rules, resulting in a quantifiable outcome”* (Salen and Zimmerman 2003); however, there are two hidden definitions behind the term “play”, namely, Paida and Ludus. (Groh 2012; Deterding et al. 2011)

Paida (playing) refers to "free form of play", e.g. playing with toys or playing in yard when no rule or goal has been specified; while *Ludus* (gaming) describes a play which has some pre-defined goals and is limited to an introduced frame. As shown in Figure 3.3, gamification focuses on the Ludus segment of term "play" and gives no attention to the Paida side, where no rule or goal has been defined for the play. Refer to studies published by Groh and Deterding to learn more about the difference between the terms "game" and "play". (Groh 2012; Deterding et al. 2011)

Figure 3.4 presents a simplified model of how gamification works. As the figure shows, first, some affordances (game elements) are utilized in the gamified model which can meet human psychological needs. As a consequence of meeting human psychological needs, several psychological outcomes such as a better motivation or engagement are expected to be seen in applicants involved in gamification. Finally, these psychological outcomes can result in a better behavioural outcome which can solve some business issues. (Hamari et al. 2014; Huotari and Hamari 2017; Koivisto and Hamari 2019)

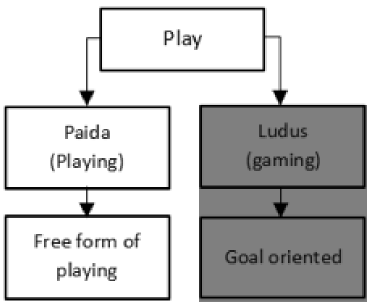

Figure 3.3: Game vs. Play (Groh 2012; Deterding et al. 2011)

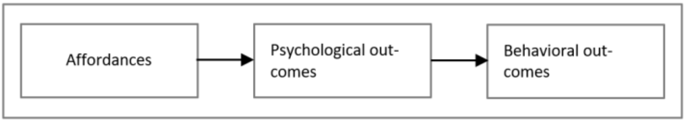

Figure 3.4: How gamification works (Hamari et al. 2014)

3.1.1 Motivation

A glance at the psychological aspects of gamification and motivation has been taken to understand how gamification works and how it affects individual's motivation. Motivation concerns what persuades people to do an activity and is initiated by the composite term "move to action". As a whole, a person who is interested in doing a job is considered as motivated; while if an individual feels no impetus to do an activity, he is characterized as an unmotivated person (amotivation). People vary not only in their motivation level (motivated, less motivated, or even unmotivated), but also in their motivation orientation (motivation type). The motivation orientation concerns why a person is motivated. In general, as Figure 3.5 shows, human motivation is categorized in three main groups with a focus on explaining the wide range of individuals' behaviour. (Ryan and Deci 2000; Patrick and Williams 2012; Deci 1975; Ryan 1995)

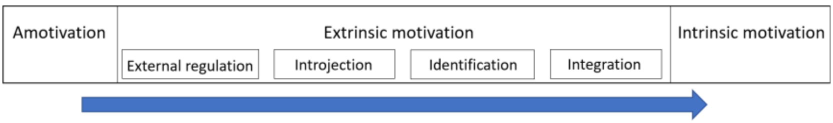

Figure 3.5: Forms of human motivation (Ryan and Deci 2000)

Amotivation

Amotivation is defined as the lack of intention to do an activity. It can be a result of not believing in the outcome of an action, not feeling to be competent to do an activity, or not valuing the activity itself. (Ryan and Deci 2000; Patrick and Williams 2012; Deci 1975; Ryan 1995)

Extrinsic motivation

Extrinsic motivation is defined as “*the desire to perform an activity with the intention to attain positive consequences such as an incentive or to avoid negative consequences such as a punishment”* (Kuvaas et al. 2017), “*doing something due to a separable outcome, such as pressure or ‘extrinsic rewards’ in the form of money or verbal feedback*” (Mekler et al. 2017; Deci et al. 1999), or even as “*a construct that pertains to a fact that whenever an activity is done, one attains some separable incomes*” (Ryan and Deci 2000).

Although extrinsic motivation as a whole is considered as an opposite to intrinsic motivation, it varies in the extent to which it is autonomous. For instance, consider two students who are preparing themselves for an exam. They are both learning hard, not because learning is enjoyable (intrinsic motivation), but because they wish to get a better grade. One of them believes that a better grade will assist him to get a better job in future; while the other student is learning hard due to fearing of sanctions exposed by his parent/teacher. Although they both are extrinsically motivated to get a better grade, one has personal endorsement and feeling of choice, while the other one is motivated due to pressure and external controls (Ryan and Deci 2000).

Organismic Integration Theory (OIT; a sub-theory for the SDT) debates different forms of extrinsic motivation presented by Figure 3.5; i.e. external regulation, introjected regulation, identification, and finally, integration. Refer to Ryan’s work to learn more about these different forms of extrinsic motivation. (Ryan and Deci 2000)

To conclude, the level of self-determination (autonomous) motivation is increasing from left to right in Figure 3.5. As a general finding, more autonomous extrinsic motivation gets closer to the intrinsic motivation and will result in a higher level of engagement, better performance, and greater psychological well-being. (Ryan and Deci 2000; DeCharms 1970; Ramlall 2004)

Intrinsic motivation

Intrinsic motivation was first studied in the experimental studies conducted to understand animal behaviour where many animals continued exploratory, playful, and curiosity-driven behaviours even when no reward was given (White 1959; Ryan and Deci 2000).

Following that, further studies extended the research area and evaluated human behaviour. Subsequently, intrinsic motivation was defined as "*the pursuit of an activity because it is inherently interesting or enjoyable*" (Mekler et al. 2017), "*doing an activity for its inherent satisfactions rather than for some separable consequence*" (Ryan and Deci 2000) or "*the desire to perform an activity for its own sake, so as to experience the pleasure and satisfaction inherent in the activity*" (Kuvaas et al. 2017).

All behaviours are motivated by rewards. The reward for intrinsic motivational activities is the activity itself, while it can naturally satisfy human psychological needs. As reported by the Self-Determination Theory (SDT), humans have three psychological needs which often are not satisfied equally among different persons. Therefore, one single activity cannot motivate all individuals in a same way. These three psychological needs are the need for autonomy, the need for competence, and finally the need for social relatedness, which are discussed in more details in section 3.1.3. (Ryan and Deci 2000; Skinner 1953; Hull 1943; Ramlall 2004)

3.1.2 Intrinsic vs. Extrinsic motivation

An important question about the relation between intrinsic and extrinsic motivation is not yet answered. Both would have positive effects on individuals. Therefore, it was initially expected to get a better result when they are combined in a single context; however, recent studies indicate that they do not fit together, and intrinsic motivation potentially declines when one is motivated by being offered some external rewards. (Kuvaas et al. 2017; Deci et al. 1999; Deci and Ryan 2008; Bowles and Polania-Reyes 2012; Frey 1993; Frey and Jegen 2001; Legault 2017a; Porter and Lawler 1968; Legault 2017b)

Furthermore, the quality of performance (behaviour) varies when one is behaving for intrinsic versus extrinsic reasons. Intrinsic motivation is autonomous which means it is volitional; while extrinsic motivation varies widely in the extent to which it is autonomous versus controlled. Although both extrinsic and intrinsic motivations can enhance human behaviour, a better creativity and psychological well-being are reached more by intrinsic motivation than by extrinsic motivation. (Ryan and Deci 2000; Cerasoli et al. 2014; Mekler et al. 2017; Ryan 2018; Nicholson 2015)

In proportion to above conclusion, gamification attempts to enhance human intrinsic motivation with the purpose of solving some business issues. Individuals have different psychological needs, and intrinsic motivation varies according to individual's characteristics. Therefore, it is a challenge to enhance the intrinsic motivation among a group of individuals in a non-gaming context (serious job). To address this issue, gamification designers are recommended to enhance more autonomous extrinsic motivation which can later get closer to an intrinsic one. In successful games, applicants normally find some other reasons to continue their appropriate behaviour when the game stops supplying the rewards. According to the SDT, this trend can be seen when the game is satisfying the three human needs of autonomy, competence, and social relatedness. (Ryan and Deci 2000; Seaborn and Fels 2015)

Figure 3.6 presents the path where the extrinsic motivation is becoming closer to the intrinsic motivation when it is getting more autonomous. To better understand the different types of human motivation, refer to the studies conducted by Legault. (Legault 2017a, 2017b)

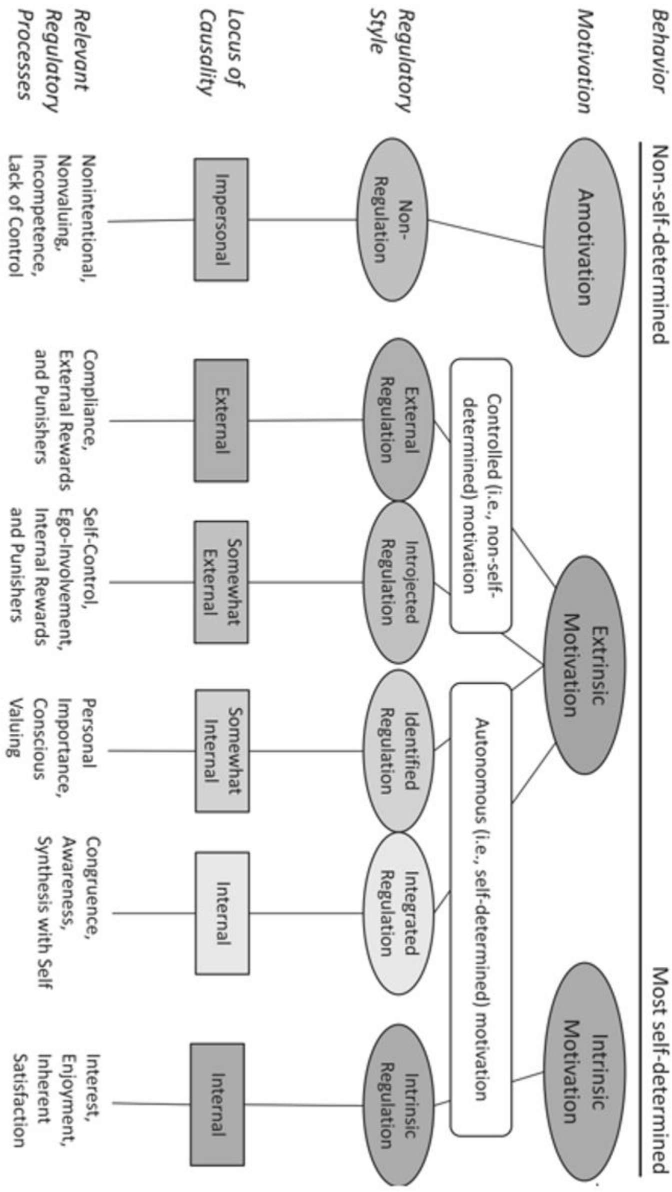

Figure 3.6: Types of motivation according to SDT (Legault 2017b)

3.1.3 Self-Determination Theory (SDT)

Diverse theories to understand human motivation are proposed in the literature. In this study, the SDT is utilized to understand how people get motivated. The STD is one of the most comprehensive theories, including a wide range of motivational mechanisms, and relatively overlaps with other proposed perspectives. Moreover, the SDT has been well accepted by various scholars and has been utilized in majority of other gamification studies. SDT is a meta-theory of human flourishing, which provides a comprehensive understanding of how/why/when individuals get motivated. It evaluates how environmental (biological, social, and cultural) conditions affect human inherent potential for psychological growth, engagement, and wellbeing. In other words, the SDT explains what individuals need from their social and psychological environments to be fully motivated and engaged. SDT is developed in accordance with six mini theories which are all merged to explain several types of intrinsic and extrinsic motivations. The SDT discusses three needs of autonomy, competence, and social relatedness to be satisfied for sustaining psychological interest, development, and wellness. (Sailer et al. 2017; Legault 2017b; Przybylski et al. 2009b; Przybylski et al. 2009a)

Furthermore, it is concluded in the literature that persuading the needs for autonomy, competence, and social relatedness is the major contributors to game enjoyment, regardless of the specific complexity, content, or genre of games. Therefore, according to the SDT, people are motivated when these three needs – autonomy, competence, and social relatedness – are promoted by social (working) environment. (Przybylski et al. 2010)

<u>The need for autonomy</u>

Autonomy is defined in the literature as "*the ability to make choices according to one's own free will*" (Psychology Today 2018) or "*the perception of being self-governed rather than being controlled by external forces*" (Legault 2017b).

Autonomy expresses the experience of freedom and volition in thought, feeling, and action. “Freedom” refers to the feeling of making decisions according to one’s own interest; while “volition” refers to the feeling of doing a task without any external pressure. Therefore, *autonomy* refers to both freedom in decision-making and task meaningfulness. Individuals feel happier, more interested, and more engaged when they feel autonomous. On the other hand, they feel helpless and more alienated when their need for autonomy is neglected. To sum up, the need for autonomy is perceived when the applicant is given the ability to choose between several tasks as well as when the task is in line with his/her own goals and interests. (Ryan 2018; Sailer et al. 2017; Broeck et al. 2010; Legault 2017c; Urdan and Karabenick 2010; Legault 2017b; Niemiec and Ryan 2013; Moller and Deci 2010)

<u>The need for competence</u>

Competence is defined as “*the innate propensity to develop skills and abilities, and to experience effectance in action*” (Legault 2017d). It is widely discussed in the literature and refers to feeling efficient and successfulness when interacting with social (working) environment. Three contexts can perceive the need for competence; i.e. 1) the need for competence is perceived when a clear structure or guidance is presented. This can define the goals more clearly, explicitly, and understandably, 2) a (unpredicted) positive feedback often meets the need for competence; while a negative feedback can lead to unfavourable results; 3) the need for competence is perceived more in situations or environments that offer the possibility to make mistakes or failures. (Ryan 2018; Sailer et al. 2017; Rigby and Ryan 2011; Legault 2017d; Reeve 2018)

<u>The need for social relatedness</u>

The need for social relatedness is defined in the literature as “*one’s feelings of belonging to, being attached to, and being cared by a group of others.*” (Sailer et al. 2017). It basically concerns feeling socially connected and is satisfied by having interaction (being cared by others or taking care of others) with the social environment. (Ryan 2018; Deci and Ryan 2012; Sailer et al. 2017)

Meaningful stories are one of the game elements which can satisfy the need for social relatedness where the player is given a relevant role (together with teammates) in the frame of the story. Furthermore, group work can also satisfy the need for social relatedness. (Groh 2012; Sailer et al. 2017; Sailer et al. 2013)

3.1.4 Game design elements

Game design elements (or motivational affordances) are defined in the literature as "*stimuli designed with the intent of meeting the user's motivational needs and affecting his/her psychological states*" (Huotari and Hamari 2017). They are known as the primary building blocks in gamification and are the rewarding system in a gamified process. These elements are used to meet human's psychological needs. In other words, game elements in gamification are very similar to the pieces in a Lego box; however, they can be assembled differently to design various gamified processes. In other words, each combination of game elements can indicate human's psychological needs differently. As discussed in chapter 3, one of the reasons that a gamification model fails is its incompetent design where not a good combination of the game elements is made. Even before the emergence of the concept of "gamification", game elements have been employed in non-gaming context as well for a quite long time. For instance, soldiers in the army receive a better badge as admiration for their experience and success, or students receive a grade (point) as feedback to their effort in an exam. Furthermore, a diploma (or a university degree) is a badge (game element) which is given to graduated students to indicate their education level in the society. (Reiners 2014; Sailer et al. 2017; Aldemir et al. 2018)

To conclude, any component or mechanism that fosters user's motivation and engagement is considered as a potential game element. A great number of game elements (3.5 game elements on average in each gamification) are utilized to design various gamification models. Koivisto reviewed the literature and summarized different game elements used in various studies. Table 3.1 presents the most popular game elements. (Koivisto and Hamari 2019)

Table 3.1: Game elements identified in the literature (Koivisto and Hamari 2019)

Game elements	**Frequency**	**Game elements**	**Frequency**
Points/Score	138	Real world/financial reward	16
Challenge/Quest/Task	91	Check-ins, location data	16
Badges/medals	85	Motion tracking	10
Leader-board/ranking	82	Physical cards	4
Levels	59	Physical playboard	2
Performance feedback	46	Real world interactive objects	1
Progress bar	32	Game resources	1
Quizzes/ questions	32	Physical dice	1
Timer/speed	23	Full game	17
Increasing difficulty	11	Assistance	15
Social networking features	49	Virtual currency	10
Teammate, cooperation	47	Reminders, notifications	9
Competition	25	Health points	7
Peer-rating	17	Safe environment to practice the rules	3
Customization/personalization	7	Adaptive difficulty	3
Multiplayer	3	Game rounds	2
Collective voting	1	Warnings	1
Avatar/Character	29	Penalties	1
Narrative/ story	22	Game Slogans	1
Virtual world, 3D world	14	Funny movies	1
In-game rewards	13	Virtual pets	1
Role play	6	Trading	1
Virtual objects	1	Making suggestions	1

As Table 3.1 shows, “point” is the most common game element in gamification. It is followed by challenge, badges, and leader board, all of which have been used in more than 80 gamification studies. There are two main reasons for popularity of these game elements: 1) these game elements are more applicable to various types of gamification approaches, compared to other game elements which can only be used in some specific formats of gamification models; 2) gamification design is a complex and multifaceted process which needs a good understanding of human psychology. In order to overcome this complexity, a great number of gamification designers have developed their gamified processes very similar to other successful gamification artifacts (patterns) which have been previously introduced and used in other domains. (Koivisto and Hamari 2019; Mekler et al. 2017; Deterding 2015; Seaborn and Fels 2015)

As discussed earlier, some game design elements meet some specific human psychological needs better than other motivational affordances do. Table 3.2 shows that which game elements can potentially perceive which needs better.

Table 3.2: Game elements by human psychological needs (Seaborn and Fels 2015)

Autonomy	**Competence**	**Relation**
Profiles, avatars, macros, configurable interfaces, alternative activities, Privacy control, Notification control	Positive feedback, optimal challenge, Progressive information, Intuitive controls, points, levels, leader-boards.	Groups, messages, blogs, connection to social networks, chat.

Following some of the most popular game elements are discussed more in detail.

<u>Points</u>

Points are normally the primary game design element employed in a great number of gamified environments. They are given to the player/applicant when a success is achieved and present the applicant's progress. In addition, points can be utilized as a tool to give continuous and immediate feedback and can mainly meet the need for competence. In general, there are different types of point systems which can be used in gamification platforms. Some examples include: (Sailer et al. 2017; Zichermann and Cunningham 2011; Werbach and Hunter 2015)

- Cash score

A number which indicates the amount of money (currency) given to a player. This point can be used to obtain some other features or advantages in the gaming environment. This freedom to use the points can potentially stimulate the need for autonomy.

- Video game score

A score which indicates how far is the player from going to the next level or even being downgraded to the previous level.

- Social networking score

The number of followers a user has in a social network such as Instagram, Facebook and twitter can present his performance in the social media.

Refer to Zichermann's study to learn more about various pointing systems and how they are used in gamification solutions to satisfy human's phycological needs. (Zichermann and Cunningham 2011)

Challenge/Task

As it is shown by Table 3.1, challenge or task is one of the most common game elements used in various gamification designs. Basically, the user is given a challenge or task and is requested to perform it. Challenge can persuade the need of competence, as is presented by Table 3.2.

Badges

Badges are given to a user/player when an achievement or success has been achieved by him/her or to represent the person's position or role in the society. Badges can meet different psychological needs. On the one hand, they are given to a user as feedback for his/her (good) performance, which can meet the need for competence. On the other hand, they can be used in the gamification platforms for various purposes by applicant's own decision, which can meet the need for autonomy[2]. Moreover, they symbolize one's membership in a group of people who have same badges, which satisfies his/her need for social relatedness. (Sailer et al. 2017; Hamari 2013; Werbach and Hunter 2012; Rigby and Ryan 2011)

Leader board

Leader-board compares different users/players' performances from a single view. It basically ranks players according to their achievements and thus is an indicator of applicant's competence. Although leader-board is a game element to enhance applicant's motivation, it can decrease the motivation as well if it is used in a wrong context. Leader-board can enhance applicant's motivation e.g., when there are only a few points left to reach the next position; however, it will decrease it when the user find himself at the bottom of the board and finds no chance to improve his position. Leader-board has more positive results when applicants have approximately same level of competence. (Sailer et al. 2017; Costa et al. 2013; Werbach and Hunter 2012; Landers and Landers 2014)

Performance graphs

A performance graph provides feedbacks about player's performance. In contrast to leader-boards (where different users/players' performances are compared), a performance graph compares user's performance with his/her preceding performance during a defined period. Therefore, it can persuade the need for social relatedness less than a leader-board does. However, it can satisfy the need for competence by providing some feedbacks to the applicants about their progress. (Sailer et al. 2017; Sailer et al. 2013)

[2] Applicants can decide how to use their badges very similar to points

<u>Meaningful stories</u>

Meaningful stories can inform user/player with one history about the game. Therefore, it can make applicant's activities more senseful, satisfying the need for autonomy. Moreover, it can meet the need for social relatedness when applicants understand the effect of their activities on other groups. In other words, meaningful stories introduce the sense behind the activities and can inform applicants about the effect of their performance on others. (Sailer et al. 2017; Kapp 2012)

3.2 State of the research gamification in construction sector

Rewarding is not a new approach and has been utilized for centuries to change applicants' behaviour. For example, rewards and punishments are employed to train children and pets, and grades and points are used to encourage students to do their homework. (Reiners and Wood 2015)

However, the concept of gamification has become more popular in the literature during the last decade. For instance, Scopus database contains more than 6,200 gamification-related publications, 3,744 of which (almost 60%) have been published after 2016[3]. Moreover, the same trend is seen in other academic databases such as IEEE Xplore, in which more than 60% of gamification-related publications have been published after 2016[4]. To conclude, gamification has become more popular among scholars during the

[3] The term "TITLE-ABS-KEY (gamification)" was used to hit gamification-related publications in Scopus database on 11.10.2020.

[4] The term (("Abstract": Gamification) OR "Author Keywords": Gamification) OR "Publication Title": Gamification) hit 1235 publications in the IEEE Xplore on 12.10.2020. More than 60% of publications have been published after 2016.

last decade and is attracting more attention as a new solution to address some of the existing business problems in several industries.

Figure 3.7 presents the distribution of gamification studies in diverse domains. Almost 47% of the publications have utilized gamification for education and learning purposes. This is followed by health and exercise domains with 14.5% share of gamification studies. Other domains such as crowdsourcing, social behaviour, software development, business, and management each have less than 10% contribution to gamification publications. (Koivisto and Hamari 2019; Seaborn and Fels 2015; Warmelink et al. 2018)

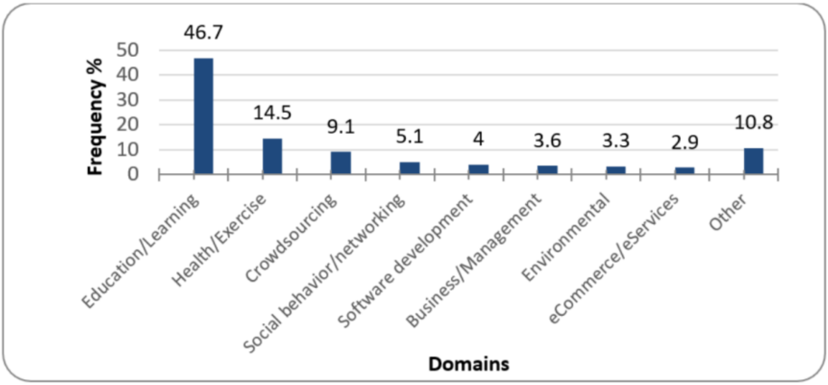

Figure 3.7: Frequency of gamification studies in various domains (Koivisto and Hamari 2019)

Figure 3.8 illustrates the results of gamification studies in three domains: health, crowdsourcing, and education. As a general finding, gamification has had strong contribution to enhancing motivation and engagement in three domains: health (85%) crowdsourcing (72%) and education (68%). (Koivisto and Hamari 2019)

A greater number of scientific publications have concluded “positive” (35.7%) results, compared to “mixed positive” (32.1%) results, in the education sector; however, a significant inverse trend has been seen in the other two domains where a larger number of studies have presented “mixed positive” results. The education domain has more experiences with gamification, thus gamification developers have achieved a better understanding to develop gamification processes in this sector, compared to other domains where gamification design is still in its infancy. (Koivisto and Hamari 2019; Seaborn and Fels 2015; Warmelink et al. 2018)

Although a promising result has been achieved in the literature, a great number of gamification projects have failed to achieve their objectives. Therefore, there are still considerable controversies around gamification designs even in the education sector. To address this issue, a new guideline is introduced in section 3.3 with the purpose of supporting gamification developers in enhancing transparency in the design phase of their models.

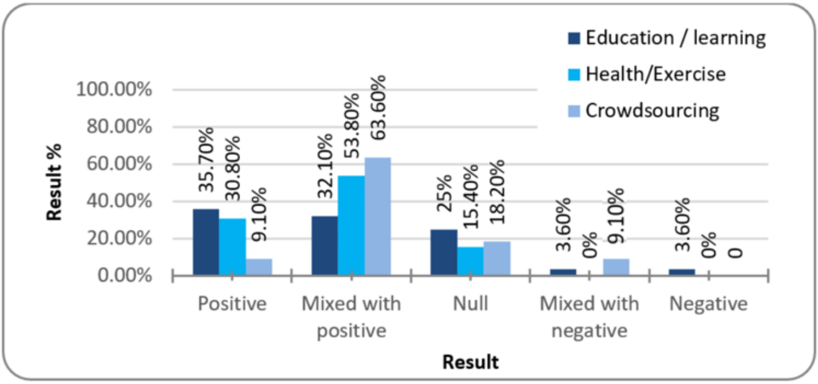

Figure 3.8: Results of gamification studies (Koivisto and Hamari 2019)

The construction industry faces with various business problems such as low productivity or high accident rates at construction sites. Among all other justifications, labour misbehaviour is known as a significant cause of these business problems. For instance, the operator’s behaviour is highlighted as one of the three major aspects affecting machine productivity in excavation works. (Frank et al. 2013)

Gamification is recognized as an approach to foster a person's motivation and engagement with the purpose of improving his/her behaviour. Bearing in mind the result of gamification implementation in other domains such as education, gamification might be a solution to various existing problems in construction and excavation projects as well. (Frank et al. 2013; Koivisto and Hamari 2019)

As reported by Koivisto, gamification applications in civil engineering are rare and limited to the transportation management and architecture(Koivisto and Hamari 2019) . However, gamification studies are increasing significantly, and meanwhile more research studies are published. Therefore, the literature is reviewed again in this study to understand the state of the research gamification in construction and excavation projects.

Discovering an appropriate scientific database as well as a proper search query to hit the most relevant publications is a challenge. With the purpose of hitting more relevant results, ASCE and Scopus databases were chosen to perform the review. On one hand, ASCE library focuses on the construction and excavation sectors. On the other hand, Scopus is a multidisciplinary database that include a wider range of scientific publications such as gamification. Therefore, performing an appropriate search query within these two libraries can hit a wide range of gamification publications with a focus on construction and excavation projects.

ASCE library is one of the world's largest full-text databases of civil engineering research publications. Therefore, utilizing the term "gamification" as a search query hits the relevant gamification publications in a wide range of civil engineering studies. However, to address all other variants like "gamified", "gamify", "gamifying", "gamifiable", all of which are grammatically valid alternatives to "gamification", the term "gamif*" has been utilized to hit all the publications which have this term in their full texts, titles (or sub-titles), or even in their abstracts. This search query could hit 12 records in ASCE library which are discussed in more details in the following.[5]

Gamification is a rapid growing methodology and has been utilized in various research projects to address several business issues. Therefore, general search queries like “gamification” or “gamification in construction” are hitting a great number of publications in Scopus databases which are rarely relevant to the construction domain. For instance, the term “gamification in construction” hits 1,993 publications, the majority of which are more relevant to the construction of a gamified process rather than gamification in the construction industry[6]. Therefore, the combination of term “gamif*” with the terms "construction industry", "construction domain", "construction sector", "excavation", "civil engineering", "construction machinery", "construction equipment", "BIM" and "telematics" has been employed to hit the publications that have these terms in their titles, abstracts or as a keyword in Scopus database. This search query could hit 32 publications that are discussed more in details in the following[6]. Table 3.3 presents an overview about the utilized search queries and the results in both databases of ASCE and Scopus.

Table 3.3: Chosen databases and search queries

	Query	**hits**	**Date**
ASCE	Gamif*	12	29.11.2020
Scopus	TITLE-ABS-KEY (gamif* AND "construction industry") OR TITLE-ABS-KEY (gamif* AND "construction domain") OR TITLE-ABS-KEY (gamif* AND "construction sector") OR TITLE-ABS-KEY (gamif* AND "excavation") OR TITLE-ABS-KEY (gamif* AND "civil engineering") OR TITLE-ABS-KEY (gamif* AND "construction machinery") OR TITLE-ABS-KEY (gamif* AND "construction equipment") OR TITLE-ABS-KEY (gamif* AND "BIM") OR TITLE-ABS-KEY (gamif* AND "Telematics")	32	12.10.2020

[5] Search was done on 29.11.2020

[6] Search was done on 12.10.2020

3.2.1 ASCE library

The term “gamif*” is used to seek gamification-related publications (which have the term “gamif” in their body, title or in their abstract) in ASCE library. This could hit 12 publications which are listed in Table 6.2 available in the appendix. These publications were scanned, and 8 records were excluded from any further analysis, 4 of which had a focus on education, 3 had discussed utility and energy consumptions in building, and the last one had discussed maintenance of ancient sites for future generations, which is not relevant to this thesis.

