Cyprus University of Technology
Faculty of Engineering and Technology

Doctoral Dissertation

The Risk of Delay in Cyprus Construction Industry: Causes, Effects and Control

Yiannis Vacanas

Limassol, November 2018

CYPRUS UNIVERSITY OF TECHNOLOGY

FACULTY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF CIVIL ENGINEERING AND GEOMATICS

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Approval Form

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To Anthea, Marietta and Frixos

SCIENTIFIC PUBLICATIONS

Scientific Journals

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Vacanas, Y. and Danezis, C. (2017) ‘An Overview of the Risk of Delay in Cyprus Construction Industry’, International Journal of Construction Management. doi: 10.1080/15623599.2018.1541703.

Vacanas, Y., Themistocleous, K., Agapiou, A. and Danezis, C. (2016) ‘Methodology for Infrastructure Project Management , Dispute Avoidance and Delay Analysis’, Anales de Edificación, 2(April), pp. 12–19. doi: 10.20868/ade.2016.3193.

International Conferences

Vacanas, Y. and Danezis, C. (2018) ‘Delay in the Cyprus Construction Industry: Causes, Effects and Mitigation Measures’, in the Second European and Mediterranean Structural Engineering and Construction Conference (EURO-MED-SEC 2).

Vacanas, Y., Themistocleous, K., Agapiou, A. and Hadjimitsis, D. (2016) ‘The combined use of building information modelling (BIM) and unmanned aerial vehicle (UAV) technologies for the 3D illustration of the progress of works in infrastructure construction projects’, in Proceedings of SPIE - The International Society for Optical Engineering - Fourth International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2016). doi: 10.1117/12.2252605.

Vacanas, Y., Danezis, C., Themistocleous, K. and Agapiou, A. (2016) ‘The use of GNSS and Mobile technologies in the collection of productivity records in infrastructure construction projects’, in Fourth International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2016).

Vacanas, Y., Themistocleous, K., Agapiou, A. and Hadjimitsis, D. (2015) ‘Building Information Modelling (BIM) and Unmanned Aerial Vehicle (UAV) technologies in infrastructure construction project management and delay and disruption analysis’, in Proceedings of SPIE - The International Society for Optical Engineering - Third International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2015). doi: 10.1117/12.2192723.

ABSTRACT

Delay in completion of construction projects is a worldwide issue with serious social and economic implications, inflicting significant financial losses to the involved parties. Consequently, disputes are generated and, therefore, costly and time-consuming judicial processes are invoked, which can be detrimental for the industry and the government. Especially for Cyprus, where its financial recovery is closely linked to the construction industry, and its burdened judicial system suffers to deliver justice on-time, delays have a significant impact. To effectively deal with this problem, one has to unveil its causes, and apply effective mitigation measures and practices. To date, the causes of delay in the Cypriot construction industry have yet to be determined using a consistent, scientific approach. The purpose of this thesis is to determine the most important causes of delay, and to detect the most applicable measures for delay mitigation, using a dataset derived from the construction industry of Cyprus. As a secondary objective, this thesis proposes a novel methodology for effective construction project control using state-of-the-art geospatial and ICT technologies. The determination of delay causes, and mitigation practices is carried out by means of an integrated statistical approach that considers the perception of the main stakeholders (i.e. owners, contractors and consultants) to identify commonly-accepted practices. Qualitative and quantitative data regarding the perception of professionals on the causes of delay and the optimal mitigation measures were collected via a voluntary sampling questionnaire process. The dataset was analyzed using an integrated statistical workflow that addressed the reliability of the sample, ranking of the most important delay causes and measures, and the determination of the perception of the involved parties via both non-parametric and parametric correlation tests. Concordantly, critical statistical indices were derived unveiling the significance of each delay cause and mitigation measure as perceived by each major stakeholder of the industry. The results illustrate that, although there is an a-priori disagreement in the perception of each stakeholder with respect to delay liability, commonly-accepted delay mitigation practices can be successfully identified and applied directly, promoting dispute avoidance.

Keywords: construction, project management, control, delay, causes, measures

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BIM:	Building Information Model
CIOB:	Chartered Institute of Building
CMR:	Construction Management Research
CCS:	Construction Central Server
CR:	Contractor
CS:	Consultant
CUT:	Cyprus University of Technology
EOT:	Extension of Time
ETEK:	Cyprus Scientific and Technical Chamber
FIDIC:	International Federation of Consulting Engineers
GCP:	Ground Control Point
GIS:	Geographical Information System
GNSS:	Global Navigation Satellite Systems
GPS:	Global Positioning System
JCT:	Joint Contracts Tribunal
KT:	Kendall's tau
LDs:	Liquidated Damages
ON:	Owner
PPMCC:	Pearson's product-moment correlation coefficient
RFID:	Radio Frequency Idendification
RII:	Relative Importance Index
SCL:	Society of Construction Law
SR:	Spearman's rho

UAE:	United Arab Emirates
UAV:	Unmanned Aerial Vehicle
UK:	United Kingdom
USA:	United States of America

CHAPTER 1: INTRODUCTION

1.1 Background

1.1.1 Construction Project Procurement

Construction projects procurement typically involves three main parties: (a) the owners (or clients), (b) the consultants, and (c) the contractors. Construction projects have certain drawings and specifications that define what is to be built, a delivery date and an agreed cost. The owners appoint the consultants that will design and supervise the project works, and the contractors that will construct the project.

An **owner** (or client) may be a private or public entity that specifies to the consultants the project requirements so that a 'scope of work' is defined. The owner is represented during the construction period by the consulting team. Note that in many occasions, there may be interference by the owner for specification or drawing alterations.

The **contractor** is usually a company (or consortium of companies) that carries out the construction works under a contract that consists of drawings, specifications and contract terms. These terms typically include clauses for the contractor to be liable for the payment of reimbursement in the case of delay, for which he owes liability (contractually known as liquidated damages). In case the contractor has no liability for the delay, contracts provide additional clauses for extension of time (EOT) award with reimbursement for the financial losses and damages sustained by the contractor. The consulting team typically consists of architects and engineers (civil, electrical, mechanical, building services, fire). Depending on the type of the project, specialists may join the consulting team, such as environmental engineers, interior designers etc.

The **consultants**, based on the brief given by the client, prepare the drawings and specifications required for the construction works. Their role is to supervise the works on-site and provide the contractor with all the required information during the construction phase. In many cases, they may instruct changes and variations to the works that may cause disruption and delay to the project.

In all cases, projects commence with best intentions by all three main parties. The owners wish to implement a necessary project for themselves or the end-users; the consultants want to design and participate in an important project and receive their agreed fees; and the contractors want to complete the project the earliest possible within the tendered price and with maximum profit.

But what happens in case of a delay? The owners cannot use the project for which they have already allocated a significant amount of funds; the consultants may be indicted as liable for the delay, and not receive their full fees; the contractors will remain on site for a longer period, and will, therefore, sustain financial damage. Finally, in the case of public infrastructures, there is a significant collateral damage for the end-users.

Apparently, considering the high costs involved in a construction project, none of the main parties wishes to be held responsible for, and bear the extra costs and expenses caused by delays. Concordantly, disputes on the liability for the delays are generated, and are usually resolved via time consuming and costly court or arbitration procedures. It is evident that delays, and subsequent disputes, claim a considerable part of the public or private budgets, which otherwise could be invested in other projects of the governing agencies or investors. Additionally, delays occurring in critical infrastructure projects affect and suspend life quality improvement of the society itself.

1.1.2 Delay in Construction Project Procurement

Delay to completion forms one of the most significant issues that are met in construction projects. Completion without delay is one of the main factors that will determine whether a project can be considered ‘successful’ (Aziz, 2013; Chang, 2002; Cooke and Williams, 2004; Frimpong et al., 2003; Olawale and Sun, 2015), and is dealt with the contract provisions of typical construction projects. The term ‘successful’ means that a project has accomplished its technical performance, maintained its time schedule, and remained within the planned budget. Oftentimes, these three elements are interconnected and interdependent (Atkinson, 1999; Chang, 2002; Cooke and Williams, 2004; Frimpong et al., 2003; Olawale and Sun, 2015).

In the event of delay i.e. a lateness or late completion (Society of Construction Law, 2002), there are usually provisions for extension of time (EOT) award to the contractor, with possible reimbursement for the extra cost and expenses caused by the extension of the contract duration. In case the contractor is not entitled to an EOT, the owner will be possibly entitled to compensation for the time prohibited from using the expected project, also known as ‘Liquidated Damages’.

Even in the event of completion within the agreed time frame, there are circumstances where the contractor may claim reimbursement for extra costs because of acceleration measures he was forced to take to deliver the project on-time. For example, in case a disruption of works is caused by the client, the contractor rightfully claims an EOT award, which is eventually denied by the consultants (Vacanas et al., 2015). Consequently, the contractor will be burdened with acceleration actions to meet the project's deadline and avoid liability for the disruption. ‘Disruption’, being distinct from delay, is termed as a disturbance, hindrance or interruption to a Contractor's normal working methods resulting in lower efficiency (Society of Construction Law, 2017) that affects the works productivity. The most appropriate way to establish disruption is to apply ‘the Measured Mile’; a technique that compares the productivity achieved on a non-impacted part of the contract with that achieved on the impacted part (Society of Construction Law, 2002).

Depending on the size of the project and the agreement amount, the reimbursement sums, which are claimed for alleged delay or disruption, may be extremely high. Ergo, parties aim to avoid liability, which in turn results in frequent disputes (Vacanas et al., 2016). Disputes are resolved via expensive and time-consuming procedures before the courts or arbitral tribunals. These procedures cause more expenses and expenditures that increase the financial losses of a party in the frame of a construction project.

Consequently, numerous studies have been carried out worldwide for the examination of delay causes in construction projects by considering the perception of the industry's main stakeholders using statistical or empirical approaches. **To date, there is no such a research endeavor with respect to the investigation and determination of the causes of delay in the Cypriot construction industry**.

Furthermore, only a small part of scientific literature has dealt with the determination of the most efficient practices to avoid delay. The problem is usually seen by means of simplified recommendations, which are solely based on the identified causes of delay. Moreover, the anticipated impact and importance of these recommendations is not investigated thoroughly, neither is their approval by the main stakeholders, which may result in serious objections and difficulty in their applicability. Such examination is needed to illustrate the degree of acceptance of the suggested practices by all the involved parties, determine the commonly-accepted ones, and hence, accelerate their application without any disapproval, or further intervention.

1.1.3 Project Control

Project control has been defined as 'the application of processes to measure project performance against the project plan, to enable variances, to be identified and corrected, so that project objectives are achieved' (Association for Project Management, 2010). Project control is an implicit part of project management (Olawale and Sun, 2015), in which, records have an immense role (CIOB, 2014, 2009, Society of Construction Law, 2017, 2002). During construction process, as well as post construction process, records will help project monitoring, updating of project schedules, preparation of claims or defences and dispute resolution.

Current literature recognizes the lack of reliable systems to capture up to date information on work progress on site, where control moves from planning straight to reporting with minimal involvement of the site management personnel (Olawale and Sun, 2015). Additionally modern technologies are inadequate to control a project just by themselves. For example BIM, although it is a robust modern technology that improved significantly the design of projects, cannot be used alone for delay mitigation, since several challenges have been reported with its use such as: information transfer bottlenecks; current lack of parametric content for significant project vender products; unfamiliarity of BIM's breadth of ability and associated experience of application in programming; and a lack of understanding of interoperability limitations and abilities (Manning and Messner, 2008). Also it has been stated that while architects can use BIM to generate a great buildings, reducing costs and material, if the thought approach when the building is being designed is not transmitted fully and correctly to the Contractor, then claims and problems will arise (Kensek and Noble, 2014).

During an UAV-based 3D model production procedure, defects do exist in the automated process - manual intervention, such as geometric repair and detailed decoration, might be needed in future optimization work (Qu et al., 2017). Project scheduling means such as Gantt charts are often not being understood by parties of the project such as the client or even the architect. Gantt charts need to be backed up by images so that as-built information is clearly communicated. Most importantly all information must be communicated in an understandable to all involved parties ways, via complete and clear reports.

It is apparent that there is a need for a system that will enable the collection of records from various sources, using modern technologies and traditional methods, and offer constant, transparent and clear communication between the involved parties. **Such system will enable efficient and transparent construction project monitoring in order to achieve more effective project management and control, acting as an early warning system for possible delays, delay prevention, dispute avoidance and cheaper dispute resolution procedures.**

1.2 Thesis Objectives

Based on the above, the delay causes that affect the Cypriot construction industry have yet to be investigated and determined. Additionally, no research has been carried out, to date, with respect to the possible measures and practices that could be applied to mitigate or even prevent delay effects. Furthermore, there is no specific methodology regarding the identification of delay mitigation measures in current literature. Ergo, the main objectives of this research are:

- The examination of important elements of the Cypriot construction industry that affect time and completion in construction projects;
- The investigation of the causes of delay in construction projects in Cyprus, and the detailed examination of their importance and criticality by considering and comparing the perception of each of the three main parties involved in a construction project (owners, contractors, consultants);
- The examination and determination of the most efficient practices for delay mitigation and avoidance by considering the perception of the involved parties (owners, contractors, consultants) to enable accelerated measure acceptance and application;

As a secondary objective, this thesis proposes the methodology design of a smart tool that can aid the **control** of a construction project for delay mitigation and enable easier and cheaper dispute resolution procedures using state-of-the-art geospatial technologies.

The answers to the aforementioned research questions will shed light to the causes of delay in the construction industry of Cyprus. Moreover, by introducing a novel perception-based statistical process chain, this thesis will try for the first time to determine measures and practices that will promote delay mitigation in Cyprus.

1.3 Methodology

To highlight and understand delay-related issues in the Cypriot construction industry, a specifically designed survey was designed and conducted. The survey questionnaire (see Appendix I) covered topics, such as delay frequency and duration, Extension of Time (EOT), disputes, project monitoring and programming, and, in great detail, the causes of delay and the measures that can mitigate their effects.

Regarding the investigation of (a) the main causes of delay, and (b) the best practices for their avoidance or mitigation, the following methodology was adopted; initially a total number of nine experts were selected from each involved party (clients, contractors and consultants) and through an interview process, they were requested to name the most significant causes of delay and disruption according to their own experience. The selection of professionals was carried out in such way as to ensure maximum reliability and uniformity of the sample. Ergo, three professionals from each category involved in the construction projects were selected. The interviews were carried out in the cities of Nicosia, Limassol, Larnaca and Paphos (four out of the six cities of Cyprus) and each had duration of approximately one hour. Furthermore, an extensive literature review was carried out to identify most significant causes and potential mitigation measures worldwide. Eventually, 20 causes were identified as candidate sources of delay and disruption by combining the findings of the interview process and the literature review. To derive the severity of each source of delay, rating scale questions, such as Likert–type scales were used to characterize the impact of each cause separately.

The investigation of the most effective practices for delay mitigation was carried out using the same methodology as the above, and addressed by specifically designed ranking-order questions. In total, 18 measures and practices identified from the literature review and the interviews were used in the questionnaire. This ranking approach was chosen instead of a Likert-type solution to evaluate the readiness of each stakeholder to apply a particular practice, rather than only estimate the perceived importance of this practice.

For the sake of the participants' convenience, quick completion, effective compilation and analysis of the results, several types of questions were designed, mainly closed-ended types. The designed questionnaire was then distributed to 242 members of the Cyprus Scientific and Technical Chamber involved in the construction industry using a voluntary sampling technique. The final dataset was formed by 54 responses originating from the three main stakeholder parties.

Consequently, an integrated statistical process workflow was used to derive the causes and measures from the dataset. Initially, the dataset was subjected to reliability testing using Cronbach's Alpha coefficient. Thereafter, for each cause and measure a relative importance index (RII) was computed to quantify their importance. The latter were then used to measure the correlation degree (perception) of each involved party using the most commonly employed correlation tests in literature, parametric and non-parametric, i.e. Pearson's product-moment correlation coefficient (PPMCC), Spearman's Rho (SR), and Kendal's Tau (KT). This was done to assess the performance of each test and determine potential discrepancies in the results. Finally, the perception between the involved parties was determined, and the measures with the highest degree of correlation with respect to importance, as perceived by all stakeholders, were identified and proposed for immediate application. To address the secondary objective of this thesis, i.e. the development of a methodology that employs smart technologies to enable robust project control, a detailed literature review of the most prominent technologies was conducted. Special focus was given on modern smartphones (and their integrated GNSS and inertial sensors), GIS, UAVs, BIMs and time-lapse cameras. Furthermore, assessment of their ability was carried out by means of experiments on actual construction projects. Based on this research results, a robust methodology and smart tool was proposed to enable efficient and transparent construction project monitoring, acting at the same time as an early warning system for possible delays, delay prevention, dispute avoidance and cheaper dispute resolution procedures.

1.4 Innovation

This thesis includes innovation in three general pillars.

Firstly, to date, there is no scientific study on the subject of delays for Cyprus. This thesis includes an exploration of the issues related to time and delay in the Cypriot construction industry. The issues investigated include delay occurrence and duration, EOT awards, dispute resolution duration etc. Most importantly this research work includes the determination of the most important causes of delay in the construction industry of Cyprus.

Secondly, the literature review revealed a lack of scientific approach regarding the determination of the most accepted, by the major construction industry stakeholders, and thus applicable, practices for delay mitigation. In fact, only a small part of scientific literature provides recommendations on delay avoidance and control, and these are solely based on simplistic conclusions derived only by the ranking of the identified causes of delay. This thesis, after determining the most important causes of delay in Cyprus, detects the most applicable measures for delay mitigation, using a scientific approach. Qualitative and quantitative data regarding the perception of professionals on the optimal mitigation measures were collected via a questionnaire process. The dataset is analyzed using an integrated statistical workflow that addresses the reliability of the sample, ranking of the most important measures, and the determination of the perception of the involved parties via both non-parametric and parametric correlation tests. As a result, critical statistical indices are derived, unveiling the significance of each mitigation measure as perceived by each major stakeholder of the industry.

Thirdly, the literature review justified the need for an integrated tool to enable effective control of construction projects. The current methods for project control and delay management do not perform well, the cost of the introduced delay is very high and the dispute resolution procedures end up being very expensive or faced with apprehension. This thesis proposes a contemporary methodology, which is a holistic integrated approach that combines traditional means of recording data during a construction project (site diary, reports, correspondence, progress meetings´ minutes, drawings´ updates, variation instructions and site photographs) and smart technology tools, such as smartphones, UAV technology with photometry, time-lapse cameras, RFID technology, satellite imagery and laser scanning, to provide important and useful information, both spatial and descriptive, to a Geographical Information System (GIS) central server, or Construction Central Server (CCS). The proposed CCS is a robust methodology and smart reporting tool, for efficient and transparent construction project monitoring in order to achieve more effective control, acting as an early warning system for possible delays, delay prevention, dispute avoidance and cheaper dispute resolution procedures.

1.5 Thesis Outline

Chapter 1 provides an introduction to this thesis. The background of the problem is stated and analysed, and the objectives of this research are formed. Finally, the methodology to achieve the objectives is described.

Chapter 2 reviews the risk of 'Delay' in construction projects. An extensive literature review was conducted with respect to the research carried out at the international level about the causes of delay in construction projects along with the suggested mitigation measures. The outcome was analysed thoroughly and focused on the points of convergence and divergence between the studied countries. Furthermore, the performance of the judicial system of Cyprus, arbitration and mediation processes are examined to illustrate the framework of dispute resolution procedures.