The gamification applications in ASCE library are limited to addressing safety matters in construction projects. Samed conducted a study on reducing fatality rate at construction sites by gamification. He considered the advantage of gamified feedbacks with the purpose of encouraging personnel to follow the safety principles which are presented in some Virtual Reality (VR) training sessions. (Bükrü et al. 2020; Ahn et al. 2019)

Moreover, Ahn reviewed the literature to evaluate the state of the art wearable sensing technology at construction sites. In general, the development of wearable sensors (sensing technologies) has provided significant possibilities to collect real-time data about workers, which can be employed for different purposes such as safety and security. Ahn evaluated both motion and physiological sensors (e.g. skin-temperature sensors, heart-rate sensors, etc.) and identified five applications of sensing technologies in construction: 1) avoiding musculoskeletal disorders; 2) preventing falls; 3) evaluating fatigue; 4) analysis of hazard-recognition abilities; and 5) tracking the mental status. To conclude, great amount of data can be captured via sensing technologies, which can be the basis for further research opportunities to build gamified models and motivate personnel to improve their behaviour at construction sites. (Bükrü et al. 2020; Ahn et al. 2019)

With a focus on transportation management, Mahmud Khan discussed the concept of Connected Vehicles (CV) and evaluated Vehicle-to-Vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. In general, as reviewed in subsection 2.2, by the advent of the IoT and telematics systems, a great amount of real-time data from vehicle, driver, and infrastructure can be captured. This data can be gamified to improve operator's behaviour, vehicle status, and infrastructure conditions. (Khan et al. 2019)

To sum up, although wearable sensing technology has provided great possibilities to collect real time data from construction personnel, equipment, and surrounding environments, the gamification applications in the construction sector are very limited.

3.2.2 Scopus database

Scopus database includes publications in various fields. Therefore, the term "Gamif*" hits a great number of gamification publications that are irrelevant to the construction and excavation sectors. To address this issue, a more solid search query should be defined and utilized. Thus, the terms "construction industry", "construction domain", "construction sector", "excavation", "civil engineering", "construction machinery", "construction equipment", "BIM", and "telematics" were added to the initial search query utilized previously. Table 3.3 illustrate the full search query employed in this study to catch gamification-related publications with a focus on the construction and excavation sectors in Scopus database. The search query hit 32 publications, including 15 conference papers, 7 articles, 2 book chapters, 7 conference reviews, and 1 review paper. The conference reviews have summarized all the articles presented in the conference and therefore, were excluded from further analysis. Table 6.3 available in the appendix presents the other 25 publications which are evaluated in more details in the following.

Some of the reviewed publications were irrelevant to gamification at construction sites or excavation projects and, therefore, were excluded from further analysis. For instance, one study had evaluated gamification in the context of urban planning and urban cycling. The other two publications had utilized gamification with a focus on archaeological excavations. The other remaining studies had investigated gamification for education and learning purposes. For example, gamification is utilized in training civil engineers (Hamzeh et al. 2017) or personnel who are working at construction sites (Schmitz et al. 2012). Although these studies focus on the construction domain, but they use gamification for education purposes rather than for gamifying a construction process at construction sites.

The integration of gamification with BIM models is evaluated in the literature. For example, Harkins utilized building models and the IoT to first attach the design to an urban environment and then gamify the way people are living in the cites. In addition, Rowland proposed gamification as a platform to integrate BIM with IoT, and Aydin utilized gamification and BIM with a focus on virtual communications to improve decision-making processes. (Harkins and Heard 2020; Rowland 2016; AYDIN and SCHNABEL 2014; Jeffrey 2016)

In addition, Selin evaluated the combination of the BIM models with gamification to illustrate and simulate different possible building usages in a series of publications. For example, he proposed to utilize BIM models in a game environment to better demonstrate the emergency exits in a building. Moreover, he has suggested to combine of the BIM models and gamification to know about the space needed for human activities in buildings or at construction sites. To sum up, gamification of building models and virtualization of building usages can add new and necessary dimensions to the whole building design process, leading to a better design and a safer building. (Selin and Rossi 2020; Selin et al. 2019; Selin and Rossi 2018; Selin and Rossi 2016)

Furthermore, gamification is utilized with the purpose of fostering motivation and engagement in construction operational teams[7]. Initially, Neto introduced a gamified system (virtual communication panels) based on the Design Science Research (DSR) method. This gamified system disseminates

[7] in the weekly meetings scheduled according to the last planner system

the weekly work packages to the all team members on the one hand and presents the operational teams' performances during the previous weeks on the other hand. As it is conducted, gamification could draw the operational teams attention more into the weekly plan and enhance the transparency among the operational teams. Moreover, it could improve the productivity and engagement in the whole construction process. (Neto et al. 2014)

Subsequently, focusing on combination of gamification and Virtual Management (VM), Leite further developed Neto's study and introduced a web tool so called "Gamified Construction Project System". He had sought to change the traditional approaches in terms of construction communication, engagement, and interactions among different parties involved in the construction via utilizing gamification at construction site. Leite concluded that gamification can enhance communications in doing weekly tasks, improve information transparency, and finally foster personnel' motivation and engagement in a given task. (Cunha Leite et al. 2016)

3.3 How to design gamification

Gamification is known as an approach to foster user's motivation with the purpose of affecting his/her behaviour. Although it has been utilized in various sectors, and even though a great number of positive results have been achieved, understanding of how to design a gamified process (gamification) is still in its infancy. On the one hand, game design itself is a complex and multifaceted process, which needs a good understanding of human psychology and design principles. On the other hand, utilizing game elements in non-game contexts (serious jobs) is a challenge due to their nature and characteristics. Beyond that, games are mainly designed to entertain people; however, gamification is more than a simple entertainment and is designed to foster user's motivation and engagement. Therefore, designing a gamified process can become even more complex compared to game design itself. (Morschheuser et al. 2018; Koivisto and Hamari 2019; Hamari 2015)

A great number of gamification developers have utilized only a simple awarding system in their gamification model to overcome these complexities and to make gamification design process more straightforward. Applicants are given an award for showing any appropriate behaviour in these systems and less attention is given to their psychological needs. If the aim was to change behaviour immediately and in short-term, an awarding system could suit well; however, it may fail in the context of a long-term strategy. An appropriate behaviour (in a simple awarding system) continues as long as rewards are given continuously, and it will stop accordingly if the organization stops giving rewards. (Reiners and Wood 2015; Legault 2017b; Patrick and Williams 2012)

Moreover, same rewards may fail to keep an appropriate behaviour, and the rewarding system probably needs to be improved continuously to keep users motivated in a longer period.

Another group of gamification designers have developed their gamified processes that are very similar to other successful gamification models introduced and utilized (in other domains) previously. This can increase the risk of gamification failure, while similar gamification models do not necessarily lead to same results in other contexts (projects). In other terms, a gamification model may lead to diverse results considering the gamification context and the applicant's psychological needs. (Seaborn and Fels 2015)

Furthermore, a lack of transparency has been seen in the design phase of several gamification models. On the one hand, the applicants are not analysed in a large number of gamification projects and therefore, the condition of their psychological needs has been ambiguous. On the other hand, a great number of gamification developers do not construe their model, and thus it is not comprehensible that how gamification model is expected to achieve its specified goals. Therefore, it is a challenge to evaluate the success/failure motive of many gamification projects due to this lack of transparency. (Seaborn and Fels 2015; Morschheuser et al. 2018)

Comprehensive guidelines, principles, and approaches to design gamified processes were introduced in the literature to address these issues. Morschheuser has recently reviewed the literature on one hand, and has interviewed the experts on the other hand to conclude 13 design principles which should be considered when designing a gamified model. Table 3.4 illustrates these Gamification Design Principles (GDPs). (Morschheuser et al. 2018)

Table 3.4: Gamification design principles (Morschheuser et al. 2018)

	Design Principles
GDP1	Understand the user needs, motivation, and behaviour, as well as the characteristics of the context
GDP2	Identify the project objectives and define them clearly
GDP3	Test gamification design idea as early as possible
GDP4	Follow an iterative design process
GDP5	Profound knowledge in game-design and human psychology
GDP6	Assess if gamification is the right choice to achieve the objectives
GDP7	Stakeholders and organizations must understand and support gamification
GDP8	Focus on user needs during the ideation phase
GDP9	Define and use metrics for the evaluation and monitoring of the success, as well as the psychological and behavioural effects of a gamification approach
GDP10	Control for cheating / Gaming-the-System
GDP11	Manage and monitor to continuously optimize the gamification design
GDP12	Consider legal and ethical constrains in the design phase
GDP13	Involve users in the ideation and design phase

Furthermore, Morschheuser has consolidated 17 different gamification design approaches and introduced a new guideline for supporting gamification developers in designing gamified software. Figure 3.9 illustrates this guideline by which a gamified model is designed in 7 steps. (Morschheuser et al. 2018)

Figure 3.9: Steps towards development of a gamification model (Morschheuser et al. 2018)

Although this guideline organizes gamification developer's thoughts and supports them in developing their gamification models step by step, it still fails to enhance the transparency in the design phase of gamification. It is missing a construing step where the gamification model is interpreted, and its success paths are evaluated and documented.

In addition, Morschheuser's guideline focuses on designing gamification software and is not comprehensive enough to support other gamification developers who are gamifying some business processes (not software). Therefore, the guideline was further improved based on the DSR approach as well as the 13 GDPs (Table 3.4), and a more comprehensive procedure to design gamification was introduced in this study.

Figure 3.10 illustrates the full picture of the new procedure which, on the one hand, can support scholars and organizations in developing gamification in various sectors such as construction, and on the other hand, helps designers to enhance transparency in the design phase of their gamification model. This guideline proposes to design gamification in 6 steps: 1) project preparation; 2) user analysis; 3) context analysis; 4) ideation and design; 5) interpretation; and 6) implementation and evaluation.

The DSR is defined as a problem-solving process which supports scholars in settling practical challenges by introducing innovative artifacts as well as by expanding human (organizational) capacities. It is known as an appropriate scientific research method to design gamification and has been utilized in majority of gamification projects. Hevner has introduced seven principles to assist researchers for understanding, executing, and evaluating an effective DSR approach to design an artifact like gamification. Refer to Table 3.5 to learn more about these seven principles. (Hevner et al. 2004; Kuechler and Vaishnavi 2012; Morschheuser et al. 2018)

Table 3.5: DSR guidelines (Hevner et al. 2004)

Guideline	Description
1- Design as an artifact	DSR must produce a viable artifact in the form of a construct, a model, a method, or an instantiation.
2- Problem relevance	The objective of DSR is to develop technology-based solutions to important and relevant business problems.
3- Design evaluation	The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.
4- Research contributions	Effective DSR must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies.
5- Research rigor	DSR relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.
6- Design as a search	The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment
7- Communication of research	DSR must be presented effectively both to technology-oriented as well as management-oriented audiences.

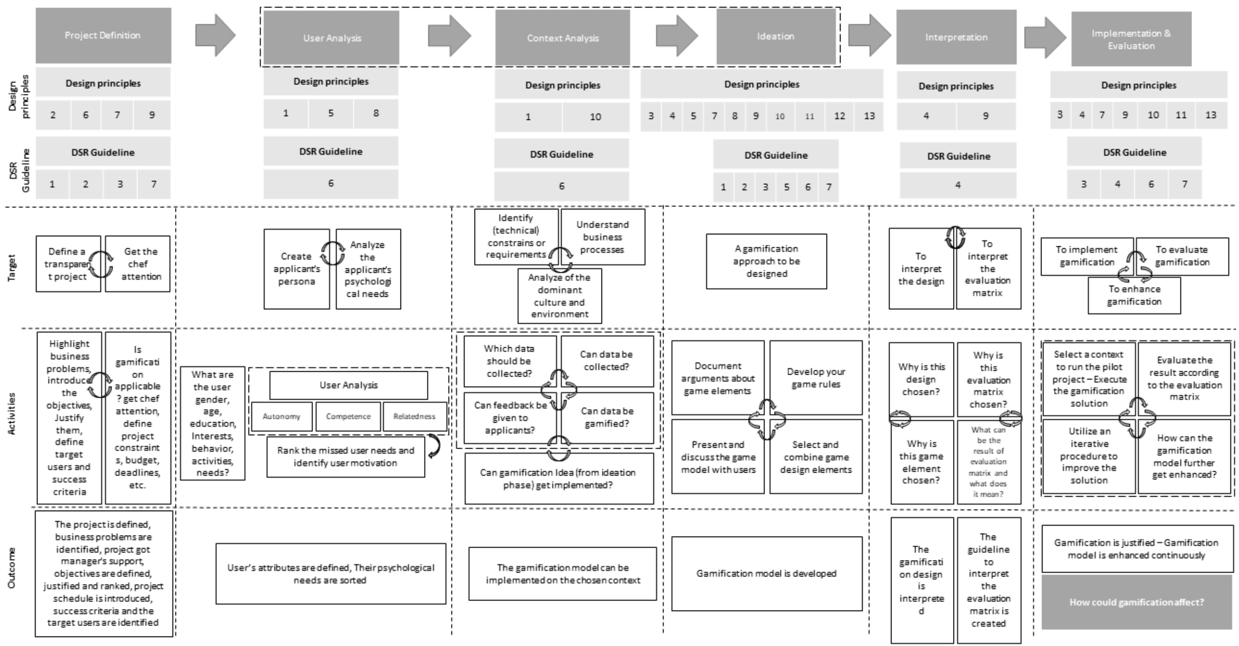

Figure 3.10: Gamification Model

3.3.1 Project definition

Project definition or project preparation is the first step to design a gamified model. First, business problem(s) and project requirement(s) which need to be addressed are identified and listed. Then, they are evaluated to justify if gamification is the right choice to address them. As discussed before, gamification is utilized to foster applicants' motivation with a focus on improving their behaviour; however, a better applicant's behaviour is not enough to solve some core business problems.[8]

Furthermore, gamification is not utilized for entertaining people; but it is employed to improve individual's behaviour in a serious (non-gaming) context, by adding a layer of fun on the top of serious tasks. To reach this goal, organizations should accept gamification as a serious concept (solution) which attempts to address some specified business problems. This can occur when managers (and other decision makers) understand and support gamification. Therefore, the concept of gamification must be presented and communicated to managers in advance to collect their attention on the one hand, and define project timeline, budget, and resources accordingly on the other hand.[9]

Furthermore, target users and project success criteria must be defined in the project preparation phase; otherwise, the success of gamification model cannot be evaluated later in the evaluation phase of the project[10]. Figure 3.11 illustrates an overview of the "project definition" phase in the gamification design. As the figure shows, there are two main purposes foreseen in this step: 1) defining (preparing) a transparent project including the goals, success criteria, time plan, and target applicants; and 2) getting the attention and support of managers and other decision-makers. (Morschheuser et al. 2018)

[8] Based on design principle 2, 6 and DSR guideline 2

[9] Based on design principle 7 and DSR guideline 1, 2, 7

[10] Based on design principle 9 and DSR guideline 3

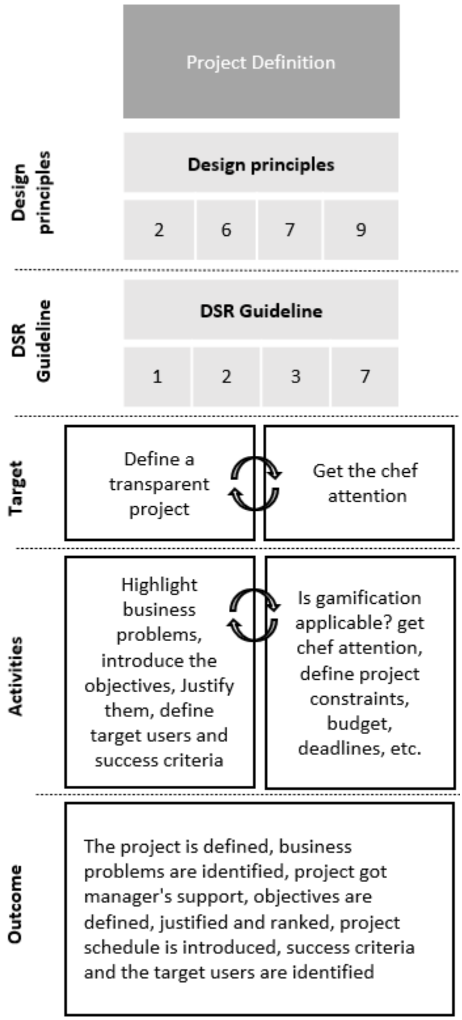

Figure 3.11: Gamification model-project definition

3.3.2 User analysis

"User analysis" is the second step in designing a gamified model. In this step, user's characteristics such as age, gender, education, interests, role, etc. are evaluated and a user profile (persona) is generated. User analysis helps gamification designers to understand their target users better and to come up with more suitable ideas (considering the applicant's characteristics) for their gamification model. Various methods such as interviews, observations, and survey are discussed in the literature to evaluate applicants' attributes.[11] (Morschheuser et al. 2018; Deterding 2015)

On step further, applicants are analysed in more details in terms of the condition of their psychological needs. As discussed in section 3.1, human becomes motivated and shows a better engagement when three needs of autonomy, competence and social relatedness are perceived simultaneously by the social (working) environment. Therefore, it is important to evaluate which psychological needs have not been met so far and perceive them accordingly via suitable game elements in the gamified environment.[12]

Evaluation of these three needs is a challenge, and it is a multifaceted and complex process that requires a good understanding of human psychology. To address this issue, the Centre for Self-Determination Theory (CSDT) reviewed the literature and introduced a questionnaire to understand the conditions of employees' psychological needs at work. The CSDT is a scientific institute which gathers scholars from various universities with a focus on sponsoring the science of the SDT and its implementations in other domains like gamification.[13]

Table 3.6 illustrates all the statements defined in the CSDT's questionnaire. Each statement concerns the user's feeling about his job and refers to one of

[11] On the basis of design principle 1 and the DSR guideline 6

[12] On the basis of design principle 5, 8 and the DSR guideline 6

[13] https://selfdeterminationtheory.org/

the psychological needs of autonomy (A), competence (C) and relatedness (R). The needs that are highlighted with X(R) are presenting an opposite relation.

Table 3.6: Satisfaction of basic needs at work

No.	Questions	A	C	R
1	I feel like I can make a lot of inputs to deciding how my job gets done	X		
2	I really like the people I work with			X
3	I do not feel very competent when I am at work		X(R)	
4	People at work tell me I am good at what I do		X	
5	I feel pressured at work	X(R)		
6	I get along with people at work			X
7	I pretty much keep to myself when I am at work			X(R)
8	I am free to express my ideas and opinions on the job	X		
9	I consider the people I work with to be my friends			X
10	I have been able to learn interesting new skills on my job		X	
11	When I am at work, I have to do what I am told	X(R)		
12	Most days I feel a sense of accomplishment from working		X	
13	My feelings are taken into consideration at work	X		
14	On my job I do not get much of a chance to show how capable I am		X(R)	
15	People at work care about me			X
16	There are not many people at work that I am close to			X(R)
17	I feel like I can pretty much be myself at work	X		
18	The people I work with do not seem to like me much			X(R)
19	When I am working, I often do not feel very capable		X(R)	
20	There is not much opportunity for me to decide for myself how to go about my work	X(R)		
21	People at work are pretty friendly towards me			X

The questionnaire can be distributed among a representative group of gamification applicants, with the purpose of understanding the condition of their psychological needs at work. Each participant according to his own feeling at work expresses how true each statement is. In order to a more accurate answer to each statement can be gathered, it is assured that the result of questionnaire will be kept confidential.[14]

The maximum point that can be given to each statement is 7, indicating that the statement is very true from the participant's view; while the minimum point is 1, presenting the participant's full disagreement. Accordingly, point 4 indicates a "somewhat true" statement. Finally, the average of points given to all the statements that are referring to a same need indicates how much that psychological need has been perceived so far. (CSDT 2020)

To conclude, user analysis or user search is a mandatory step in the gamification design. On the one hand, it helps to gather applicant's persona which can provide the necessary information for the gamification designers in order to introduce better ideas for the gamified model. On the other hand, it supports gamification developers in understanding the condition of applicants' psychological needs.

[14] Participants maybe not express their true feeling if the result of questionnaire is shared with their boss.

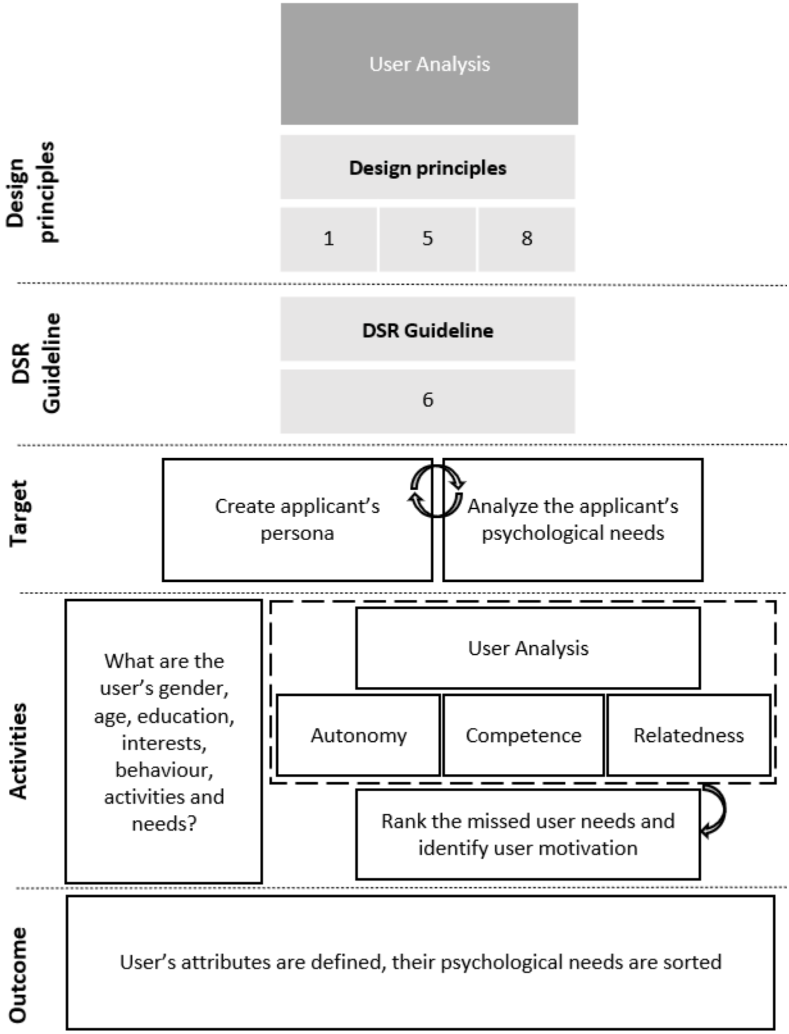

Figure 3.12: Gamification design-user analysis

3.3.3 Context analysis

Gamification is a reciprocal approach by which applicants and gamified model have real-time interactions. On the one hand, user's behavioural data should be captured by the context and be sent to the gamified model. On the other hand, the gamified outputs from the model should be presented to the applicants via the context. Therefore, the gamification context should have suitable infrastructures which allow the applicants and the model to experience real-time interactions continuously.

On step further, it is essential to 1) understand the technical constrains and requirements of the model, 2) analyse the dominant culture in the organization, and 3) understand the common business process of the organization, to design a suitable and successful gamified model. Therefore, "context analysis" was introduced as one primary step in development of a gamification model, in which the business processes, corporate culture in the organization, and all the (technological) constrains or requirements (to ensure secure transfer of information between the applicants and the gamified model) are evaluated and documented.[15] (Morschheuser et al. 2018)

Although "user analysis", "context analysis", and "ideation" are three different steps in gamification design; they are somehow interwoven. On the one hand, to analyse the (technical) constrains, the initial idea of gamification should be clear. On the other hand, context evaluation (understanding of the dominant culture in the organization and the common business processes) can reveal a lot of information about the applicants and vice versa. Therefore, as Figure 3.13 shows, it is proposed to perform these three steps correspondingly. (Morschheuser et al. 2018)

[15] On the basis of design principle 1, 10 and the DSR guideline 6

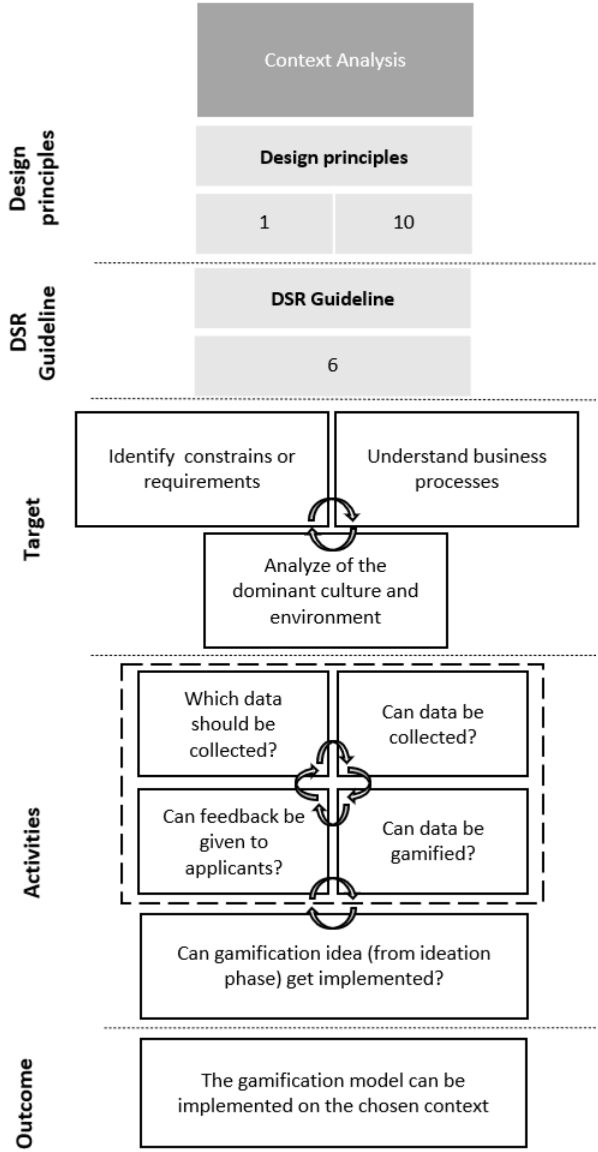

Figure 3.13: Gamification model-context analysis

3.3.4 Ideation and design

Ideation is a creative and iterative step in gamification design, in which various gamification concepts are introduced and investigated upon the applications of rigorous methods. Ideation seeks to add a layer of fun on the top of serious jobs to solve the business issues highlighted in the “project preparation” step. The explorative brainstorming is highlighted in the literature as an important approach to list a variety of gamification concepts that utilize different game design element to satisfy applicant’s psychological needs (Morschheuser et al. 2018). It is proposed to gain knowledge in terms of game-design and human psychology to design a more suitable gamification that addresses applicant’s psychological needs evaluated in the “user analysis” step.[16]

There are two main aspects in designing a gamification concept. Firstly, a gamification model should be attractive for applicants to utilize the model, otherwise, it will stay inutile, and the project will fail to reach its objectives. Although external rewards like money might fail to change human’s behaviour in a longer period, they are known as an appropriate solution to encourage applications to start utilizing the gamification models. (Reiners 2014)

Secondly, the gamification model should keep applicants interested to further utilize the model and continue their appropriate behaviour. The appropriate behaviour is continued either if external rewards continue to come or if human psychological needs are satisfied. Although both extrinsic and intrinsic motivations can enhance human’s behaviour, but a better creativity and psychological well-being is reached more by enhancing intrinsic motivation. (Ryan and Deci 2000; Cerasoli et al. 2014; Mekler et al. 2017; Ryan 2018; Nicholson 2015)

[16] On the basis of design principle 4, 5, 8 and DSR guideline 1, 2, 5

Therefore, ideation refers to the detailed process of choosing and combining several game elements with a focus on designing a gamified model which can meet applicants' needs of autonomy, competence, and social relatedness to reach a better creativity and psychological well-being in applicants (Reiners 2014; Morschheuser et al. 2018). To sum up, it is proposed to initially use external awards in the gamification model and then improve the applicant's intrinsic motivation step by step by combining various game design elements which can satisfy the applicant's psychological needs.

A game element (e.g., point or leader-board) can satisfy different human psychological needs[17], leading to diverse results. It is proposed in the literature to collect comprehensive gamification ideas based on a search process and the applications of rigorous methods to employ the most suitable game elements for better meeting applicant's psychological needs. Moreover, although the gamification contexts (technical constrains, business processes, and the dominant culture in the organization) have been analysed previously, it is proposed to conduct close communications with key users (who later will utilize the model), managers, and other-decision makers when developing gamification to understand if the model can fulfil their requirements and see if it has any conflict with all the legal and ethical constrains introduced in the "project preparation" step.[18]

Furthermore, an evaluation matrix should be developed to analyse the gamification model both in the design phase and in the execution phase. The matrix should be designed based on the applications of rigorous methods and on a search process. Various approaches are proposed in the literature to evaluate gamification models such as interviews with the applicants, surveys, site observation, etc. both in the design phase and in the execution phase of the model. In general, experts have concluded that observing applicant's performance is a more suitable approach to analyse gamification results,

[17] According to the gamification design.

[18] On the basis of design principle 7, 8, 12, 13 and DSR guideline 5, 6, 7

compared to interviewing the users in which the participants might face some difficulties in expressing verbally their experience with gamification (Morschheuser et al. 2018). Table 3.7 presents five methods for designing evaluations in an artifact model introduced by Hevner.[19]

Table 3.7: Design evaluation method (Hevner et al. 2004)

1- Observational	Case study: Study artifact in depth in business environment
	Field study: Monitor use of artifact in multi projects
2- Analytical	Static analysis: Examine structure of artifact for static qualities (e.g., complexity)
	Architecture analysis: Study fit of artifact into technical IS architecture
	Optimization: Demonstrate inherent optimal properties of artifact or provide optimality bounds on artifact behaviour
	Dynamic analysis: study artifact in use for dynamic qualities (e.g., performance)
3- Experimental	Controlled Experiment: Study artifact in controlled environment for qualities (e.g., usability)
	Simulation – Execute artifact with artificial data
4- Testing	Functional (black box) testing: execute artifact interfaces to discover failures and identify defects
	Structural (White Box) testing: Perform coverage testing of some metric (e.g., execution paths) in the artifact implementation
5- Descriptive	Informed Argument: User information from the knowledge base (e.g., relevant research) to build a convincing argument for the artifact's utility
	Scenarios: Construct detailed scenarios around the artifact to demonstrate its utility

[19] On the basis of design principle 3, 9, 10, 11 and DSR guideline 3, 5, 6

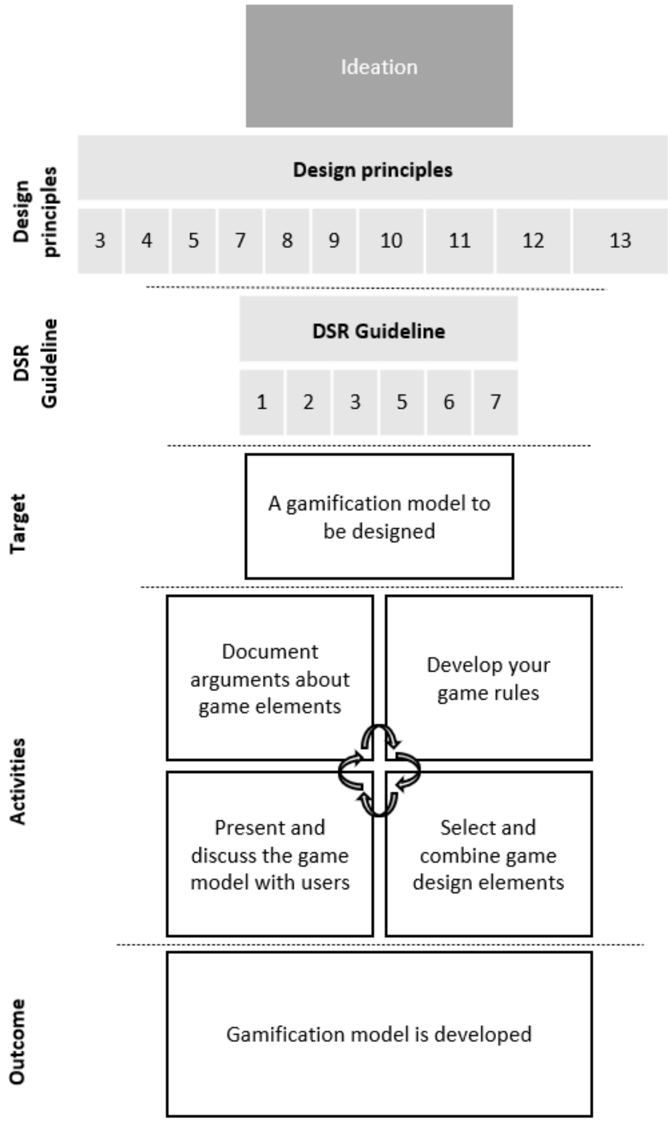

Figure 3.14: Gamification model ideation

3.3.5 Interpretation

A large number of gamification developers do not construe their model and, therefore, it is not obvious that how their gamification solution is expected to achieve the specified goals. In other words, the path to success has not been identified in a great number of gamification designs, and subsequently, it has been a challenge to evaluate the factors of success or failure in many gamification projects.

To address this issue, the “Interpretation” step was introduced in gamification designs; in this step, the model itself as well as its evaluation matrix are interpreted. “Interpretation” on the one hand discusses the main reasons for selection of each game element or the game design as a whole and explains how applicant’s psychological needs are expected to be met. Therefore, it can contribute to the literature to identify factors of success or even failure of gamification.

On the other hand, the evaluation matrix is construed in the “Interpretation” step as well to discuss the potential outcomes of this matrix and prepare a guideline to analyse the result of the evaluation. This can help gamification designers to better analyse the potential issues in the design and utilize an iterative procedure to address them.[20]

To conclude, the “Interpretation” step helps gamification designers to better evaluate the results of gamification implementation and easier follow an iterative design process. Figure 3.15 presents the “interpretation” step in the gamification guideline.

[20] On the basis of design principle 4, 9 and the DSR guideline 4

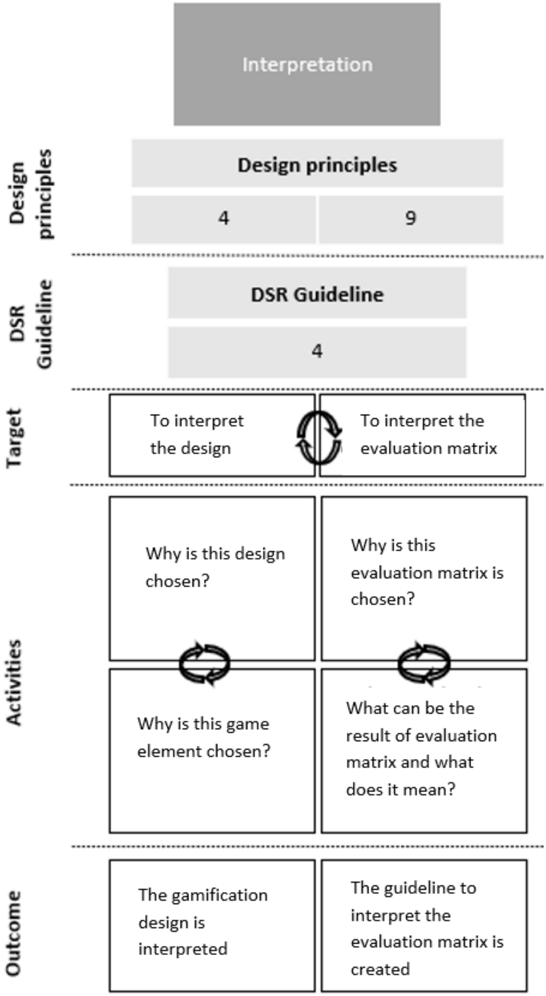

Figure 3.15: Gamification model-Interpretation

3.3.6 Implementation and evaluation

"Implementation and evaluation" is the last step in developing gamification. This step is implemented both in the design, and in the execution stage of a gamified solution. It is proposed to carry out a pilot project in the design phase of gamification in order to examine, verify, and enhance the model. In other words, the gamification model should be tested[21] as early as possible to recognize the potential issues and address them in an iterative procedure. Furthermore, the gamified process must be also monitored continuously even in the execution stage in order to 1) investigate the model usages in certain intervals, 2) verify if the initial goals of the gamification have been achieved, and 3) maintain and enhance the gamification model accordingly and continuously to improve its benefits and minimize any fault or cheating chance. In other terms, gamification projects do not have a classical end date and should be monitored, evaluated, and enhanced continuously.[22] (Morschheuser et al. 2018)

Moreover, in order to further enhance the gamification solution, the outcomes of the evaluation step both from the pilot and live implementations should be communicated to both technology-oriented and management-oriented audiences to get the technical and other infrastructure supports as well as permissions. Moreover, to provide a contribution to the literature, it is proposed to analyse these results according to the guideline introduced in the "interpretation" step.[23]

To conclude, regardless of the evaluation method, gamification design should be an iterative process to first analyse the model and then enhance it accordingly. As shown in Figure 3.16, the targets of this step are to: 1) verify the gamification model as soon as possible and enhance it accordingly; and 2)

[21] based on the evaluation matrix introduced in the "ideation and design" step.

[22] On the basis of design principle 3, 4, 9, 10, 11 and DSR guideline 3, 6

[23] On the basis of the design principle 7,13 and SDR guideline 4,7

monitor the gamification model in the execution step and improve it continuously.

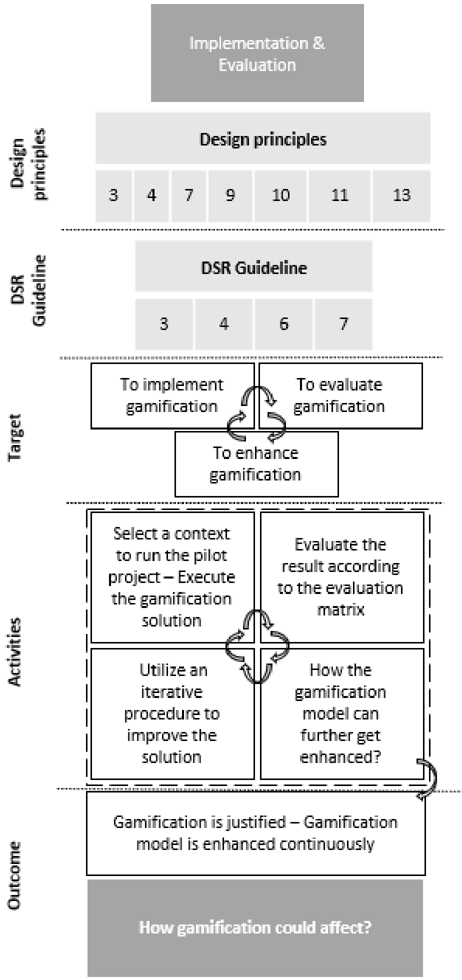

Figure 3.16: Gamification model-implementation and evaluation

4 Gamification in excavation

Construction industry is suffering from low productivity rate in various projects. This issue is discussed literature. Although a large number of positive solutions have been proposed, the productivity rate is still low in construction compared to other sectors like manufacturing (Bock 2015; Linner 2013).

Three core components directly affect the productivity rate at construction sites; i.e. 1) labour productivity, 2) raw material productivity, and 3) machine productivity. These components are evaluated, and harmful human (worker or operator) behaviour is concluded as one reason for low productivity rate. Put differently, it is expected to reach a better productivity if machine operators and, in general, construction labours improve their working behaviour. (Frank et al. 2013; Bock 2015; Linner 2013)

Gamification is known as an approach to foster human engagement and motivation with a focus on improving their behaviour at work. It has been a trending topic during the last decade and is widely employed in other domains such as education, health, crowdsourcing, etc. Although mainly positive and mixed positive results are reported from gamification implementations, it has been (mostly) neglected in the construction industry. Read chapter 3.2 to learn more about the state of the art gamification at construction sites.

Although construction is a diverse sector where each project has its own attributes and characteristics, there are still a considerable number of tasks in many construction, mining, or recycling sites which are repeated daily or whole the day. Excavation is one example where an excavator or a loader is repeating a same cycle of work (Figure 4.1). These types of work (repetitive tasks) could get monotonous and affect operator's behaviour in a longer period, resulting in lower productivity rate. Gamification can be a solution in this context to foster operator’s motivation and encourage him to improve his behaviour continuously (or to keep his appropriate behaviour).

Figure 4.1: A loader performing repetitive cycles (Frank 2018)

This chapter is devoted to develop and implement an example of gamification on excavation works and analyse how does it affect the machine productivity where a repetitive task is being performed. The gamification approach is designed first in chapter 4.1, and its implementation on two sites are discussed in chapters 4.2 and 4.3

4.1 Development of the gamification model

Gamification design is a challenge which needs an understanding of human psychology. Plenty of gamification implementations failed to achieve their objectives due to their inadequate design. To overcome this complexity and minimize the risk of failure, the gamification model is designed in 6 steps according to the guideline was introduced in section 3.3.

4.1.1 Project definition

Project definition represents the first step in gamification design. In this step, the project objectives are identified, justified, and ranked. Moreover, the gamification concept is presented to the managers and other decision-makers to capture their attention and support. Furthermore, project plan, important deadlines, budget, all constrains, desired actions, resources, success criteria, and legal and ethical considerations are determined. To summarize, the "project preparation" step supports gamification designers in developing a transparent project on one hand, and in attracting manager's attention and support on the other hand.

The productivity rate in construction is lower than other domains like manufacturing. Machine productivity has a direct effect on overall productivity at construction sites. Thus, an increase in machine productivity can improve the overall project benefit. Three factors enhance machine productivity; i.e. 1) machine specifications or machine base productivity, 2) working environment or site layout, and 3) operator' behaviour. (Frank et al. 2013)

Although other aspects such as machine safety or fuel consumption are of high importance, the goal of this project is limited to improving the operator's behaviour with the purpose of enhancing the machine productivity via gamifying the telematics data. Figure 1.1 illustrates the project objectives.

On one hand, construction companies are continuously seeking to enhance productivity rates at their sites. On the other hand, gamification has been implemented successfully in other sectors to enhance applicant's behaviour. Therefore, gamification may help construction companies to enhance productivity rate at their sites. This project is conducted to implement a gamification model on two (recycling and mining) sites and evaluates how it can affect the productivity rate.

Table 4.1 presents other parameters which are identified in the "project definition" step.

Table 4.1: Project definitions

Criteria	
Objective	Improving machine productivity at excavation works via gamification.
Target users	Machine operators (loaders and dump trucks)
Success criteria	Enhancement in machine productivity
Legal and ethical	The gamification approach should respect the General Data Protection Regulation (GDPR). All the gathered data from all operators should be in line with GDPR. The gamification approach should not encourage operators toward hazardous actions or activities that are against firm's interest.
Project time plan and deadlines	The project started on 01.10.2016 and its result was finalized on 01.04.2022. Three deadlines were set for 1) developing the gamification model, 2) implementation of the gamified process and 3) analysing the achieved results.
Budget	Developing the gamification model and its analysis was one part of a PhD study. There was a certain budget allocated to this research as a whole, which partly was assigned to develop the gamification model.
Resources	There was a team involved in the project. One project owner who was leading the project (PhD candidate). In addition, there were two business analysts allocated to the project to analyse the business requirements and firm's main interests. Moreover, there were several students involved in the project to write their thesis focusing on telematics as well as gamification at construction sites. Furthermore, three loaders, two excavators, two dump-trucks and six operators were allocated to the project for six days in order to implement and evaluate the gamification model at a recycling as well as a mining site.
Constraints	Introducing an innovative approach or technology at construction sites is a challenge. In general, the labours at construction sites accepts new methods of working harder than other labours in other domains like manufacturing. (Schmitz et al. 2012) In addition, (due to missing resources), no mobile app was developed in this study. Therefore, the gamification model had to be designed in a way that can be implemented at both sites without any mobile application.

4.1.2 User analysis

The user persona helps to understand operator's general attributes, as discussed in section 3.3.2. In this study, the persona is created based on two site observations, and general talks were conducted with six wheel-loader operators. Table 4.2 illustrates the user persona for this gamification model. In other words, the gamification model is designed for a person with the attributes presented in Table 4.2.

Table 4.2: Applicant's persona

Attributes	**Description**
Age	Between 22-67 years old.
occupation	Machine operator (loader or excavator)
Gender	Men
Education level	They (mostly) have no university degree. They have specific certificates to operate construction machinery like wheel-loader or excavator. They normally have (even the younger operators) a lot of practical experiences.
Attributes	Normally they are not high tech in IT and mobile applications. They usually do not like to be ordered or be bossed. They typically have detailed knowledge in technical aspects of construction machinery. They have a competitive mindset at construction sites and normally feel competence at work. Normally feel they are not paid fairly.
Motivation	Money is the main motive to work.

Furthermore, the CSDT's questionnaire was utilized to perceive the operator's psychological condition. A group of six machine operators were selected and the CSDT's questionnaire was distributed among them[1]. The result of each questionnaire is presented in the appendix (Table 6.4) and is summarized here in Table 4.3.

The maximum point can be given to each statement is "seven". This point indicates the statement is very true from the participant's perspective. The minimum point is "one" which indicates participant's full disagreement. Accordingly, point "four" indicates a "somewhat true" statement. The

[1] The operators were informed that the result of the questionnaire will be kept anonymous (to achieve more accurate answers to each statement).

average points given to all the statements referring to a same need, indicates how much that psychological need is perceived. Read chapter 3.3.2 to learn more about CSDT's questionnaire.

Figure 4.2 indicates all three psychological needs are neglected in some degrees. The need for social relatedness is ignored more than other two are, and therefore more attention should go to the need for social relatedness. The other two needs should be addressed in the gamification model as well; otherwise the operators will not get motivated according to the SDT. To conclude, the gamification model has to focus on the need for social relatedness first, and then address the other two needs of autonomy and competence accordingly.

Table 4.3: Questionnaire results (Table 6.4 in appendix)

	Autonomy	**Competence**	**Relatedness**
Average	**4.71**	**5.11**	**4.48**
Operator 1	3.86	3.83	4.25
Operator 2	4.86	5.5	3.63
Operator 3	5	5.5	5.13
Operator 4	4	3.83	3.38
Operator 5	5.14	6.17	5.13
Operator 6	5.43	5.83	5.38

Figure 4.2: Degree of need satisfaction on average

4.1.3 Context analysis

A successful gamification approach is in line with the dominant culture in the organization and follows the standard business approaches of the company. As discussed before, context analysis is performed to 1) evaluate the constrains or requirements of the context, 2) understand the ordinary business processes of the company and 3) evaluate the dominant culture of the organization.

Analysis of the constrains or requirements of the context:

The gamification model seeks to improve the productivity rate of machines which are performing a same cycle of work whole the day at a recycling or mining site (where similar work like excavation activities are performed). Productivity is defined as an input-to-output ratio (with a focus on a single factor of production) (Linner 2013). Therefore, the machine productivity is defined as the amount of materials (t) which is transported per unit of time (min) from one location to another.

$$\text{P}roductivity\ rate\ = \frac{The\ amount\ of\ excacation\ (t)}{Time\ (min)}$$

IT and its infrastructures have introduced modern systems, such as telematics, to collect operational data of the machine (on real-time basis) and calculate machine productivity rate accordingly. These information can simultaneously be presented to the operator via a built-in screen available in the machine cabin.[2]

These telematics platforms can utilize some game features (elements) to provide operators with some gamified feedbacks. This can enhance the operator's motivation to improve his behaviour with a focus on enhancing the overall productivity of the machine. Therefore, there is no technical limitation

[2] Read chapter 2.2

to capture the operator's behavioural data and provide them with some gamified feedbacks.

Although there is no technical limitation in theory, but modern telematics systems are exclusively available on new machines and a significant number of operating machineries at construction sites do not have advanced telematics systems. Moreover, due to the lack of resources and budget, it was impossible in the frame of this study to develop a new mobile app to capture operator's behavioural data on one side, and provide some gamified feedbacks to the operator on the other side. To address these issues, the gamification model should work properly without any advanced telematics system or even any mobile application. A large number of excavators or wheel-loaders contain some sensors (or sensors can be installed) to calculate the amount of loaded materials in the machine bucket during each loading/unloading cycle. This is the minimum technical requirement which should be provided via the gamification context. The duration of each loading/unloading cycle can be recorded separately and therefore, the machine productivity can be calculated without any advanced telematics system or mobile application.

Construction or excavation projects are diverse, and each project has its own characteristics. Moreover, operators have different levels of competence and skills, therefore it is a challenge to introduce a gamified process which is applicable to a broad range of projects and works for various operators simultaneously. This issue should be addressed in the design phase of the gamification, and the gamification context should be evaluated once more to understand if it has any constrain or limitation to the gamification design. In other words, "user analysis", "context analysis", and "ideation" are three different phases in a gamification design which are somewhat interwoven and should be executed iteratively.

Common business processes of the companies:

The first target company is a construction firm which owns a recycling site where the asphalt chunks are recycled. As a part of whole recycling process, a wheel-loader loads the asphalt granulate from the recycling location and moves them to other location where they are stored. Figure 4.1 presents an example of such loading/unloading cycle. Although the gamification model seeks to improve machine productivity while doing such loading/unloading cycles, it should not stimulate the operator to show a dangerous behaviour which can risk his safety.

The second target company maintains a mining site where sand/stones are mined, classified (according to their size) and stored. The gamification model will get implemented on two working processes at this mining site.

1) A dump-truck is transferring mined materials from the mining location to a classifier.

2) A loader is transferring the classified material to the storage room.

<u>The dominant culture in both organizations:</u>

A business analyst from each company who is familiar with the dominant culture in the firm participated in design phase of the gamification model. The business analysts were continuously evaluating the design of gamification to prove if it is 1) based on the general targets and objectives of the organization and 2) in line with the dominant culture in the organization.

4.1.4 Ideation and design

"Ideation and design" is the next step in designing a gamified process. In this step, various ideas are discussed, evaluated and finally the gamification model is designed. As concluded in subsection 4.1.2, the gamification applicants are machine operators, who are normally man and older than 22 years old. Moreover, they have usually detailed knowledge of and are interested in technical aspects of construction machineries; however, they are not generally skilled in high tech, IT, and mobile applications. In addition, they do not like to be ordered or to be bossed.

Furthermore, the gamification model should focus more on the need for "social relatedness" compared to other two needs of "autonomy" and "competence" (it does not mean to neglect the other two needs)[3]. The objective is to address all three psychological needs and bring them all in a similar level of fulfilment simultaneously, which can finally foster operator's intrinsic motivation and engagement.

As concluded in the literature, some game elements such as badges, leaderboard, avatars, meaningful stories, and teammates can address the need for social relatedness better than other game elements such as deadlines do. Therefore, these types of game elements should be utilized more in this gamification approach[4]. An explorative brainstorming (together with both business analysts) has been done, and six principles have been introduced for this gamification model. These principles first seek to encourage operators to utilize the gamification model by supplying some external awards. Then try to address operator's psychological needs in order to motivate him to enhance his behaviour continuously, or to maintain his appropriate behaviour. These principles are:

- The gamification model should be optional to use. In other words, nobody should be forced to utilize the gamified approach.
- The gamification model should include an award system to encourage operators to utilize the model. Without any award system, the operators might not start to utilize the model.
- The gamification model should contain some degree of group work and corporation to inculcate operators the feeling of belonging to a society or a group.

[3] Read subsection 4.1.2
[4] subsection 3.1.4

- The gamification model should include some degree of competitions to inculcate operators the feeling of being competence.

- The operators should be allowed to elect between various options or possibilities in the gamified environment.

- The gamified environment and its design should be meaningful from operator's perspective and should be in line with operator's own interests.

The gamification model was designed according to these six principles and has three main gaming concepts; i.e. 1) profile creation, 2) individual-oriented competition, and 3) group-oriented competition.

Profile creation:

Profile creation is the first gaming concept in this gamification model. It allows operators to create a profile and have social relation with other operators. Based on operator's own decision, the profile can be public (visible to all other operators), half public (visible to close friends), or even private (only visible to the operator).

Just as in other social networks like Instagram, Facebook, or LinkedIn, the operators can text other colleagues and have communications with each other via their profiles. Therefore, this element can satisfy the need for social relatedness among operators. Furthermore, operators can voluntarily make their profile public, half-public, or even private and can also freely select an avatar for their profiles. These features can satisfy the need for autonomy as well, so that the operators have freedom to configure their own profile. Finally, operators can post their successes and achievements in their profiles and, thus, inform their colleagues about any achievement (just as in LinkedIn). This can fulfil the need for being competence on one hand and the need for social relatedness on the other hand.

To sum up, “profile” is a game element utilized in this gamification model which can meet all three needs of autonomy, competence, and social relatedness. As mentioned earlier, no mobile app was developed by which operators can create their profiles. To overcome this difficulty and simulate profile creation situation, profiles are created in excel sheets and are saved in a folder shared by permission. According to the operator’s own decision, each excel sheet (profile) can be shared with other operators.

Individual-oriented competition:

Individual-oriented competition is the second gaming concept, referring to individual competitions in which operators can take part. In general, designing a competition between operators who are doing a simple Y-shape loading/unloading (Figure 4.1) cycle is a challenge. On one hand, the productivity rate of two machines operating in two different construction sites (even in a single site) cannot be compared while there are other parameters like site layout, weather condition, or machine base productivity affecting directly the overall productivity rate of the machine. On the other hand, it is not simple to compare operators with different background and experience. More experienced operators are probably more competence than the younger persons are, and therefore such comparison can reduce operator’s motivation (among younger ones) and lead to some inverse results.

Construction machinery manufactures seek to introduce intelligent systems to first predict the expected productivity rate for a machine according to the working characteristics, and then evaluate the most proper approaches to operate the machine with a focus on reaching the expected productivity rate[5]. Read the dissertation published in cooperation with “Volvo Construction Equipment” which discuss such possibilities in more details. (Frank 2018)

[5] This is one of the initial steps to machine automation.

The expected productivity rate which is calculated by these intelligent systems[6] is the initial input to the gamified environment. The gamification model will also calculate an easier and harder productivity rate (e.g., +/- 5% of the expected rate) and propose all three rates to the operator before starting the work. The operator is requested to target one of the proposed productivity rates and seek to reach it (or record a better productivity) when performing the job. Subsequently, he is scored by comparing his final productivity rate with what he targeted at the beginning. Figure 4.3 illustrates a big picture of this approach where the operator is given a better score if he successfully completes the harder challenge. If he fails to reach the chosen productivity rate, the achieved productivity rate will be compared with other easier challenges, and he will get scored accordingly. Challenge 1 is the easiest available challenge to be chosen; while challenge 2 is the standard challenge introduced by the intelligent system, and accordingly, challenge 3 is the hardest one. The challenges are introduced based on the operator's competence as well as other factors which can influence the machine productivity. Moreover, the same scoring system is used for all the participants. Therefore, all the operators who are operating various machines at different construction sites can use same gamification model and be compared and ranked in a leader-board accordingly.

[6] The operator competence is considered when calculating the expected productivity rate.

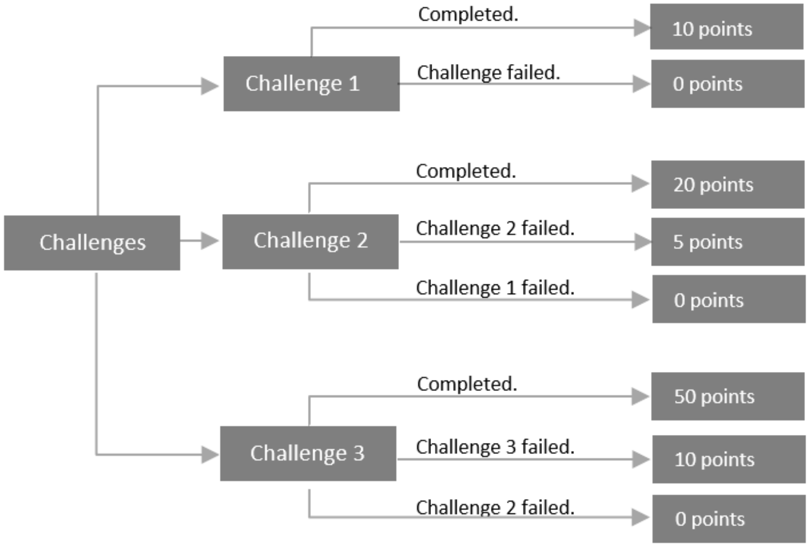

Figure 4.3: 3 challenges in the gamification approach

Due to the lack of such intelligent application in this study, all three productivity rates were defined by an expert (a referee). All the factors which can affect the productivity rate like site layout, weather condition and operator's competence are considered when proposing these three challenges.

The operators can select a challenge voluntarily so their need of autonomy is addressed. Moreover, this concept can satisfy the need for competence while operators are given some points according to their achievements and are ranked in a leader-board according to their points. Moreover, it is expected (even little) to meet the need for social relatedness where a leader-board can establish a social relation between participants.

Group-oriented competitions:

A "group work" was added to the individual-oriented competition to persuade all three psychological needs for autonomy, competence, and social relatedness, with a special focus on the need for social relatedness. As Figure 4.4 shows, the participants can create a group up to five operators and choose its name and avatar voluntarily. This freedom to create a group and to customize it can meet the need for autonomy among the members of the group.