Chapter 3 provides a detailed review of the methodology used for the data analysis and forms the integrated statistical workflow used for the identification of the most important causes of delay and the mitigation measures practices. Concordantly, dataset reliability, quantification of importance of delay causes and mitigation measures and determination of stakeholder perception via parametric and non-parametric correlation tests are thoroughly discussed.

Chapter 4 presents the analysis and the results of this research. The results include an examination of the time-related issues appearing in construction projects, determination of the most significant delay causes, and identification of delay mitigation measures that are most applicable and, thus, acceptable by all involved parties.

Chapter 5 proposes a robust methodology for the development of smart tool that employs cutting-edge technologies to achieve efficient project control, transparent construction works monitoring, which may be used as an early warning system for possible delays, and promote delay prevention, dispute avoidance and cheaper dispute resolution procedures.

Chapter 6 provides a summary of the results gathered within the frame of this research. The findings lead to specific conclusions on the risk of delay in the Cypriot construction industry. The thesis concludes with specific recommendations for future work.

CHAPTER 2: THE RISK OF DELAY IN CONSTRUCTION

2.1 Introduction

In the construction industry, the completion of projects within the agreed time constraints is considered an important contractual issue. In the case of delayed completion, all the main parties involved will suffer financial losses and/ or will be restrained from delivering to the end-users much needed infrastructure projects such as hospitals and transportation infrastructure. The problem of delay in construction is present internationally and concerns all construction industries worldwide.

2.2 Effects of delay in construction projects

Despite the size of a construction project, delay events may have major consequences on the works progress, completion and cost of the project. The causes of delay may vary from a geographical area to another - depending on factors such the state of the economy of a country or even cultural particularities. However, the negative effects are always challenging and costly.

2.2.1 Cases at the International Level

2.2.1.1 The Carrilion case

The case of the construction giant Carrilion is probably the most recent example of the detrimental consequences that delay may have. Carrilion is well known for hundreds of important construction projects such as the Royal Opera House, the Channel Tunnel, the Tate Modern Gallery, various NHS hospitals in the UK, the Grand Mosque in Oman, the Toronto's Union Station revitalization etc. In January 2018, it was announced that Carrilion, employer of 43,000 people internationally, entered into liquidation because of inability to secure financing. One of the main causes of cashflow blockage was the almost parallel delay on four major infrastructure projects: the New Royal Liverpool University Hospital (£335M) because of "extensive" asbestos found on the brownfield site and cracks in the new building; the Midlands Metropolitan Hospital (£350M) because the fitting of pipes and wires were taking longer than expected; the Aberdeen Western Peripheral Route because of cold weather during winter; and the 2022 FIFA World Cup Venues (Doha, Qatar) because of 1-year delayed payments by the client. The collapse of Carillion did not affect only the employees, but also the patients who were awaiting new hospitals and the drivers who needed the new road for faster and safer transportation ("The four contracts that finished Carillion," 2018).

2.2.1.2 Wembley stadium, UK

The reconstruction of the famous football stadium commenced in September 2002, and planned to be completed in May 2006. The project was eventually completed in May, 2007. The planned cost was £757m but the final cost was exceeded £900m. This increase in cost of about £150m triggered a number of disputes. The contractor (Multiplex) commenced an action against its steelwork subcontractor (Cleveland Bridge) as well as the structural design consultant (Mott MacDonald) for 'not fit for purpose' design and 'unsatisfactory' provision of services, with 11.000 changes to Mott MacDonald original drawings. The contractor claimed £253m in damages plus cost and interest ("£253m legal battle over Wembley delays," 2008).

Regarding the dispute resolution costs it was stated that the contractor's costs on a sub-trial alone were quoted as being £45m - with £1m spent on photocopying alone ("The century's most troublesome construction projects," 2015)!

2.2.1.3 Dubai Metro, UAE

The Dubai metro works commenced in 2005 with planned completion in 2009. However, it was co-mpleted in 2014, with 5 years delay. The planned cost increased from $4.2bn to $7.8bn ("The century's most troublesome construction projects," 2015).

Most of the increase in duration and cost was due to the changes in terms of its design and facilities ("US $2.5 billion claim over Dubai Metro," 2009).

Part of the delay was due to the delayed payment of disputed amounts. The consortium members – including Mitsubishi Heavy Industries, Mitsubishi Corporation, Obayashi Construction and Kajima Corporation of Japan and Yapi Merkezi of Turkey – slowed down their works in the beginning of 2010 until the dispute was settled with Dubai Roads & Transport Authority ("Dubai Metro payment dispute resolved," 2010).

2.2.1.4 Gorgon LNG Plant, AUS

The Gorgon LNG Plant in Australia construction works commenced in 2009, planned to be completed in 2014. The works were completed with 18 months of estimated delay. The planned cost was $37bn, but the final cost was estimated to have reached the staggering amount of $54bn ("The century's most troublesome construction projects," 2015).

The client (Chevron) cited the high Australian dollar, high wages, low productivity, weather delays and the logistical challenges of building a gas plant in Barrow Island, a Class A nature reserve as the major reasons for the delays and cost overruns ("Gorgon gas project costs blowout again," 2013).

2.2.1.5 Olkiluoto 3 Nuclear Power Plant, FIN

Finland's Olkiluoto 3 nuclear plant construction works were delayed for almost a **decade**. The works commenced in 2005 with expected completion in 2009, however the works were completed in 2019 ("Olkiluoto 3 EPR parties agree settlement," 2018). The delays have been due to various problems related to planning, supervision, and workmanship ("Olkiluoto 3 delayed beyond 2014," 2012).

The works were carried out by the consortium Areva GmbH, Areva NP SAS of France and Siemens AG of Germany for the Teollisuuden Voima Oyj (TVO). There were claims of billions of euros from TVO (estimated €2.6bn) and counter-claims from the contractor consortium (estimated €3.4bn) over the plant, which were settled with the consortium paying TVO the amount of 450 million Euro as compensation. When TVO signed the turnkey contract, the cost of the new unit was set at €3.2 billion, but the end cost of TVO total investment was increased to around €5.5 billion ("Olkiluoto 3 EPR parties agree settlement," 2018).

2.2.2 Projects in Cyprus

2.2.2.1 Eleftherias Square

The works for the construction of a world-class landmark designed by the famous

architectural firm founded by the late Dame Zaha Hadid, in the centre of Nicosia were commenced in February 2012 and planned to be completed in 2014. Severe delays were faced mainly due to technical issues, unavailability of specific materials and disputes between the client (Nicosia Municipality) and the main contractor regarding the liability of the continuing delay as early as the beginning of the project ("An open wound in the heart of the capital," 2017). After the appointment of a new contractor and a more than 100% increase of the original budget, the project is expected to be delivered in 2019.

2.2.2.2 Nicosia Hospital

The works of the most important hospital in Cyprus commenced in May 1997 with agreement to be completed in February 2002. The project was completed in February 2006 with a 4-year delay in completion.

2.2.2.3 Larnaca Hospital New Wing

The construction works for the new wing of the hospital of Larnaca started in September 2013 with completion agreed to be within September 2016. However, due to the financial disputes risen between the client and the contractor and delay in payments, a new delivery date was agreed upon, first until December 30, 2017, then until April 2018 but now is expected to be delivered in 2019 ("Larnaca hospital upgrade delayed again," 2018).

2.3 Dispute Resolution in Cyprus

The dispute resolution length of proceedings is a matter that is important to governments and the public. Without independent, high-quality and efficient justice systems there is no rule of law, no business friendly environment and no mutual trust (European Commision, 2018).

In Cyprus, usually disputes are referred to courts for resolution. In addition to **litigation**, construction disputes can also be resolved via alternative dispute resolution methods, such as **arbitration** or **mediation**. Furthermore, efforts are made by the Cyprus Scientific and Technical Chamber (ETEK) for the introduction of **adjudication** to the standard form of contracts, mainly used in Cyprus for non-public projects (MEDSK). There is a large number of arbitration centres, with the ETEK centre being the largest followed by the Chartered Institute of Arbitrators, Cyprus branch.

The duration, and cost, of dispute resolution processes affects the involved parties as well as the economy of a country in general. For this reason, European Commission has formulated the EU Justice Scoreboard. The EU Justice Scoreboard is an information tool aiming at assisting the EU and Member States to achieve more effective justice by providing objective and comparable data on the quality, independence and efficiency of justice systems. The Scoreboard aims to contribute to identifying improvements and good practices, to assist Member States in their efforts for a more investment, business and citizen-friendly environment (European Commision, 2016).

In the 2018 report of EU Justice Scoreboard, it was stated that the duration of litigation procedures in Cyprus increased from 1.5 years in 2010 to 2.5 years in 2014 and 2.2 years in 2015 and 2016 respectively, which are among the longest between the EU Member States (Figure 1). This is the duration for first instance trials (European Commision, 2016). These results look very optimistic compared to reality, since according to the Cyprus Ministry of Justice records, the accumulation of a big number of old cases could be pending for between six to eight years in the district courts (first instance) and five to six years in the appeal court, i.e. the Supreme Court in Cyprus's case ("Our View: New judges to clear case backlog need to be up to scratch," 2018). Because of the **relatively low cost of litigation**, it is common practice to take decisions for second instance to the appeal court, thus the final resolution of a court case may last **for more than 10 years**.

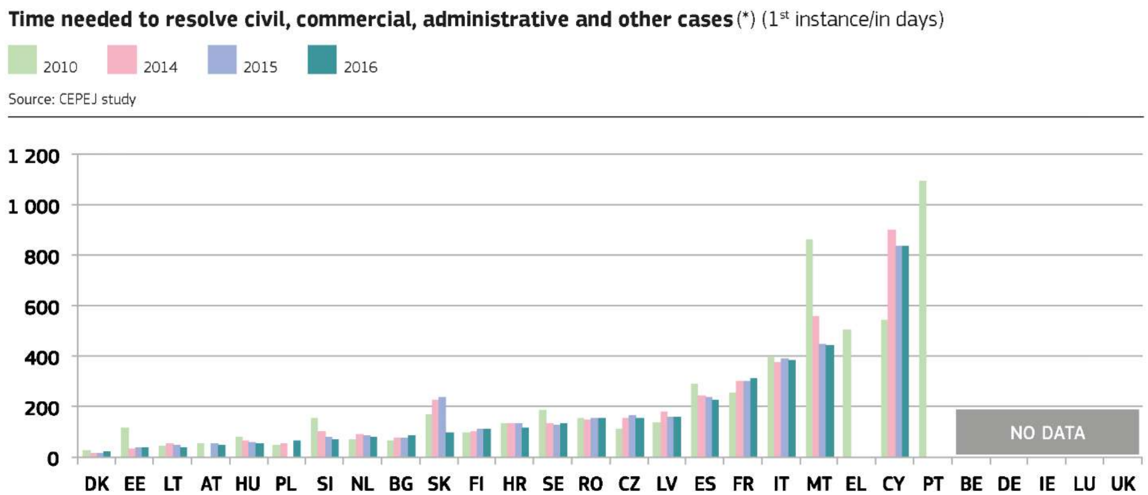

Figure 1: Time needed to resolve civil, commercial, administrative and other cases (source EU Justice Scoreboard 2018)

The pending cases per 100 habitants are also the most in EU, amount to approximately 7 per 100 habitants, with only 3 Member States having more pending cases. The number of pending cases increased dramatically since 2010, when the number of pending cases was approximately 5 per 100 habitants (Figure 2).

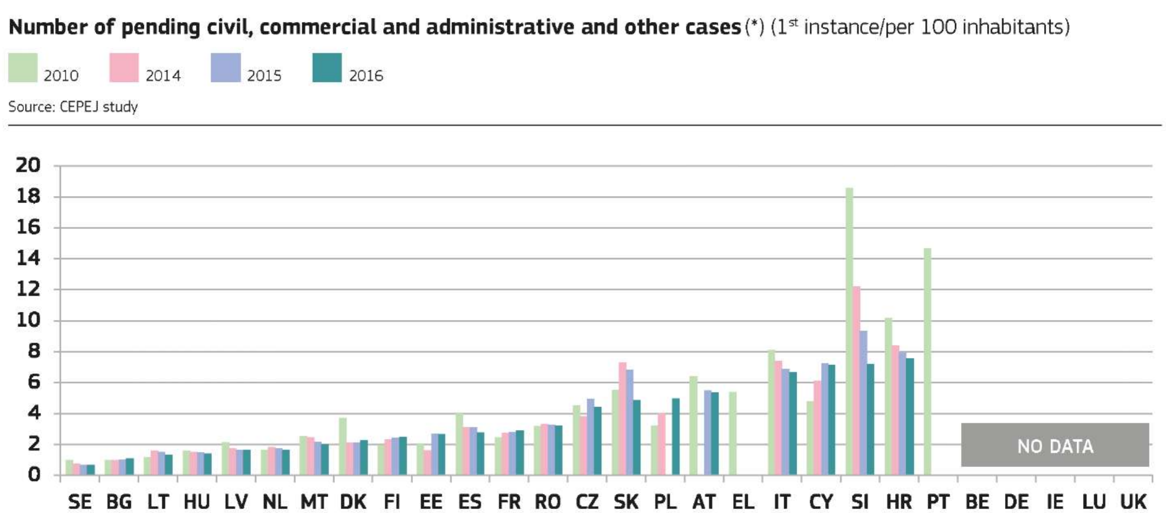

Figure 2: Number of pending civil, commercial and administrative case (source EU Justice Scoreboard 2018)

The delays in Cyprus's judiciary system form an issue highlighted in the recent years not only by the public but also by lawyers and judges themselves. Understaffing, because of austerity measures, and civil procedures that allow for an abuse of the system and a waste of court's time, are the main reasons behind these delays, which do not seem to improve ("Judicial system 'unacceptable', court buildings 'a disgrace' top judge says," 2017).

On the other hand, the promising increasing use of **Arbitration** is ambushed by the Cyprus Arbitration Law itself. Cyprus Arbitration Law, also known as CAP. 4, was enacted in 1944 establishing a legal framework similar to that of the English Arbitration Act 1950. This outdated law has various flaws, with possibly the most serious one its provision to the parties to request courts' intervention at every stage of the arbitral proceedings. This provision of CAP. 4 is abused by parties to cause deliberately delay usually with allegations of dishonesty etc., or requests for the removal of arbitrators for misconduct to be decided by a Court.

Mediation is an alternative dispute resolution method that is essentially a negotiation facilitated by a third party, the mediator. The result of the process is an agreement signed by both parties that resolves their dispute. The signing of such an agreement is not compulsory, i.e. the process might end without an agreement. In the UK the use of alternative dispute resolution methods such as mediation in encouraged, because they believe that litigation should be seen as a last resort; parties who do not participate in mediation must justify their position to a judge (CIOB, 2014). In Cyprus although there are accredited mediators and the need for mediation is evidently recognized ("Mediation in civil and commercial matters," 2018), this alternative dispute resolution procedure is not preferred due to the lack of mediation culture. Mainly, the lack of trust between the involved parties to a guaranteed result through mediation, discourages them to enter to such a process as they perceive it as a potential waste of time and money.

The 2018 EU Justice Scoreboard stated that based on a proposal from the Commission, the European Council addressed country-specific recommendations related to their justice system to five Member States: Hungary, Italy, Portugal, Slovakia and Cyprus. The Council Recommendation was given on the 2017 National Reform Programme of Cyprus and delivering a Council opinion on the 2017 Stability Programme of Cyprus (European Commision, 2018).

2.4 Delay Causes

According to the Chartered Institute of Building (CIOB) survey report 'Managing the Risk of Delayed Completion in the 21st Century' (CIOB, 2009), delays occur in 29% to 81% of construction projects in the UK, depending on the type of projects. The report notes that in more than a one third of the building projects and four-fifths of the engineering projects, the contractor was predominantly held responsible for any delay to completion.

In the frame of a study carried out to identify the major causes of delays in construction projects in Florida, USA, it was found that the ten most critical causes of delay are: building permits approval, change orders (variations), changes in drawings, incomplete documents, inspections, changes in specifications, decision during development stage, shop drawings approval, design development and changes in laws and regulations (Ahmed et al., 2002).

Zou et al identified the main project time delay risks in the Chinese construction industry in the following order of ranking: project funding problems, variations by the client, inadequate program scheduling, contractor's difficulty in reimbursement, design variations, tight project schedule, contractors' poor management ability, excessive procedures of government approvals, price inflation of construction materials, suppliers' incompetency to deliver materials on time (Zou et al., 2007).

Xiao and Proverbs (Xiao and Proverbs, 2003) attempted to compare the overall contractors' performance in three large construction industries: in Japan, the UK and the USA; by considering the case of high-rise concrete framed buildings. They concluded that contractors' performance is influenced by the contractors' previous performance on similar projects, commitment towards lifetime employment, perceived importance of time performance, relationships with subcontractors and the number of design variations during construction. The authors suggested that in order to improve their performance, contractors should focus on construction time, reduction of delays, maintenance of stable workforce, and establishment of partnerships with their subcontractors. On the other hand, clients should aim to reduce design variations during construction.

In the UAE construction industry, one of the fastest developing construction industries in the recent years, inflation and sudden changes in prices, owners' unreasonably imposed tight schedule, subcontractors' poor performance and management, delay of material supply by suppliers, change of design required by owners, owners' improper intervention during construction, shortage in manpower supply and availability, delays in approvals, lack or departure of qualified staff and shortage in material supply and availability are the most significant risks (El-Sayegh, 2008).

A study by Chua at al. showed that project success in Singapore is determined by the project management, monitoring and control efforts; and in addition by project characteristics and contractual arrangements. The authors concluded that the plausibility of project success can be increased if inherent characteristics of the project can be thoroughly understood, appropriate contractual arrangements are adopted, competent management team is assigned, and sound monitoring and control system is established (Chua et al., 1999).

A research on Australian pipeline projects, revealed as main causes of delays: the design changes, design errors, poor communication, customer/ end-user related issues, subsurface investigation inadequacies, issues regarding permissions/ approvals, weather conditions, procurement delays, site management problems, subcontractor issues, rework, cultural heritage management issues(Orangi et al., 2011).

A study by Kumaraswamy and Chan (1996) on factors contributing to construction delays in Hong Kong observed that almost 70% of building projects were completed behind schedule, and concluded that the six common significant factors from both building works and civil engineering works are the unforeseen ground conditions, poor site management and supervision, low speed of decision making involving all project teams, client-initiated variations, necessary variations of works and inadequate contractor experience (Kumaraswamy and Chan, 1998).

A recent study carried out in Norway found that the main reasons for time issues in major Norwegian projects are the poor planning and scheduling, slow/poor decision-making process, internal administrative procedures and bureaucracy within project organizations, resources shortage (human resources, machinery, equipment), poor communication and coordination between parties, slow quality inspection process of the completed work, design changes during construction/change orders, sponsor/owner/client lack of commitment and/or clear demands (goals and objectives), office issues, late/slow/incomplete/ improper design, and user issues(Zidane and Andersen, 2018).

Gündüz et al. found that the most important factors causing delays in Turkey are the inadequate contractor experience, the ineffective project planning and scheduling, poor site management and supervision, design changes by owner or agent during construction, late delivery of materials, unreliable subcontractors, delay in performing inspection and testing, unqualified/inexperienced workers, change orders, delay in approving design documents, delay in progress payments and slowness in decision making (Gündüz et al., 2013). Another study carried out in Turkey showed that amongst the most important causes of cost overrun are the following factors connected to delays: design problems, delays in receiving progress payments, frequent change orders, oral requests from the owner and need for reworks (Polat et al., 2014).