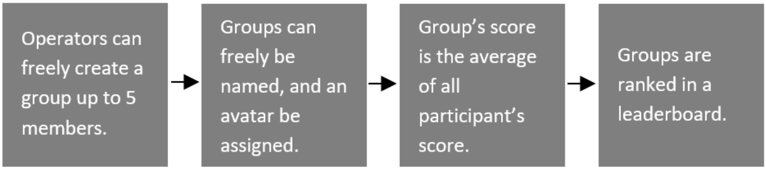

Figure 4.4: The group competition

Furthermore, each operator can participate in the same challenge as discussed above and the group score is the average point achieved by all the members. On one hand, the behaviour of one member directly influences the overall performance of the group. Therefore, it can address the need for social relatedness. On the other hand, the operators as well as the groups are scored according to their performance, meeting the need for competence. In addition, the needs for competence and social relatedness can be met via a leader-board which ranks the operators as well as their groups in a table.

To conclude, the gamification model in this study has three gaming concepts to meet all three psychological needs for autonomy, social relatedness, and competence simultaneously.

<u>Evaluation matrix:</u>

As proposed by the "gamification design guideline", an evaluation matrix should be developed in the "ideation and design" step. This matrix will be utilized later to analyse the result of the gamification and indicates how much the gamification model was successful in reaching its objectives[7]. The evaluation matrix in this study contains three parameters: 1) the machine productivity rate; 2) the applicant's continuous appropriate behaviour; and 3) the diversion rate. These parameters are discussed following in more details.

1) Machine productivity rate:

"Machine productivity rate" presents the amount of materials (t) which is transported from one location to another per minute. The objective of this gamification project is to enhance the overall machine productivity rate. Therefore, "the machine productivity rate" is **<u>the first</u>** and **<u>the most important</u>** factor that indicates the success of the project.

Furthermore, it is essential to evaluate the source of the applicant's motivation with the purpose of evaluating how and in which conditions his appropriate behaviour will continue. Thus, the other two factors of "applicant's continuous appropriate behaviour" and "the diversion rate" were added to the evaluation matrix.

2) Applicant' continuous appropriate behaviour:

The quality of performance (behaviour) varies when one behaves for intrinsic versus extrinsic reasons. Although both extrinsic and intrinsic motivations can enhance human behaviour, a better creativity and psychological well-being are reached more by intrinsic motivation. Moreover, human finds a reason to continue the appropriate behaviour when he is intrinsically motivated (Ryan 2018; Ryan and Deci 2000; Mekler et al. 2017). Therefore, to predict how operator's behaviour will continue in a longer period, it is important to understand the source of operator's motivation (extrinsic or intrinsic).

"Applicant's continuous appropriate behaviour" is an indicator which evaluates how operator's behaviour changes during an observation round. If

[7] Read chapter 3.3.4

the operator presents a similar or more proper behaviour at the end of one round, compared to the beginning, he is potentially intrinsically motivated[8]; however, he is extrinsically motivated if he forgets the motive of his appropriate behaviour after a while and goes back gradually to his ordinary (previous) behaviour.

3) The diversion rate:

Another indicator of operator's psychological well-being is his *diversion rate*. The diversion rate is calculated by the following formula and represents how stable is the operator's behaviour during the observation round. Higher diversion rate represents the operator's less stable behaviour and subsequently his less psychological well-being. While lower diversion rate can be a result of operator's better psychological condition.

$$\text{diversion rate (\%)} = \frac{(Best\ performance - \text{Worst performance}) * 100}{Best\ performance}$$

According to the SDT, better psychological well-being is achieved if applicants are more intrinsically motivated. Therefore, a lower diversion rate is expected to be achieved if the operators are more intrinsically motivated. To sum up, an appropriate behaviour is expected to be continued if the operator express a lower diversion rate compared to his ordinary behaviour.[9]

4.1.5 Model interpretation

Interpretation of the design can help designers to better evaluate the success (or failure) causes of the model later in the analysis phase of the gamification. The gamification model in this study is designed based on 6 principles. These

[8] while he has found one internal reason to continue his appropriate behavior in a longer period
[9] Read chapter 3.1.

principles are interpreted in this section to present how the model is expected to work.

The gamification model should optionally be used, and nobody must be forced to utilize it. This principle targets the need for autonomy where a mandatory gamification may affect it negatively. Gamification seeks to add a layer of entertainment to the top of serious jobs and therefore should be optional for the applicants.

Furthermore, an awarding system will provide some rewards like money to encourage operators to utilize the gamification model at the beginning. Although external awards may not affect the operator's intrinsic motivation, but it can improve his extrinsic motivation to utilize the model and therefore, provides more time for the model to enhance the operator's intrinsic motivation gradually. In an ideal gamification, the applicants will continue their proper behaviour after a while even without any external award.[10]

According to the result of applicant analysis (subsection 4.1.2), the need for social relatedness is ignored more compared to other two needs. Therefore a "group work" was introduced to include more social interactions among operators in order to meet their need of social relatedness. Furthermore, the needs for competence and autonomy should be addressed as well; otherwise, gamification will potentially fail to reach its objectives[11]. Thus, on one hand, some "competitions" will be utilized in the model to address the need for competence. On the other hand, the operator will be given the chance to choose between some options to meet his need for autonomy. Moreover, the full concept of gamification should make sense to the operators; otherwise, it cannot meet their need for autonomy.

[10] Read chapter 3.1

[11] Gamification will reach its objectives when all the human psychological need are addressed simultaneously.

4.2 Model implementation at the recycling site

The gamification model was implemented at a permanent asphalt recycling site in Belgium to evaluate how it can affect the operator's behaviour in order to enhance the productivity rate of the wheel-loader. The recycling site receives asphalt chunks from several construction sites and grinds them into asphalt granulate. This process is illustrated by Figure 4.5 where an excavator first loads the asphalt chunks in a cold planer; then the cold planer grinds the asphalt and produces asphalt granulate; following that, a loader loads this asphalt granulate and moves it to another location at the recycling site where it is loaded to several trucks and delivered to various construction sites.

Very similar to the typical loading/unloading cycles performed at excavation sites, the loader performs "Y"-shape loading/unloading cycles whole the day. Therefore, it is a suitable case to evaluate the gamification model.

Figure 4.5: The recycling process

Figure 4.6 presents a nearly 2 years old aerial photo from the recycling site. Area A indicates the location of the asphalt chunks when the photo was taken; however, area C represents the location of the asphalt chunks at the time of site observation. In addition, area B presents the spot where the asphalt granulate is stored. To conclude, during the observation, the wheel-loader was transporting the asphalt granulate from area C to area B by performing typical Y-shape loading/unloading cycles. Finally, point D presents the site manager's office where the research team attended to observe the operator's behaviour. Due to safety instructions, only one person from the research team was allowed to get close to the loader in order to: 1) provide the operator with some gamified feedbacks; and 2) read the machine telematics data to document the amount of asphalt granulate that was transported within the previous round.

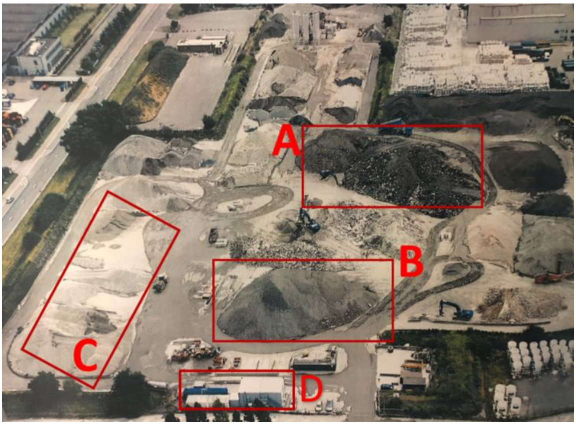

Figure 4.6: The aerial photo of the recycling site

The site observation was performed in three days (in a row), and the combination of two operators as well as two wheel-loaders were utilized to analyse the gamification model. Figure 4.7 presents both loaders which the white one has a bigger bucket size (about seven tons) compared to the yellow one with a buck volume of about six tons.

A different combination of the machine/operator was studied during each day; therefore, three observation sets were conducted at the recycling site.

Table 4.4 illustrates the combination of the loader and the operator which was utilized in each observation set.

Each observation set (day) included several observation rounds. Different game elements were utilized in each round to understand their effect on the operator's behaviour separately. Table 4.4 presents the number of observation rounds conducted in each day. Furthermore, each observation round included several loading/unloading cycles. A cycle begins when the wheel-loader starts to load the asphalt granulate into its bucket (area C in Figure 4.6) and continues until it unloads the granulate (area B) and returns back to the loading location in order to load its bucket again. In sum, 412 loading/unloading cycles were monitored in 21 rounds during three days of site observation.

Figure 4.7: The loaders which were utilized to evaluate the model

Both wheel-loaders were equipped with a load assistance system. This system can calculate the actual weight of the asphalt in the loader bucket, and further illustrate it on a built-in screen available in the machine cabin. Moreover, the load assistance system also stores the cumulative weight of the materials loaded into the loader bucket. This feature was utilized to record the total weight of the asphalt transported in a single round and to calculate the machine productivity rate for that round accordingly.[12]

Table 4.4: The combination of loader-operator utilized in each set

Observation sets	Combination	No. of rounds	Total cycles
Set one	1st operator & 1st loader	5	175
Set two	1st operator & 2nd loader	8	156
Set three	2nd operator & 2nd loader	8	81

4.2.1 First observation set

The first operator who had around 12 years of working experience in operating wheel-loaders and excavators operated the first loader (with a bucket volume around 7t) during the first observation set. In total, 175 (loading/unloading) cycles were observed in this set (day). The first 35 cycles were monitored in the first round, in which no gamification was utilized. The goal was to find the normal machine productivity without having any gamification involved. This productivity rate is utilized later as the basis to evaluate how gamification could achieve its objective.

The next 35 cycles were observed in the second round, in which a simple pointing system was employed to persuade the operator with the purpose of enhancing his behaviour. The operator was offered to gain some points if he can improve the machine productivity rate compared to the previous round. No further information about how the pointing system works or what can be done with the achieved points was given to the operator in this stage. The goal was to perceive how the operator's behaviour is affected by having a simple pointing system, without including a well-defined procedure to earn points or any strategy to utilize them.

[12] The duration of each round was recorded by a mobile phone separately.

The pointing system was explained in more details, and some guidelines to earn points were given to the operator before beginning the third round, in which the next 35 cycles were observed. Moreover, the operator was explained how he can utilize the achieved points and he was offered to get some hours off if he grasps the targeted points. This round was conducted to understand how a better-defined pointing system can affect the applicants' behaviour compared to the situation where they are simply requested to improve their behaviour to gain some rewards.

The individual-oriented competition was utilized as the motive element to encourage the operator with the purpose of enhancing his behaviour during the 4^{th} observation round. The three challenges of 4t/min, 5t/min, and 6t/min were defined based on a consultation with the site manager (as a referee) and were offered to the operator (Figure 4.8). The operator was requested to select one of the challenges and try to reach the target productivity rate during the round. As the figure shows, he will be scored by comparing his actual performance (productivity rate) with the selected target. For instance, he will gain 50 points if he chooses the challenge of 6t/min and reaches an overall productivity rate of 6t/min or higher. To conclude, before performing the round, Figure 4.8 was explained to the operator, and he chose a target rate of 5t/min.

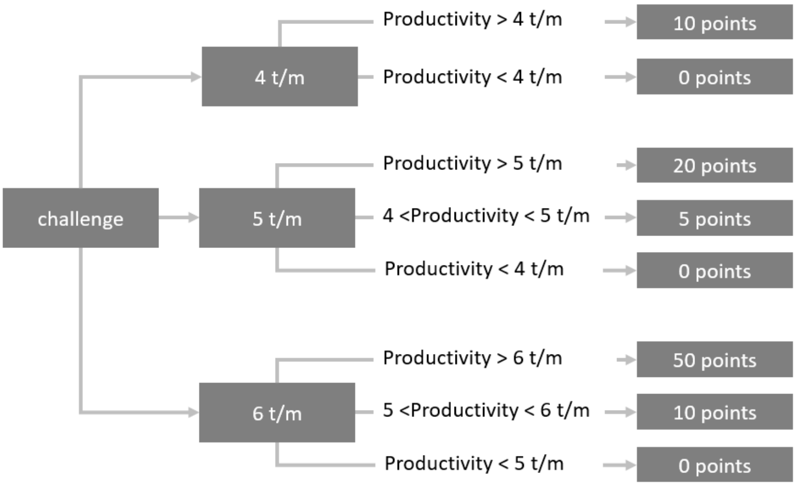

Figure 4.8: 3 challenges in the first set

Finally, as Table 4.5 shows, the group-oriented competition was utilized as gaming element during the fifth observation round. The same challenge system as in the fourth round was employed to score the operator, and he was given the possibility to take part in a group competition as discussed in section 4.1.4.

Due to the limited number of operators (only two), they could not create their groups by their own and therefore, some imaginary groups were introduced. To sum up, the operator was allocated to an imaginary group alone with other four operators from Germany. All group members are given the same challenge concept and are scored accordingly. The group's overall score would be the average of the scores achieved by all the members. Moreover, the group would be ranked in a leader-board (compared to the other groups) according to its achieved score.

After explaining the rules and conditions, the operator chose the challenge of 6t/min. To learn about the results of this set and its analysis, refer to section 5.1.

As a general role, other criteria (e.g., site layout, weather conditions, or machine base productivity rate), which could affect the machine productivity, were kept unchanged during the whole observation set (day). Therefore, any change in the machine productivity is an indicator of how the operator's behaviour has been affected by the gamification model.

Table 4.5: Game elements utilized during the first set

	Purpose	**cycles**
Round 1	Normal productivity (no gamification)	35
Round 2	Gamification (simple point system)	35
Round 3	Gamification (well-defined point system)	35
Round 4	Gamification (individual-oriented competition)	35
Round 5	Gamification (Group-oriented competitions)	35

4.2.2 Second observation set

The same operator (as in the first set) was monitored while operating a new wheel-loader during the second day. The loader had a smaller bucket size and, thus, had a smaller productivity rate than that of the first loader. Therefore, even though the operator remained the same, the normal productivity rate of the machine had to be measured once again. Moreover, the number of cycles in each round was decreased to 20 cycles (from 35) with the purpose of conducting more observation rounds during the day (round 2 had an exception and only 16 cycles where observed). In total, 156 loading/unloading cycles were monitored in 8 rounds within the second observation set.

The first 20 cycles were monitored in the first round, in which no gamification was utilized. The operator was informed at the beginning of the round that his performance is being monitored to understand the normal productivity rate of the machine/operator. This (normal) productivity rate is utilized later as the basis to evaluate how gamification could affect the overall productivity of the machine.

The next 16 cycles were observed in the second round, in which the operator was offered the same “individual-oriented competition” concept, as explained earlier.[13] However, the challenge was slightly adjusted, and the operator was offered three productivity rates of 3t/min, 4t/min and 5t/min; and he chose the target rate of 5t/min.

The “group-oriented competition” was utilized as the motive element within the next observation rounds to evaluate how it can affect the operator’s behaviour in a more extended period. The operator was informed about two separate teams, each of which included five operators[14]. There was a competition between these two teams and the team that achieves more points will win the competition. The team’s overall point was the average of the points achieved by all its members, and the same challenge logic (as in the second round) was utilized to gain points.

Table 4.6: Game elements utilized during the second set

	Purpose	**No. of cycles**
Round 1	Normal productivity (no gamification)	20
Round 2	Gamification (individual-oriented competition)	16
Round 3	Gamification (group-oriented competition)	20
Round 4	Gamification (group-oriented competition)	20
Round 5	Gamification (group-oriented competition)	20
Round 6	Gamification (group-oriented competition)	20
Round 7	Gamification (group-oriented competition)	20
Round 8	Gamification (group-oriented competition)	20

The operator was given no feedback at the end of the 3rd, 4th, 6th, 7th rounds and he was performing same job continuously; however, he was informed at

[13] This round was limited to 16 cycles while the operator got a phone call after the 16th cycle.

[14] The operator is a member of the first group.

the end of the fifth round that both groups are having a tough competition and currently the other group (the second group) is leading slightly. To learn about the results of these rounds and their analysis, refer to section 5.2.

As a general role (as in the previous day), other criteria (e.g., site layout, weather conditions, or machine base productivity rate), which could affect the machine productivity, were kept unchanged during the whole observation set (day). Therefore, any change in the machine productivity was an indicator of how the operator's behaviour has been affected by the gamification model.

4.2.3 Third observation set

The last observation set was executed on a Friday when the recycling site finalizes its activities earlier than in other working days. Therefore, each observation round was limited to 10 loading/unloading cycles with the purpose of conducting more observation rounds. To sum up, 81 (one round was extended to 11 cycles) cycles in 8 rounds were observed during the third day.

The second operator who was operating the second loader (the smaller one) was monitored during the third set. This operator had more than 20 years of working experience (in operating loaders and excavators); however, he was unable to talk English. Therefore, there were some difficulties to communicate with him. In general, the operator was receiving a feedback directly after each round to first learn about his performance during the previous round, and then to obtain the instructions for the upcoming round.

The first ten cycles (first round) were monitored to evaluate the normal productivity rate of the machine/operator.[15] This rate is utilized later as the basis to evaluate how gamification could affect the overall machine productivity. The "individual-oriented competition" was utilized as the motive

[15] Because a new operator was operating the loader.

element to enhance the operator's behaviour during the next observation round. The similar concept as in the previous observation day was implemented in this round as well in which the operator was proposed three productivity rates of 3, 4 or 5t/min and was requested to select one of these target rates and try to attain it. To learn more about this challenge and its pointing structure, refer to subsection 4.1.4.

The "individual-oriented competition" was utilized during the third round as well to analyse how it can enhance the operator's behaviour in a longer period. Then, as Table 4.7 shows, the meaningful story was employed as game element during the 4th round. The operator was informed about the importance of recycling and its effects on global environment, with the purpose of fulfilling his need for autonomy.

Table 4.7: Game elements utilized during the third set

	Game element	**No. of cycles**
Round 1	Normal productivity (no gamification)	10
Round 2	Gamification (individual-oriented competition)	10
Round 3	Gamification (individual-oriented competition)	11
Round 4	Gamification (meaningful story)	10
Round 5	Gamification (group-oriented competition)	10
Round 6	Gamification (group-oriented competition)	10
Round 7	Gamification (group-oriented competition)	10
Round 8	Gamification (80 t challenge)	10

The same "group-oriented competition" as in the previous day was utilized within the fifth, sixth, and seventh rounds to understand how it can influence this operator's behaviour during a longer period of gamification implementation. The three challenges of 3t/min, 4t/min and 5t/min were defined by the site manager (as referee) and were offered to the operator in all three rounds. The operator targeted the challenge of 4t/min within the fifth and sixth rounds, while he chose the challenge of 5t/min for the seventh observation round. To learn about the result and analysis of these rounds, refer to section 5.3.

Finally, a new challenge was employed as the game design element within the last round. The operator gains some extra points if he reaches an overall productivity rate of 5t/min during the eighth round. As discussed in the literature, this kind of rewarding system could suit well for short-term behaviour adjustments; however, it would potentially fail in a longer implementation period. Eventually, as in the previous two sets, other criteria which could affect the machine productivity (e.g., site layout, weather conditions, or machine base productivity rate) were kept unchanged during this observation set.

4.3 Model implementation at the mining site

The gamification model was implemented at a mining site in Bavaria, Germany as well. Various mining activities such as extraction, excavation, transportation, and classification take place at this site. Figure 4.9 presents two locations of A and B where the gamification model was implemented. Location A indicates the spot where an excavator is extracting stones and loads them to two dump-trucks 1 and 2. These trucks transport stones to location B (as shown by the red arrows in Figure 4.9) where the stones are getting classified by a crusher. Figure 4.10 presents the excavator while loading one of the trucks at location A; however, Figure 4.11 presents the crusher which filters stones according to their dimension at location B.

The trucks are performing a repetitive job whole the day, therefore they are providing a suitable context to implement and analyse the gamification model. As it is discussed in chapter 4.1.1, the goal of the model is to improve machine productivity. Machine productivity in this context is the amount of stones (t) transported per hour. As the trucks are loaded by an external machine (an excavator), the operators can improve machine productivity only if they decrease each cycle duration.

Figure 4.9: Site layout

Figure 4.10: Location A - Stone extraction

Figure 4.11: The crusher

A cycle in this context begins when the truck leaves location A and it ends when the truck is back to the location A (to get loaded for the next cycle). The gamification model is implemented on both dump-trucks in 6 rounds where different game elements were utilized. As indicated by Table 4.8, each round includes ten cycles, and the truck operators are given the instruction for each round before round begins.

In addition, the gamification model was implemented in 6 rounds at location B where one loader loads the classified stones and transports them to the storage room. Figure 4.12 presents the loader while transferring the stones via a Y-shape movement. As presented by Table 4.9, each round includes 10 cycles where different game elements were utilized.

Table 4.8: Game elements utilized during the fourth and fifth sets

Observation rounds	**No. Cycles**	**Game element**
1st round	10	No Gamification
2nd round	10	Simple pointing system
3rd round	10	Well-defined pointing system
4th round	10	Individual-oriented competition
5th round	10	Individual-oriented competition with feedback
6th round	10	Group-oriented competitions

Figure 4.12: Wheel-loader transfers sized materials

Table 4.9: Game elements utilized during the sixth set

Observation rounds	No. Cycles	Game element
1st rounds	10	No Gamification
2nd rounds	10	Simple pointing system
3rd rounds	10	Well-defined pointing system
4th rounds	10	Individual-oriented competition 1
5th rounds	10	Individual-oriented competition with feedback
6th rounds	10	Group-oriented competitions

The objective is to enhance machine productivity (section 4.1.1). Machine productivity in this context, is the amount of sized material (t) transported per hour. As the loader did not have any sensor to calculate the amount of stones loaded in its bucket, the loading time and the loaded stones were excluded from all observation cycles. In other words, one cycle starts when the loader leaves the classifier (after loading the stones) and ends when the loader is again back to the classifier. Therefore, the operator can only improve machine productivity by decreasing each cycle duration.

4.3.1 Fourth and fifth observation sets

Both operators (who are driving dump-trucks) have almost 15 years of working experience in operating wheel-loaders as well as dump-trucks. In total, each operator performed 60 working cycles in 6 rounds. The first 10 cycles (for both operators) were monitored during the first round, in which no gamification was utilized. The objective was to figure out the normal cycle duration for each operator. This info later is utilized as the basis to evaluate how gamification could affect the overall operator's behaviour.

The next 10 cycles were observed during the second round, in which a simple pointing system was employed to motivate each operator with the purpose of improving his behaviour. Both operators were offered to gain some points if they can decrease the cycle duration. No further information about how the pointing system works or what can be done with the achieved points was given to the operators. The goal was to perceive how the operator's behaviour is affected by having a simple pointing system.

The pointing system was explained in more details before starting the third round. The operators were explained how to achieve points and were offered to get some hours off if they gain certain points. This round was conducted to understand how a better-defined pointing system can affect the applicant's behaviour compared to the situation where they are merely requested to improve their behaviour.

Individual-oriented competition was utilized as the motive element to encourage the operators with the purpose of enhancing their behaviour during the 4th round. The three challenges of 640s, 580s, and 530s were offered to both operators (Figure 4.13). The operators were requested to choose one of the challenges and try to reach it during each cycle. The operators will get scored by comparing their actual performance with the selected target as is explained in chapter 4.1.4. Both operators chose target duration of 580s.

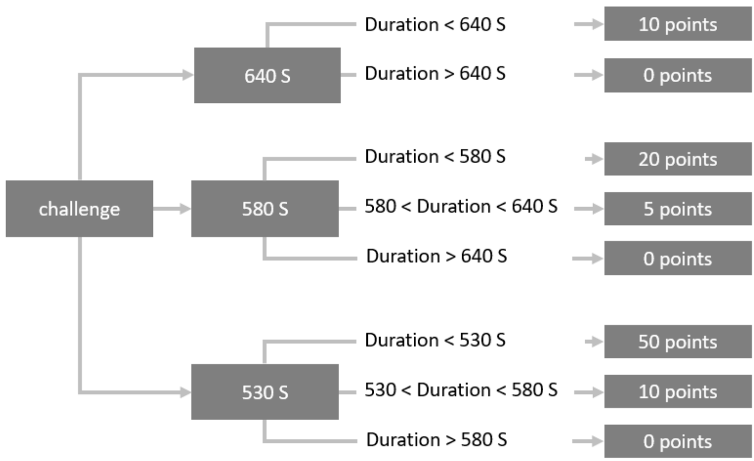

Figure 4.13: The challenge system for dump-trucks operators

The same challenge system was utilized for the fifth round as well. The operators were provided feedback about their performance in the previous round and were requested to choose a challenge again. Both operators chose same challenge of 580s for each cycle during the fifth round as well.

Finally, as Table 4.8 indicates, the group-oriented competition was utilized as the gaming element during the sixth round. The same challenge system as the fifth round was employed to score the operators, and they were given the possibility to take part in a group competition as discussed in section 4.1.4. Due to the limited number of operators (only two), they could not create their groups by their own and therefore, some imaginary groups were introduced. Each operator was allocated to an imaginary group with other 4 operators from other construction site. All group members are given the same challenge concept and are scored accordingly. The group overall score is the average of the scores achieved by all the members. Following, the groups are ranked in a leader-board according to their score.

After explaining the rules and conditions, the operators were requested to choose a new challenge (same as in the previous round). The first operator (truck 1) decided for the challenge of 580s; however, the second operator chose the harder challenge of 530s. Read sections 5.4, and 5.5 to learn about the result of these sets.

As a general role, other criteria (e.g., site layout, weather conditions, or machine base configuration), which could affect the cycle duration, were kept unchanged during the whole observation set. Therefore, any change in the cycle duration is an indicator of how the operator's behaviour has been affected by the gamification model.

4.3.2 Sixth observation set

The same gamification concept was implemented on a loader operating at the location B to transfer the classified stones to the storage room. In total, 60 Y-shape working cycles were observed during 6 rounds. The first 10 cycles were observed to understand the normal cycle duration, in which no gamification was utilized. This information is utilized later as the basis to evaluate how gamification could affect the overall operator's behaviour.

The next 10 cycles were observed during the second round where a simple pointing system was employed to motivate the operator for a better working performance. The operator was offered to obtain some points if he can decrease each cycle duration. No further information about how the pointing system works or what can be done with the achieved points was given. As discussed before, the goal was to understand how the operator's behaviour is affected by a simple pointing system, without containing a well-defined procedure to earn and expend points.

The pointing system was explained in more details before starting the third round and the operator was offered some hours off if he can gain certain points. The next 10 cycles were observed in this round and operator performance was documented. This round was conducted to understand how a better-defined pointing system can affect the applicants' behaviour compared to the situation where they are simply requested to improve their behaviour.

The individual-oriented competition was introduced to the operator just before starting the 4th round. The same principle as previous set was utilized as shown by Figure 4.14. The operator chose challenge of 65s for the 4th round.

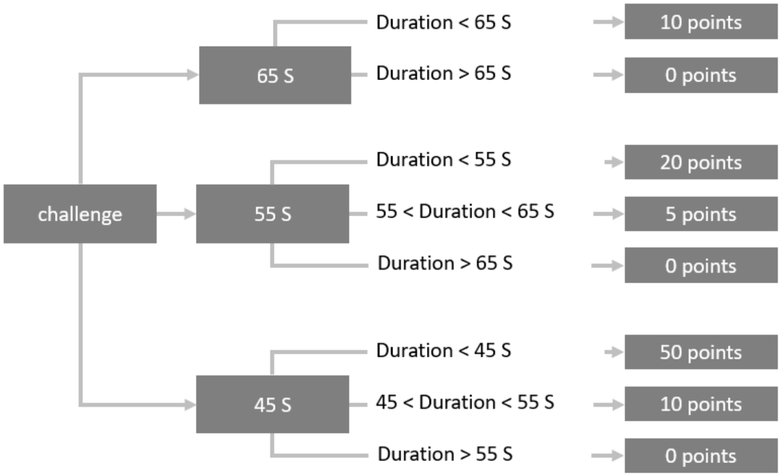

Figure 4.14: The challenge system for the wheel loader operator

The operator was provided feedback about his performance and was offered to choose a new challenge just before starting the fifth round. He again decided for same challenge of 65s.

Finally, as Table 4.9 presents, the group-oriented competition was utilized as gaming element during the sixth observation round. The operator was placed in a group with other 4 imaginary operators and the same challenge system as previous round was employed to score the operator. The group overall score is the average of the scores achieved by all the members. Moreover, the operator was informed that the groups are ranked in a leader board according to their score.

As previous gamification implementation, other criteria (e.g., site layout, weather conditions, or machine base configuration), which could affect the cycle duration, were kept unchanged during the whole observation set. Therefore, any change in the cycle duration is an indicator of how the operator’s behaviour has been affected by the gamification model.

5 Analysis

This chapter is conducted to present and analyse the result of gamification implementation. The gamification model was implemented first at a recycling site in three days (sets) where several observation rounds were conducted. Each observation round studies the effect of one game element on the operator's behaviour and contains several loading/unloading cycles. The result of this gamification implementation is discussed below in sections 5.1, 5.2, and 5.3.

The gamification model was implemented on two dump-trucks and one wheel-loader (three sets in total) at a mining site in Bavaria as well. Each observation set had 10 rounds where different game elements were utilized to motivate the operator towards more proper working performance. Read sections 5.4, 5.5, and 5.6 to learn about the result of this gamification implementation.

5.1 Analysis of the first set

The performance of the first operator (who was operating a wheel-loader at the recycling site) was observed during the first observation set. In total, five rounds were conducted, each of which includes 35 loading/unloading working cycles.[1] (see Table 4.5)

<u>The first round</u>

No gamification was implemented during the first round to find the normal machine productivity rate. The round lasted about 49min, where 250t of

[1] Read subsection 4.2.1.

asphalt granulate was transferred by the wheel-loader. It indicates an overall productivity rate of 5.098t/min, which was moderately higher than the expected rate, said by site manager. This result can be justified because human behaviour is naturally affected when they are being watched. In other words, a large number of people act differently when they are being watched, and they go typically back to their ordinary behaviour gradually.

Figure 5.1 illustrates the duration of first 35 cycles. The trending line shown in the figure indicates that the required time to perform a working cycle increases (on average) during the round. In other words, the operator forgot the fact that he is being watched and he is going back to his normal behaviour gradually.

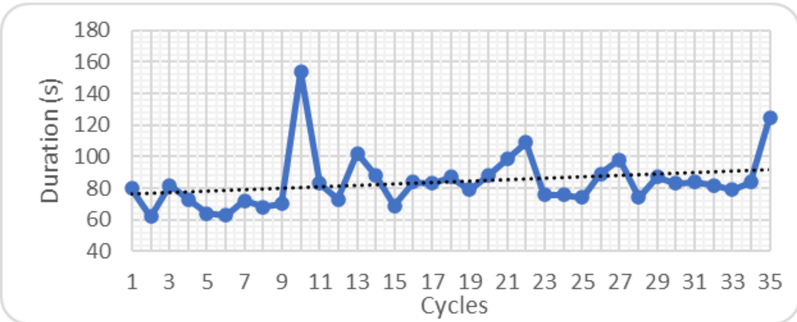

Figure 5.1: Duration of each cycle in the 1st round, the 1st set

Table 5.1: Highlights of the 1st round, the 1st set

Tons of asphalt	Duration	Fastest cycle	Slowest cycle	Diversion rate	Productivity
250t	49min	62s	154s	148%	5.098t/min

Furthermore, Table 5.1 presents the highlights of the round. The fastest performance was recorded during the second cycle, in which the work was done in 62s. The slowest cycle was submitted during the tenth circle where the job was conducted in 154s. This presents a diversion rate of around 148% between the fastest and the slowest cycle.[2]

Although it is uncitable to analyse the diversion rate without including any scale, 148% difference in a period of only 49min (for a same job) could indicate the operator's unstable behaviour. This unstable behaviour could be a consequence of no psychological well-being[3]. Furthermore, the operator was texting (using his mobile phone) during the tenth cycle, indicating he was not motivated to concentrate on his job.

<u>The second round</u>

A simple pointing system was utilized during the second round. The operator was offered to earn some points if he enhances the machine productivity rate[4]. The round lasted around 53.3min where 245t of asphalt was transported. It results in an overall productivity rate of 4.594t/min, which is interestingly almost 10% lower than the productivity rate recorded during the first round (where no gamification had been utilized).

Table 5.2 illustrates the highlights of the round. The operator's fastest performance was recorded during the first cycle where the work was done in 67s; however, the slowest cycle was recorded during the eighteenth cycle where the job was performed in 125s.

This indicates a diversion rate of almost 86.6% between the fastest and the slowest cycle, which is much lower compared to the previous round where a diversion rate of 148% was recorded. A lower diversion rate indicates the operator's more stable behaviour.

[2] All other factors which can affect cycle duration kept unchanged during the round.
[3] Because of being watched during the round.
[4] Operator was told "improve machine productivity to get some points".

As illustrated by Figure 5.2, same behaviour was seen in this round as well, where the cycle duration slightly increases (on average) during the round[5]. In other terms, the operator showed a better performance at the beginning of the round compared to its end. This indicates 1) the operator forgets the motive for his appropriate behaviour during the round, and 2) continuous feedback helps the operator to keep his appropriate behaviour.

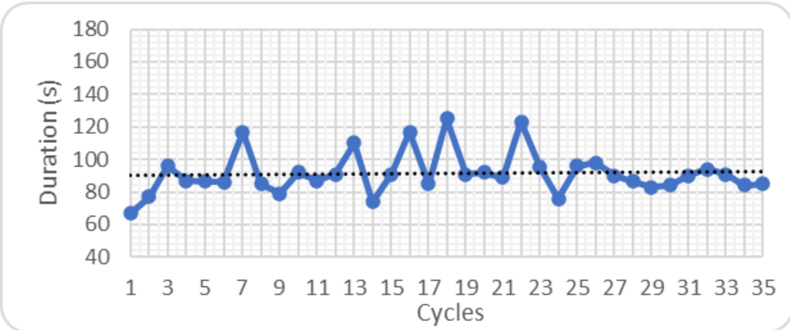

Figure 5.2: Duration of each cycle in the 2nd round, the 1st set

Table 5.2: Highlights of the 2nd round, the 1st set

Tons of asphalt	Duration	Fastest cycle	Slowest cycle	Diversion rate	Productivity
245t	53min	67s	125s	87%	4.6t/min

The third round

The pointing system was presented in more details to the operator before starting the third round. On one hand, he was explained the rules to gain points, and on the other hand, he was informed how to utilize the points.

[5] The trending line is increasing during the round.

In total, 265t of asphalt was transported in a period of about 51min, indicating an overall productivity rate of 5.2t/min which is almost 2% higher than the rate recorded during the first round. In addition, it presents almost 13% enhancement in machine productivity compared to the second round.

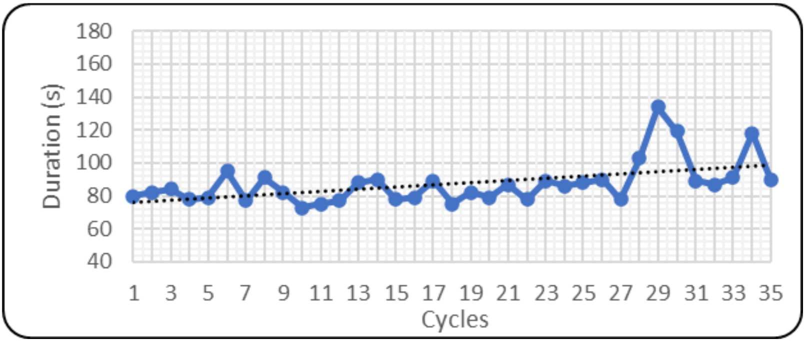

Figure 5.3: Duration of each cycle in the 3rd round, the 1st set

Table 5.3: Highlights of the 3rd round, the 1st set

Tons of asphalt	Duration	Fastest cycle	Slowest cycle	Diversion rate	Productivity
265t	51min	73s	134s	84%	5.2t/min

Table 5.3 presents the highlights of the round in which the fastest cycle was performed in 73s, while the slowest cycle was done in 134s. This results in a diversion rate of almost 84%, which is decreased compared to both previous rounds[6]. Although both machine productivity and operator's consistent behaviour are enhanced during the third round, the operator is still

[6] This indicates that the operator has shown more stable behavior compared to both previous rounds.

performing a better job at the beginning of the round (when pointing system was explained) compared to its end (Figure 5.3)[7].

The fourth round

The “individual-oriented competition” was proposed to the operator before starting the fourth round. In total, 259t of asphalt was transported in a period of around 50.6min, resulting in an overall productivity rate of 5.114t/min. Although it shows around 0.3% increase in machine productivity compared to the first round (in which no gamification had been utilized), it decreased by 1.6% compared to the previous round, in which a “pointing system” had been implemented.

Table 5.4 illustrates the highlights of the round in which the fastest cycle was performed in 67s and the slowest cycle was conducted in around 151s. This presents a diversion rate of 125%, which is much higher compared to two previous rounds. Therefore, the operator was less consistent in his behaviour.

Figure 5.4 illustrates the duration of each cycle during the round. As the trending line indicates, the operator could keep his appropriate behaviour continuously. In other terms, he could find a reason to continue his appropriate behaviour during the round.

Table 5.4: Highlights of the 4th round, the 1st set

Tons of asphalt	**Duration**	**Fastest cycle**	**Slowest cycle**	**Diversion rate**	**Productivity**
259t	51min	67s	151s	125%	5.1t/min

[7] The trending line increases during the round.

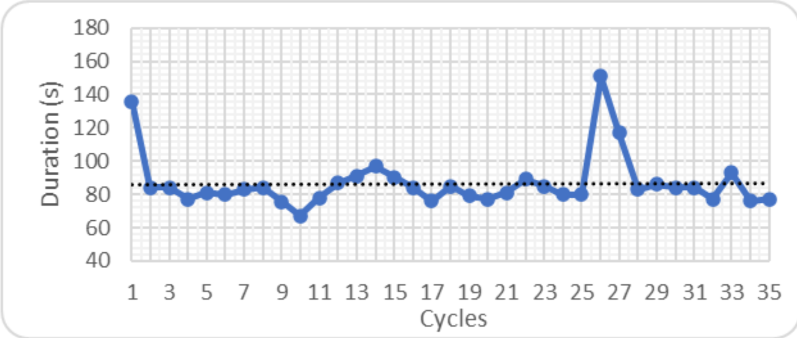

Figure 5.4: Duration of each cycle in the 4th round, the 1st set

The fifth round

The “group-oriented competitions” was utilized as the game element during the fifth round. The operator could transport 329t of asphalt in a period of around 55.8min, indicating an overall productivity rate of 5.9t/min. This rate was the highest recorded rate during the day and illustrates 15% enhancement in machine productivity compared to the previous round.

Furthermore, the operator strongly focused on keeping his appropriate behaviour during this round. As Table 5.5 presents, the fastest cycle was performed in 84s; however, the slowest cycle was done in 114s which concludes a diversion rate of 36%.

Figure 5.5 illustrates the duration of each cycle. As the trending line shows, the operator was doing a better job at the beginning of the round compared to its end. Therefore, although he presented a more consistent behaviour during the round, he gradually forgot the motive for his appropriate performance.

Table 5.5: Highlights of the 5th round, the 1st set

Tons of asphalt	Duration	Fastest cycle	Slowest cycle	Diversion rate	Productivity
329t	56min	84s	114s	36%	5.9t/min

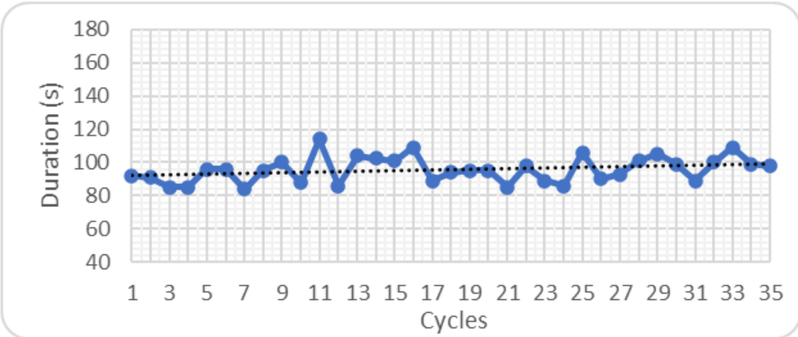

Figure 5.5: Duration of each cycle in the 5th round, the 1st set

<u>Discussion</u>

Figure 5.6 illustrates how the wheel-loader productivity rate was improved in the first set by gamification. The lowest rate was seen during the second round, which was almost 10% lower than the recoded rate in the first round. However, as shown in Figure 5.7, the operator presented a more stable behaviour during the second round. This indicates he was more excited during the first round and could probably reach a better productivity rate because of the new feeling of being watched. However, he got used to it in the second round and probably went back to his normal behaviour. Therefore, he was more relax and presented a more stable behaviour especially at the end of the second round.

The operator's best performance was recorded during the last round, in which the "group-oriented competition" had been utilized. This game element was designed to address all three psychological needs simultaneously and therefore, could motivate the operator to 1) enhance his performance and 2) present more stable behaviour. Refer to section 4.1.4 to understand how “group-oriented competition” can meet all three human needs simultaneously.

The operator could present a better productivity rate and a more stable behaviour during the third round (where a well-defined pointing system had been utilized) compared to the fourth round (where the challenge system was introduced for the first time). However, an inverse result was expected. This can be justified since the challenge system was new to the operator and thus, he was not familiar with it at the beginning. Subsequently, the operator presented a better behaviour in the fifth round when he became more familiar with the challenge system.[8]

As an overall finding, the gamification model could improve machine productivity gradually during the first observation day. Moreover, as Figure 5.7 shows, it could encourage the operator to present a more consistent behaviour progressively. Therefore, it can be concluded that the model was successful in improving the operator’s extrinsic motivation towards more intrinsic one gradually.[9]

Although the gamification model could achieve its objectives during the set, the operator was forgetting the motive for his appropriate behaviour at the end of almost all rounds. This concludes, he was not fully (intrinsically) motivated and therefore, he is not expected to maintain his proper performance in a longer observation period without any external rewards. Continuous feedback can address this issue in short term; however, the gam-

[8] The same challenge system was utilized during 4th and 5th rounds.

[9] Read session 3.1.1

ification design should be adjusted to better meet the operator's psychological needs for autonomy, competence, and social relatedness.[10]

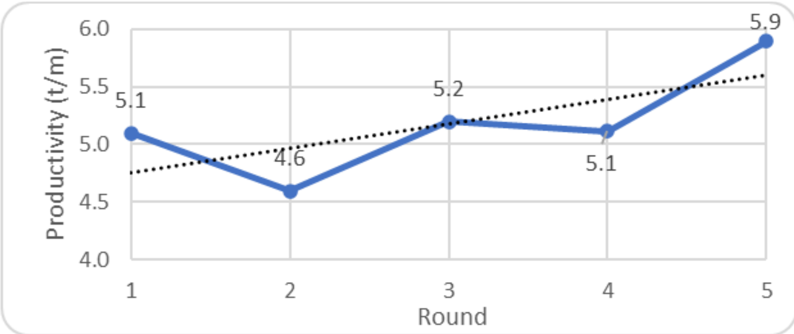

Figure 5.6: Productivity rate for all rounds in the 1st set

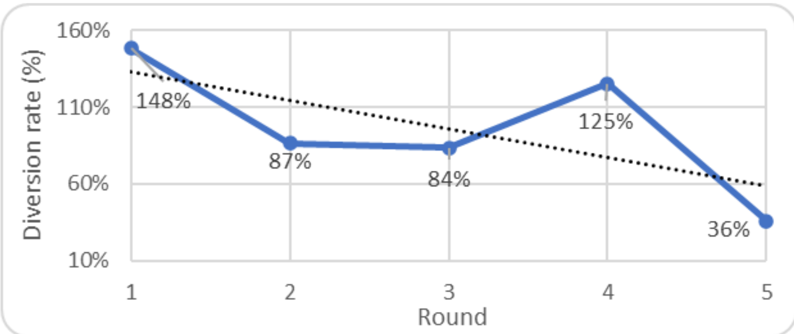

Figure 5.7: Diversion rate for all rounds in the 1st set

[10] When a person is intrinsically motivated, he finds a reason to continue his good behavior continuously. Read section 3.1

5.2 Analysis of the second set

The operator's performance while operating the second loader (the smaller one) was monitored during the second set at the recycling site. As mentioned before, the number of monitored loading/unloading cycles in each round was limited to 20 cycles. This allows to monitor more rounds and evaluate more gaming elements during the day.

<u>The first round</u>

Although the behaviour of same operator was monitored during the day, he was operating another loader (the yellow one in Figure 4.7). Therefore, no gamification was utilized during the first round to understand the normal productivity rate of the set. In this round, 132t of asphalt was transported in a period of around 39min which indicates an overall productivity rate of 3.401t/min. As discussed earlier, this (normal) productivity rate is utilized later as the basis to evaluate how gamification has affected machine productivity within the next observation rounds.

Figure 5.8 presents the duration of each cycle during the round. As illustrated by the figure, the operator presents a better behaviour at the beginning of the round compared to its end (the trending line in the figure). This indicates the operator was forgetting the motive for his appropriate behaviour during the round gradually.

Table 5.6 presents the highlights of the round. The fastest cycle lasted 102 s and the slowest cycle was done in 150 s. This indicates a diversion rate of 47%.

Table 5.6: Highlights of the 1st round, the 2nd set

Tons of asphalt	**Duration**	**Fastest cycle**	**Slowest cycle**	**Diversion rate**	**Productivity**
132t	39min	102s	150s	47%	3.4t/min

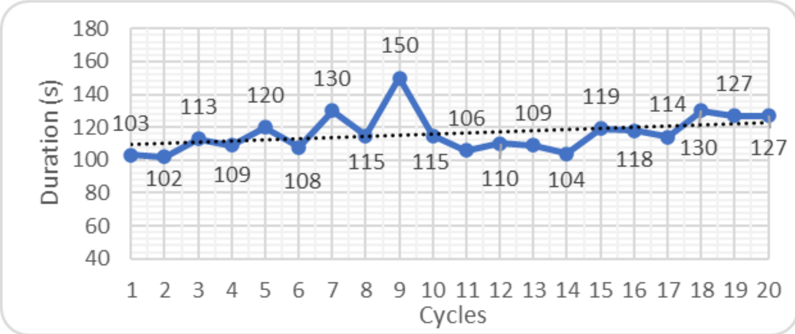

Figure 5.8: Duration of each cycle in the 1st round, the 2nd set

<u>The second round</u>

The second round was limited to 16 cycles, since the operator took a break after the sixteenth cycle. The "individual-oriented competition" was utilized as the game design element in this round. In total, 133t of asphalt was transported during a period of 28.2min. This indicates an overall productivity rate of 4.71t/min, which is almost 38% better than machine productivity during the previous round where no gamification had been utilized. Furthermore, the trending line in Figure 5.9 is decreasing. It illustrates the operator has submitted a better performance (on average) at the end of the round compared to the beginning. This happened for the first time and could be justified because 1) the "individual-oriented competition" potentially could meet the operator's need for autonomy (by providing a freedom to choose a challenge) as well as the need for competence (by the pointing system). Therefore, the operator's intrinsic motivation was probably better enhanced during the round and he found a reason to improve (continue) his appropriate behaviour without any external feedback, 2) The operator was more familiar with the challenge system and was better involved in the gamification[11].

[11] He was doing same challenges in the first set as well.

Table 5.7 illustrates the highlights of the round. The operator's best (fastest) performance was recorded during the fourth cycle when he finalized a loading/unloading cycle in 83s. However, the worst (slowest) performance was seen during the fifth cycle where the same job was conducted in 124s. This indicates a diversion rate of 49%. As Figure 5.9 shows, the operator presented a more stable behaviour from sixth cycle which could conclude he was more excited at the beginning of the round and gradually got adapted to the gamification.

Table 5.7: Highlights of the 2nd round, the 2nd set

Tons of asphalt	Duration	Fastest cycle	Slowest cycle	Diversion rate	Productivity
133t	36min	83s	124s	49%	4.7t/min

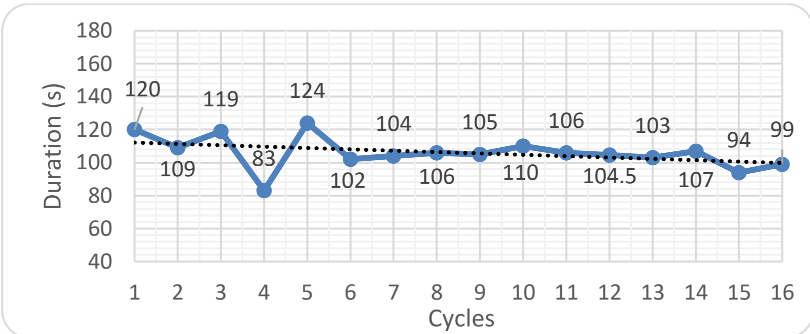

Figure 5.9: Duration of each cycle in the 2nd round, the 2nd set

The third round

"Group-oriented competition" was utilized as game element during the third round. In total, 141t of asphalt was transported within a period of almost 35min. This indicates an overall productivity rate of 4.025t/min, which is almost 14.5% lower than the recorded rate during the previous round. However, it is still higher (by around 18%) than the submitted rate during the first round where no gamification was utilized.

Figure 5.10 presents the duration of each cycle. As shown by the figure, the trending line is increasing which concludes a better operator's performance at the beginning of the round (on average) compared to its end. In other words, the operator is gradually forgetting the motive for his proper behaviour.

Table 5.8 provides the highlights of the round. The best performance was recorded during the first cycle where the job was done in 71s; however, it took 147s to perform the similar work during the tenth cycle. This presents a diversion rate of 107%, which is more than double compared to the previous round (107% vs. 49%).

To conclude, the operator submitted a lower productivity rate during the third round compared to the previous (second) round. Moreover, he had less stable performance (diversion rate of 107%) and was forgetting the motive for his appropriate behaviour. Therefore, the gamification clearly failed in this round to encourage the operator with the purpose of enhancing his behaviour (compared to the previous round). There could be two reasons to justify this result. 1) The "individual-oriented competition" could successfully satisfy the operator's psychological needs and, therefore, he was intrinsically motivated. This is why a better performance was seen during the second round. 2) Modifying the game element had a negative effect on the operator's behaviour, and he presented worse performance (compared to the previous round) immediately after the change.

Table 5.8: Highlights of the 3rd round, the 2nd set

Tons of asphalt	Duration	Fastest cycle	Slowest cycle	Diversion rate	Productivity
141t	35min	71s	147s	107%	4t/min

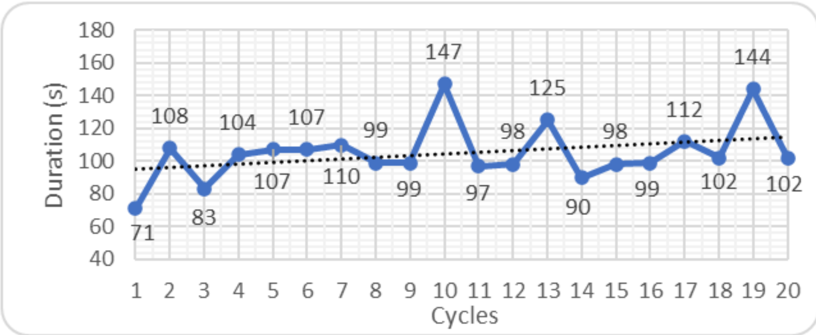

Figure 5.10: Duration of each cycle in the 3rd round, the 2nd set

<u>The fourth round</u>

Same game element as third round ("group-oriented competition") was utilized. In total, 145t of asphalt was transported in a period of 35min. This indicates a total productivity rate of 4.14t/min, which is around 2.9% higher than the recorded rate within the previous round. Furthermore, as Figure 5.11 shows, the trending line is almost straight, indicating the operator had the same behaviour during the round.

Table 5.9 presents the highlights of the round where a diversion rate of 53% was recorded. This rate was lower than the diversion rate submitted within the previous round.

To conclude, the operator could reach a better productivity as well as diversion rate compared to the third round. Moreover, he presented almost same behaviour from the beginning of the round to its end. Therefore, it can conclude he was in a better psychological condition during the fourth round compared to its previous round.

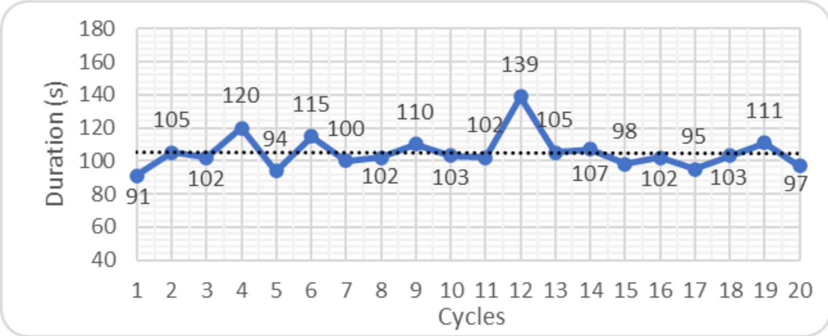

Figure 5.11: Duration of each cycle in the 4th round, the 2nd set

Table 5.9: Highlights of the 4th round, the 2nd set

Tons of asphalt	Duration	Fastest cycle	Slowest cycle	Diversion rate	Productivity
145t	35min	91s	139s	53%	4.1t/min

The fifth round

The same "group-oriented competition" was utilized as game element during the fifth round as well. As discussed in section 4.2.2, the purpose was to evaluate how a single game element can affect the operator's behaviour in a longer observation period. In total, 150t of asphalt was transported in a period of around 37.5min. This indicates an overall productivity rate of 4.002t/min, which is almost 3.5% less that the productivity rate recorded during the fourth round. Moreover, Figure 5.12 shows, the operator had a better behaviour at the beginning of the round compared to its end. In other words, he was forgetting the motive of his appropriate behaviour gradually.

Table 5.10 provides the highlights of the round. As the table presents, the operator recorded a diversion rate of 59%, which is higher than the obtained rate during the previous round. To conclude, the operator had a better performance during the previous round both in machine productivity and diversion rate. This can get justified due to the fact that operator was not given any feedback before starting the round.

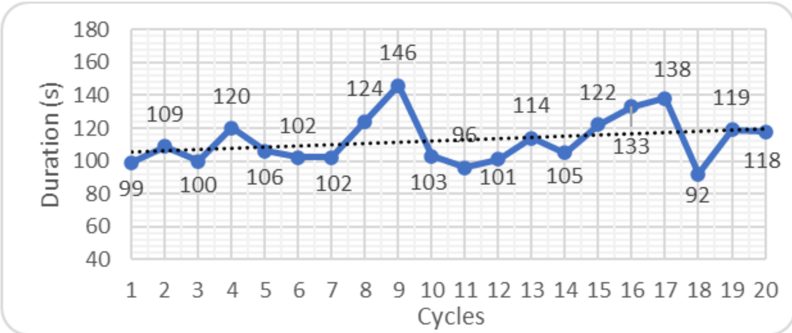

Figure 5.12: Duration of each cycle in the 5th round, the 2nd set

Table 5.10: Highlights of the 5th round, the 2nd set

Tons of asphalt	**Duration**	**Fastest cycle**	**Slowest cycle**	**Diversion rate**	**Productivity**
150t	37min	92s	146s	59%	4t/min

<u>The sixth round</u>

The same game element was utilized during the sixth round as well. However, the operator was given feedback just before starting the round. He was informed both groups are having a tough competition and currently the other group is leading slightly.

In total, 168t of asphalt was transported in a period of almost 27.4min. This indicates a productivity rate of 6.135t/min, which is 53.3% higher than the recorded rate during the previous round. Figure 5.13 presents the duration of each cycle. As shown by the figure, the trending line is increasing during the round, indicating the operator had a better performance at the beginning of the round compared to its end. Furthermore, as Table 5.11 presents, a diversion rate of 120% was observed, which is much higher than the rate recorded during the fifth round.

To conclude, the operator could enhance machine productivity significantly; however, he failed to present stable behaviour during the round. Therefore, this performance is not expected to continue in a longer period.

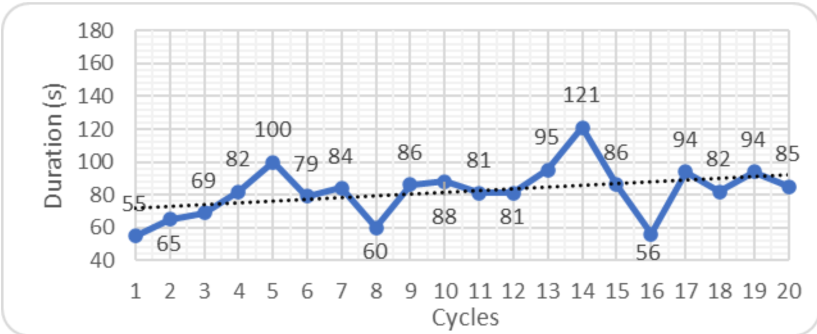

Figure 5.13: Duration of each cycle in the 6th round, the 2nd set

Table 5.11: Highlights of the 6th round, the 2nd set

Tons of asphalt	Duration	Fastest cycle	Slowest cycle	Diversion rate	Productivity
168t	27min	55s	121s	120%	6.1t/min

The seventh round

The same “group-oriented competition” was utilized during the seventh round with the target of perceiving how the operator’s behaviour is affected by a similar game element during a longer period. In total, 145t of asphalt was transported in a period of almost 34min, indicating an overall productivity rate of 4.2t/min. This rate is around 30.5% fewer than the productivity rate in previous round; however, it is close to the rate reached within the fifth round.

Moreover, as Figure 5.14 shows, the operator presented a better behaviour at the end of the round compared to its beginning, indicating he found a reason to continue his proper behaviour. In addition, as Table 5.12 presents, the operator showed a lower diversion rate (almost 50%) compared to its previous round, concluding that he had more consistent behaviour.