Aziz studied the most important delay factors in projects in Egypt especially after 25/1/2011 (Egyptian revolution). Out of 99 identifies possible factors of delay the 9 factors which have the highest impact factor are the delay in progress payments, different tactics patterns for bribes, shortage of equipment, ineffective project planning and scheduling, poor site management and supervision, poor financial control on site, rework due to errors and selecting inappropriate contractors (Aziz, 2013). According to another survey regarding the construction industry of Egypt, the most important causes of delays are: the difficulties in financing by contractor during construction, delays in contractor's payment by owner, design changes by owner or his agent during construction; partial payments during construction and non-utilization of professional construction/ contractual management (Abd El-Razek et al., 2008).

In Iran the most important causes of delay in the Iranian construction industry as identifies by Shahsavand et al. are the change orders by owner during construction, the underestimation of time and cost for completion, delay to site delivery to the contractor, the soil and water level condition, unqualified workforce, delay in permits' issuance and slow decision making (Shahsavand et al., 2018).

A study on Ghana groundwater construction projects, revealed the following five most important factors as the main causes of delay: the difficulty for execution of monthly payment from agencies, poor contractor management, material procurement, poor technical performances, and escalation of material prices (Frimpong et al., 2003). Note that the aforementioned factors were commonly identified and acknowledged by all parties involved, i.e. owners, contractors and consultants.

In Uganda, the most significant factors of construction delays were identified as the delay in assessing changes in the scope of work by the consultant, financial indiscipline/dishonesty by the contractor, inadequate contractor's experience, design errors made by designers and inadequate site investigation by the consultant (Muhwezi et al., 2014).

Kaliba et al (Kaliba et al., 2009) studied the causes of schedule delays in road construction projects in Zambia. Their study established that delayed payments, financial processes and difficulties on the part of contractors and clients, contract modification, economic problems, materials procurement, changes in drawings, staffing problems, equipment unavailability, poor supervision, construction mistakes, poor coordination on site, changes in specifications and labour disputes and strikes were found to be the major causes of schedule delays in road construction projects in Zambia.

A research carried out by Niazi and Painting (Niazi and Painting, 2017) that aimed to identify the significant factors that lead to construction cost overruns in Afghanistan found among the key critical causes that potentially result in construction cost overruns in Afghanistan are the delay in progress payment by owner, difficulties in financing project by contractors and change orders by the owner during construction.

In a survey carried out in Jordan the results indicated that contractors and consultants agreed that owner interference, inadequate contractor experience, financing and payments, labour productivity, slow decision making, improper planning and subcontractors are among the top ten most important factors responsible for the occurrence of delays (Odeh and Battaineh, 2002). Also Sweis et al found that financial difficulties faced by the contractor and too many change orders by the owner are the leading causes of construction delay; whereas severe weather conditions and changes in government regulations and laws ranked among the least important causes (Sweis et al., 2008).

In Malaysia the most important factors of delay are the financing by the owner as well as the contractor, slowness in decision making and supervision, material shortages, poor site management, construction mistakes, lack of consultant's experience and incomplete documents (Alaghbari et al., 2007). Memon et al examined the causes that affect the construction cost in government large construction projects of Malaysia and they concluded that cash flow and financial difficulties faced by contractors, contractor's poor site management and supervision, inadequate contractor experience, shortage of site workers, incorrect planning and scheduling by contractors are the most significant factors (Memon et al., 2010).

In a study carried out in Pakistan the major delay causes were found to be the law and order situation, design changes, improper availability of funds with client, war and terrorism, poor site management, discrepancies between drawings and specifications, payment delays, inflation of local currency, unrealistic time durations and political/ bureaucratic influences (Gardezi et al., 2014).

In India the most critical factors of construction delay were identified as the lack of commitment, inefficient site management, poor site coordination, improper planning, lack of clarity in project scope, lack of communication and substandard contract (Doloi et al., 2012).

Considering the above analyses, Figure 3 compares the causes of delays identified by researchers for specific countries or geographical areas. As it can be seen the most frequent causes of delay mentioned by most researchers are (a) changes and variations by consultants, (b) delay in payments to contractor, (c) contractor's poor management ability and (d) intervention and changes to design by client/ owner.

Figure 3: Main delay causes at the international level

It is apparent that in the countries with less strong economies, i.e. Egypt, Ghana, Uganda, Jordan, Malaysia, Zambia, Afganistan, a common cause of delay is the difficulty of the contractor to finance the construction projects they undertake to complete.

Countries with less strong economies (Ghana, Uganda, Jordan, Zambia, Turkey and Malaysia) have also as a common cause of delay the inadequate contractor experience and poor technical performances. However, this cause of delay was mentioned to apply in Hong-Kong.

The thriving construction industries of China and UAE face as a common cause of delay the very tight programme schedules applied to the projects. This appears as a common approach by the clients/ owners to achieve ambitious timeframes and simultaneously apply pressure to the project participants to accomplish the earliest completion period possible. These two large industries also have as common cause of delay the suppliers' difficulty to deliver materials on time. Nevertheless, the same cause of delay was mentioned for Ghana because of the bureaucratic structures in material procurement processes that hinder the easy flow of construction materials. In Ghana, the processing of an order can take from a week to several months especially in public sector (Frimpong et al., 2003).

It is interesting to note that the UAE construction industry faces the issue of lack or departure of qualified staff, a delay cause that was not mentioned for any other industry. Also, the USA construction industry has several delay causes related to the performance of the consultants. This observation could be viewed as a result of the more demanding approach towards the performance of the consultants rather than an insufficient performance of the US consultants compared to other countries.

In general, a large number of complex and interdependent factors can influence productivity in a construction site. Namely, weather variability, material shortages, lack of experienced design and project management personnel, ineffective communications, inadequate planning and scheduling, lack of sufficient supervisory training, restrictive union rules, slow approvals and issue of permits, lack of management training for supervision, project management and large number of changes (Dozzi and AbouRizk, 1993). Each of these causes has to be examined closely so that the relevant methods and/ or policies can be identified and where possible be applied for the control and even avoidance of delay. For example, late change is more disruptive of project productivity than early change, all other things being equal; therefore, if changes are necessary, they should be recognized and incorporated as early as possible (Ibbs, 2005).

2.5 Delay Mitigation Measures

In various studies related to the causes of delays, recommendations for delay mitigation were made based on the causes. It is noted that in all cases, a simplified approach was followed without considering the perception of the involved parties with respect to the acceptability of the measure.

CIOB's study (CIOB, 2009) recommends the establishment of best practice in the management of time on construction projects by the related institutions through a Code of Best Practice for the Time Management of Construction Projects. According to CIOB the training of professional and senior managers responsible for projects is required to promote best practice in order to enable informed strategic and business decisions about the management of time and delay avoidance. Furthermore, they recommend the training and accreditation for planning engineers and project managers to raise the standards of planning and scheduling on construction projects. Finally, it is suggested that a CIOB working group should be established to address the issues of education, training and accreditation and to make recommendations as to the appropriate way forward for the development of such training schedules.

The Society of Construction Law Protocol suggests that as early as possible within the frame of a project, the Contractor should submit and the Architect should accept a programme (using commercially available critical path method project planning software) showing the sequence in which the Contractor plans to carry out the works. The programme should be read in conjunction with a method statement describing in detail how the Contractor intends to construct the works. According to the SCL Protocol, the contract should require the Accepted Programme be updated with actual progress using the agreed project planning software and saved electronically at intervals of no longer than one month. The SCL Protocol also underlines the importance of Records and it recommends that that the parties reach a clear agreement on the records to be kept (Society of Construction Law, 2017, 2002).

In a study carried in the construction industry of the UK, the authors (Olawale and Sun, 2015) underlined that 'Monitoring' is a weak link for both time and cost control of construction projects. They found that there is a lack of reliable systems to capture up to date information on work progress on site, where control moves from planning straight to reporting with minimal involvement of the site management personnel.

In a study carried out regarding the construction industry of Saudi Arabia (Assaf and Al-Hejji, 2006) the authors recommended the progress payment to the contractor to be made on-time because it impairs the contractors ability to finance the work; Minimize change orders during construction to avoid delays; Avoid delay in reviewing and approving of design documents than the anticipated; Check for resources and capabilities, before awarding the contract to the lowest bidder; Contractors should assign enough number of labors and be motivated to improve productivity; contractor should manage his financial resources and plan cash flow by utilizing progress payment; contractors to continue planning and scheduling processes during construction and match with the resources and time to develop the work to avoid cost overrun and disputes; administrative and technical staff should be assigned as soon as project is awarded to make arrangements to achieve completion within specified time with the required quality and estimated cost; Consultants should review and approve the design submittals prior to construction phase, could delay the progress of the work; Architect/design engineer should focus on Producing design documents on time and avoid mistakes and discrepancies in design documents since they are common reasons for redoing designs and drawings and may take a long time to make necessary corrections.

Aibinu and Jagboro who studied the delay causes in Nigeria construction industry (Aibinu and Jagboro, 2002) suggested the use of acceleration of subsequent site activities to reduce or if possible eliminate time overrun, an effective clients' project management procedure, the use of adequate contingency sums in the precontract estimate of projects to offset cost overrun.

Frimpong et al in a study regarding delay in Ghana construction industry recommended the determination of appropriate funding at the planning stage of the project so that regular payment should be paid to contractors for work done, the continuous work-training to contractors to improve their managerial skills, the use in projects of effective and efficient material procurement systems and the development of effective and efficient technical performances(project planning, scheduling, time and cost control, and the information systems) through different types of training programs (Frimpong et al., 2003).

Zou et al concluded that clients, designers and government agencies of the Chinese construction industry should work cooperatively from the feasibility phase onwards to manage potential risks effectively and in time; contractors and subcontractors with robust construction and management knowledge and skills must be employed early (Zou et al., 2007).

In a study regarding the construction industry of Malaysia (Alaghbari et al., 2007) it is recommended that financial support and technical support are a very necessary and urgent step for construction investments, since the results of the analysis show that financial problems are the major factor causing delay in construction projects. Technical support is also necessary since the study shows that coordination problems are the second major factor causing delays in construction projects in Malaysia.

In a study regarding the Egyptian construction industry (Marzouk and El-Rasas, 2014) a series of delay mitigation measures were recommended: to specify a realistic duration in the contract for the contractor to execute the project; to prepare sufficient feasibility study for the project, as well as the preparation of a comprehensive financial plan and cash flow; to obtain the required approvals for the project from the relevant authorities and ensure the availability of the necessary funding; the consultant to the project to have sufficient experience in the field of work and has a good reputation; to make sure tender documents are complete, clear and free of errors and/or contradiction; payment of the dues to the contractor for the work being carried as well as the payments of finished items according to terms of the contract; to hire an experienced contractor in the field of work who has a good reputation; the consultants to avoid delay the response to contractor's queries as well as the approval the submitted submittals and shop drawings; the establishment of a control system to handle, control, and evaluate variation orders, initiated by the owner; the contractors should develop a comprehensive financial plan and cash flow; the contractors must develop a monitoring and periodical reporting of critical and long lead items and periodically providing a narrative explanation of causes of any experienced delay; the development of a good system for site management and supervision ; use of effective planning and scheduling for the project; project parties should preview the site due-diligence reviews and execution of necessary borings during the tender stage to make sure that the need for adjustments in design or make amendments if necessary before the issuance of notice to proceed; and finally formal relationships among project parties should be clearly identified, as well as roles and responsibilities.

In a study regarding time extension factors in construction industry in Pakistan it was recommended that a close coordination with law enforcing agencies of the country, proper security arrangements, and compensations against currency devaluations, proper planning before project award and proper arrangement of funds are the incentives if adopted can result in lowering the effects of delays in construction industry. It was stated, however, that a specific vision and environment needs to be developed with stable political environment, sustainable fiscal policies in financial sector and long term planned accomplishments in the country which can only be achieved by serious efforts and cooperation of government authorities and construction industry stake holders (Gardezi et al., 2014). In another study regarding the effects of delays in the construction industry of Pakistan (Haseeb et al., 2011) it was suggested, in order to decrease delay in large construction projects, to diminish the changes in drawing during the construction; the contractors to increase productivity by increasing number of labors; the contractors must have knowledge about his resources strength and obtain up-to-date machinery; the contractors must manage the capital resources throughout the project and use it appropriately because he doesn't countenance economic and cash flow problems; for reducing delay managerial and technical staff should be acquired for site management and supervision; it is necessary to include skilled and experienced workers; the client must be fait on contractor and consultant; continuation of government development plans without changes despite changing in government; and adopting new ideas of construction from developed countries like China, Japan etc.

In a study regarding construction industry of Jordan it was suggested that liquidated damages should be enforced and incentives for early completion should be offered in projects; incentives should be given for the development and training of human resources on managerial skills, scheduling, time and cost control and information systems; contractors should be chosen based on their capabilities and past performance; and new approaches to contracting such as design and built should be explored (Odeh and Battaineh, 2002).

2.6 Summary

Chapter 2 presented the literature review of research work carried in countries other than Cyprus as to the causes of delay in construction projects and the proposed mitigation measures. Before the presentation of the results of the literature review, Chapter 2 illustrated a number of examples of projects that were delayed in order to highlight the effects of delay to society. The effects of delay can affect thousands of people in case they concern infrastructure projects in the fields of transport or energy. Delay in projects' completion may affect the quality of living when the projects concern public projects such as schools; delay in residential and hotel developments may cause a mere financial effect to the investors, or in the case a hospital is delayed human lives may be affected. Chapter 2 also includes an overview of dispute resolution procedures in Cyprus, and highlights their drawbacks. Construction industry suffers not only from the delays caused during the construction of projects, but also during the resolution of disputes related to the late completion of projects. This fact increases the losses generated by delays in construction projects. This is another reason for examining the causes of this problem and finding measures and practices that can be immediately applied for the mitigation or even avoidance of delay and disputes.

CHAPTER 3: DETERMINATION OF DELAY CAUSES AND MITIGATION MEASURES

3.1 Introduction

As seen in the previous chapters, the efficient understanding of the causes of disruption and delay in construction projects and identification of methods for their control has been the subject of numerous studies carried out by researchers and institutions related to the construction industry in various countries. The aims of such research endeavours are to identify the details behind the occurrence of a delay, and the causality of delays and disruption in construction projects.

According to current literature, the most frequently encountered causes of delay are ‘changes and variations by consultants’, ‘delay in payments to contractor’, ‘contractor's poor management ability’ and, ‘intervention and changes to design by owners’. Additional identified important causes of delay were ‘delay in issuing permits and approvals by government’, ‘incomplete documents and design errors’, ‘inadequate programme scheduling and improper planning’, ‘price inflation of construction materials’, ‘suppliers' incompetency to deliver materials on time’, and ‘subcontractors' poor performance and management’ (Abd El-Razek et al., 2008; Ahmed et al., 2002; Assaf and Al-Hejji, 2006; Doloi et al., 2012; El-Sayegh, 2008; Frimpong et al., 2003; Kumaraswamy and Chan, 1998; Le-Hoai et al., 2008; Memon et al., 2010; Muhwezi et al., 2014; Odeh and Battaineh, 2002; Orangi et al., 2011; Polat et al., 2014; Sambasivan and Soon, 2007; Zou et al., 2007). **To date, in Cyprus a similar research endeavor has yet to be carried out**.

Furthermore, current literature focuses on the identification of delay causes by considering the perceptions of the industry’s main stakeholders using statistical or empirical approaches. In most cases, delay sources are examined by computing relative importance indices (RII) on data acquired by means of questionnaires (Abd El-Razek et al., 2008; Doloi et al., 2012; El-Sayegh, 2008; Fallahnejad, 2013; Le-Hoai et al., 2008; Odeh and Battaineh, 2002; Sambasivan and Soon, 2007). For the quantification of the correlation degree between the stakeholders’ opinions with respect to delay causes, Spearman's rho (SR) is the most commonly used test along with Pearson's product-moment correlation coefficient (PPMCC) and Kendall's tau (KT) (Abd El-Razek et al., 2008; Assaf et al., 1995; Assaf and Al-Hejji, 2006; Doloi et al., 2012; El-Sayegh, 2008; Fallahnejad, 2013; Le-Hoai et al., 2008; Memon et al., 2010; Odeh and Battaineh, 2002; Sambasivan and Soon, 2007).

To date, only a small part of scientific literature provides recommendations on delay avoidance and control, and these are solely based on simplistic conclusions derived only by the ranking of the identified causes of delay. Furthermore, the anticipated impact and importance of these recommendations is not investigated, neither is the perception of the construction industry's main stakeholders on the expected impact of the recommended practices on delay avoidance. Such examination may illustrate the degree of acceptance of the suggested practices by all the involved parties, and hence, accelerate their application without disapproval by the stakeholders, or any further intervention. Ergo, this research suggests an integrated statistical methodology to identify the causes of delay and determine the most effective measures that can be applied with immediate acceptance.

3.2 Data collection - Survey Questionnaire

To identify the main issues related to the risk of delay and the most important causes of delays in Cypriot construction projects, a specifically designed survey was conducted. The survey questionnaire (Appendix I) covered issues related to the risk of delay such as the frequency of delay, delay frequency and duration, Extension of Time (EOT), delay disputes related issues, project monitoring and programming and, in great detail, the causes of delay.

Regarding the investigation of (a) the main causes of delays, and (b) the best practices for their avoidance or mitigation, initially a total number of nine (9) highly–experienced professionals were selected from all involved parties in a construction project (clients, contractors and consultants) and through an interview they were requested to name the causes of delay and disruption. The selection of the professionals was carried out in such way as to ensure maximum reliability and uniformity of the sample. Ergo, three professionals from each category involved in the construction projects were selected.

The interviews were carried out in the cities of Nicosia, Limassol, Larnaca and Paphos (four out of the six cities of Cyprus) and each had duration of approximately one hour. The opinions of the interviewees were plenty and overlapping and their number was found satisfactory. Eventually, 20 causes were identified as the main sources of delay and disruption in the Cypriot construction projects through the interviews and the examination of delay causes at the international level. Also, through an interview process they were requested to identify the causes of delay and possible measures and practices for their control and avoidance, regardless of their significance, according to their personal expert opinion.

To efficiently understand the severity of each source of delay and disruption, the survey participants were requested to characterize the impact of each cause separately using rating scale questions and more specifically Likert-type scales: on a scale of 1 to 5; (1) corresponds to a very high level of impact, (2) to a high level, (3) indicates an average level, (4) a low level and (5) shows a very low level of impact, respectively.

The causes and practices identified by the literature review were used in conjunction with the outcome of the nine interviews to develop the final questionnaire, which was distributed to 242 members of the Cypriot construction industry. In total 54 participants filled the survey, using either face-to-face or email, originating from the three main stakeholder parties; 16 professionals with the main role of the 'Owner' (ON), 14 acting as 'Contractors' (CR) and 24 acting as 'Consultants' (CS), occupying 30%, 26% and 44% of the sample respectively (see Figure 4).

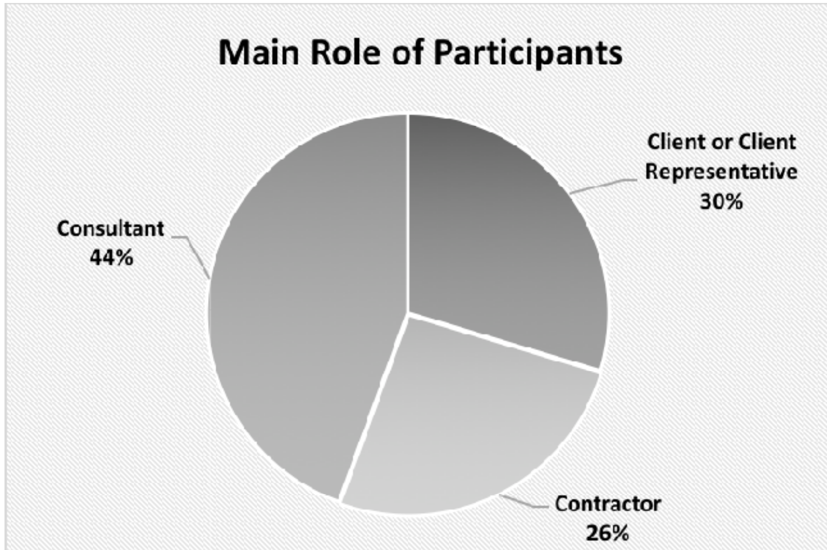

Figure 4: The main roles of the participants

For the sake of the participants' convenience, quick completion, effective compilation and analysis of the results, several types of questions were designed, mainly closed-ended types.

3.3 Determination of Delay Causes

The extraction of delay causes was carried out using rating scale questions, and more specifically Likert–type scales. Their design was done in such way as to avoid ambivalence and extract reliable information from the participants. A Likert–item possesses optimum psychometric properties, expressed in between four and seven response categories (Lozano et al., 2008). Likert scales with an odd number of response categories are preferable since the middle category may represent a neutral or average response (neither positive nor negative). In this research, a number of five response categories (1-5) was used, which is the more commonly used and convenient (Jamieson, 2004).

3.3.1 Dataset Reliability Testing

The degree of internal consistency of the collected data, in cases where multiple Likert-type questions are used in a survey, can be determined via a suitable reliability test. In this research, the reliability degree was measured using Cronbach's alpha (a) coefficient, also known as tau-equivalent reliability, which is more commonly used in psychometrics and relevant disciplines, and given by Eq.1:

$$a = \frac{K}{K-1} \cdot \left(1 - \frac{\sum V_i}{V_{test}}\right) \tag{1}$$

where K is the number of questions, V_i is the variance of scores on each question and V_{test} is the total variance of overall scores on the entire exercise. Reliability is considered low when a is less than 0.3, and high when its value is greater than 0.6 (Memon et al., 2014; Polat et al., 2014).

3.3.2 Ranking by Relative Importance Index

The derivation of the most significant causes of delay was based on the statistical analysis of the survey results. Specifically, Relative Importance Indices (RII) were computed for each delay cause to quantify the significance of each source. RIIs are commonly used throughout literature in similar Construction Management Research (CMR) surveys, which employ 'Likert-type' items (Abd El-Razek et al., 2008; Assaf and Al-Hejji, 2006; Aziz and Abdel-Hakam, 2016; El-Sayegh, 2008; Le-Hoai et al., 2008; Sambasivan and Soon, 2007). An RII is more frequently described by the following equation (Holt and Edwards, 2015):

$$RII = \sum_{i=1}^{n} \frac{W_i}{A_{\max} \cdot N} \tag{2}$$

Where n is the number of response points in the Likert scale; W_i is the sum of scores awarded to a specific variable x_i from N respondents, and $A_{\max}$ is the maximum integer value used in the response scale. Typically, W_i can be computed as the product of the number of respondents (N_i) that chose response value A_i multiplied by the response value A_i. Ergo, Eq.1 can be written as:

$$RII = \sum_{i=1}^{n} \frac{A_i \cdot N_i}{A_{\max} \cdot N} \tag{3}$$

By using relative frequency notation, i.e. the normalized frequency by the total number of responses (i.e. $f_i = N_i / N$), Eq. 3 can be written in the following form:

$$RII = \sum_{i=1}^{n} \frac{A_i \cdot f_i}{A_{\max}} \tag{4}$$

For the sake of convenience, RIIs can also be expressed in a simple percentage model, as:

$$RII(\%) = \sum_{i=1}^{n} \frac{A_i \cdot f_i}{A_{\max}} \times 100(\%) \tag{5}$$

Eventually, Eq.5 was used to quantify the significance of the causes of delay acquired throughout this survey. Consequently, all causes were ranked based on their respective importance index, and classified per involved party (owners, contractors, consultants) to determine potential correlation with regards to group's point of view.

3.3.3 Quantification of correlation degree between involved party rankings

The correlation, i.e. the potential agreement or disagreement vis-à-vis the delay cause importance between the involved parties, can be determined using a suitable test. In this research, ranking correlation is examined by means of the three most indicative methods; Pearson's product-moment correlation coefficient (PPMCC), Spearman's rho (SR) and Kendall's tau (KT). All three coefficients operate on bivariate samples, and are well defined in literature by the following equations (Xu et al., 2013):

$$r_p(x_i, y_i) = \frac{\sum_{i=1}^{n} (x_i - \overline{x}) \cdot (y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \overline{x})^2 \cdot \sum_{i=1}^{n} (y_i - \overline{y})^2}} \tag{6}$$

$$r_s(x_i, y_i) = 1 - \frac{6 \cdot \sum_{i=1}^{n} (P_i - Q_i)^2}{n \cdot (n^2 - 1)} \tag{7}$$

$$\tau(x_i, y_i) = \frac{\sum_{i \neq j=1}^{n} \operatorname{sgn}(x_i - x_j) \cdot \operatorname{sgn}(y_i - y_j)}{n \cdot (n-1)} \tag{8}$$

where: (x_i, y_i) data pairs drawn from a bivariate sample, n is the number of individual data pairs (x_i, y_i), P_i is the rank of the individual value x_i within the range $[x_1, x_n]$, and Q_i the rank of the individual value of y_i within the range $[y_1, y_n]$. All three correlation coefficients measure both the strength of association between variables x, y and the direction of their relationship. Concordantly, their values lie between -1 and +1, with +1 being a perfectly positive correlation, and -1 being a perfectly negative association. Evidently, values around zero, indicate a weak association. To date, PPMCC is the dominant method in the quantification of the correlation degree between bivariate normal samples due to its optimality in describing the intensity of the linear relationship between two variables that can be measured quantitatively (Hauke and Kossowski, 2011). However, there are cases where PPMCC can be undesirable or misleading; especially in situations where (a) data are described by ranks, (b) samples are affected by monotone transformations, and (c) samples are prone to outliers. In these cases, non-parametric tests, such as SR and KT are likely to provide more reliable conclusions. SR is a non-parametric, i.e. distribution-free, statistic that compares sample medians rather than means. Ergo, it is not affected by outliers and can be used with small samples (Croux and Dehon, 2010). SR is one of the most commonly used tests in literature for the determination of the agreement between owners, contractors and consultants with respect to delay causes (Abd El-Razek et al., 2008; Assaf et al., 1995; Assaf and Al-Hejji, 2006; El-Sayegh, 2008; Fallahnejad, 2013; Le-Hoai et al., 2008; Memon et al., 2010; Odeh and Battaineh, 2002; Sambasivan and Soon, 2007). It is a regular PPMCC in terms of the proportion of variability accounted for. KT is well-known measure of concordance between two rankings and can be used as an alternative to SR (Kendall and Gibbons, 1990). KT is inferred as the difference between the probabilities of two variables being ranked and not being ranked in the same order. Ergo, KT differs from SR, in the sense that the latter is a regular PPMCC.

KT's distribution has slightly better statistical properties, which can be directly interpreted as a probability of the concordance or discordance between the examined pairs. KT is based on the same assumptions as SR, but they are not equivalent in magnitude because of the different way they are computed. The relationship between the two correlation measures is described by Eq.9:

$$-1 \leq 3\tau - 2r_s \leq +1 \tag{9}$$

In general, the values of KT and SR should be close and depict similar conclusions. However, it is still unclear as to which method is more suitable in cases where the PPMCC may be misleading (Fieller et al., 1957; Gilpin, 1993). A disadvantage of non-parametric tests is that loss of information might occur when converting data to ranks. It should also be noted than in case of normally distributed variables, PPMCC is more powerful than SR (Gauthier, 2001). Ergo, in this research all three measures were computed to compare their performance with respect to the research findings and results.

3.4 Determination of Effective Delay Mitigation Practices

The investigation of the most effective practices to enable delay mitigation was addressed by a ranking-order question model. In total, 18 measures and practices identified from the literature review and the interviews were used in the questionnaire. The respondents were asked to select 12 out of the 18 measures and rank them from a scale of 1 to 12, with 1 having the greatest impact on delay avoidance, and 12 the least. This ranking approach was chosen instead of a Likert-type solution (e.g. independent grading of the importance of each practice in a 1-5 scale) because the main objective of this part is to evaluate the readiness of each stakeholder to apply a particular practice, rather than only estimate the perceived importance of this practice. Had a Likert-type form been used, the risk of ending-up with multiple practices having the same score would have been higher (Coe, 2002). For example, a respondent who believes that more than one practice are of the same importance will possibly attribute them with the same grade, therefore obscuring his readiness on applying a practice with respect to another. The integrated process proceeds in the following workflow i.e. dataset reliability testing, computation of relative importance indices for each practice, and determination of the correlation degree between the involved parties' answers.

3.5 Summary

Chapter 3 explains the methodology and process followed for the identification of the most important causes of delay and the measures and practices that have the highest acceptability and thus applicability in the construction industry of Cyprus.

The degree of internal consistency of the collected data, are determined using Cronbach's alpha (a) coefficient, also known as tau-equivalent reliability, which is more commonly used in psychometrics and relevant disciplines.

The derivation of the most significant causes of delay is based on the statistical analysis of the survey results. Specifically, Relative Importance Indices (RII) are computed for each delay cause to quantify the significance of each source. Similarly, RII importance index is computed to quantify the importance of each measure.

In this research, the degree of agreement between the participating parties, i.e. the ranking correlation, is examined by means of the three most indicative methods; Pearson's product-moment correlation coefficient (PPMCC), Spearman's rho (SR) and Kendall's tau (KT) correlation coefficients. This is done as an additional measure of convergence between the stakeholder views. Ergo, a breakdown of the overall importance index is carried out to the three stakeholder groups; owners (ON), contractors (CR) and consultants (CS). The three groups are treated as three separate variables, and their concordance is investigated in pairs.

Furthermore, Chapter 3 highlights the need for a smart tool that will aid efficient, unbiased and transparent record collection, and automatic communication of the results to all interested parties within the framework of a project. This is a crucial element towards more effective project management and decision making for delay and dispute avoidance and, if needed, a more effective and cheaper dispute resolution procedure.

CHAPTER 4: ANALYSIS AND RESULTS

4.1 Introduction

In order to understand the risk of delay in a construction industry, the overall understanding of the issues related to time in construction projects is essential. Based on the literature review carried out in Chapter 1, and the opinions of distinguished members of the industry, a survey questionnaire was designed and distributed to a total number of 242 members of the Cyprus Scientific and Technical Chamber. The analysis of the results obtained by 54 respondents indicated particular common-practice issues that affect completion in construction projects in Cyprus, such as duration of delays, Extension of time (EOT) awards and agreements, recording methods and programmes of works. The importance of delay causes and the applicability of delay mitigation measures were also examined by analysing the respondents opinion by means of an integrated statistical approach that considers the perception of the main stakeholders (i.e. owners, contractors and consultants) to identify commonly-accepted practices.

4.2 Time in Cyprus Construction Industry

4.2.1 Delay occurrence

Initially, participants were asked to define the percentage of construction projects they were involved where a delay has occurred. The findings illustrated the frequency of delays in Cyprus and were as follows; 28% of the participants stated that delays occurred in a percentage of 21-40% of the projects they were involved, 26% defined this percentage at the range of 41–60%, 17% answered that 61-80%of their projects were affected by delays, whilst 13% stated that delays occurred in more than 80% of the projects they were involved. It is noted that only 17% asserted that delays took place in to less than 20% of the projects they were involved (see Table 1). Evidently, the majority of the sample (56%) stated that delays occurred in more than 40% of times (41% - 100%) they were involved in a construction project.

Table 1: Delay Occurrence in projects

Delay Occurrence in Projects	**%**
Delay occurred in 0-20% of projects	17%
Delay occurred in 21-40% of projects	28%
Delay occurred in 41-60% of projects	26%
Delay occurred in 61-80% of projects	17%
Delay occurred in 81-100% of projects	13%

Further analysis of the results illustrated a significant difference between civil and structural engineering projects. Specifically, all participants involved mainly in civil engineering projects stated that they experienced delays in more than 20% of their projects. Consequently, there was no answer at the range of 0% - 20% of projects. On the contrary, in the case of structural engineering projects, the corresponding percentage is 18%. Ergo, it can be concluded that building projects in Cyprus have only a nearly 20% probability to be accomplished seamlessly, with no occurrence of delays whereas for civil engineering projects it is more probable that will face delay (see Figure 5).

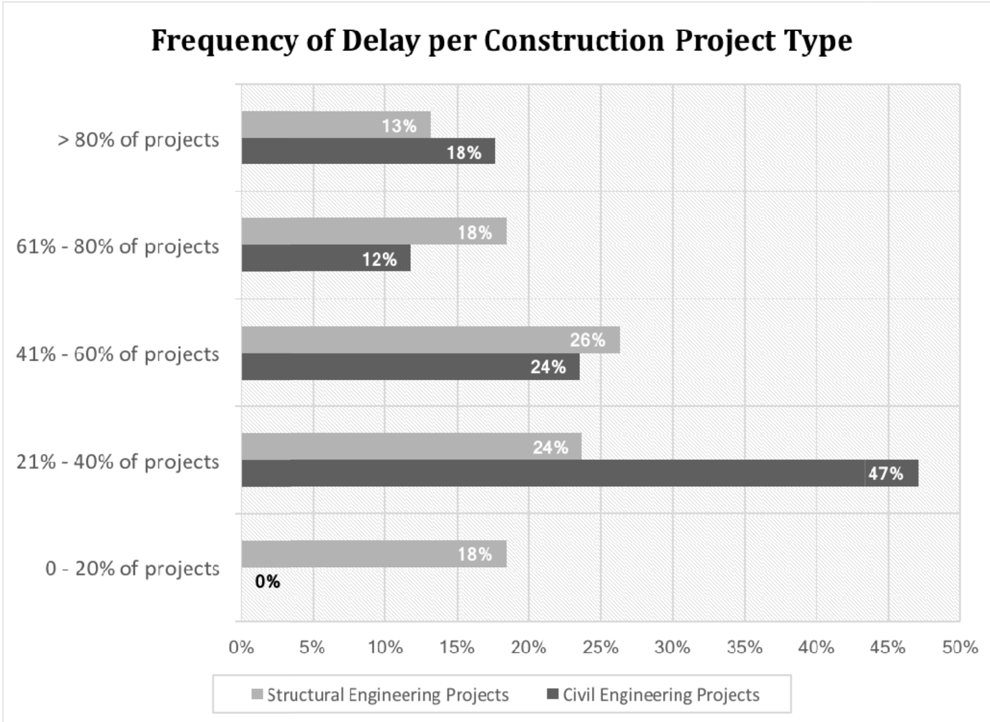

Figure 5: Delay frequency with respect to construction project type

4.2.2 Duration of delays

The duration of delays was the next subject of this research. 80% of the participants stated that the average duration of delay they experienced is up to 30% of the original duration of the project. Furthermore, this research showed that in 54% of times, a delay can occur with duration of up to 20% of the original contract duration for which the Contractors are exposed to Liquidated Damages (Table 2). 26% of the participants stated that they experienced delays of the order of 21% - 30%, whereas the remaining 20% came across delays of more than 30% of the original contract duration. This outcome translates to a significant amount that a Contractor would not be ready to accept without disputing the cause of delay and the Extension of Time duration awarded.

Table 2: Delay Duration in projects

Delay Duration in projects	%
0-10 % of original duration	28%
11-20 % of original duration	26%
21-30 % of original duration	26%
31-40 % of original duration	9%
41-50% of original duration	7%
> 50% of original duration	4%

4.2.3 Programme of works

The survey participants were asked to state the frequency and/ or occasions where the programme of the works is updated. From Figure 6, it can be seen that almost 13% of the participants answered that the programmes are never updated, whereas 57% stated that they are updated upon request of the Consultants or the Client. Note that only the 56% of the sample updates the programme when there is a delay event. The lack of a thorough programme review policy is further illustrated by a secondary question, which showed that only the 54% of the participants is using the critical path method in their programme planning.

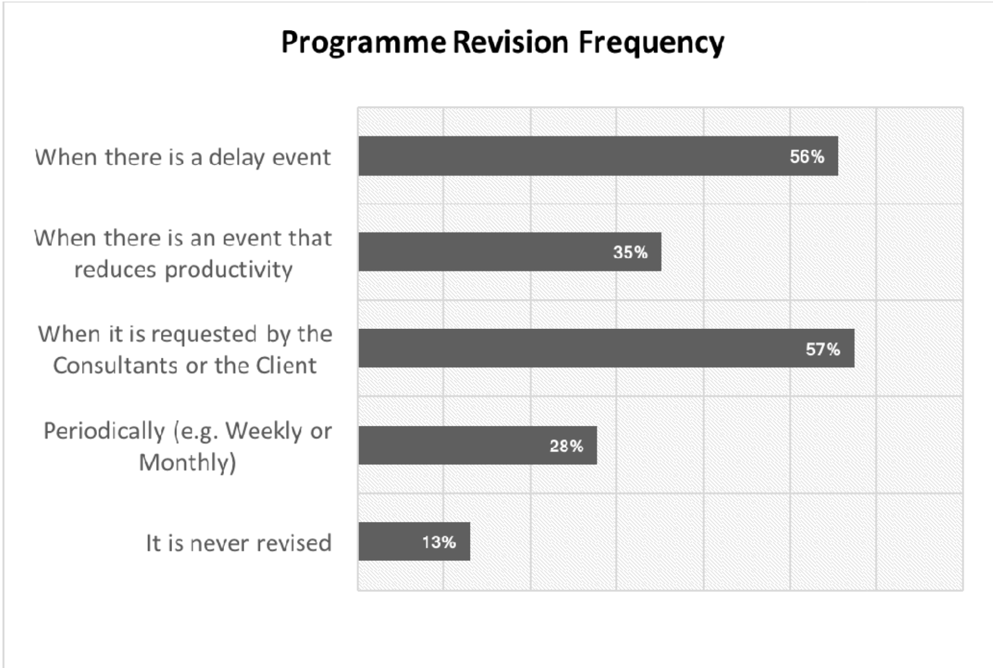

Figure 6: Programme revision frequency

The question of which software participants use for planning purposes (again multiple responses were allowed) was also addressed. 70% of the involved parties are using Microsoft® Project, and 41% Oracle® Primavera. There was no answer on the use of Elecosoft® Asta Powerproject or any other project management-oriented software. At the same question, 28% of the participants answered that they use Microsoft® Excel spreadsheets and, interestingly, 11% stated that they accomplish planning programme 'by hand'.

Table 3: Planning software selection

Delay Duration in projects	**%**
Microsoft® Project	70%
Oracle® Primavera	41%
Elecosoft® Asta Powerproject	0%
Microsoft® Excel	28%
By hand	11%

This finding is aligned with the conclusions of the 2008 Chartered Institute of Building (CIOB) study, which indicates that education and training required to prepare all involved parties in the management of time in construction projects is unsatisfactory (CIOB, 2008). Apparently, this issue is also detected in the Cypriot construction industry. Time in projects should be managed by planning engineers with a university degree. Professionals and managers involved in construction projects need to be able to understand the meaning of terms, such as critical path and the importance of programme updating. This can be achieved by educating the industry about the benefits and importance of correcting programming of works and monitoring the programme during the whole duration of the works.