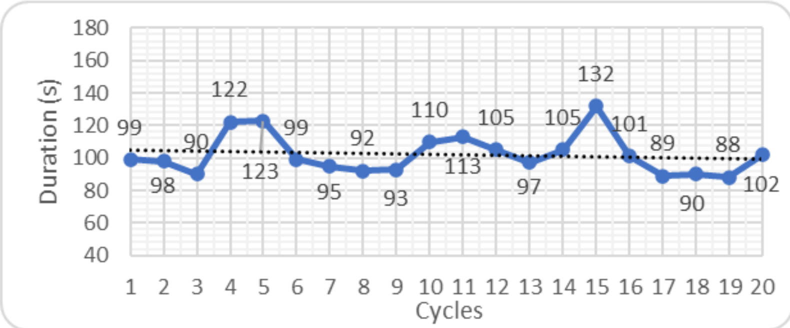

Figure 5.14: Duration of each cycle in the 7th round, the 2nd set

Table 5.12: Highlights of the 7th round, the 2nd set

Tons of asphalt	**Duration**	**Fastest cycle**	**Slowest cycle**	**Diversion rate**	**Productivity**
145t	34min	88s	132s	50%	4.2t/min

The eighth round

The same game element (without providing any feedback) was employed during the eighth observation round. The round lasted for around 36.30min, and 146t of asphalt was transported. This indicates an overall productivity rate of 4.022t/min, which is almost 5% fewer than the recorded rate during the previous round. Moreover, the operator showed almost same behaviour at the end of the round compared to its beginning (Figure 5.15).

As Figure 5.15 presents, the operator's best performance (fastest) was recorded during the twelfth cycle where the work was finalized in 86s ; while the operator's worst (slowest) behaviour was recorded during the sixth cycle where the job was done in 140s. This indicates a diversion rate of 62.8%, which is higher than the recorded rate within the previous round.

To conclude, the operator had a better productivity rate and more stable behaviour during the seventh round compared to the eighth round. This can get justified due to the fact that he was not given any feedback before starting the round. In other words, longer operation period without any feedback led to worse operator's performance.

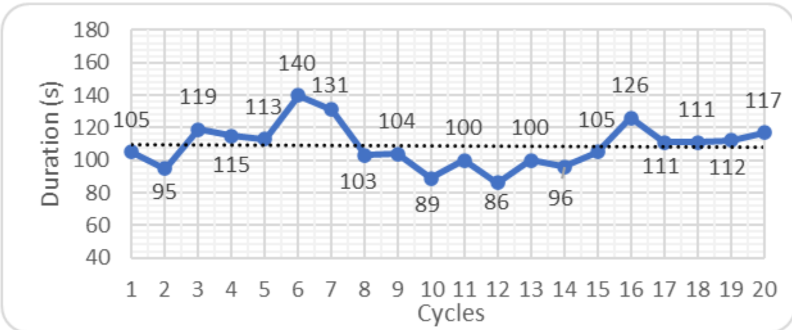

Figure 5.15: Duration of each cycle in the 8th round, the 2nd set

Table 5.13: Highlights of the 8th round, the 2nd set

Tons of asphalt	Duration	Fastest cycle	Slowest cycle	Diversion rate	Productivity
146t	36min	86s	140s	63%	4t/min

Discussion

Figure 5.16 illustrates the submitted productivity rate in each round during the second day. The lowest productivity rate was recorded during the first round where no gamification had been utilized. Therefore, the gamification could enhance the machine productivity in all other rounds.

The highest productivity rate was recorded during the sixth round when the operator was given feedback. He was notified that both teams are having a tough competition and the other team is leading. This feedback could enhance the operator's behaviour with the purpose of improving the machine productivity significantly; however, it probably failed to improve his psychological well-being. The operator presented an unstable and aggressive behaviour during this round (a diversion rate of 120%), which can be very risky both for the operator himself as well as for the surrounding environment. In addition, the operator had a better performance at the beginning of the round compared to its end and, thus, he was forgetting the motive for his appropriate behaviour gradually. Therefore, (according to the SDT), the operator is expected to be more extrinsically motivated during this round and his proper behaviour potentially would not continue without any external rewards.

The "individual- oriented competition" was utilized during the second round and could derive a more impressive result compared to the "group-oriented competition". On one hand, it could encourage the operator to enhance the machine productivity (4.707t/min) better than the "group-oriented competition" could do. On the other hand, it could enhance the operator's psychological well-being since 1) the operator was enhancing his behaviour (on average) continuously during the round, 2) the diversion rate during the second round was around 49.4%, which was one of the best recorded rates during the day. To sum up, although it was expected to gain a better result by the "group-oriented competition", the "individual-oriented competition" could better satisfy the operator's psychological needs.

As another finding, the operator submitted a nearly same productivity rate during the 3rd, 4th, 5th, 7th, and 8th rounds. It concludes that a stable model can result in more consistent operator's behaviour.

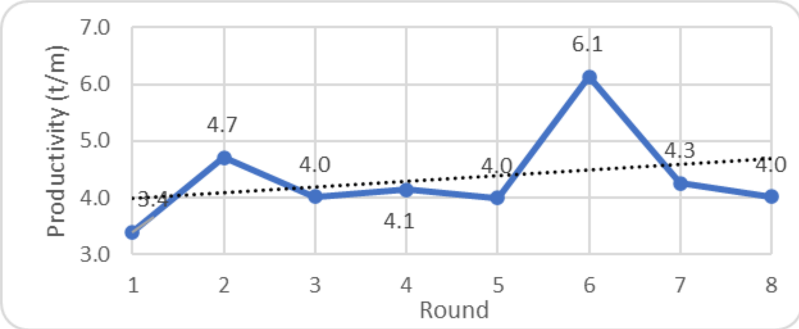

Figure 5.16: The productivity rate for each round in the 2nd set

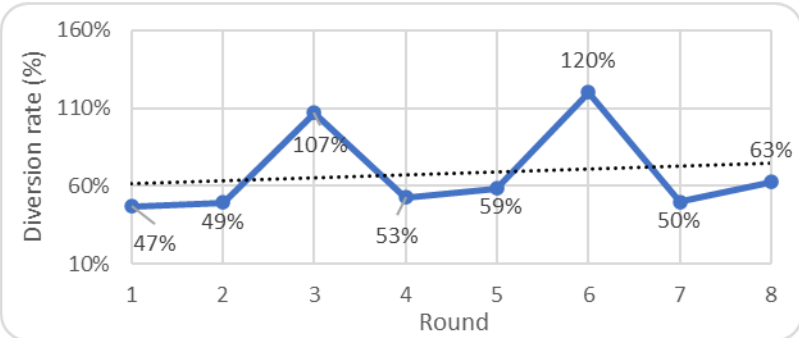

Figure 5.17: Diversion rate for all rounds in the 2nd set

5.3 Analysis of the third set

Performance of the second operator, that was operating the smaller loader (the second one), was observed during the third set. As discussed in section 4.2.3, eight rounds were conducted during the day, each of which included ten loading/unloading cycles.[12]

The first round

The first ten cycles were monitored to understand the normal machine productivity rate. Therefore, no gamification was utilized in this round. In total, 60t of asphalt was transported in almost 17min, which indicates an overall productivity rate of 3.535t/min. This is almost 4% higher than the normal productivity rate recorded in the previous day when the first operator was operating same wheel-loader.

Although no gamification was utilized in this round, machine productivity was higher than the expected rate, said by the site manager. This result can be justified because human behaviour is naturally affected when they are being watched. Put differently, a large number of people act differently when they are being watched, and they get typically back to their ordinary behaviour gradually.

Figure 5.18 illustrates duration of each cycle in the round. As the figure shows, the operator had a better performance at the beginning of the round compared to its end[13]. In other terms, he was forgetting the fact of being watched and got back to his normal behaviour gradually.

[12] The observation was done on Friday when the recycling site closes earlier compared to other normal working days. Therefore, each round was limited to 10 cycles, which could result in eight observation rounds. Read subsection 4.2.3 for more information.

[13] Trending line in Figure 5.18.

Table 5.14 provides the highlights of the round. The fastest cycle lasted for 97s, while the slowest cycle took 111s. This presents a diversion rate of around 14.4%. This rate was calculated based on only ten cycles; therefore, it could not get compared to the rates obtained during previous days.

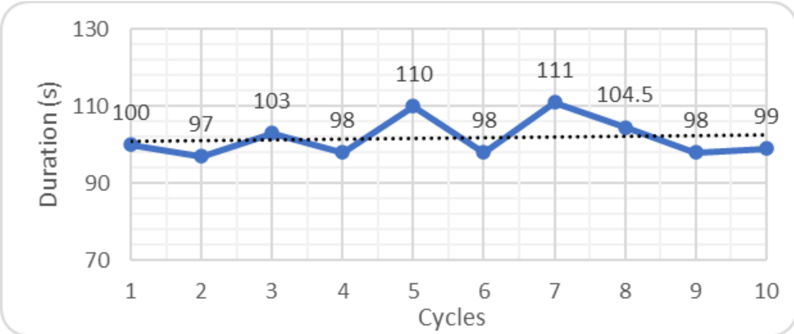

Figure 5.18: Duration of each cycle in the 1st round, the 3rd set

Table 5.14: Highlight of 1st round, the 3rd set

Tons of asphalt	Duration	Fastest cycle	Slowest cycle	Diversion rate	Productivity
60t	17min	97s	111s	14%	3.5t/min

<u>The second round</u>

The “individual-oriented competition” was utilized during the second round. The round lasted for around 15.4min and 67t of asphalt was transported. This indicates an overall productivity rate of 4.341t/min, which is around 23% higher than the rate obtained during the first round.

Table 5.15 illustrates the highlights of the round where the fastest cycle was conducted in 87s, while the operator performed the slowest cycle in 103s. This indicates a diversion rate of 18.4% in operator’s performance, which is higher than recorded rate within the first round. Therefore, although the productivity rate was increased, the operator's behaviour was less consistent during the second round. This can be justified since the operator was more excited.[14]

Moreover, as shown by Figure 5.19 (the trending line), the operator had a better behaviour at the beginning of the round compared to its end. This can indicate he was gradually losing the motive for his appropriate behaviour.

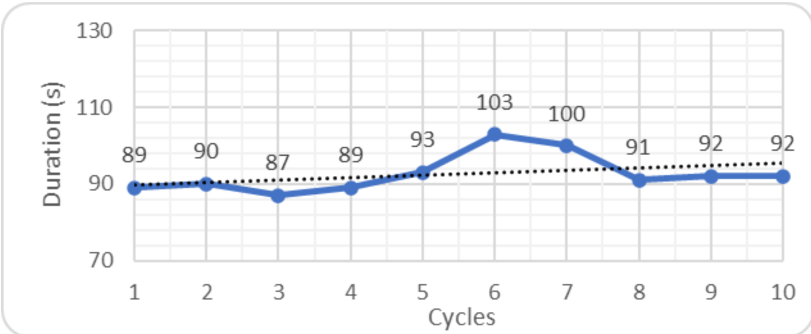

Figure 5.19: Duration of each cycle in the 2nd round, the 3rd set

Table 5.15: Highlight of the 2nd round, the 3rd set

Tons of asphalt	**Duration**	**Fastest cycle**	**Slowest cycle**	**Diversion rate**	**Productivity**
67t	15min	87s	103s	18%	4.3t/min

<u>The third round</u>

The operator was provided feedback on his performance after the second round and was requested to start the upcoming round with the same game

[14] The second round was the first round where the gamification was utilized for this operator.

element (the “individual-oriented competition”).[15] The round lasted for around 17.2min and 75t of asphalt was transported. This indicates an overall productivity rate of 4.369t/min, which is almost 0.65% higher than the recorded rate during the previous round. In addition, machine productivity increased by 23.5% compared to the first round where no gamification had been utilized.

As Figure 5.20 shows, the trending line is decreasing, indicating that the operator could present a better performance (on average) at the end of the round compared to its beginning. Thus, it can conclude he found a reason to continue his appropriate behaviour. Although the machine productivity as well as the operator’s performance (during the round) were enhanced, the operator’s behaviour was unstable during the 3rd round compared to previous rounds. As Table 5.16 presents, a diversion rate of 38.6% was recorded between the fastest and slowest cycles, which is higher than the submitted diversion rates in other previous rounds.

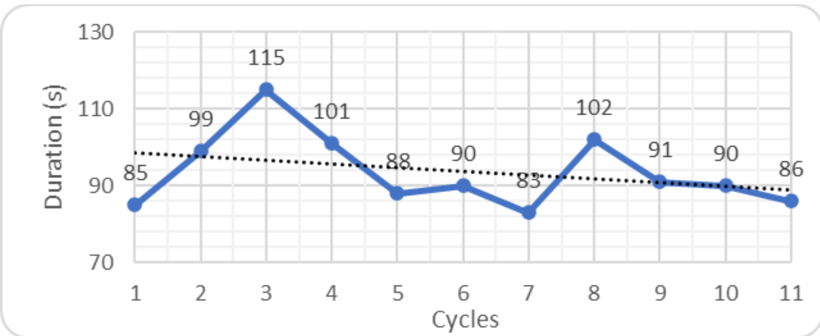

Figure 5.20: Duration of each cycle in the 3rd round, the 3rd set

[15] The operator could reach the selected challenge in the second round and chose a harder challenge for the third round.

Table 5.16: Highlight of the 3rd round, the 3rd set

Tons of asphalt	**Duration**	**Fastest cycle**	**Slowest cycle**	**Diversion rate**	**Productivity**
75t	17min	83s	115s	39%	4.4t/min

<u>The fourth round</u>

The meaningful story was utilized as the game element. In sum, 72t of asphalt was transported in a period of around 18.3min, indicating an overall productivity rate of 3.942t/min. Although the machine productivity increased by 11.5% compared to the first round, it decreased by 10% compared to the previous round. Moreover, as Table 5.17 presents, the operator presented a less consistent behaviour (the diversion rate of 41.6%) compared to the previous rounds.

To conclude, the operator's performance decreased during this round compared to the previous rounds. This can be justified since the operator was unable to talk English and thus could not follow the story. Therefore, his psychological needs apparently were not persuaded by the gamification model in this round.

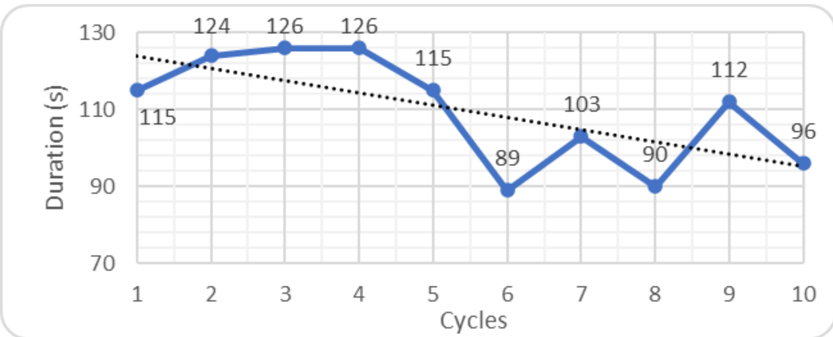

Figure 5.21: Duration of each cycle in the 4th round, the 3rd set

Table 5.17: Highlight of the 4th round, the 3rd set

Tons of asphalt	**Duration**	**Fastest cycle**	**Slowest cycle**	**Diversion rate**	**Productivity**
72t	18min	89s	126s	42%	3.9t/min

The fifth round

The “group-oriented competition” was utilized during the fifth, sixth and seventh rounds to analyse how one game element can affect the operator’s behaviour in a longer observation period. Almost 67t of asphalt was transported in a period of around 16.7min during the fifth round. This indicates an overall productivity rate of 4.008t/min, which is almost 1.7% higher than the recorded rate in the previous round. Moreover, this indicate a 13.4% improvement in machine productivity compared to the first round where no gamification had been utilized.

Although cycle duration was decreasing (Figure 5.22), the operator presented less consistent behaviour during the fifth round where a diversion rate of 67% was recorded. Therefore, according to the SDT, the operator was extrinsically motivated, and his appropriate behaviour would not probably continue without any external rewards.[16]

Table 5.18: Highlight of the 5th round, the 3rd set

Tons of asphalt	**Duration**	**Fastest cycle**	**Slowest cycle**	**Diversion rate**	**Productivity**
67t	17min	82s	137s	67%	4t/min

[16] Read session 3.1

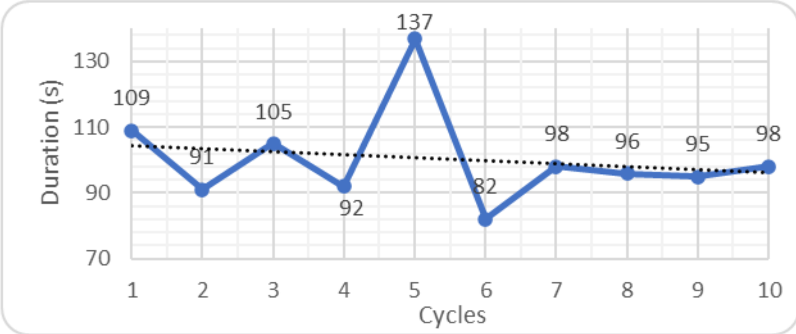

Figure 5.22: Duration of each cycle in the 5th round, the 3rd set

<u>The sixth round</u>

75t of asphalt was transported in a period of 16.3min during the sixth round. This indicates an overall productivity rate of 4.599t/min, which represents an increase by 14.7% in machine productivity compared to the previous round. In addition, it is increased by 30% compared to the first round.

Moreover, as Table 5.19 presents, the operator showed a more consistent behaviour (with a diversion rate of 45%) compared to the fifth round where a diversion rate of 67% was recorded. Although both the machine productivity and the operator's consistent behaviour were improved, the operator had a better progress at the beginning of the round compared to its end (Figure 5.23). In other words, the operator was gradually losing his motive to keep his appropriate behaviour.

To conclude, the operator had a better performance during the sixth round compared to the previous round. This can be justified since he was more familiar with the "group-oriented competition" and therefore was better motivated during this round.

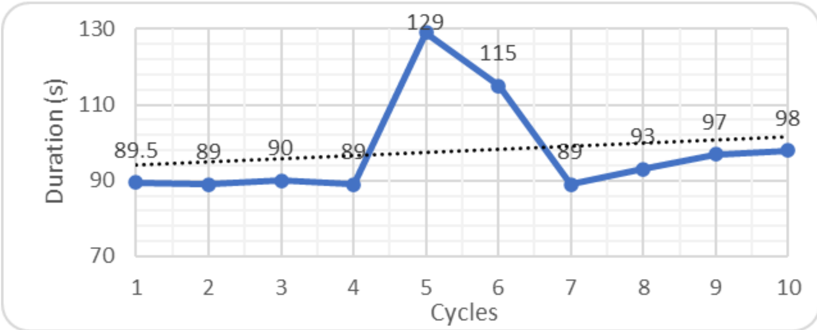

Figure 5.23: Duration of each cycle in the 6th round, the 3rd set

Table 5.19: Highlights of the 6th round, the 3rd set

Tons of asphalt	Duration	Fastest cycle	Slowest cycle	Diversion rate	Productivity
75t	16min	89s	129s	45%	4.6t/min

The seventh round

Same “group-oriented competition” was utilized during the seventh round where 74t of asphalt was transported in around 16min. This indicates an overall productivity rate of 4.66t/min, which is almost 1.4% higher than the submitted rate during the previous round. In addition, the machine productivity increased by 32% compared to the first round where no gamification was utilized.

Table 5.20 shows that the operator had a diversion rate of 24.5% between his best and worst performances during the round. This indicates more stable operator behaviour compared to the previous round where a diversion rate of almost 45% was recorded. Therefore, gamification could enhance the machine productivity on one hand, and encourage the operator to have more consistent behaviour on the other hand.

Figure 5.24 shows the operator had a better performance at the beginning of the round compared to its end. Thus, the operator was progressively forgetting the motive for his appropriate behaviour in this round as well.

To conclude, although the operator was not fully intrinsically motivated (he was gradually forgetting the motive for his appropriate behaviour during the round), he was in a better psychological condition compared to the previous round. Therefore, gamification could lead to better results when the applicants are more familiar with its principles.

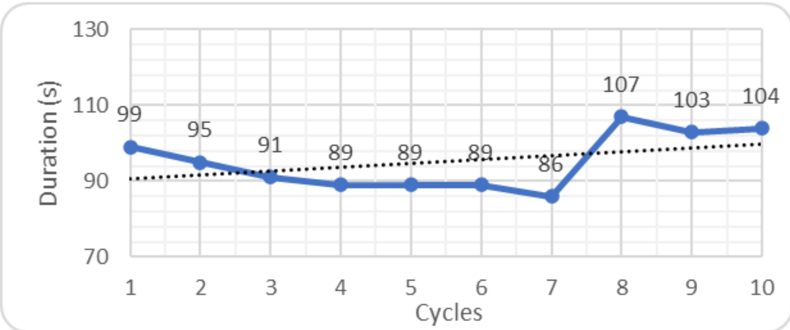

Figure 5.24: Duration of each cycle in the 7th round, the 3rd set

Table 5.20: Highlights of the 7th round, the 3rd set

Tons of asphalt	**Duration**	**Fastest cycle**	**Slowest cycle**	**Diversion rate**	**Productivity**
74t	16min	86s	107s	24%	4.7t/min

<u>The eighth round</u>

A new challenge was utilized as the game element in the last round. The operator was offered to gain extra points if he reaches an overall productivity rate of 5t/min during the eighth round. In sum, 73t of asphalt was transported in a period of around 15min, indicating an overall productivity rate of

4.84t/min. Although the new challenge could enhance the machine productivity rate, the operator demonstrated a more aggressive behaviour during this round where his diversion rate increased to 42%.[17] Moreover, as Figure 5.25 shows, the operator had a better performance at the beginning of the round compared to its end, indicating that he was gradually forgetting the motive for his appropriate behaviour. According to the SDT, the operator is not intrinsically motivated and probably his appropriate behaviour will not continue without any external rewards.[18]

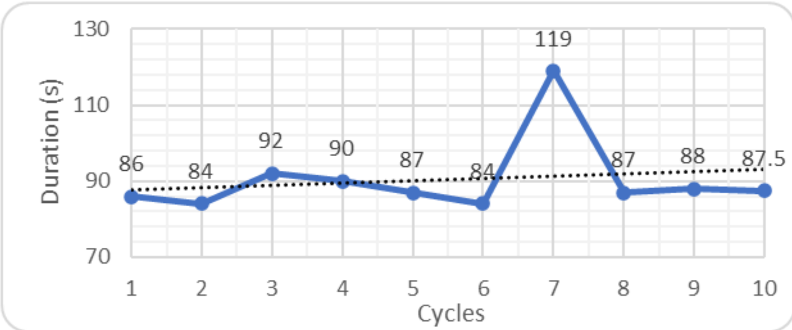

Figure 5.25: Duration of each cycle in the 8th round, the 3rd set

Table 5.21: Analysis of the 8th round, the 3rd set

Tons of asphalt	Duration	Fastest cycle	Slowest cycle	Diversion rate	Productivity
73t	15min	84s	119s	42%	4.8t/min

[17] It was 24.5% in the 7th round.

[18] Read section 3.1.2.

Discussion

Figure 5.26 presents the productivity rate for each observation round during the third day. As in the previous set, the lowest productivity rate was recorded during the first round where no gamification had been used. This indicates that gamification could improve the machine productivity in all rounds.

The highest productivity rate was recorded in the last round where a new challenge was utilized.[19] Although this challenge could improve the operator's motivation to enhance the machine productivity, it failed to encourage him to present a more consistent behaviour compared to the previous round. Moreover, the operator forgot the motive for his appropriate behaviour during the round gradually. Therefore, he was not intrinsically motivated during the round.

Furthermore, as shown by Figure 5.26, the machine productivity rate increased continuously from fifth round. This indicates that the "group-oriented competition" could improve machine productivity continuously. Moreover, as Figure 5.27 shows, the recorded diversion rate was decreasing from fifth till seventh round as well. Therefore, the "group-oriented competition" could transform the operator's extrinsic motivation to a more intrinsic one; however, the operator was not yet intrinsically motivated because he was forgetting the motive for his appropriate behaviour during the sixth and seventh rounds.

To conclude, as shown in Figure 5.26 and Figure 5.27, the gamification model was successful in improving machine productivity; however, it failed to meet operator's psychological needs. In other words, although the operator was motivated extrinsically to improve the machine productivity, the gamification model failed to enhance his intrinsic motivation.[20] read section 3.1.2 to

[19] The operator was told that if he reached an overall productivity rate of 5 t/min, he would be given some extra points.

[20] The trending line in Figure 5.27 is increasing.

understand the difference between being intrinsically motivated compared to extrinsic motivation.

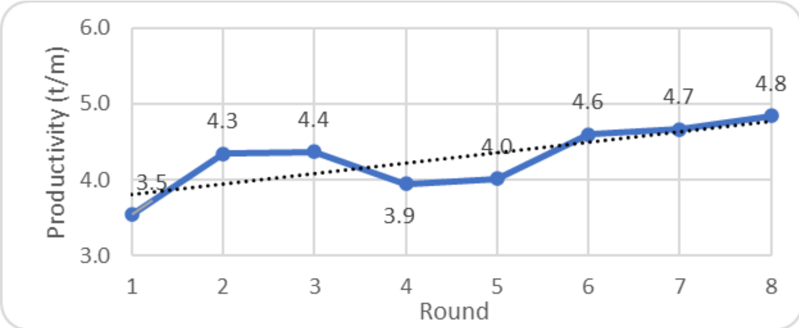

Figure 5.26: The productivity rate in each round in the 3rd set

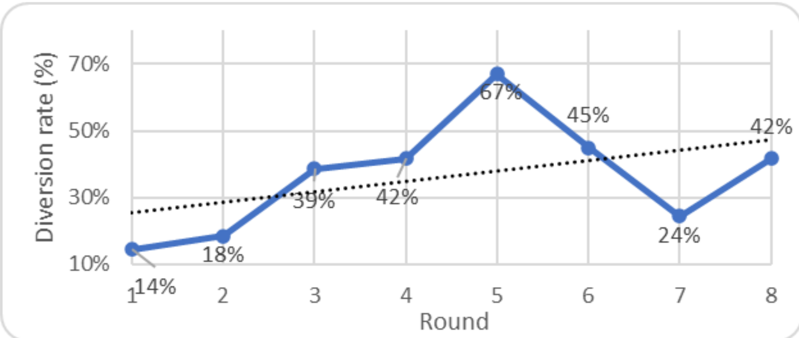

Figure 5.27: Diversion rate for all rounds in the 3rd set

5.4 Analysis of the fourth set

The gamification model was implemented in six rounds (Table 4.8) on a dump-truck at a mining site. The result of each round is discussed below.

<u>The first round</u>

The first ten cycles were monitored to find normal cycle duration. In total, 10 cycles were performed in 6,081s which indicate 608.1s on average per circle. This is almost in line with site manager's expectation where he believes each operator needs around 10min to perform one cycle. Figure 5.28 illustrates the duration of each cycle in the first round and Table 5.22 presents the highlights of the round. The fastest cycle took place in 568s; however, the slowest one was performed in 676s. It indicates a diversion rate of around 19%. In addition, the trending line in Figure 5.28 is increasing which concludes the operator is forgetting about the motive of his proper behaviour gradually.

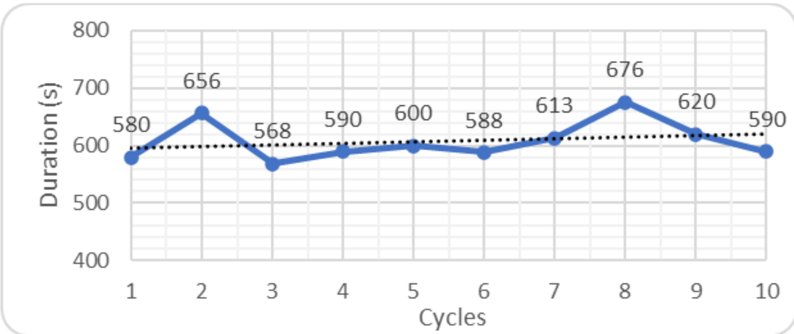

Figure 5.28: Duration of each cycle in the 1st round, the 4th set

Table 5.22: Highlights of the 1st round, the 4th set

Round Duration	Fastest cycle	Slowest cycle	Diversion rate
101min	568s	676s	19%

Second round

The next 10 cycles were observed during the second round, in which a simple pointing system was employed. The operator performed the round in 6,288s which is around 3% longer than the previous round. In other words, machine productivity was decreased by 3% during the second round.

Figure 5.29 presents each cycle duration. As it is shown by the figure, the trending line has a positive slope. Therefore, the operator had a better behaviour at the beginning of the round compared to its end. In other words, he was forgetting the motive for his proper behaviour during the round.

In addition, Table 5.23 summarizes the highlights of the round where, the best performance was recorded during the fourth cycle (560s); however, the worst result was submitted in 9th cycle (704s). This indicates a diversion rate of 26% which indicates 7% increase compared to the last round. Put differently, the operator showed more stable behaviour during the first round.

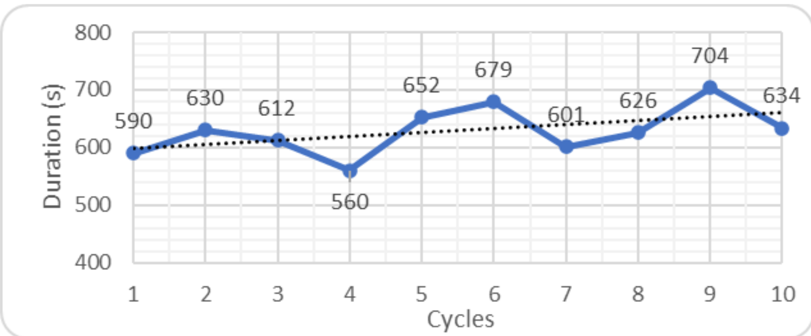

Figure 5.29: Duration of each cycle in the 2nd round, the 4th set

Table 5.23: Highlights of the 2nd round, the 4th set

Round Duration	Fastest cycle	Slowest cycle	Diversion rate
105min	560s	704s	26%

<u>The third round</u>

The pointing system was explained to the operator before starting the third round and he was offered to get some hours off if he collects certain points. All the ten cycles were conducted in 5,859s which is around 7% faster than previous round (where simple pointing system was utilized). Moreover, the third round was performed faster (around 4%) compared to the first round where no gamification had been employed.