4.2.4 Recording in construction projects

The methods used by the involved parties to record the progress of works in the frame of a project was also addressed (multiple options were allowed). More than 80% of the participants answered that they use conventional means, such as photographs, meeting minutes and correspondence. Only 57% use works programme updates, 48% prepare progress reports, 26% monitor activities' productivity, and 35% monitor the activities' progress and share the results (Figure 7).

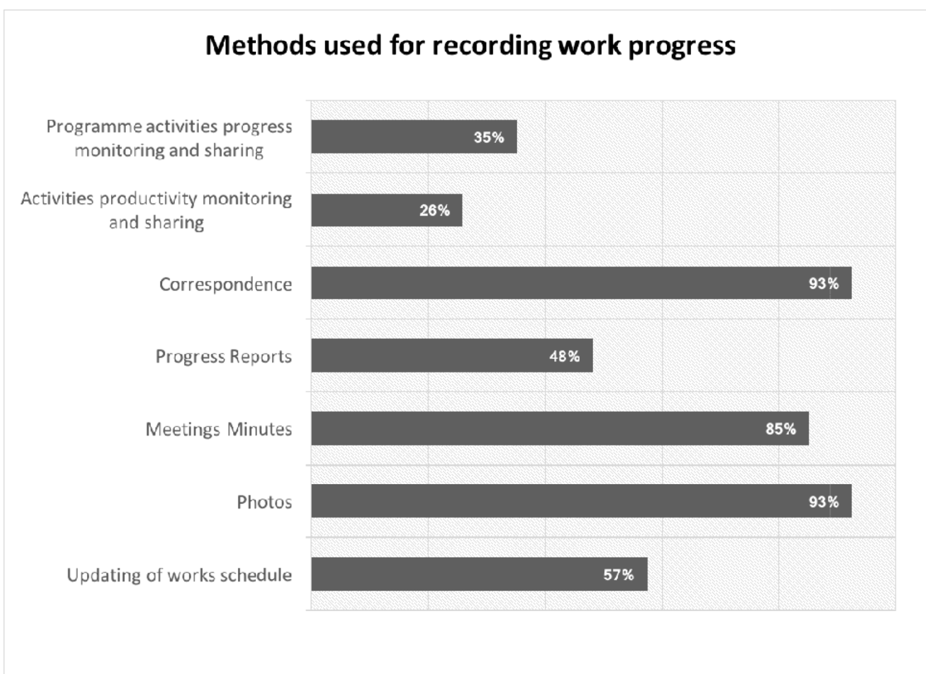

Figure 7: Recording of works progress methods

These figures exhibit that progress reporting, programme activities monitoring and progress updating are not applied to a satisfactory degree, so that early warnings for low productivity can be provided to be tackled before they develop into significant dispute issues. It is a fact that the quality of the contractor is important on applying measures for low productivity early identification and for this reason the quality and experience of the contractor should be taken into account during tendering and contractor selection process.

4.2.5 Extension of Time

In the case of large-scale projects, the amounts that the Client is entitled to be paid by the Contractor as compensation (Liquidated Damages) are extremely high. Consequently, this is a major source of disputes in the Cypriot construction industry; the amounts at stake for delay are of great significance, and the party liable for it, will not accept liability without disputing its causality.

The dispute resolution frequency was addressed by means of a specific question on whether the disputes on delay and Extension of Time award are settled until the delivery of the project. 53% of the respondents stated that disputes are always or usually settled until the delivery of the project, whilst and 46% stated mentioned that disputes are never or rarely resolved (see Table 4). Ergo, approximately half of the delayed construction projects in Cyprus will probably suffer from complications arising due to the inefficient national strategy on dispute resolution.

Table 4: Agreement of EOT award duration until the delivery of a project

Answer	Percentage
Always	7%
Usually	46%
Rarely	39%
Never	7%

4.2.6 Dispute resolution procedure duration

Depending on the contract, the disputes in construction contracts are resolved via arbitration or court proceedings. The standard form contracts for construction projects in Cyprus are based on JCT 63 (private building projects) or FIDIC 4 (public works).

More that 60% of the participants replied that the arbitration proceedings have a duration of up to 2 years, whereas most of the court proceedings last more than 3 years without taking into account the time spent on appeals (Table 5).

Table 5: Duration of arbitration proceedings

Answer	Arbitration Proceedings	Court Proceedings
1 - 12 months	28%	2%
13 - 24 months	33%	2%
25 - 36 months	15%	26%
more than 36 months	9%	41%
I do not know	15%	29%

4.2.7 Enforcement of Arbitral Award

The enforcement of an Arbitral Award is an issue that has not been investigated thorough so far. According to the participants' experience usually there is requirement for the Court's intervention for the enforcement of the Arbitrator's award (Table 6). This is possibly because the parties that have the obligation to pay the amounts of the award know that they can delay their payment without serious consequences. Therefore, it is preferable to retain the amounts in their accounts for as long as possible, taking into advantage the slow judiciary system of Cyprus.

Table 6: The Arbitrator's Award requires the Court's aid to be enforced

Answer	Percentage
Always	9%
Usually	54%
Rarely	11%
Never	4%
I do not know	22%

4.3 Determination of Delay Causes

4.3.1 Dataset Reliability test

The assessment of dataset reliability was carried out using Cronbach's alpha coefficient. Therefore, coefficient values were calculated for the total number of questions regarding the causes of delay and for each group of the respondents. As it is presented in Table 7 the value of a is 0.9238 for the total number of respondents (ALL), 0.9610 for the owners (ON), 0.8118 for the contractors (CR) and 0.9180 for the consultants (CS). Since all coefficients were higher than 0.6, the internal consistency degree of the collected data is considered acceptable.

Table 7: Cronbach's alpha values for the overall responses and the responses of each stakeholder (ON, CR, CL)

Group	Number of Respondents	Cronbach's alpha values (α)
Overall	54	0.924
Owners	16	0.961
Contractors	14	0.812
Consultants	24	0.918

4.3.2 Relative Importance Ranking of Delay Causes

In total, 27 causes of delay were selected from the interviews and the literature review for examination. To examine the importance of each source of delay, the survey participants were requested to characterize the impact of each cause separately on a scale of 1 to 5; (5) corresponds to a very high level of impact, (4) to a high level, (3) indicates an average level, (2) a low level and (1) shows a very low level of impact, respectively. To analyse the importance of the identified causes, a relative importance index (RII^k) was computed for each cause according to Eq. 5.

The computed RIIs are illustrated in Table 8. Note that this table shows the ranked delay causes according to the total number of responses and their corresponding RII for all participants of the survey (ALL) and per stakeholder party: owners (ON), contractors (CR), consultants (CS). Table 8 also contains an additional column for each delay cause ('Risk'), which identifies the risk of liability in the case of the occurrence of this cause of delay according to the standard forms of contracts normally used in Cyprus (based on JCT 63 & 80 and FIDIC 4).

Table 8: Main causes of delay in the Cypriot construction industry ranked by their overall importance index (ALL), and with importance index by the involved parties (ON, CR, CL)

Rank	Causes	Risk	RII (ALL) [%]	RII (ON) [%]	RII (CR) [%]	RII (CS) [%]
1	Changes by the Owner	Owner	77.78	67.50	85.71	80.00
2	Inadequate programming of works	Contractor	71.85	76.25	70.00	70.00
3	Mistakes and Missing Information from Consultants drawings	Consultant	69.26	63.75	82.86	65.00
4	Difficulties in Financing of the works by the Contractor	Consultant	67.41	70.00	58.57	70.83
5	Low productivity by Contractor	Contractor	67.41	71.25	65.71	65.83
6	Delayed Instructions by Consultants	Consultant	67.41	57.50	88.57	61.67

7	Problems between Contractor and his Subcontractors	Contractor	67.04	68.75	57.14	71.67
8	Inadequate experience by Consultants on specialized projects	Consultant	66.30	57.50	84.29	61.67
9	The involvement of a large number of parties	Neutral	62.59	67.50	67.14	56.67
10	Problems between Contractor and his Suppliers	Contractor	60.74	58.75	52.86	66.67
11	Payments Delay by Owner	Owner	60.74	51.25	70.00	61.67
12	Delay to responses by Consultants to requests of information	Consultant	60.37	48.75	81.43	55.83
13	Delay to responses by Owner to requests of information	Owner	60.00	52.50	75.71	55.83
14	Bad communication between Contractor and the other parties	Contractor	59.26	51.25	72.86	56.67
15	Low productivity of labour	Contractor	58.15	58.75	57.14	58.33
16	Works required by public authorities (Electricity, Water, Telecommunication)	Neutral	57.41	55.00	62.86	55.83
17	Delay to approval of final drawings by Owner	Owner	56.67	50.00	67.14	55.00
18	Delay to material approval by Owner	Owner	54.81	45.00	70.00	52.50
19	Delayed approval of material and sample work	Consultant	52.96	42.50	68.57	50.83
20	Suspension of Works by Owner	Owner	51.11	36.25	71.43	49.17
21	Delay in project delivery and possession by the Owner	Owner	51.11	50.00	51.43	51.67
22	Uniqueness of construction projects	Neutral	50.74	55.00	47.14	50.00
23	Non-availability/ breakdowns of machinery/plant	Contractor	47.78	41.25	60.00	45.00
24	Low productivity of plant/ machinery	Contractor	47.78	45.00	55.71	45.00
25	Bad weather	Neutral	42.96	38.75	50.00	41.67
26	Accessibility to site	Neutral	40.74	37.50	48.57	38.33
27	Accidents	Neutral	34.44	32.50	41.43	31.67

Based on the overall results, the most important identified sources of delay are the 'changes by the owners', 'inadequate programming of works', 'mistakes and missing information from consultants' drawings', 'difficulties in financing of the works by the contractor', 'low productivity by contractor' and 'delayed instructions by consultants', which are in line with the main sources of delay identified in the literature.

In the owners' perception, among the ten most important causes of delay there are five causes of delay with contractor owned risk, three with consultant owned risk, one with owner owned risk and one neutral cause of delay. According to the consultants' perception, among the ten most important causes of delay there are four causes of delay with contractor owned risk, four with consultant owned risk and two with owner owned risk. In the contractors' perception, among the ten most important causes of delay there are four causes of delay with consultant owned risk, five with owner owned risk and one cause of delay with the risk of occurrence owned by the contractor. Following the data, it can be initially observed that there is a high level of agreement in the perceptions of owners and consultants regarding the party that mainly owns liability for the delay caused in constructions projects. However, there is moderate level of agreement between the consultants and the contractors and low level between the owners and the consultants.

The aforementioned findings can be clearly illustrated in Table 9, which shows the ranking of the ten most important delay causes according to the answers of each stakeholder group. This table enables the study of each party separately, and foremost the comparison of their perception regarding the importance of delay causes.

Table 9: Main causes of delay in the Cypriot construction industry ranked by their importance index according to the perception of each involved party (ON, CR, CL)

Owners	Contractors	Consultants
Inadequate programming of works	Delayed Instructions by Consultants	Changes by the Owner
Low productivity by Contractor	Changes by the Owner	Problems between Contractor and his Subcontractors

Difficulties in Financing of the works by the Contractor	Inadequate experience by Consultants on specialised projects	Difficulties in Financing of the works by the Contractor
Problems between Contractor and his Subcontractors	Mistakes and Missing Information form Consultants drawings	Inadequate programming of works
Changes by the Owner	Delay to responses by Consultants to requests of information	Problems between Contractor and his Suppliers
The involvement of a large number of parties	Delay to responses by Owner to requests of information	Low productivity by Contractor
Mistakes and Missing Information form Consultants drawings	Bad communication between Contractor and the other parties	Mistakes and Missing Information form Consultants drawings
Problems between Contractor and his Suppliers	Suspension of Works by Owner	Payments Delay by Owner
Low productivity of labour	Payments Delay by Owner	Delayed Instructions by Consultants
Delayed Instructions by Consultants	Delay to material approval by Owner	Inadequate experience by Consultants on specialised projects
Inadequate experience by Consultants on specialised projects	Inadequate programming of works	Low productivity of labour

4.3.3 Correlation of stakeholder perceptions on delay sources

The degree of agreement between the participating parties was assessed by the computation of Pearson, Spearman and Kendall's correlation coefficients. This was done in order to evaluate the performance of each coefficient according to literature. A breakdown of the overall importance index was carried out in the three stakeholder groups; owners (ON), contactors (CR) and consultants (CS) according to Table 8. These three groups were treated as three separate variables, and their correlation was investigated in pairs. The results of the correlation tests are shown in Table 10.

Table 10: Correlation of delay cause importance per pair of involved parties using Pearson, Spearman and Kendall correlation tests

Pair	Test	Correlation Coefficient (r_p, r_s, τ)	p-value ($a = 0.05$)
ON – CR	Pearson (r_p)	0.329	0.009
	Spearman (r_s)	0.259	0.019
	Kendall (τ)	0.217	0.012
ON – CS	Pearson (r_p)	0.882	0.000
	Spearman (r_p)	0.906	0.000
	Kendall (τ)	0.748	0.000
CR - CS	Pearson (r_p)	0.538	0.004
	Spearman (r_p)	0.461	0.016
	Kendall (τ)	0.337	0.016

According to Table 10, there is strong to very strong agreement on the perceived sources of delay between the ‘owners’ and the ‘consultants’. All three correlation approaches agree and demonstrate, along with the findings from Table 9, that both parties consider the ‘contractors’ as the main responsible group for the occurrence of delay in construction projects.

This finding is further justified by the examination of the correlation of the second pair, ‘contractors’ vs ‘owners’. The results are uniform and indicate a low positive agreement. A moderate agreement is apparent between the perceptions of ‘contractors’ and ‘consultants’. It is noted that all three coefficients led to the same conclusions, with KT having the smaller magnitude. This was anticipated because of the different way KT and SR (and PPMC) are computed; i.e. KT is computed by the proportions of concordant pairs versus discordant pairs, whereas the calculation of SR is based on deviations between the ranks being compared. The results were further verified with respect to the relationship KT and SR should have according to Eq. 9.

It is apparent that through the years the opinion of the parties regarding the real causes of delay has been formed in such way that they hold the other stakeholder parties responsible. This fact restricts the industry from finding a clear way through practices and policies for delay and dispute avoidance. Evidently, there is an urgent need for setting out a map of practices and measures that will assist in avoiding the causes of delay and mitigating their impact in the unwanted case of occurrence. Research on the subject and education of the involved parties is deemed necessary and important.

By comparing the results to Figure 3, it is evident that the most important causes of delay in the Cypriot construction industry are aligned with the perceptions at the international level. However, two main differences are identified. Firstly, the cause 'delay in payments to contractor' that was one of the most important causes mentioned in the literature review is not considered as one of the most important in by the Cypriot respondents. In this case Cyprus is more in line with the countries with more developed economies since 'delay in payments to contractor' was not mentioned in the studies carried out in USA, UAE, Australia, Hong Kong and Norway (Ahmed et al., 2002; El-Sayegh, 2008; Kumaraswamy and Chan, 1998; Orangi et al., 2011; Zidane and Andersen, 2018). Secondly the 'inadequate programming of works' is considered by the Cypriot respondents as a very important delay cause whereas in the literature review was not mentioned as many times as other causes of delay. According to the literature review this perception in Cyprus construction industry is in line with the results of studies carried out in China, Turkey, Egypt, Jordan, Malaysia, Norway and India (Aziz, 2013; Doloi et al., 2012; Gündüz et al., 2013; Memon et al., 2010; Odeh and Battaineh, 2002; Zidane and Andersen, 2018).

4.4 Determination of the most effective practices

The survey participants were asked to select 12 out of 18 identified practices they consider that will have the most significant impact on the attempt to avoid and mitigate delays and subsequent disputes in construction projects. They were also asked to rank them in order of significance (i.e. from 1 to 12) giving 1 to the measure they think it will have the greatest impact on delay avoidance and 12 to the one with the least impact.

4.4.1 Relative Importance Ranking of Practices and Measures

Consequently, a relative importance index was computed to quantify the importance of each measure (RII^k) using Eq. 5. The results are shown in Table 11. The practices and measures are illustrated with their corresponding importance index and rank for all the participants of the survey (ALL), and for each one of the main parties; owners (ON), contractors (CR), consultants (CS), separately. Additionally, Table 11 provides the category each practice or measure belongs to.

Table 11: Ranking of practices and measures for delay control and avoidance

Practices and Measures	Category	Rank (ALL)	RII (ALL) [%]	Rank (ON)	RII (ON) [%]	Rank (CR)	RII (CR) [%]	Rank (CS)	RII (CS) [%]
Preparation of realistic programme of works with critical path method	Programming related	1	71.76	1	71.35	1	63.69	1	76.74
In the case a disruption event occurs the programme to be updated and distributed to all parties	Programming related	2	64.81	2	70.31	3	58.93	2	64.58
Complete design and construction details preparation by the Consultants prior the tender period	Design related	3	54.48	4	54.17	2	63.10	5	49.65
Periodical (weekly, monthly) update of the works programme according to progress of works, with all changes highlighted to all parties	Programming related	4	53.55	4	54.17	10	36.31	3	63.19
Frequent progress meetings with the participation of all parties	Communication and Cooperation related	5	52.01	6	53.13	4	52.98	4	50.69
Realistic tender preparation by contractors with consideration to all real costs	Tender related	6	40.43	8	35.42	8	37.50	6	45.49
Better materials supply management and control from the beginning of the project	Materials supply management	7	35.49	15	14.58	5	48.21	7	42.01

Monitoring of the progress and productivity of activities with smart modern technologies for early warning in the case there is reduced productivity or progress of works	Recording related	8	35.19	7	50.00	9	36.90	13	24.31
Introduction of frequent, clear and transparent updating of the parties for the works progress	Communication and Cooperation related	9	33.49	3	58.33	13	27.38	14	20.49
Use of alternative more productive methods and machinery in the case there is reduced productivity as compared to the planned	Recording related	10	33.49	10	32.81	6	44.64	12	27.43
Improvement of communication with the contractual use of a Project Manager.	Communication and Cooperation related	11	33.33	9	33.33	15	22.62	8	39.58
During the contractor selection attention should be given to the relevant experience of the companies	Tender related	12	32.87	11	31.25	7	38.10	11	30.90
Immediate and final resolution of any disputes occur during a project	Contract related	13	32.56	13	18.75	10	36.31	9	39.58
In the case there is a delay event, immediate EOT award	Contract related	14	27.93	14	17.71	14	25.60	10	36.11
Use of international design standards with specific design stages and deliverables	Design related	15	23.15	12	28.13	12	31.55	15	14.93
Introduction of applicable quick dispute resolution methods, including updating and improvement of Arbitr. Law (CAP.4)	Dispute resolution related	16	13.43	17	8.33	16	16.67	15	14.93

Use of alternative methods of procurement such as Design and Build	Design related	17	7.41	16	11.98	17	4.76	17	5.90
Introduction of compulsory Indemnity Insurance for Consultants	Design related	18	4.63	18	6.25	17	4.76	18	3.47

It is noted that the top ten practices with the expected greatest impact on delay mitigation and avoidance span across the categories of 'programming' (3), 'communication and cooperation between the parties' (2), 'recording and productivity monitoring' (2), 'tender-related' (1), 'design-related' (1) and 'material supply-related' (1). For the sake of clarity, a comparison of the practices and measures per stakeholder group ranking is illustrated in Table 12. This table facilitates the study of the perception of each party separately regarding the anticipated impact of each practice or measure.

Table 12: Ranking of practices and measures for delay control and avoidance according to importance as perceived by stakeholders (ON, CR, CL)

Rank	Overall	Owners	Contractors	Consultants
1	Preparation of realistic programme of works with critical path method	Preparation of realistic programme of works with critical path method	Preparation of realistic programme of works with critical path method	Preparation of realistic programme of works with critical path method
2	In the case a delay event occurs the programme to be updated and distributed to all parties	In the case a delay event occurs the programme to be updated and distributed to all parties	Complete design and construction details preparation by the Consultants prior the tender period	In the case a delay event occurs the programme to be updated and distributed to all parties
3	Complete design and construction details preparation by the Consultants prior the tender period	Introduction of frequent, clear and transparent updating of the parties for the works progress	In the case a delay event occurs the programme to be updated and distributed to all parties	Periodical (weekly, monthly) update of the works programme according to progress of works, with all changes highlighted to all parties
4	Periodical (weekly, monthly) update of the works programme according to progress of works, with all changes highlighted to all parties	Periodical (weekly, monthly) update of the works programme according to progress of works, with all changes highlighted to all parties	Frequent progress meetings with the participation of all parties	Frequent progress meetings with the participation of all parties

5	Frequent progress meetings with the participation of all parties	Complete design and construction details preparation by the Consultants prior the tender period	Better materials supply management and control from the beginning of the project	Complete design and construction details preparation by the Consultants prior the tender period
6	Realistic tender preparation by contractors with consideration to all real costs	Frequent progress meetings with the participation of all parties	Use of alternative more productive methods and machinery in the case there is reduced productivity as compared to the planned	Realistic tender preparation by contractors with consideration to all real costs
7	Better materials supply management and control from the beginning of the project	Monitoring of the progress and productivity of activities with smart modern technologies for early warning in the case there is reduced productivity or progress of works	During the contractor selection attention should be given to the relevant experience of the companies	Better materials supply management and control from the beginning of the project
8	Monitoring of the progress and productivity of activities with smart modern technologies for early warning in the case there is reduced productivity or progress of works	Realistic tender preparation by contractors with consideration to all real costs	Realistic tender preparation by contractors with consideration to all real costs	Improvement of communication with the contractual use of a Project Manager.
9	Introduction of frequent, clear and transparent updating of the parties for the works progress	Improvement of communication with the contractual use of a Project Manager.	Monitoring of the progress and productivity of activities with smart modern technologies for early warning in the case there is reduced productivity or progress of works	Immediate and final resolution of any disputes occur during a project
10	Use of alternative more productive methods and machinery in the case there is reduced productivity as compared to the planned	Use of alternative more productive methods and machinery in the case there is reduced productivity as compared to the planned	Periodical (weekly, monthly) update of the works programme according to progress of works, with all changes highlighted to all parties	In the case there is a delay event, immediate EOT award

4.4.2 Correlation of stakeholder perception on Delay Mitigation Practices

The degree of agreement between the participating parties was again assessed by the computation of the three correlation coefficients; PPMCC, SR, KT. This was done as an additional measure of convergence between the stakeholder views. Ergo, a breakdown of the overall importance index was carried out to the three stakeholder groups; owners (ON), contractors (CR) and consultants (CS) according to Table 11. The three groups were treated as three separate variables, and their concordance was investigated in pairs. The correlation results are illustrated in Table 13.

Table 13: Correlation of measure importance per pair of involved parties using Pearson, Spearman and Kendall correlation tests

Pair	**Test**	**Correlation Coefficient** (r_p, r_s, τ)	**p-value** ($a = 0.05$)
ON – CR	Pearson (r_p)	0.724	0.001
	Spearman (r_s)	0.660	0.003
	Kendall (τ)	0.502	0.004
ON – CS	Pearson (r_p)	0.711	0.001
	Spearman (r_s)	0.703	0.001
	Kendall (τ)	0.554	0.002
CR - CS	Pearson (r_p)	0.810	0.000
	Spearman (r_s)	0.774	0.000
	Kendall (τ)	0.616	0.001

It can be seen that in general there is a high correlation (> 0.5) on the perception of the three main stakeholders, which signifies common acceptance of the suggested measures. Apparently, the strongest agreement is detected in the 'contactor – consultant' pair (CR – CS), which probably is because these two main stakeholders of the industry have a more professional understanding of how the industry functions. The quantification of the general agreement may also be an additional check on the degree of direct applicability of the proposed practices. Evidently, a high correlation degree increases the probability of direct applicability of the suggested measures, without the occurrence of any sort of objection or further delay imposed by the involved parties.

By taking into consideration Table 11, Table 12 and Table 13 specific practices can be identified as the most effective and functional, which can be applied in the construction industry for delay avoidance and mitigation. Foremost, they can be employed with immediate acceptance by the industry, without any disapproval by any of the main stakeholders of the construction industry or any further interventions. Ergo, the practices identified by the statistical analysis are the following:

- Implementation of procedures for preparation of realistic programme of works with application of critical path method. Additionally, to the implementation of specific procedures, there could be a requirement so that time in projects is managed by planning engineers with adequate academic qualifications and experience;
- In the case a delay event occurs there must be a contractual requirement for the programme to be updated and distributed to all parties;
- There must be implementation of processes for periodical (weekly, monthly) update of the works programme according to progress of works, with all changes highlighted to all parties. Extending the implementation of such processes, the practice of periodical programme updating must be promoted by educating the members of the construction industry about its importance;
- Design stages completion strategy must be applied to ensure complete design and construction details preparation by the consultants prior the tender period;
- Frequent progress meetings with the participation of all parties must be obligatory during the whole progress of the works;
- There must be introduction of frequent, clear and transparent updating of all involved parties for the works progress;
- Monitoring of the progress and productivity of activities with smart modern technologies (UAVs equipped with high resolution cameras, mobile sensing techniques, digital photogrammetry, image processing, laser scanning, RFID, BIM techniques for 3D documentation, and time-lapse camera) for early warning in the case there is reduced productivity or progress of works can be applied;
- A methodology that will detect unrealistic tenders by contractors must be applied. Also, the contractors' financial condition during contractor selection must be examined so that it is confirmed that the contractor selected is in a

position to complete the project. Moreover, education of the contractors about the consequences of non-realistic tendering is required.

- The aforementioned changes must also be stimulated by continuous training organized by the professional bodies that form the construction industry, along with the participation of the related professional institutions and public authorities. These bodies have the influence and accessibility to inform the industry as to the long-term benefits of delay and dispute avoidance.

4.5 Summary

Chapter 4 presents an examination of the main issues related to the risk of delay in the Cypriot construction projects. This was accomplished by using the data gathered by a specifically designed questionnaire survey. The questionnaire was designed by using the results of the literature review on the causes of delay at an international level, along with the outcomes of interviews of nine distinguished, highly experienced professionals. All the participants were members of the Cyprus construction industry.

An integrated statistical methodology and workflow was used to identify both delay causes in construction projects and the practices to avoid or mitigate their effects, which are commonly accepted by all stakeholders with imminent applicability. The views of the three main parties (owners, consultants, contractors) regarding the main causes of delay and the practices that can be applied for delay avoidance and mitigation were analysed separately, and the correlation of their perceptions was investigated.

With respect to the origination of delay in projects, the examination showed that there is a high correlation between the perceptions of the owners and consultants, moderate correlation between the consultants and contractors and low between the owners and the contractors. By considering the risk of liability for each delay source, it was concluded that the lower correlation in the delay causes ranking perception is affected by the liability risk for delay under the contract. It is evident that through the years the opinion of each party regarding the real causes of delay has been formed in such way as to hold the other involved parties responsible.

Unlike their perceptions regarding the causes of delay, all stakeholder parties exhibit a high agreement with respect to the importance of the practices that can be applied for delay mitigation and avoidance. Based on the results, the practices, with which all three parties agree on their importance, were statistically identified and reported. It is evident that these practices can be applied immediately without acceptance issues by all major stakeholders.

The statistical methodology was tested using a dataset derived from the construction industry of Cyprus. Note that in Cyprus the construction industry mainly uses international standard form contracts (JCT 63 & 80 and FIDIC 4 based contracts) and, hence, embraces an international approach in contract procurement and management. In this way, the proposed methodology can be applied on an international scale.

CHAPTER 5: ARCHITECTURE OF A SMART DELAY CONTROL AND PRODUCTIVITY MONITORING TOOL

5.1 Introduction

It is evident that delays in construction projects, and subsequent disputes, claim a considerable part of the construction industry financing investments, including the public budget for infrastructure works, which otherwise could be invested in other projects of investors or the governing agencies. Additionally, delays in much needed infrastructure and of public interest projects affect and delay the improvement of life quality of the society itself. The current methods for project monitoring, control, delay analysis and dispute resolution are in many occasions inadequate, the cost of caused delay very high and the dispute resolution procedures end up being very expensive or faced with apprehension by the investors, public and officials.

The findings of the questionnaire research which is part of this thesis as well as current literature review show the severe need for improvement in project control, recording, works programme updating according to the progress of works, transparency and communication of important issues related to the works progress of construction projects. The number of the cases that delay is the origin of disputes could be substantially reduced by the introduction of a transparent and unified approach to the understanding of programmed works, their expression in records, and identifying the consequences of delay and disruption (CIOB, 2009; Society of Construction Law, 2017, 2002).

In a study regarding the construction project control in the UK (Olawale and Sun, 2015) it was found that 'Monitoring' is a weak link for both time and cost control. It was stressed that there is a lack of reliable systems to capture up to date information on work progress on site; and that control moves from 'planning' straight to 'reporting' with minimal involvement of the site management personnel. It was pointed out that there must be a formal reporting mechanism between the site and the office.

Based on the outcome of this research and the recommendations found in literature, a robust methodology for efficient and transparent construction project control was designed to act as an early warning system for possible delays, delay prevention, dispute avoidance and cheaper dispute resolution procedures for having sustainable and successful construction projects. The designed contemporary methodology utilizes modern technology tools to provide important and useful information, both spatial and descriptive, to a Geographical Information System (GIS) central server, or a Construction Central Server in our case, which in turn will be able to provide information reports as output regarding day-to-day and milestone issues related to the project works. In addition to the traditional means of recording data during a construction project (site diary, reports, correspondence, progress meetings´ minutes, drawings´ updates, variation instructions and site photographs), smart technology tools, such as smartphones, UAV technology with photometry, time-lapse cameras, RFID technology, satellite imagery and laser scanning, will be used for efficient and effective provision of information to the Construction Central Server.

Furthermore, a novel technique for construction plant (machinery) productivity monitoring by means of smartphones' inertial sensors was designed. Monitoring and assessing the works of construction plant during a construction activity can prove an important tool in improving the construction operations productivity by detecting reduced productivity and avoiding foreseeable delay. The advent of new intelligent multi-sensor portable devices, namely smartphones, introduced a new era in location awareness applications. Modern smartphones carry a multitude of sensors, such GNSS and inertial chipsets that not only enhance positioning performance but allow the identification of specific motion patterns of the bearer. Low-cost smartphone inertial sensors can be used in assessing the productivity of construction plants in construction works to promote project control.

The purpose of proposed system is to introduce a holistic approach in the use of smart technologies for the benefit of the investors, the public authorities, and consequently the public interest. The prevention of delays and avoidance of disputes can assist in saving investments and public funds wasted on extra payments for costs and losses inflicted by delays and promote effective dispute resolution procedures. Additionally, the system will assist in the timely delivery of important projects.

5.2 Existing knowledge

Transparency, clear visualisation and ease of retrieving information will allow early warning for possible delay and will minimise the existence of subjective allegations on liability and disputes.

5.2.1 Traditional means for project control

The current means of record keeping, and communication of works progress are namely the site diary, progress reports, project correspondence, progress meetings´ minutes, drawings´ updates, variation instructions and site photographs. These means do not reveal on-time reduced productivity, caused disruption or delay so that they can be efficiently controlled.

The progress of works is usually presented and monitored by the contractor by updating the initial programme, which is in the form of Gantt charts (see Figure 8). As it has been seen in the findings of the survey (see Section 4.2.3), 13% of the participants stated that they never update the programme of works. Only 28% of the participants stated that they update the works periodically and 35% when there is an event that reduces productivity. 56% of the participants stated that they update the programme of works when there is a delay event.

However as-built programmes may have uncertainties and inaccuracies, and there may be certain mistrust from the part of the receivers, including the courts, regarding the objectivity of the information (Gorse et al., 2005). Additionally, many interested parties that need to take important decisions related to the project progress may find it hard to visualise the progress of the works as described by Gantt Chart representations, and obtain an accurate position and location from text-based illustrations of a traditional schedule (Moon et al., 2014).

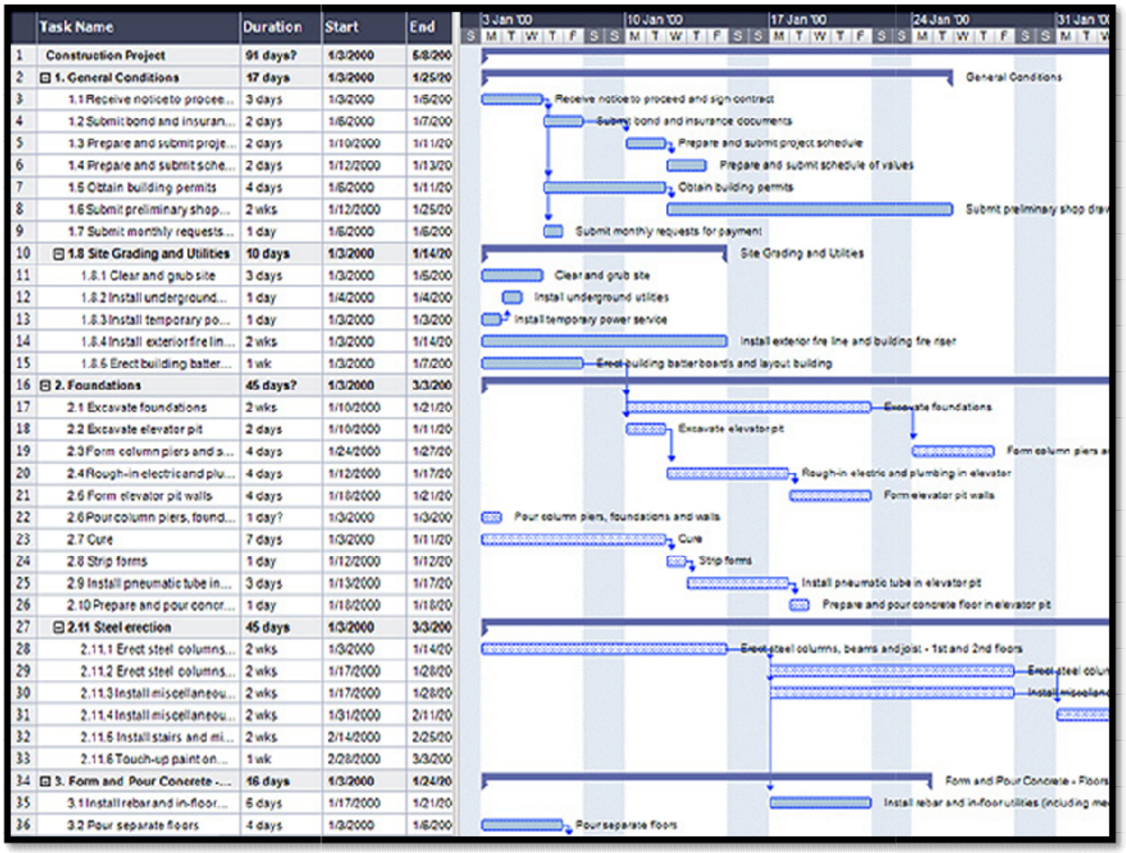

Figure 8: A typical works programme in the form of a Gantt chart.

At this point, the question that arises is whether there are any other alternative options that could provide efficient and transparent record keeping, to increase the effectiveness in project management and decision making in order to avoid delay. Can there be a framework able to increase the transparency of the construction process, and works progress to such a level that disputes will be avoided? In case of a dispute, is it possible to have the actual facts presented in detail before the arbitrator or adjudicator and, thus, decrease the duration and cost of the resolution procedure?

Modern technologies, initially developed for the military, science, business or other purposes, can be used for the acquisition of spatial or visual information of the works progress of a construction project. Such technologies are the following:

5.2.2 Unmanned Airborne Vehicles (UAV)

Until recently, Unmanned Airborne Vehicles (UAV), Unmanned Aerial Systems (UAS) and Remotely Piloted Vehicles (RPV), were mostly developed and used for military applications. These systems are remotely-controlled aircrafts or helicopters. With the recent availability of accurate and low-cost Global Navigation Satellite System (GNSS) receivers, the possibility opened up to maintain a UAV system's position in a global reference system nearly everywhere in the world and in real-time (Siebert and Teizer, 2014).

Figure 9: UAV used for the data collection

UAVs have undergone significant advances in equipment capabilities and now have the capacity to acquire high-resolution imagery from different angles in a cost effective, efficient manner. By using Metric Photogrammetry and Structure for Motion techniques, metric 3D information can be extracted. Distances, angles, areas, volumes, elevations, object sizes, and object shape within overlapping images are some of the many characteristics that can be determined using photogrammetric techniques (Adams et al., 2010).

UAV techniques have been used in order to examine damages on buildings because of hurricane events, and monitor the progress of roads and bridges (Ezequiel et al., 2014). UAVs are also suitable for a wide range of applications, particular in land surveying, façade construction, archaeological, cultural heritage, environmental applications, monitoring of a rock slide, management of construction site safety (Eisenbeiß, 2009;

Irizarry et al., 2012; Theodoridou et al., 2000). Images taken from UAVs have been used for the generation of 3D-models of existing buildings (Theodoridou et al., 2000).

However, although several researchers have previously introduced UAV technology to civil engineering applications, and it indeed promises to provide more cost- and task-efficient ways to conventional approaches, its performance in the construction environment has yet to be scientifically explored and evaluated (Siebert and Teizer, 2014).

With the stereoscopic images by the model helicopter, it is possible to obtain surveying products such as digital models of excavations' ground, linear designs in digital form and/or printed and rectified images. The derived digital files contain 3D information and can also be used in 3D modelling programmes for photorealistic computer representations. A whole UAV system that can be used for the generation of 3D models normally includes radio-controlled aerial photography with the help of a model helicopter, digital photogrammetry, image processing, and GPS for the measurement of checkpoints (Theodoridou et al., 2000).

5.2.3 Terrestrial Laser Scanners

Terrestrial laser scanning (TLS) once a high-tech, experimental and expensive technology, is now being steadily adopted on building sites. The rapid development of TLS and BIM in the construction industry offers opportunities for novel and effective ways of acquiring the 3D as-built status of a site and comparing it to the 3D as-planned status as defined in the project 3D (BIM) model (Bosché, 2012).

Laser scanning has been used in construction as a nonintrusive scanning technology for data retrieval (Tseng et al., 2002). A scanner seems to be feasible for use with a ground profile at a large construction site with a relatively demand for accuracy about less than 1cm@100m and for cost estimations to be made for interior renovation sites. Previous industrial applications were not suitable for data retrieval of large objects such as buildings until the recent development of long-range laser scanner (Shih and Wang, 2004).

Contrary to digital imaging, laser scanning actually acquires 3D data (point clouds), thus, despite their initial cost laser scanners present characteristics that are well adapted to project 3D status tracking, and thus can be used for progress tracking and dimensional quality control (Bosché, 2010). For this reason systems have been developed that use a 3D free-form shape recognition algorithm for automatically recognizing CAD objects in laser point clouds (Bosché, 2010 : Gordon et al., 2003).