Figure 5.30 presents the duration of each cycle. As it is shown by the trending line, the operator again presented a better performance at the beginning of the round compared to its end. This concludes he was forgetting the reason for his proper behaviour on average during the round. Moreover, Table 5.24 recaps the result of the third round where the best performance was recorded during the second cycle; however, the worst act was seen in the 9th cycle. It presents a diversion rate of 30% that concludes less operator's consistent behaviour during the round compared to previous rounds.

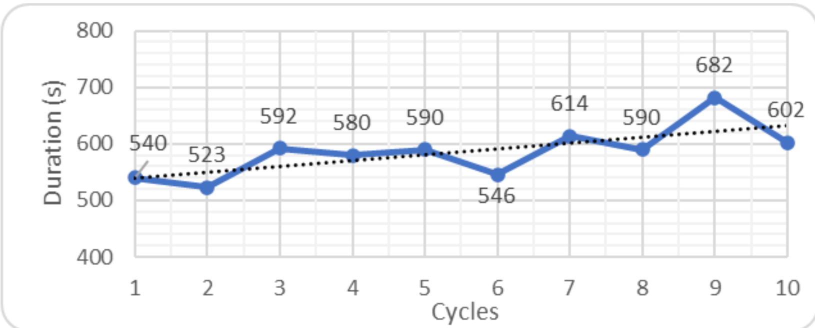

Figure 5.30: Duration of each cycle in the 3rd round, the 4th set

Table 5.24: Highlights of the 3rd round, the 4th set

Round Duration	Fastest cycle	Slowest cycle	Diversion rate
98min	523s	682s	30%

The fourth round

Individual-oriented competition was utilized as the motive element to encourage the operator with the purpose of enhancing his behaviour during the fourth round. As discussed in session 4.3.1, the operator chose target duration of 580s and finalized the round in 5094s. In other words, the average cycle duration was 509s; therefore, the target is achieved. Moreover, machine productivity was improved by 13% during the fourth round compared to its previous round.

Figure 5.31 presents the duration of each cycle. Although the machine productivity was improved, the operator was forgetting the motive for his proper behaviour as the trending line in Figure 5.31 is increasing.

Table 5.25 presents the highlights of the round where the fasted performance was recorded in 390s, and the slowest work was performed in 630s. This indicates a diversion rate of 61% which is almost double of the diversion rate recorded during the previous round.

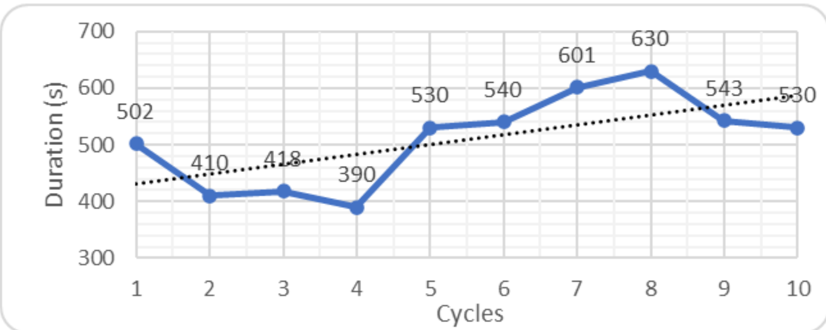

Figure 5.31: Duration of each cycle in the 4th round, the 4th set

Table 5.25: Highlights of the 4th round, the 4th set

Round Duration	Fastest cycle	Slowest cycle	Diversion rate
85min	390s	630s	62%

The fifth round

The operator was provided with feedback (about his performance during the previous round) before starting the fifth round. In total, it took 5,189s to perform ten cycles which is around 1% longer than the previous round. Although machine productivity decreased compared to the previous round, it increased by around 15% compared to the first round where no gamification had been utilized.

Figure 5.32 indicates the duration of each cycle. The trending line in this round is increasing which means the operator had better performance at the beginning of the round. It concludes the operator was losing his motivation for a proper performance during the round gradually.

Table 5.26 presents the highlights of the round. The operator recorded his fasted cycle in 370s; however, the slowest cycle was performed in 645s. It concludes a diversion rate of 74% which is higher than the recorded rate in the previous round.

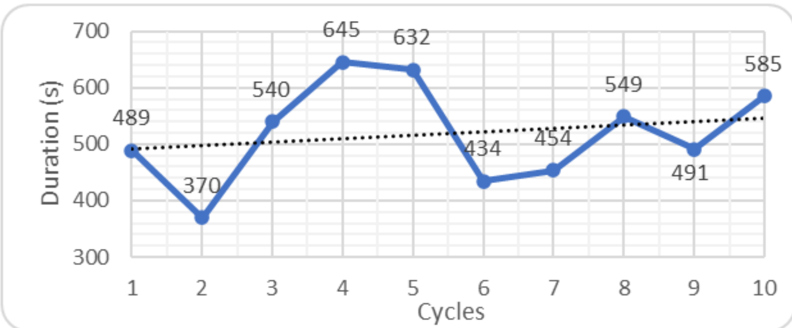

Figure 5.32: Duration of each cycle in the 5th round, the 4th set

Table 5.26: Highlights of the 5th round, the 4th set

Round Duration	Fastest cycle	Slowest cycle	Diversion rate
86min	370s	645s	74%

The sixth round

Group-oriented competition was utilized during the sixth round where the operator performed ten cycles in 5,021s. This indicates 3% enhancement in operator's performance compared to his previous round. Although the operator performance was improved, he was losing the motive for his proper behaviour during the round (as shown by Figure 5.33).

Table 5.27 highlights the main findings in the sixth round. The fastest cycle was performed in 320s; however, the slowest cycle took place in 643s. This indicates a diversion rate of 101% which is higher that the submitted rate during the previous round.

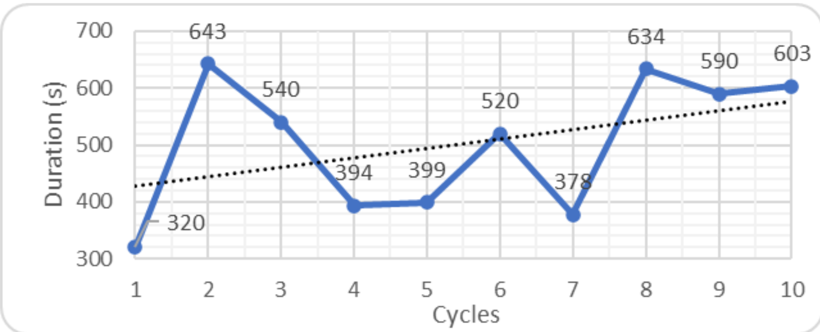

Figure 5.33: Duration of each cycle in the 6th round, the 4th set

Table 5.27: Highlights of the 6th round, the 4th set

Round Duration	Fastest cycle	Slowest cycle	Diversion rate
84min	320s	643s	101%

Discussion

The dump-trucks were loaded via an excavator (external machine) during the fourth and fifth sets. Therefore, their load is excluded from the examination during these two sets. Put differently, operators can only enhance machine productivity by improving the cycle duration[21].

Figure 5.34 presents the duration of all rounds in the fourth set. As it is shown by the figure, the trending line is decreasing which concludes gamification could motivate the operator to enhance machine productivity continuously. The fastest cycles were conducted during the last round where “group-oriented competition” was utilized. Therefore, “group-oriented competition” could enhance operator’s motivation better than other game elements.

The worst operator’s performance was recorded during the second round where a simple pointing system had been utilized. This can get justified since 1) the operator apparently had the new feeling of being watched during the first round, and therefore, presented a better performance. However, he forgot about that feeling and went back to his ordinary behaviour gradually. 2) The simple pointing system could not enhance operator’s motivation and failed to achieve its objectives.

The operator performed faster cycles during the fourth round compared to the fifth round. Although “feedback” could encourage other operators (in previous sets) to improve their behaviour, it failed to motivate this operator towards a more proper working behaviour.

Moreover, Figure 5.35 indicates the diversion rate is increasing continuously during the set. This concludes the gamification model failed to fulfil operator’s psychological needs. Therefore, the model is not expected to keep the

[21] Read section 4.3.1

operator motivated in a longer observation period, without having any external rewards.[22]

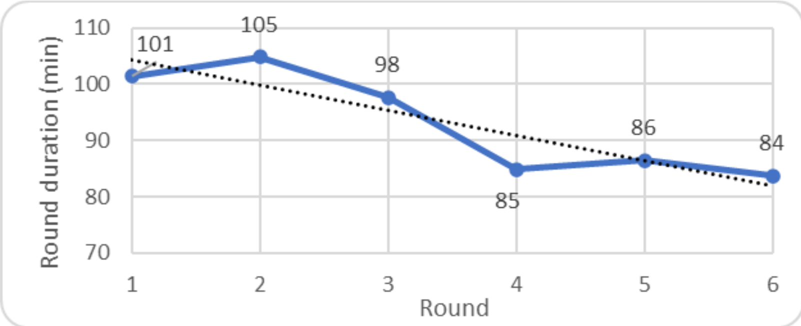

Figure 5.34: The duration of each round in the 4th set

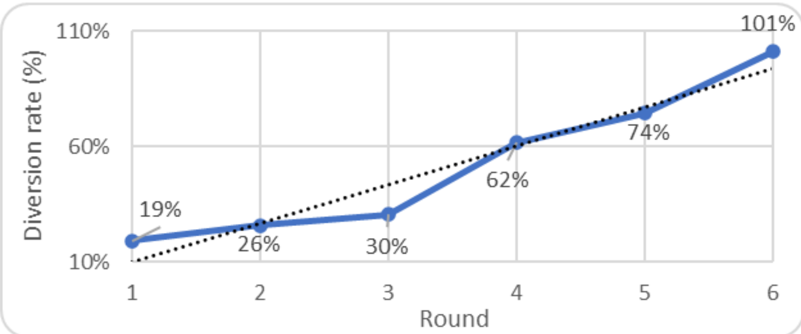

Figure 5.35: Diversion rate for all rounds in the 4th set

[22] Read section 3.1.2

5.5 Analysis of the fifth set

The gamification model was implemented and analysed in 6 rounds on the second dump-truck (with another operator). The result of this gamification implementation is discussed below.

<u>The first round</u>

No gamification was implemented during the first round. The aim was to perceive the ordinary behaviour of the operator. In total, he performed 10 working cycles in 6,007s which concludes 600s per cycle on average.

Moreover, the fasted cycle was performed in 430s; however, the slowest cycle was finalized in 689s which results in a diversion rate of around 60%. In addition, as is indicated by Figure 5.36, the operator had better performance at the beginning of the round compared to its end.

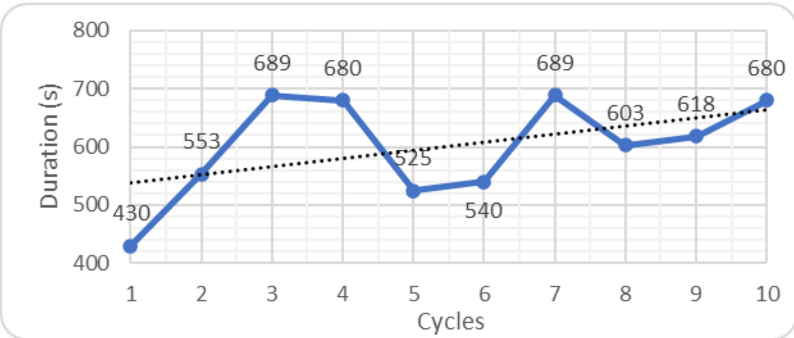

Figure 5.36: Duration of each cycle in the 1st round, the 5th set

Table 5.28: Highlights of the 1st round, the 5th set

Round Duration	Fastest cycle	Slowest cycle	Diversion rate
100min	430s	689s	60%

The second round

The next ten cycles were monitored in the second round where the simple pointing system had been utilized. The operator performed the round in 5,960s which is almost 0.8% faster than previous round. Put differently, the machine productivity was improved by 0.8%.

As is shown by Figure 5.37, the trending line has a positive slope which indicates the operator was forgetting the motive for his proper behaviour during the round. Moreover, Table 5.29 summarized the highlights of the round where, the best performance was recorded during the fifth cycle (398s); however, the worst result was submitted during the sixth cycle (765s). This indicates a diversion rate of almost 92% that is higher than recorded rate during the previous round. Therefore, the operator presented a more stable behaviour during the first round compared to his second round.

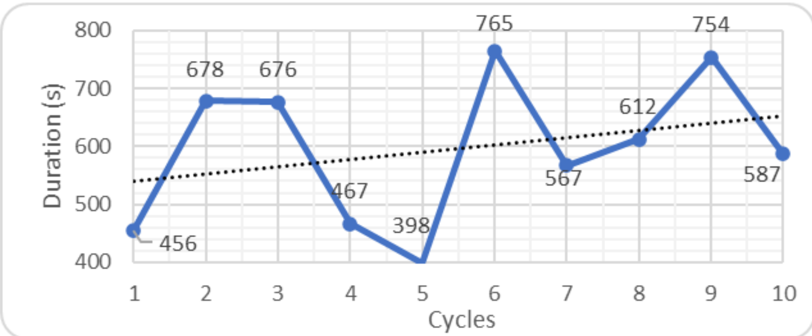

Figure 5.37: Duration of each cycle in the 2nd round, the 5th set

Table 5.29: Highlights of the 2nd round, the 5th set

Round Duration	Fastest cycle	Slowest cycle	Diversion rate
99min	398s	765s	92%

<u>The third round</u>

The pointing system was presented in more details to the operator before starting the third round and he was offered to get some hours off if he gains certain points. All ten cycles were conducted in 5,462s which is around 8% faster than previous round where simple pointing system had been utilized.

Figure 5.38 presents the duration of each cycle. As it is shown by the trending line, the operator again presented a better performance at the beginning of the round compared to its end. This concludes he was forgetting the motive for his proper behaviour gradually.

Moreover, Table 5.30 recaps the highlights of the third round where the best performance was recorded in the third cycle; however, the worst act was seen during the last cycle. Furthermore, the diversion rate of 92.7% was recorded during this round.

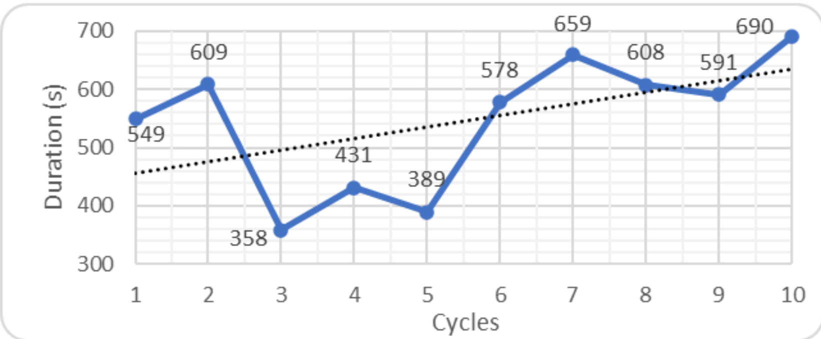

Figure 5.38: Duration of each cycle in the 3rd round, the 5th set

Table 5.30: Highlights of the 3rd round, the 5th set

Round Duration	Fastest cycle	Slowest cycle	Diversion rate
91min	358s	690s	93%

<u>The fourth round</u>

Individual-oriented competition was utilized as the motive element to encourage the operator with the purpose of enhancing his behaviour during the fourth round. As discussed in session 4.3.1, the operator chose target duration of 580s and finalized the round in 5,980s. In other words, he performed each cycle on average in 598s and therefore, failed to achieve his target. Moreover, round's duration increased by 9.5% compared to the previous round.

Figure 5.31 presents the duration of each cycle. As is indicated by the figure, the operator is forgetting the motive for his proper behaviour during the round. In addition, Table 5.31 summarizes the highlights of the round where the fasted performance was recorded during the second cycle (346s) and the slowest work was performed during the third cycle (765s). This indicates a diversion rate of 121% that is higher than the recorded rate in its previous round.

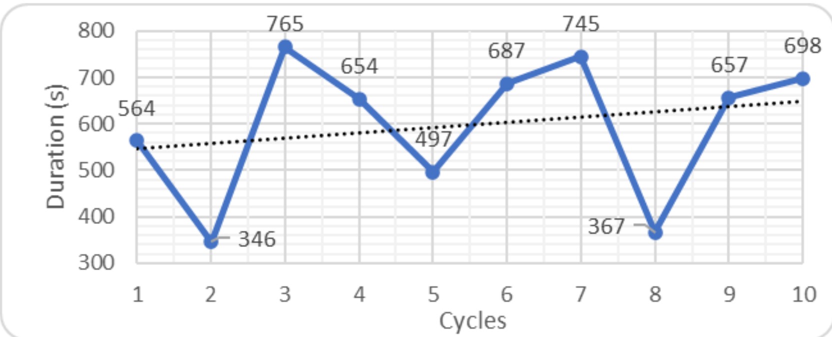

Figure 5.39: Duration of each cycle in the 4th round, the 5th set

Table 5.31: Highlights of the 4th round, the 5th set

Round Duration	Fastest cycle	Slowest cycle	Diversion rate
99.7min	346s	765s	121%

<u>The fifth round</u>

The operator was provided with feedback (about his performance during the previous round) before starting the fifth round. In total, he performed ten cycles in 5,235s which is around 12.5% faster than previous round.

Figure 5.32 indicates the duration of each round. The trending line in this round is still increasing which means the operator had better performance at the beginning of the round compared to its end. It concludes the operator was losing the motive for his proper behaviour gradually.

Table 5.26 presents the highlights of the round. The fastest cycle was recorded in 349s, however, it took 890s to perform the 9th cycle. It concludes a diversion rate of 155% that is higher that recorded rates in all previous rounds.

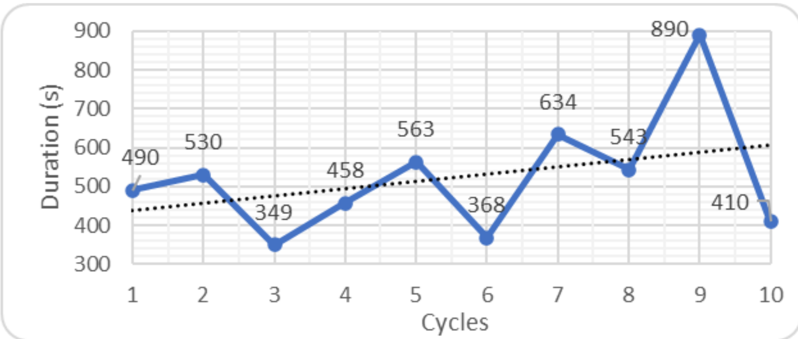

Figure 5.40: Duration of each cycle in the 5th round, the 5th set

Table 5.32: Highlights of the 5th round, the 5th set

Round Duration	Fastest cycle	Slowest cycle	Diversion rate
87.2min	349s	890s	155%

The sixth round

“Group-oriented competition” was utilized as the gaming element during the sixth round. Ten cycles were performed in around 87min which is almost same as previous round. Although the performance was almost same during these two rounds, the operator presented more stable behaviour during the last round. This indicates better operator’s psychological conditions in the sixth round.

Although the operator was in a better psychological situation, he was not intrinsically motivated since he was forgetting the motive for his appropriate behaviour during the round gradually (the trending line in Figure 5.41 has a positive slope).

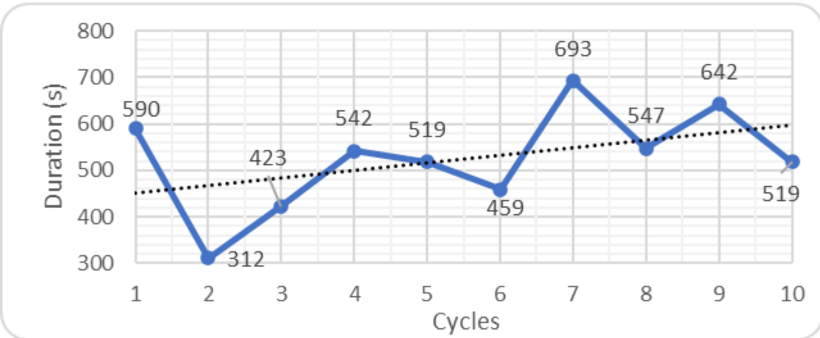

Figure 5.41: Duration of each cycle in the 6th round, the 5th set

Table 5.33: Highlights of the 6th round, the 5th set

Round Duration	Fastest cycle	Slowest cycle	Diversion rate
87.4min	312s	693s	122%

Discussion

Figure 5.42 presents the duration of all the rounds in the fifth set. As is shown by the figure, the duration of rounds on average is decreasing (the trending line has a negative slope). It concludes the gamification model could motivate the operator to perform faster cycles gradually (the round duration was decreased by almost 13% during the set).

Although the gamification model could decrease rounds' duration gradually, it failed to motivate the operator towards a more stable behaviour as shown by Figure 5.43 where the trending line has a positive slope. To conclude, it is not expected that the operator continuous his appropriate behaviour without any external rewards (since the gamification failed to motivate him intrinsically). Read section 3.1.2 to learn when a user is intrinsically motivated.

The fastest performance was submitted during the fifth round where feedback was provided to the operator just before starting the round. This can conclude the importance of feedbacks on the operator's performance. In general, the operator is expected to perform a more proper work when he is given feedback consciously, compared to a situation where he is merely requested to enhance his behaviour.

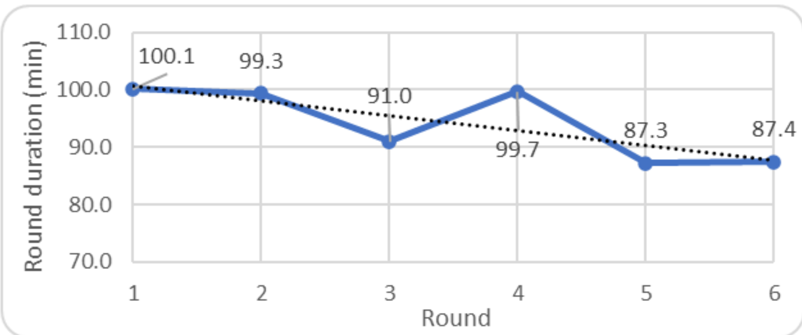

Figure 5.42: The duration of each round in the 5th set

Although providing feedback could enhance operator's performance, it failed to motivate him towards more stable behaviour as the highest diversion rate is recoded during the fifth round.

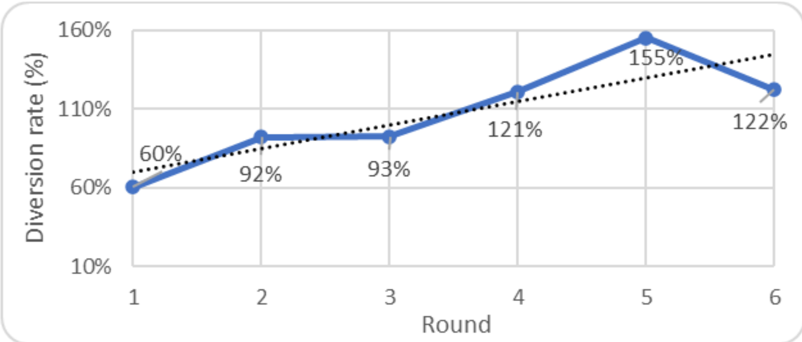

Figure 5.43: Diversion rate for all rounds in the 5th set

5.6 Analysis of the sixth set

The gamification model was implemented in six rounds on a wheel-loader at the mining site. The result of each round is discussed below.

The first round

No gamification was utilized during the first round to find the ordinary round's duration. The operator performed ten cycles in 8.9min. In addition, the fastest cycle was performed in 47s; however, the slowest cycle was completed in 61s. This indicates a diversion rate of almost 30%.

Moreover, the trending line in Figure 5.44 has a positive slope which indicates the operator is forgetting the motive for his proper behaviour during the round. This can get justified since the operator had the feeling of being watched at the beginning of the round and was going back to his ordinary behaviour gradually.

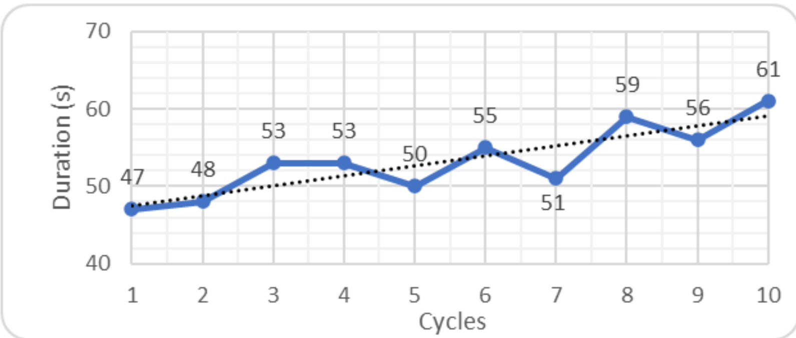

Figure 5.44: Duration of each cycle in the 1st round, the 6th set

Table 5.34: Highlights of the 1st round, the 6th set

Round Duration	Fastest cycle	Slowest cycle	Diversion rate
8.9min	47s	61s	30%

The second round

The simple pointing system was utilized during the second round and the operator was merely requested to improve his performance to obtain some points. Ten cycles were performed in 8.91min that is almost 0.37% longer than previous round. This concludes nearly similar operator's performance in both rounds.

The fastest cycle was performed in 49s; however, the slowest cycle lasted 60s. It concludes a diversion rate of around 22% which indicates more stable operator behaviour during this round compared to its previous round.

To conclude, although no significant enhancement in round's duration was recorded, the operator presented more stable behaviour during the second round.

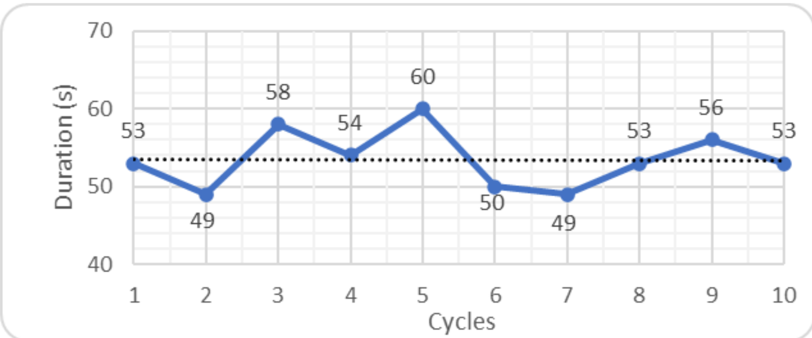

Figure 5.45: Duration of each cycle in the 2nd round, the 6th set

Table 5.35: Highlights of the 2nd round, the 6th set

Round Duration	Fastest cycle	Slowest cycle	Diversion rate
8.9min	49s	60s	22%

The third round

The pointing system was explained in more details before starting the third round and the operator was offered some hours off if he improves his performance. Ten working cycles were performed in 8.6min which is almost 3.5% faster than previous round. It can conclude that a better-defined pointing system improved machine performance by 3.5% compared to the situation where the operator is simply requested to enhance his behaviour.

As indicated by Table 5.36, the fastest cycle was performed in 48s; however, the slowest cycle took place in 57s. This indicates a diversion rate of around 19% which is better than obtained rate during the previous round. Therefore, a better-defined pointing system could enhance machine productivity on one hand, and enhance operator's phycological well-being on the other hand.

The trending line in Figure 5.46 has a positive slope which concludes the operator probably will not continue his appropriate behaviour in a longer observation period without having any external rewards.

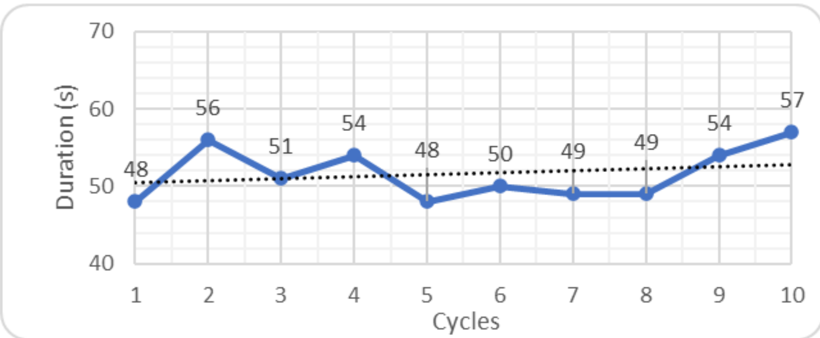

Figure 5.46: Duration of each cycle in the 3rd round, the 6th set

Table 5.36: Highlights of the 3rd round, the 6th set

Round Duration	Fastest cycle	Slowest cycle	Diversion rate
8.6min	48s	57s	19%

The fourth round

The individual-oriented competition was introduced to the operator before beginning the fourth round. He finalized ten loading/unloading cycles in 8.2min which is almost 4% faster compared to the previous round. Moreover, it is almost 7.1% quicker than the first round where no gamification had been utilized.

The fastest cycle was completed in 46s, and the slowest cycle was performed in 54s. This indicates a diversion rate of 17% which is better than the obtained rate during the previous round.

To conclude, individual-oriented competition could motivate the operator to perform the round faster with more stable behaviour. In addition, the trending line in Figure 5.47 is decreasing which indicates the operator found a reason to enhance his performance continuously during the round.

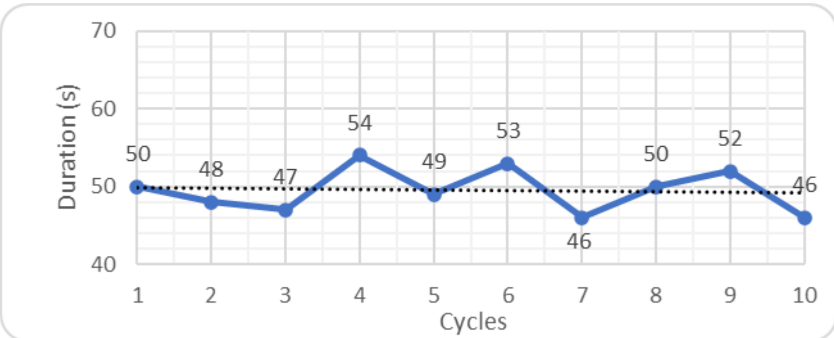

Figure 5.47: Duration of each cycle in the 4^{th} round, the 6^{th} set

Table 5.37: Highlights of the 4^{th} round, the 6^{th} set

Round Duration	Fastest cycle	Slowest cycle	Diversion rate
8.2min	46s	54s	17%

The fifth round

The operator was given feedback about his performance before starting the fifth round. He was informed about his position in the leader-board and was requested to start the round. In total, ten working cycles were performed in 8.1min which is 1.6% faster than previous round where no feedback had been provided.

Moreover, the fastest cycle was performed in 45s; however, the slowest cycle took place in 54s. This indicates a diversion rate of 20% which is higher than recorded rate in the previous round. It concludes the operator was more excited during this round compared to the previous round. In addition, the trending line in Figure 5.48 is increasing which concludes the operator is forgetting about the motive of his proper behaviour gradually.

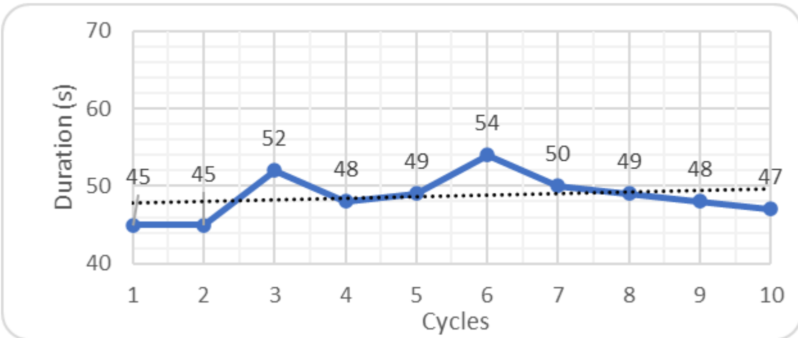

Figure 5.48: Duration of each cycle in the 5th round, the 6th set

Table 5.38: Highlights of the 5th round, the 6th set

Round Duration	Fastest cycle	Slowest cycle	Diversion rate
8.1min	45s	54s	20%

Sixth round

The group-oriented competition was utilized during the last round. The operator was allocated to an imaginary group of other operators and was requested to start the round. He performed all ten cycles in around 8min that indicates almost 48s per cycle on average. This is almost 0.8% faster than previous round. The fastest cycle was performed in 44s; however, the slowest one was finalized in 52s. It indicates a diversion rate of 18% that is lower than the obtained rate in the previous round.

To summarize, group-oriented competition could improve machine productivity by almost 0.8% on one hand, and enhance operator's consistent behaviour on the other hand. However, the trending line in Figure 5.49 is still increasing. It can conclude the operator will probably not continue his appropriate behaviour in a longer observation period without having any external rewards.

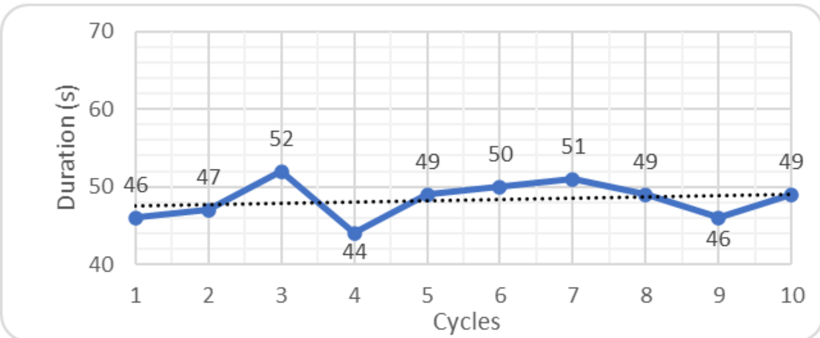

Figure 5.49: Duration of each cycle in the 6th round, the 6th set

Table 5.39: Highlights of the 6th round, the 6th set

Round Duration	Fastest cycle	Slowest cycle	Diversion rate
8min	44s	52s	18%

<u>Discussion</u>

Figure 5.50 illustrates the duration of each round in the sixth set. As it is shown by the figure, the duration of rounds is decreasing. It concludes the gamification model could motivate the operator to perform faster cycles gradually (the round duration was decreased by 9.4% in last round compared to the first round).

Moreover, Figure 5.51 indicates the gamification model could motivate the operator towards more stable behaviour. It concludes that the model probably developed operator's motivation from extrinsic towards more intrinsic, since both round's duration as well as the diversion rate are decreasing continuously.

The fastest performance was submitted during the last round where "group-oriented competition" had been utilized. As is discussed in section 3.3.4, "group-oriented competition" is designed to address all three human psychological needs of autonomy, competence, and social relatedness. Therefore, it summarizes covering all three needs of autonomy, competence and social relatedness could result in a better operator's psychological well-being.

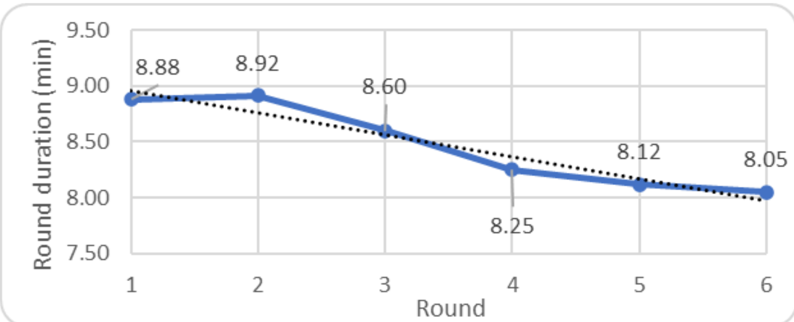

Figure 5.50: The duration of each round in the 6th set

Moreover, the worst operator's performance was submitted during the second round where simple pointing system had been employed. This can get justified since 1) the operator probably had the feeling of being watched during the first round and presented a more proper behaviour compared to the second round, and 2) the simple pointing system could not motivate the operator towards a better working habit at work.

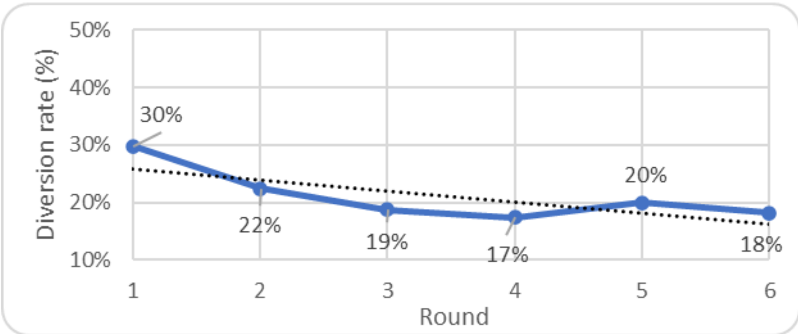

Figure 5.51: Diversion rate for all rounds in the 6th set

Figure 5.52 concludes the performance improvement during all the sets. As it is shown by the figure, machine performance was improved during all the sets. Therefore, it concludes that gamification model was successful to enhance operator's behaviour during the site observation.

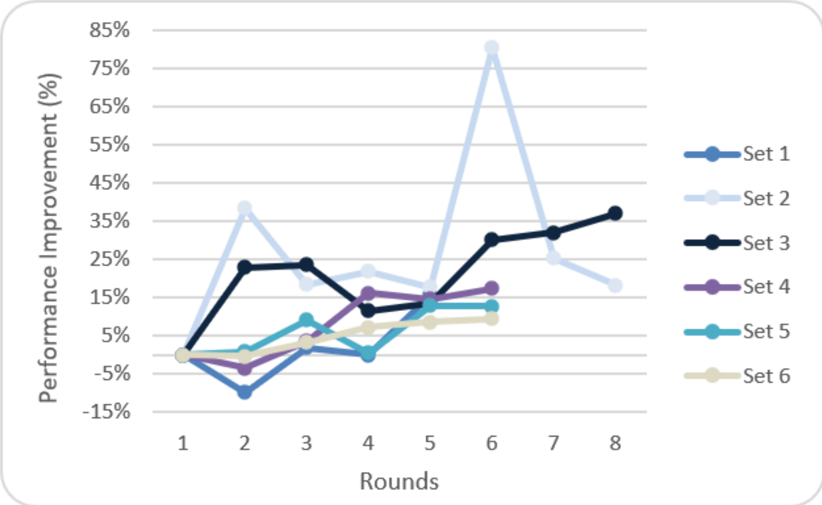

Figure 5.52: Performance improvement during all sets

6 Conclusion and future work

Productivity rate in construction projects is low compared to other domains, such as manufacturing. "Negative labours' behaviour" is highlighted in the literature as a key reason for low productivity rate at construction sites.

On one hand, gamification is a trending approach attempts to enhance employees' engagement, motivation, participation, achievement, and satisfaction at work. Although promising results are reported from gamification implementations in other domains, its applications in construction sector are limited.

On the other hand, telematics and wearable sensing technologies have introduced promising solutions to collect real-time operational data from labours and construction machineries. This data can be a significant input to one gamification model which seeks to motivate machine operators to improve their behaviour and stop miscellaneous activities at work.

Therefore, this study seeks to introduce a gamification model which gamifies telematics data. The model is designed to persuade operators' psychological needs for autonomy, competence, and social relatedness. Put differently, it seeks to enhance operators' motivation towards a more proper working behaviour to enhance machine productivity at construction sites.

6.1 Key findings and contributions

This dissertation consists of three main parts, each of which resulted in some findings. Telematics technologies were discussed in the first part and an overview about its enabling technologies was provided. Moreover, a comprehensive literature review was conducted to document the state of the art telematics at construction sites.

Gamification was evaluated in the second part, and state of the art gamification in construction sector was analysed. Furthermore, a guideline was introduced, which can assist gamification designers to develop their gamified models more transparent.

Furthermore, a gamified model was established in the third part. The model seeks to enhance machine productivity by persuading operators to improve their working habits. The model was implemented and analysed at two sites (one recycling and one mining site) in six examination sets. The key findings of each part are discussed below.

Telematics

The state of the art telematics both in the literature as well as practice was reviewed. The search query "Telematics OR GPS OR IoT" was utilized to hit all publications that have terms "telematics", "IoT", or "GPS" in their title and were published after 2009 in ASCE database. This search query hit 187 records, including 114 proceeding papers, 68 journal papers, and 1 book. The other 4 hits were discussion or editorial documents and therefore were excluded from further analysis. To conclude, telematics services are discussed in the literature for below use-cases.

1) Vehicle monitoring and tracking applications.

2) Operator identification and behaviour recognition.

3) Safety and productivity enhancement.

4) Logistics purposes.

The term *"telematics in construction projects"* was googled[1] and all results in the first five pages were reviewed. In addition, the author visited various

[1] The search was performed on 09.11.2020

construction equipment manufacturers in Bauma 2019[2], and discussed the most recent applications of telematics with their experts. To summarize, Telematics is utilized in practice at construction sites for following use-cases.

1) Operator's assistance features and machine productivity.

2) Maintenance purposes.

3) Safety of the operator, machine, and surrounding environment.

4) Innovative concepts of "digital site management" and "digital site documentation".

To sum up, modern sensors are utilized to collect data from the vehicle. These data are analysed, and meaningful information is generated according to various innovative business models. This information can be a great input to one gamification model.

Gamification

The concept of "gamification" was discussed in the second part of this study, and a literature review was conducted to evaluate the state of the research gamification in construction sector. The term "gamif*" was utilized to seek gamification-related publications (that have term "gami" in their body, title or in their abstract) in ASCE library. This could filter 12 publications.

Furthermore, Scopus database was scanned to find gamification-related studies and 32 publications were hit. To summarize, gamification (in the construction sector) is evaluated in the literature for below use-cases.

1) To address safety matters. Gamified feedbacks are utilized with the purpose of encouraging personnel to better follow safety principles.

[2] https://www.bauma.de/de/

2) To improve the decision-making process by utilizing BIM models together with gamification.

3) To enhance the traditional approaches of communication, engagement, and interactions among diverse parties involved in a construction project.

In addition, a guideline was introduced in the second part of this dissertation which can help gamification designers to develop more transparent gamification models (by introducing a new phase Interpretation) in six steps; i.e. 1) project preparation, 2) user analysis, 3) context analysis, 4) ideation and design, 5) interpretation of the model, and finally 6) implementation and evaluation.

This guideline was utilized in the third part of the study to introduce a gamified model. The model seeks to enhance operators' motivation with a focus on increasing machine productivity.

Gamification in Excavation

A gamified model was introduced in the third part to encourage machine operators towards a more proper behaviour at work. The model was developed in six steps and was implemented and evaluated in six examination sets at a recycling as well as mining site. Each set consists of several observation rounds where different game element is utilized.

The first set

The gamified model could persuade the operator to enhance machine productivity by almost 15.6%. The productivity rate was 5.098t/min during the first round (where no gamification had been utilized); however, it increased to 5.9t/min during the last round.

Moreover, the operator presented more stable behaviour at the end of the day compared to its beginning where his diversion rate decreased from 148%

to 36%. Thus, the gamification model could encourage the operator to present more consistent behaviour as well.

Although machine productivity was enhanced, the operator was attaining a more impressive result at the beginning of each round compared to its end. Put differently, he was losing his motive for a better behaviour during the rounds (indicating he was not intrinsically motivated). Therefore, his appropriate behaviour is unexpected to continue without any external award system.

<u>The second set</u>

The operator was extremely excited during one of the observation rounds when he got an exciting feedback. Although machine productivity increased by almost 53.3%, he presented dangerous and less consistent behaviour during this round, compared to its previous round.

Excluding that specific round, the gamification model could enhance machine productivity by 18.2% from 3.401t/min to 4.022t/min; however, it failed to encourage the operator to present more consistent behaviour. To sum up, although the model was successful to improve the overall machine productivity, it failed to enhance the operator's psychological well-being.

<u>The third set</u>

The model could improve machine productivity from 3.535t/min to 4.842t/min indicating 37% enhancement. Moreover, machine productivity was increasing continuously from the fifth to the seventh round, where same game element had been utilized. It indicates more proper operator's behaviour when he gets more familiar with the gamification model.

Although machine productivity was improved during the set, the operator's diversion rate increased from 14.5% to 41.7% as well. It concludes the model could motivate the operator extrinsically; however, it likely failed to satisfy the operator's psychological needs for autonomy, competence, and social relatedness.

The fourth set

Round duration remained the only parameter could affect machine productivity during the fourth, and fifth sets. The operator could reduce the round duration from 101min to 84min indicating 17.4% enhancement. Therefore, the model achieved its objective to enhance overall machine productivity.

Although machine productivity was increased, the operator failed to present more consistent behaviour during the set. This can conclude he was intrinsically unmotivated, and his appropriate behaviour is unexpected to continue without any external rewards.

The fifth set

The same result as fourth set was achieved during the fifth set. Although the round duration was decreased by almost 13%, the gamification model failed to motivate the operator intrinsically. Therefore, the operator's appropriate behaviour will not apparently continue in a longer observation period without having any external award system.

The sixth set

The gamification model could decrease the round duration from 8.8min to almost 8min. This concludes almost 9.5% decrease in round duration. In addition, the operator presented a more stable behaviour at the end of the day compared to its beginning where his diversion rate decreased from 30% to 18%. Thus, the gamification model could encourage the operator to present more consistent behaviour as well.

Although the operator could present more consistent behaviour, he achieved more promising result at the beginning of each round (expect fourth round) compared to its end. In other words, he was losing the motive for a better behaviour during the rounds.

To conclude, the gamification model could encourage the operators to abandon miscellaneous activities like texting, phoning, and even eating (at least during the site observation) while operating the machine. Although the model was successful in improving machine productivity during all six sets, it failed to persuade operators' phycological needs. Therefore, the gamification model would probably fail to keep operators motivated in a longer observation period without any external reward system.

6.2 Research limitations and suggestions for future work

A guideline to develop gamification was introduced in this study which helps gamification designers to enhance transparency in their gamification design. Although this guideline was successfully utilized in this dissertation, it should be analysed in more gamification studies to better evaluate its highlights and challenges.

No mobile application was developed in this dissertation. Therefore, telematics data had to be collected manually, and all the feedbacks had to be given to operators verbally. In addition, due to lack of a mobile application, operators had no chance to create a proper profile (like Facebook profile) where they could publish their progress and success. This probably affected the achieved results negatively. Therefore, it is suggested to develop a mobile app to better persuade operator's psychological needs and evaluate the gamification model once more.

Furthermore, the gamification model tried persuading operators' need for social relatedness (Read section 4.1.2). However, only six operators were allocated to implement and analyse the model. Thus, it was a challenge to introduce some teamwork (with the purpose of satisfying the need for social relatedness). It is proposed to involve more operators in next studies so that more teamwork can be allocated.

In addition, this study utilized gamification to enhance machine productivity (work done per unit of time) rate. It is proposed to consider and award operators' other appropriate behaviours like their consistent, safe, and environment-friendly activities.

To conclude, a gamified platform in which different operators from different organizations can share their achievements, or can get scored and ranked in a leader-board will potentially lead to a better operators' behaviour at work.

Appendix

Table 6.1: Publications for transportation management applications

No	Title	Year
1	An Accurate Autonomous Vehicles Positioning Method Based on GPS/Lidar/Camera in V2V Communication Environment	2020
2	Travel-Time Variability Analysis of Bus Rapid Transit System Using GPS Data	2020
3	Modeling Trip-Length Distribution of Shopping Center Trips from GPS Data	2019
4	Investigating Correlation between Personal Route Choice Behaviors and Macroscopic Traffic Flow Distribution Based on Long-Term GPS Trajectory Data of Floating Vehicles	2019
5	Dynamic Estimation of Queue Length at Signalized Intersections Using GPS Trajectory Data	2019
6	Travel Time of Buses Based on GPS Trajectory Data: Analysis and Prediction	2019
7	Examining Travel Time Reliability-Based Performance Indicators for Bus Routes Using GPS-Based Bus Trajectory Data in India	2018
8	Public Transit Transfer Recognition Method Based on Vehicle GPS and Smart Card Data	2018
9	Traffic Flow Prediction Based on Probe Vehicle GPS Traces Considering Temporal and Spatial Correlations	2018
10	Bus Travel Time Prediction Based on GPS Data: A Case Study of Nanjing City	2018
11	Measuring Traffic Congestion with Taxi GPS Data and Travel Time Index	2015
12	City-Wide Examining Transport Network Accessibility Using Taxi GPS Data	2015
13	Identification Method of Transportation Mode Based on GPS Data	2015
14	Community Bus Demand Characteristics Analysis Based on Smart Card Data and GPS Data	2015
15	Analyzing Travel Time Variability on Transit Route Using GPS Data	2015
16	Automatic Horizontal Curve Identification and Measurement Method Using GPS Data	2015
17	Using a GPS Data Set to Examine the Effects of the Built Environment along Commuting Routes on Travel Outcomes	2014
18	Characteristic Analysis of Bus Travel Speed on Commuting Corridors Based on GPS Data	2014
19	Revealing Taxi Driver Route Choice Characteristics Based on GPS Data	2014

20	Intelligent Supervision System of Passenger Transport Based on IOT	2014
21	Development of a Data-Driven Platform for Transit Performance Measures Using Smart Card and GPS Data	2014
22	Experimentation-Based Sampling Scheme for GPS-Smartphone Probe Vehicles	2013
23	Optimal Method of Information Collection Cycle for GPS-Equipped Probe Car	2013
24	Bus Arrival Time Prediction Based on GPS Data	2013
25	Data Acquisition and Analysis of Individual Travel Based on GPS	2013
26	Bus Rapid Transit (BRT) Bunching Analysis with Massive GPS Data	2013
27	Urban Road Travel Time Prediction Based on Taxi GPS Data	2013
28	Modeling and Analysis for IOT-Based Intelligent Transportation System Based on IDEF Methods	2013
29	A Design and Realization of Traffic Information Security Scheme Based on GPS	2013
30	Transportation Process Monitoring of Car-Carrier in IoT Environment	2013
31	Using Truck Probe GPS Data to Identify and Rank Roadway Bottlenecks	2013
32	Full Bayesian Method for the Development of Speed Models: Applications of GPS Probe Data	2012
33	Things Identification Support System Based on IoT	2012
34	Discussion on the Linear Enveloped Description Method and Position Estimation Algorithm of Road Section Based on GPS Data	2012
35	Design and Implementation of Traffic Signal Controller with GPS Timing Function	2012
36	Prediction Model of Bus Arrival Time at Signalized Intersection Using GPS Data	2012
37	A Design and Implementation of GPS-MTD Based on Intelligent Agent in the Vehicle Navigation and Guidance System	2011
38	Study of Queue Length and Delay Calculation Based on Taxi GPS Data	2011
39	Analysis and Application of Spatial Distribution of Taxi Service in City Subareas Based on Taxi GPS Data	2011
40	Public Transportation Trip OD Matrix Inference Using IC Card Data and GPS Information	2011
41	Intelligent Distribution System Based on IOT Technology	2011
42	Performance Comparison of GPS Probe-Vehicle-Based Methods in Urban Traffic State Estimation	2011
43	Lane-Level Positioning Method Based on 3D Map for Vehicle Navigation System with Single GPS	2011
44	Using GPS Data to Gain Insight into Public Transport Travel Time Variability	2010

45	Deriving Rules for Trip Purpose Identification from GPS Travel Survey Data and Land Use Data: A Machine Learning Approach	2010
46	Research for Advanced Public Transport Solutions Based on the IOT	2010
47	Estimating Dynamic Transport Population for Official Statistics Based on GPS/GSM	2010

Table 6.2: Result of the search query in ASCE library

Authors	Title	Year
Eiris; Wen; and Gheisari	iVisit: Digital Interactive Construction Site Visits Using 360-Degree Panoramas and Virtual Humans	2020
Bükrü; Wolf .et al	Using Field of View and Eye Tracking for Feedback Generation in an Augmented Virtuality Safety Training	2020
Hgazy; Mostafa .et al	Hands-On Class Exercise for Efficient Planning and Execution of Modular Construction	2020
Changbum R. Ahn. et al	Wearable Sensing Technology Applications in Construction Safety and Health	2019
Sakib Mahmud Khan. et al	Synergizing Roadway Infrastructure Investment with Digital Infrastructure for Infrastructure-Based Connected Vehicle Applications: Review of Current Status and Future Directions	2019
Charles Rougé. et al	Assessment of Smart-Meter-Enabled Dynamic Pricing at Utility and River Basin Scale	2018
The University of Athens	Faithful Rehabilitation	2017
Ece Erdogmus. et al	Does Gamer Personality Affect the Experience and Engagement of Architectural Engineering Sophomores in Fundamental Classes?	2017
Chacón and Oller	Designing Experiments Using Digital Fabrication in Structural Dynamics	2017
Kosonen and Kim	Quantifying Plug Load Energy Use in a LEED Gold Building—Lessons Learned in the Installation Phase	2016
Abreu. et al	Identification of Residential Energy Consumption Behaviors	2016
Khosrowpour and Taylor	One Size Does Not Fit All: Eco-Feedback Programs Require Tailored Feedback	2015

Table 6.3: Result of the search in Scopus database

Title	Year
Collaboration or competition: The impact of incentive types on urban cycling	2020
Lessons learned from supplementing archaeological museum exhibitions with virtual reality	2020
Modern serious board games: Modding games to teach and train civil engineering students	2020
The functional design method for public buildings together with gamification of information models enables smart planning by crowdsourcing and simulation and learning of rescue environments	2020
Immersive Virtual Reality Environment for Construction Detailing Education Using Building Information Modeling (BIM)	2020
Irelics: Designing a tangible interaction platform for the popularization of field archaeology	2019
Emergency exit planning and simulation environment using gamification, artificial intelligence and data analytics	2019
Interfacing the city: Mixed reality as a form of open data (Book Chapter)	2019
Case study on mobile virtual reality construction training	2019
Turning a traditional teaching setting into a feedback-rich environment	2018
The functional design method for buildings (FDM) with gamification of information models and AI help to design safer buildings	2018
Qualitative assessment of urban virtual interactive environments for educational proposals	2018
Application of hands-on simulation games to improve classroom experience	2017
Simulation of universal design by a functional design method and by Gamification of Building Information Modeling	2016
An overview of game-based learning in building services engineering education	2016
BIM to IoT: The persistence problem	2016
Combining bim models and data with game technology to improve the decision making process: ‘playconstruct’	2016
Gamification technique for supporting transparency on construction sites: A case study	2016
Crowdsourcing the National Map	2015
BIM and interoperability for cultural heritage through ICT	2015
Blended learning in multi-disciplinary claßrooms: Experiments in a lecture about numerical analysis	2015
Cursos online de paleografía: herencias, limitaciones, logros y propuestas	2014
A survey on the visual communication skills of BIM tools	2014
The impact of using gamification on the eco-driving learning	2014
Visual communication panels for production control using gamification techniques	2014

Table 6.4: Result of the questionnaire

O= Operator A= Autonomy	R= Relatedness C= Competence				(R)= Reverse		
Questions	**Need**	**O1**	**O2**	**O3**	**O4**	**O5**	**O6**
I feel like I can make a lot of inputs to deciding how my job gets done.	A	4	4	7	6	4	6
I really like the people I work with.	R	4	4	6	3	7	5
I do not feel very competent when I am at work.	C(R)	6	1	2	3	1	4
People at work tell me I am good at what I do.	C	7	6	7	2	4	6
I feel pressured at work.	A(R)	1	4	1	4	2	5
I get along with people at work.	R	5	5	7	6	6	7
I pretty much keep to myself when I am at work.	R(R)	7	6	6	7	7	7
I am free to express my ideas and opinions on the job.	A	4	5	6	6	4	7
I consider the people I work with to be my friends.	R	3	2	4	2	4	6
I have been able to learn interesting new skills on my job.	C	1	5	5	4	7	7
When I am at work, I have to do what I am told.	A(R)	7	3	5	5	6	5
Most days I feel a sense of accomplishment from working.	C	5	6	6	6	6	6
My feelings are taken into consideration at work.	A	3	5	6	5	7	6
On my job I do not get much of a chance to show how capable I am.	C(R)	7	6	5	2	2	2
People at work care about me.	R	4	4	7	1	6	6
There are not many people at work that I am close to.	R(R)	5	6	6	6	4	2
I feel like I can pretty much be myself at work.	A	4	6	6	7	7	7
The people I work with do not seem to like me much.	R(R)	1	2	2	1	1	2
When I am working, I often do not feel very capable.	C(R)	1	1	2	6	1	2
There is not much opportunity for me to decide for myself how to go about my work.	A(R)	4	3	4	6	2	2
People at work are pretty friendly towards me.	R	7	4	7	5	6	6

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Karlsruher Institut für Technologie (KIT)

INSTITUT FÜR TECHNOLOGIE
UND MANAGEMENT IM BAUBETRIEB

Prof. Dr.-Ing. Dipl.-Kfm. Shervin Haghsheno
Prof. Dr.-Ing. Sascha Gentes

Gamification seeks to place a layer of entertainment and pleasure to the top of serious activities with a focus on improving the applicant's behaviour. Telematics platforms are utilized to collect operational data from various projects. These data can be the initial input to a gamification model to gamify different processes which can encourage construction workers to improve their behaviour at work. A model is introduced in this work that gamifies telematics data with a focus on enhancing operators' behaviour. This model could encourage operators to prevent redundant activities like texting, phoning, and even eating while operating the machine. Subsequently, it enhanced overall machine productivity up to 37% during the site observation. To summarize, a gamified platform in which different operators can share their achievements, or can get ranked in a leader-board will potentially lead to a more proper operators' behaviour.

ISBN 978-3-7315-1301-8

9 783731 513018

ISSN 2363-8222 | ISBN 978-3-7315-1301-8

Gedruckt auf FSC-zertifiziertem Papier