5.2.4 Building Information Models (BIM)

The 3D imaging potential of the above tools is naturally interrelated with Building Information Models (BIM). Various visual representations of a project's schedule and associated information combined with visual representations of the project in progress (Tserng et al., 2014), can assist with tasks, such as record keeping and management, that can eventually assist in identifying effective construction strategies for managing a project's duration, and as evidence in dispute resolution procedures (Burr and Pickavance, 2010).

The rising importance and use of BIM is evident in the fact that the UK government has decided that all major construction projects in the public sector must be working with Building Information Modelling (BIM) technology since 2016. The drivers for the adoption of BIM as set out in the BIS BIM Strategy and the Government Construction Strategy are: (a) the reduction of the asset costs and achievement of greater operational efficiency, (b) the facilitation of greater efficiency and effectiveness of construction supply chains, and (c) the provision of assistance in the creation of a forward-thinking sector on which growth ambitions can based upon. The use of BIM has also been applied in China's construction industry and the government has promoted the development of standards so that the related industrial chains in the construction industry could share the application of BIM. The Chinese Ministry of Science and Technology has included BIM in the Outline of the National Long-Term Science and Technology Development Plan (2006-2020) and has been defined as an important project. Moreover, the Ministry of Housing and Urban-Rural Construction revised the construction standards to develop five BIM related standards (Sui, n.d.).

5.2.5 Time-lapse Photography

Time-lapse photography has been used for many years in the fields of astronomy, biology and botanic studies to study various phenomena. In effect, it is the use of photography to illustrate elapsed time in a still or moving image. In this way, it enables the observation of events and conditions in order to be evaluated in an easier and more consistent fashion (Brown et al., 2016; Vacanas et al., 2016).

In the recent years, the concept of time-lapse photography slowly started being used in engineering projects having as objective the creation of records with respect to time of a dynamic system placed at a particular, unchanging, physical location (Abeid et al., 2003; Han and Golparvar-Fard, 2017). Compared with progress reporting techniques, which generate words and numbers, techniques such as time-lapse photography and videotaping provide a rich data set that can be a good source for as-built data collection and act as good communication tools for progress monitoring amongst the project participants (Golparvar-Fard et al., 2009).

Time-lapse cameras placed in various positions of a project site, can create videos comprised out of photographs. These videos can be a modern version of the traditional "site diary" and provide general but important information of the project site during the project as well as in the future when required (Awolusi et al., 2018; Vacanas et al., 2016).

5.2.6 RFID technology

Radio frequency identification (RFID) refers to a branch of automatic identification technologies in which radio frequencies are used to capture and transmit data from a tag, or memory chips, embedded or attached to objects. Compared to barcode, RFID is more advantageous, especially for materials tracking, because it has larger data storage capabilities, it is more rugged, it does not require line-of- sight, and it is faster to collect data about batches of components (Navon, 2008).

RFID integrated with the global positioning system (GPS) can be used for machinery and human resources monitoring and material quantities tracking. RFID technology has already been used to uniquely identify precast components and to track and locate them using minimal or no worker input (Ergen et al., 2007), and to monitor the production, hauling and spreading of asphalt (Navon, 2005). Furtermore, RFID has been used for locating materials in a construction site using RFID and GPS, by scanning daily in detail to identify the location of materials on a given site (Song et al 2006). Costin et al. proposed the design and implementation of a wireless passive RFID technology system that was successfully implemented in a high-rise renovation project in order to record important project data for the analysis of efficiency of construction personnel, equipment and material (Costin et al., 2012).

5.2.7 Satellite Imagery

Satellite images have been used in civil engineering and construction industry for the study of rural constructions with respect to their subsequent reuse (González et al., 2006), detection and monitoring of the land use and land use changes to provide accurate and timely information for planning and management (Deng J.S. et al., 2009), and for mapping and monitoring land-cover (Rogan and Chen, 2004).

Satellite imaging technology can be used for automated progress measurement and online progress reporting of repetitive construction tasks in linear infrastructure projects. Satellite imaging technology systems can be used as verification tools which can provide the overall progress information in an automated and quick process. In particular, such tools can be useful for client and top managers to verify the progress data produced by contractors (Behnam et al., 2016).

Behnam at al. proposed a system, which could derive the key repetitive construction stages using multi-sensor and multi-temporal satellite imagery. Furthermore, the system could perform extraction of information automatically, prior to populating and updating a spatiotemporal GIS database. The suggested system integrated a database with the planned schedule in order to provide the inputs for measurement and documentation of the construction progress, which could be then visualised using progress map and location-based reporting techniques on a web-based platform (Behnam et al., 2016).

Satellite images can be used to some extent for the works progress monitoring of large-scale construction projects in a macro scale approach. However, new satellite sensors with 25cm pixel resolution launched in 2016, provide even higher spatial resolution satellite data to the end-users.

5.2.8 GNSS-Mobile Technology

Global Navigation Satellite Systems (GNSS) tend to be a panacea in addressing positioning needs. Electronic devices such as smartphones or tablets integrate GNSS receivers to deliver position information in a wide area of applications ranging from safety of life (SoL) to leisure activities (Danezis and Gikas, 2012). The combination of

GNSS and mobile technologies enables the documentation of movement trajectories of construction resources (personnel, equipment, and materials).

Documenting the movement of construction equipment is helpful in controlling and continuously improving construction operations. Specifically, documenting the trajectories of construction resources can allow the analysis of travelling patterns of construction workers, assess equipment operators' work, labor activity, or study variability in construction processes (Vasenev et al., 2014).

Mathur et al. attempted to improve performance of excavation equipment fleet operations by estimating their cycle times with the use of three-dimensional acceleration data gathered from smartphone inertial sensors (Mathur et al., 2015).

5.3 Construction Site Experiment 1 - Exercise in 3D illustration of the works progress by using BIM and UAV technologies

5.3.1 Use of UAV and BIM technologies for record collection and 3D imaging for progress of works monitoring

Collecting progress information of a construction project can be expensive and complicated. The required on-site progress data collection is normally carried out by the contractor's engineers on site, and the site works progress is recorded by updating the project programme manually, backed up by photographs, the site's diary, progress meetings minutes and correspondence (Vacanas et al., 2015). The integrated use of UAV and BIM technologies could be used so that that contractors can obtain and manage as-built data more effectively and efficiently. BIM technology, with the particularly useful 3D illustrations it provides, can support the monitoring and management of the progress of works. Furthermore, UAV can be incorporated to this tool in order to provide more accurate and efficient collection of data.

BIM technology can be used to illustrate a project's as-built information in 3D and enable all the involved parties appreciate the actual works progress and identify possible causes of delay. The project managers can also utilize this information to take appropriate decisions in order to avoid or reduce the effect of such delay events.

Furthermore, even in the event of a delay, if the cause and effect is illustrated in a clear manner, the parties will accept their share of liability and disputes will be avoided.

5.3.2 Use of UAV and BIM technologies in dispute resolution

Visual means are not strange to dispute resolution proceedings, since courts and tribunals have had photographic evidence before them in the frame of construction cases since at least 1875. Computerised visualizations have become relatively easy and cheap to produce using modern computers and software, and 3D and 4D animations in identifying causation in construction disputes as visual narratives and as evidence, and in various cases animations were used successfully in resolving the cause and effect of disruption in complex scenarios (Pickavance, 2005).

5.3.3 The Construction Site Location

The project revolves around the creation of an artificial lake at the west end of Limassol. The main construction works are excavation, backfilling and formation of ground, road and pavement construction, and construction of reinforced concrete elements of the project. The area of the project is 20.000 m^2 and attention was paid to the construction of the road at the east side of the project as shown on Figure 10.

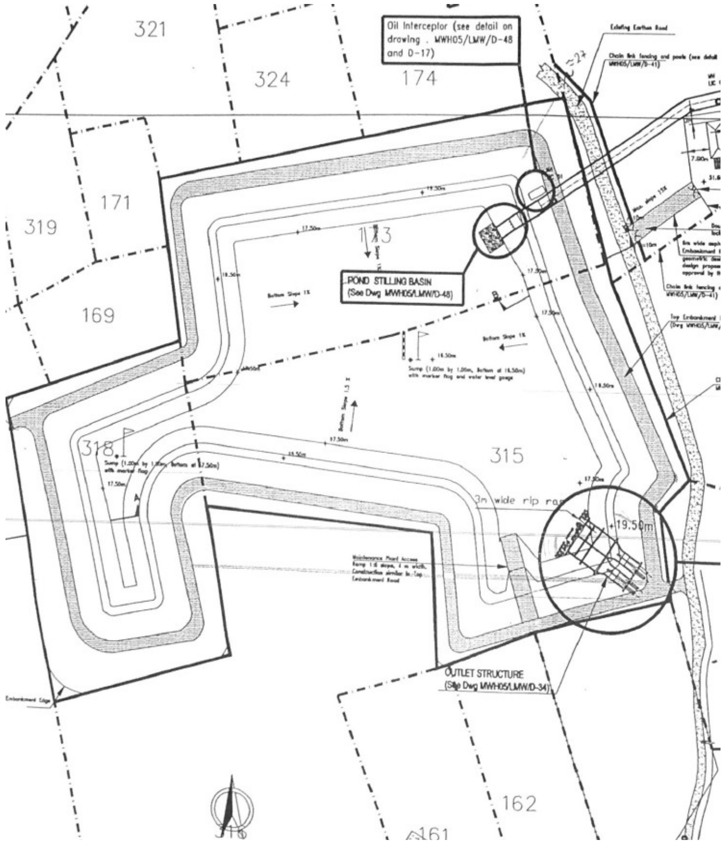

Figure 10: The construction site - a plan view construction drawing. The east road was studied for the purposes of this research.

Figure 11: The construction site.

5.3.4 Combined use of UAV and BIM technologies

For the gathering of the required data the following instruments were used:

- UAV quadcopter
- Camera: The data have been collected using the GNSS Leica Viva+ sensor with an accuracy of less than 2 cm (in 3 dimensions).
- GPS/GNSS: GPS/GNSS was used to determine the coordinates of ground control points (GCPs).

Figure 12: The UAV quadcopter with GNSS Leica Viva+ sensor with an accuracy of less than 2 cm (in 3 dimensions).

The quadcopter was flown at a height of 10-30m above ground for about 15 minutes, and orthophotos were taken with an accuracy of around ±2 cm (in 3 dimensions). The orthophotos provided the data required for the generation of the 3D images.

Figure 13: Orthophotos taken from the scene of the project

Site ground control points (GCPs) had been measured earlier. These GCPs were used to establish a GCP network in order to correct and geo-reference the images obtained from the UAVs flights. The collected data were used to render 3D illustrations of the construction site.

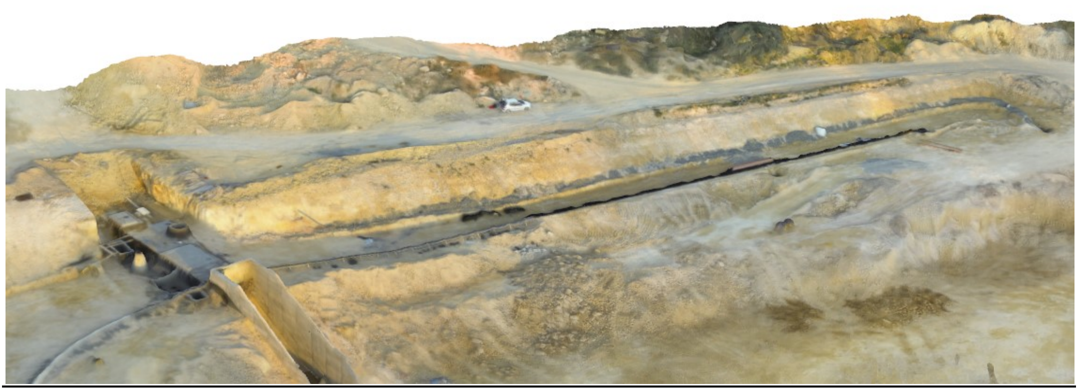

Figure 14: The road 3D image derived from the data.

The undertaken exercise enabled the generation of BIM-compliant information, which is an integral part of the construction industry and it is considered as very useful in all phases of a construction project. Its ability to give clear and dynamic visualisation and illustration of the works progress can play a vital role in effective project management. UAV technology has also been used in the construction industry for the efficient execution of various tasks. An integrated use of BIM and UAV technologies may well comprise an alternative process that will enable an efficient and accurate as-built data collection and clear 3D illustration of the works progress during an infrastructure construction project.

5.4 Construction Site Experiment 2 - Assessment of the ability of smartphone technology for monitoring productivity of plant with cyclic operation

5.4.1 Productivity measurement in cyclical construction activities

Monitoring productivity can give information on the disruption of the normal progress of works because of the occurrence of a delay event. Also, it is generally a common ground of approach that in order to improve productivity, we must be able to measure it. The measured values of productivity can then be compared either to those used to compile the estimate or to some production standards (Dozzi and AbouRizk, 1993).

Based on this approach there has been considerable research work on methods for measuring and monitoring productivity of activities. It has been noted that many engineering and construction projects are based upon repetitive or cyclical processes, such as concreting or earthmoving. Successful planning of these processes can result in considerable amounts of time and money being saved over the duration of a project (Graham and Smith, 2004).

Repetitive, cycling operations can be monitored and controlled with automated collection of data by using new technologies. Moreover, the need for the automated monitoring of the construction works on-site is significant since supervisory personnel allocates a major part of its time in recording and analyzing field generated data using traditional means and the quality of records is not consistent and constant (Navon et al., 2004).

5.4.2 Automated productivity monitoring of Excavation works

Earthworks and earthmoving operations are a major part of many civil engineering construction projects. Because of their labour and plant intensity, the planning and estimation of such operations is crucial to both the cost and duration of the project; earthworks are considered by many practitioners to be indicators of the success or failure of the project as a whole (Smith et al., 2000).

Earthmoving operations are performed under conditions that may give rise to uncertainty, such as equipment breakdown, inclement weather, unexpected site conditions, bad operator skills and unmotivated operators (Edwards et al., 2007; Filipsson and Eriksson, 1989; Marzouk and Moselhi, 2003). Also productivity depends on certain factors such the capacity of the plant used, the swing angle, the relative position between the plant and the soil to be excavated and the digging depth in relation to the machine's maximum depth capacity (Tam et al., 2002). Prediction of the productivity at any activity, including excavation is essential for realistic planning of the works. By having an efficient and easily accessible methodology for monitoring the productivity of excavators, studies could be conducted to examine the factors that affect the activity of excavation.

Navon et al for example examined the automated measurement of the locations of all members of a fleet of earthmoving equipment by means of GPS and produced real-time control data for the determination of the activity an equipment is engaged in and its productivity. In this way, the computed productive can be compared with the planned one to give an early warning on deviations as they occur to achieve timely analysis of the causes of delay (Navon et al., 2004).

Productivity monitoring is important to determine productivity reduction during works as a preventive measure for delay. In the occurrence of a delay, records will be required to examine the cause and its impact. Moreover, because comprehensive cycle time data for excavation works is partially available (not every plant manufacturer provide this kind of information), accurate prediction of hydraulic excavator productivity is difficult. Edward and Holt attempted to predict the productivity of hydraulic excavators calculating the cycle time, where one 'cycle' has been defined as (a) excavation, (b) swing of loaded bucket to a target, (c) dumping time, and (d) swing back to original position with bucket empty, and they, furthermore, developed an equation that could predict the excavator productivity by taking into account the machine weight, digging depth and machine swing angle (Edwards and Holt, 2000).

Attempts for productivity monitoring were made by using stop watches, instrumented vehicles and simulation models. All methods have certain disadvantages. Vehicle instrumentation provides an overload of data and the benefit of a large data set is lost, and in the stopwatch method the analysis process becomes seriously flawed without statistically sufficient data (Kannan and Vorster, 2000). The conventional method —a calculation by intuition— for devising such estimates has been considered as laborious and inaccurate (Graham and Smith, 2004). Instrumented vehicles have been used as the medium to generate data, however there are some concerns associated with instrumented vehicle with the primary one being cost. Also instruments are fixed and they cannot be moved easily form a vehicle to another (Kannan and Vorster, 2000).

Researchers were involved in simulating earthmoving activity in order to aid the works management, improve productivity, predict earthmoving operations and study the various factors influencing productivity (Chao, 2001; Kim and Gibson, 2003; Marzouk and Moselhi, 2004, 2003; Tam et al., 2002; Zhang, 2008). Also attempts were made for the development of systems for construction practitioners to predict earthmoving operations by using data patterns obtained from simulation because of limited data availability from industrial sources (Shi, 1999). These simulation systems allow the project managers to evaluate complex construction operations, including excavation works, under different conditions and produce a more reliable prediction of the operation performance for more efficient operation designs, and it is considered that the use of construction simulation has high potential as a construction management tool (Kim and Gibson, 2003; Marzouk and Moselhi, 2004, 2003; Zhang, 2008).

Examination of the actual excavation activity via simulation has been contacted by Chao on the production rate of an excavator with a certain tool capacity, by considering the cycle times achievable in given physical job conditions and its repositioning times incurred during the operation (Chao, 2001). The capacity of an earth-moving operation was assessed with respect to physical factors only, without considering any management delays. Chao considered as a cycle of the excavator to consist of (a) swinging the bucket to a cut location, (b) digging and loading the bucket, (c) swinging back to the truck, and

(d) dumping the bucket load. It was also considered that a cut location is defined by the depth of cut and swing angle from the truck.

Although the above new technologies can contribute to the study of productivity, there is a lack of a methodology that could allow the uncomplicated and non-expensive in-situ monitoring of excavation plant productivity. Early warning innovative methods with the exploitation of modern technologies can help to monitor the productivity of the machinery on-site.

5.4.3 GNSS and Smartphone sensors technology

The combination of GNSS and mobile technologies allows documentation of the movement trajectories of construction resources (personnel, equipment, and material).Documenting the movement of construction equipment during construction projects is helpful in controlling and continuously improving construction operations. Specifically, documenting the trajectories of construction resources can allow the analysis of travel patterns of construction workers, assess equipment operators' work, labor activity, or study variability in construction processes (Vasenev et al., 2014).

GNSS is a self-contained navigation system capable of providing absolute positions around the Earth and in all weather conditions, in areas prone to impertinent or difficult satellite signal reception it can fail. Such areas are usually found in the urban road environment, in tunnels and in large-scale, multi-storey parking facilities and depots, which are of particular interest in this study. In cases of limited satellite availability, various augmentation schemes are used to integrate additional information to provide viable location information (Antoniou et al., 2015). Because of the importance of record keeping, various instruments using GNSS have been developed in the construction industry that can be placed on construction machinery in order to measure their productivity, but these instruments are expensive to acquire and use. A less expensive methodology should be derived using GNSS that could assist in productivity measurement in excavation activities.

It has been suggested that sensors, which are currently available in most modern smartphones, such as accelerometers and gyroscopes, can be used to directly obtain information about the driving patterns of the individual driver. This information can then be used to develop insight into the driving behaviour of the driving population. For example, driving patterns along different terrains and network features could be developed, allowing the operator, for the specific conditions, to identify abnormal driving behaviour (Antoniou et al., 2015). These sensors could be used to identify the various typical movements of construction plant, such an excavator for example, and thus use them to document the productivity of the machinery. The classification of the various actions of a hydraulic excavator (CAT 330CL) using smartphone accelerometer sensor based approach has been attempted, by calculating the cycle time of the excavator from data classification results for various cycles (Mathur et al., 2015).

5.4.4 Examination of smartphone technology at a construction site

The potential use of GNSS and smartphone Mobile Sensor technologies for the examination and documentation of the works productivity was examined at a project construction site with earthwork operations. Principally, the project works were designed to increase the stability of a slope on the side of the highway road connecting the cities of Paphos and Limassol in Cyprus (Figure 15, Figure 16).

Figure 15: Satellite photo of the construction site.

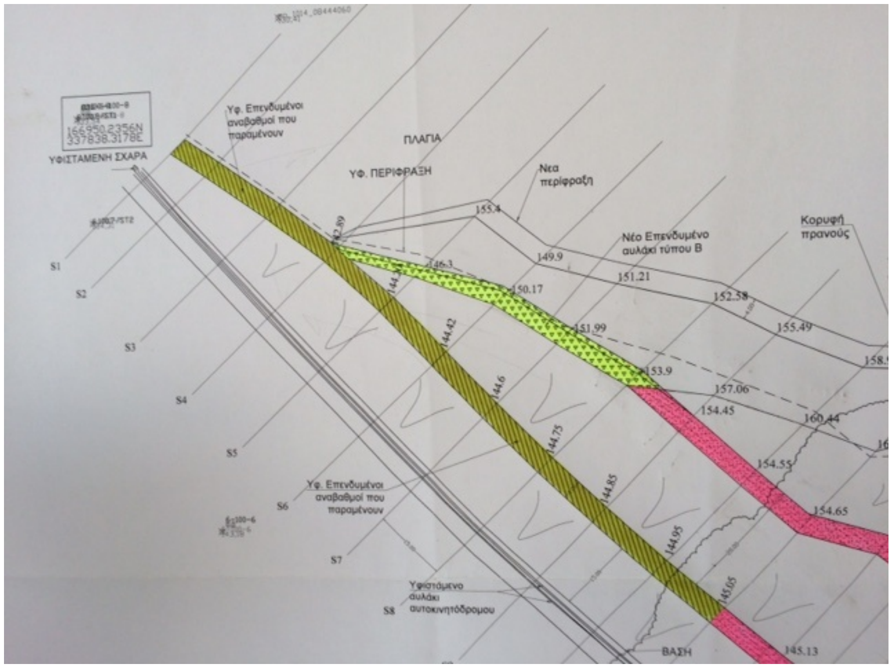

Figure 16: Construction drawing of the works.

The presented study concentrated on the behaviour of the excavator while it was executing excavation and earthmoving activities. The data was collected on January 28th, 2016.

It was observed that certain construction activities were executed in a constant periodic manner such as excavation and earthmoving, involving an excavator and two dump trucks, and the productivity of these activities could be documented for examination. Smart phone sensors measuring and documenting the acceleration and gyro on axis Z were used to investigate the possibility of estimating plant productivity by using GNSS and smartphones.

Three smartphones were placed in three different positions of the excavator: one Samsung Galaxy Note 4 (SGN4) at the arm, one Samsung S6 (S6) in the cab of the excavator and one LG G4 (LG4) on top of the engine at the back of the excavator, in order to investigate particular actions during its activity (see Figure 17).

Three main activities were observed to be periodical and repetitive: (a) excavation, (b) lifting of the soil material and turning towards the truck, and (c) releasing the material in the truck. These activities were examined by studying the dynamics of the vehicle using the measurements of the accelerometer and gyro sensors of the smart mobile phones.

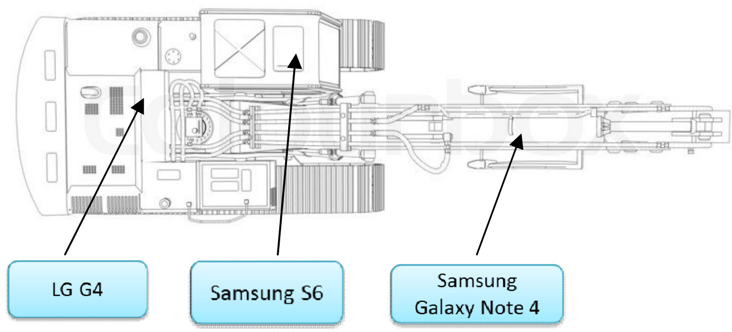

Figure 17: Smartphones positions on the excavator

The periods for each of the three main excavation activities were studied on site and examined as documented on a video (Figure 18). The video was used to record the duration of the period for each activity so that it could be compared with the sensors data (Table 14).

Figure 18: Frame from the video documentation.

Table 14: The three different repetitive periodic activities observed from the video.

Excavation (h:m:s)	Lift and Turning (h:m:s)	Releasing (h:m:s)
13:30:49	13:30:58	13:31:11
13:31:21	13:31:29	13:31:45
13:32:02	13:32:09	13:32:21
13:32:38	13:32:49	13:32:57
13:33:09	13:33:20	13:33:28
13:33:34	13:33:43	13:33:52
13:34:56	13:35:05	13:35:13
13:35:24	13:35:34	13:35:47

5.4.5 Data Collected by the Sensors of the three different smart phones and results

The sensors of the smart phones collected a number and variation of information: acceleration in axis x y z, gyro in x y z, gravity, latitude, longitude, altitude, date & time and time since start. For the purpose in examination, only the measurements of the Accelerometers and Gyro in axis Z were considered.

The LG4 sensors gathered 45586 records per sensor corresponding to a time span of 76 min (13:15:42 - 14:31:40). The S6 sensors gathered 40149 records per sensor corresponding to a time span of 67 min (13:22:56 - 14:29:51). The SGN4 sensors gathered 36360 records per sensor corresponding to a time span of 64 min (13:24:57 - 14:29:04) (Table 15). For all three devices the data were collected every, approximately, 10ms.

Table 15: The records gathered for each of the three smart phones.

Smart phone Model	Records (number)	Time Span	Sampling Rate (Hz)
LG4	45586	13:15:42 - 14:31:40	50
S6	40149	13:22:56 - 14:29:51	50
SGN4	36360	13:24:57 - 14:29:04	50

Because of the large number of data the study was concentrated on a period of 3 minutes (180 seconds). With careful comparison of the video documentation it was observed that these measurements can provide a visual presentation of standard activities of the excavator, such as the activity of the excavator lifting the soil material and turning towards the truck. The main activities observed in the time-frame studied are shown in Table 16.

Table 16: Periods of the three main activities.

Excavating (h:m:s)	Lift and Turn (h:m:s)	Releasing (h:m:s)
13:34:56	13:35:05	13:35:13
13:35:24	13:35:34	13:35:47
13:35:58	13:36:05	13:36:15
13:36:23	13:36:35	13:36:49
13:36:58	13:37:09	13:37:22
13:37:28	13:37:35	13:37:49

By using the data in these 3 minutes, graphs of the gyro (gyro Z) and accelerometer (AccZ) data in axis Z were produced against time (Figure 19, Figure 20).

Figure 19 shows the gyro measurements of the three devices. It can be observed that the measurements are comparable between them and they respond similarly to the rotation of the excavator. A complete periodical cycle can be observed in the approximate time span 13:35:24 - 13:35:58, which confirms the video observation shown in Table 2. At approximately 13:35:24 the excavation commences until 13:35:34. At 13:35:34 there is a rotation of the excavator against axis Z which stops at 13:35:47 when the material is released in the truck. After that, again, there is rotation against axis Z in the opposite direction until approximately 13:35:58 when excavation starts again. Clearly there is a correlation between these repetitive cycles of works which can be observed by using the gyro sensors of the smart phones used. The fact that there is a correlation of the results of three different smart phones additionally provide a strong basis for further examination of the capabilities of mobile smart phone sensors for productivity measurements of excavators in construction sites.

Figure 20 shows the acceleration measurements of the three devices. It can be observed that the alteration in acceleration measurements is comparable between them in terms of change, but the alteration of acceleration in magnitude is much higher in SGN4. One of the causes for this difference is probably the position that the device was placed (the arm of the excavator). However further examination will be carried out because there may be a difference in the way the accelerometer of the particular smart phone responds. Also it is obvious that there is a lot of noise that needs to be cleared before secure conclusions. In the time span 13:35:24 - 13:35:58, a complete cycle of the periodic movement can be observed as described above using the gyro results. Despite the levels of noise in the graphs the magnitude of change in the acceleration measurements show that the results are comparable to that of gyro.

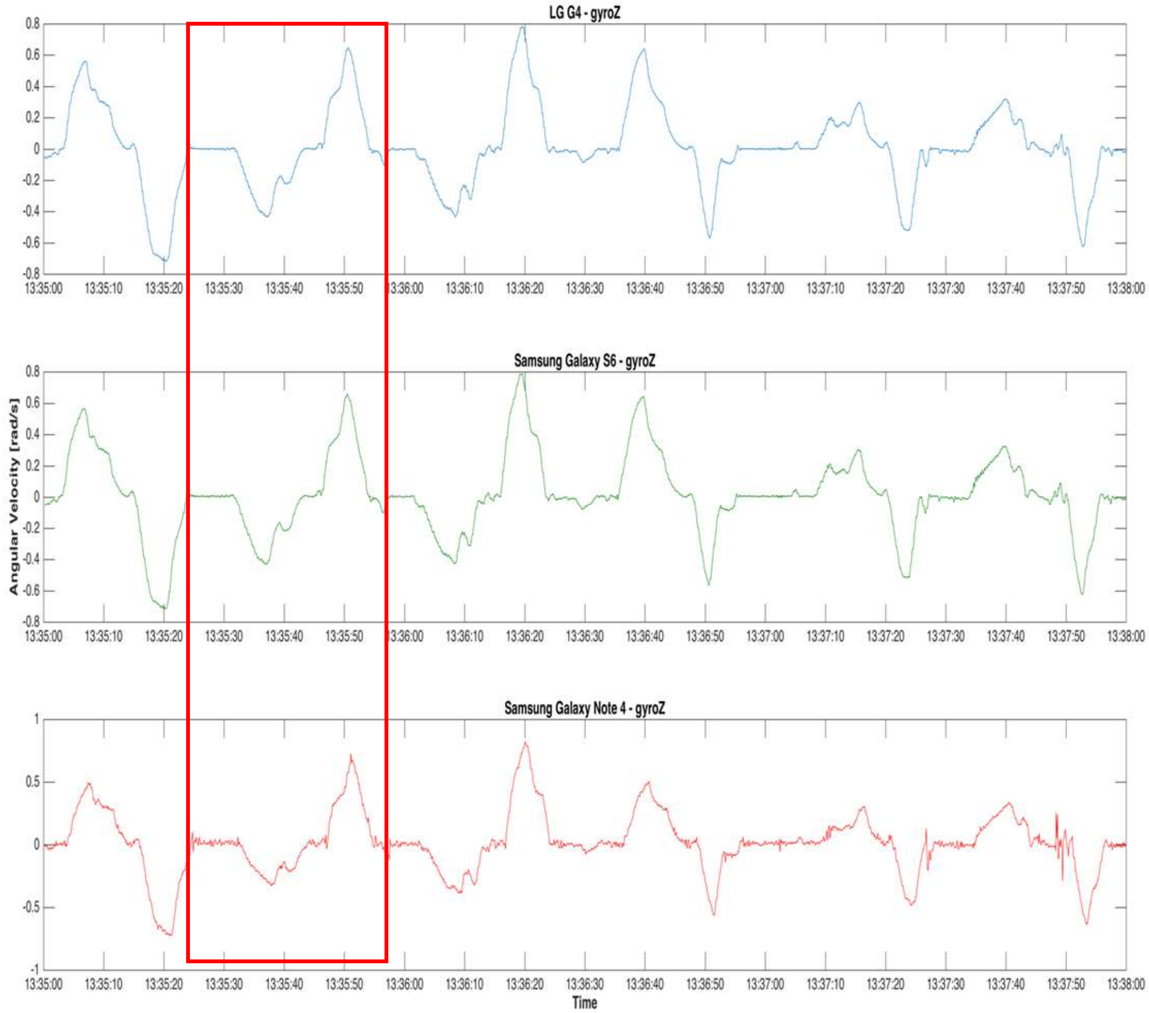

Figure 19: Gyro measurements on Z-axis

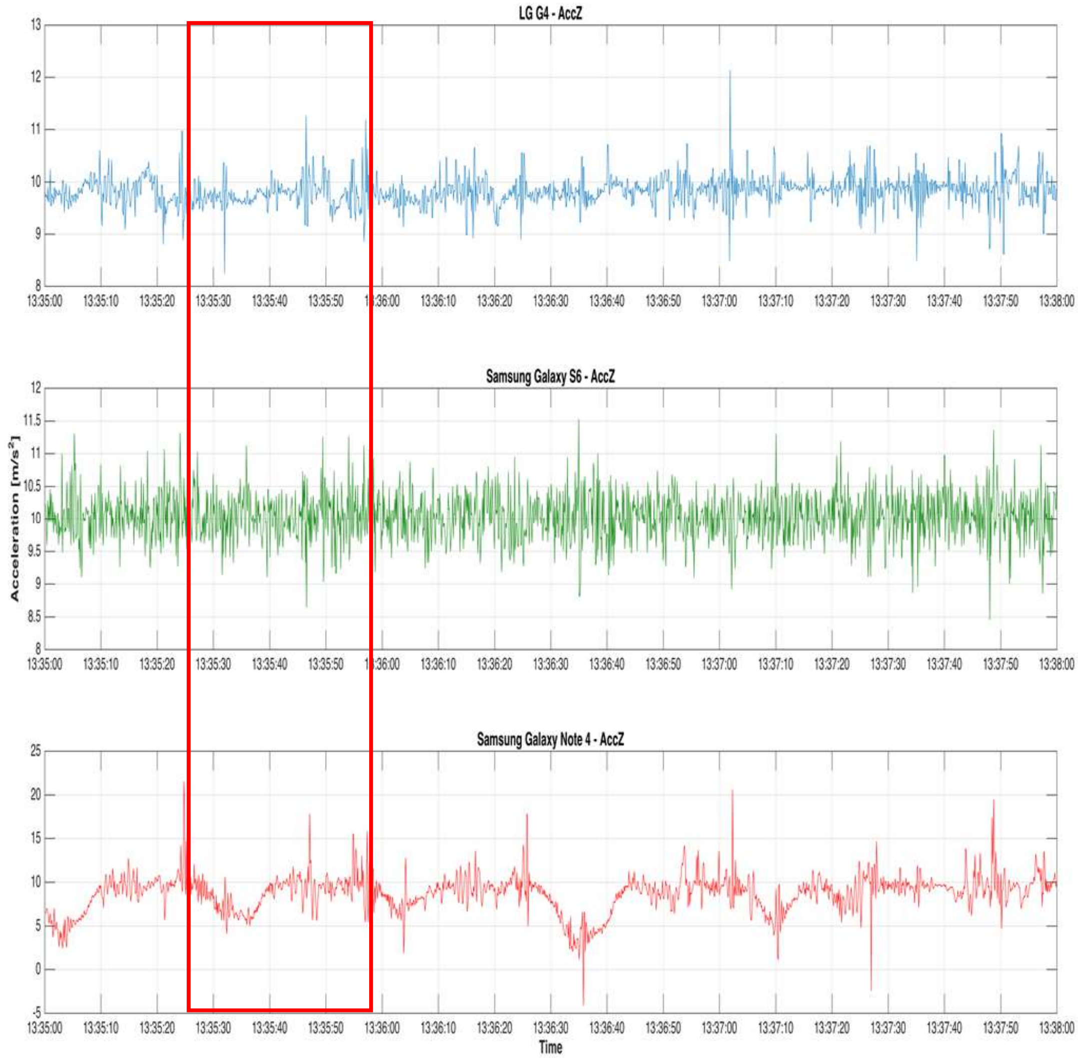

Figure 20: Accelerometer measurements on Z-axis

It is evident that smart phone sensor technology and GNSS can provide important information details regarding the movement and working behaviour of an excavator working in a construction site. This information can follow the standard periodical course of works, and with data analysis the productivity of the construction plant can be observed and monitored. Further analysis and research must be conducted, also with the use of more excavation plants, for more detailed behaviour observation and more valuable results.

5.5 Construction Central Portal

The proposed methodology is an innovative holistic approach for construction works progress control and monitoring. The aim is to provide a tool that can be used in construction projects for efficient project management, the prevention of delays in projects, dispute avoidance and faster and less expensive dispute resolution procedures. The end objective to aid the purpose of having sustainable construction projects delivered on time and within budget. The users will be able to monitor the progress of works during their execution, and additionally in the case they need to have information regarding the project after the completion of the works for any period of construction they will be able to do so.

The proposed methodology is designed around a contemporary tool, a Central Portal, as shown in Figure 21. This Central Portal enables the collection of information from traditional means of recording data during a construction project (site diaries, correspondence, programme updates, variation orders, progress meetings´ minutes, drawings´ updates, variation instructions, material testing results and site photographs), as well as from numerous sensors by means of modern technologies (mobile technology, time lapse cameras, UAV technology, RFID technology, laser scanning).

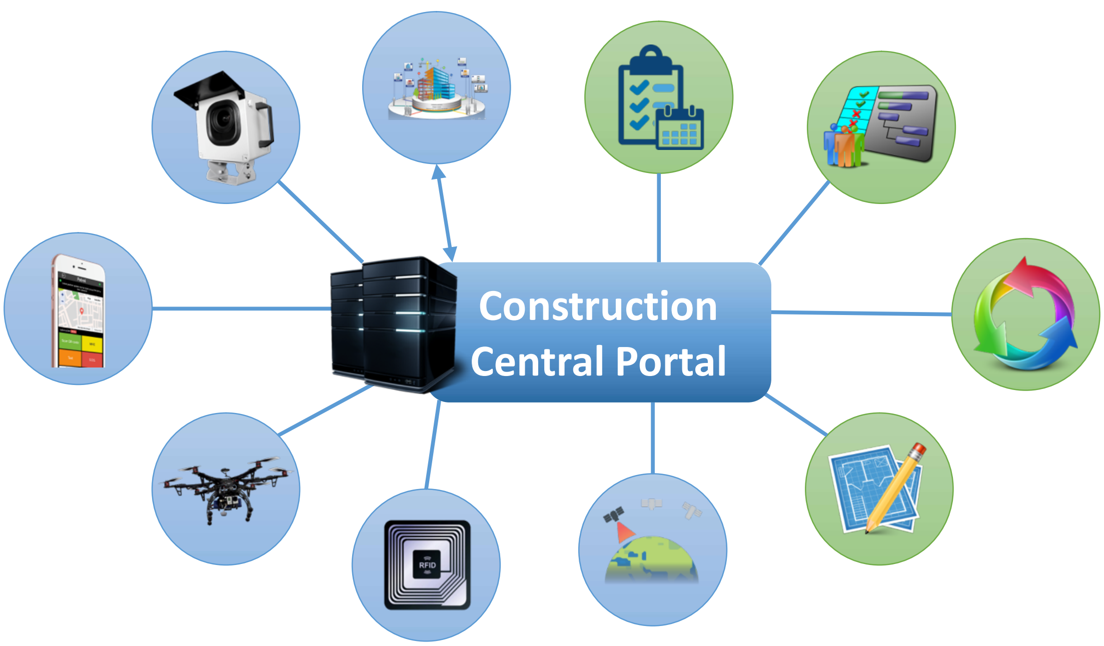

Figure 21: The Construction Central Portal data sources

The system will be able to generate reports on significant issues pertinent to the project. Specifically, the central server will be continuously accepting information from various sources and, depending on the required information; the relevant data will be used to provide the necessary report Figure 22.

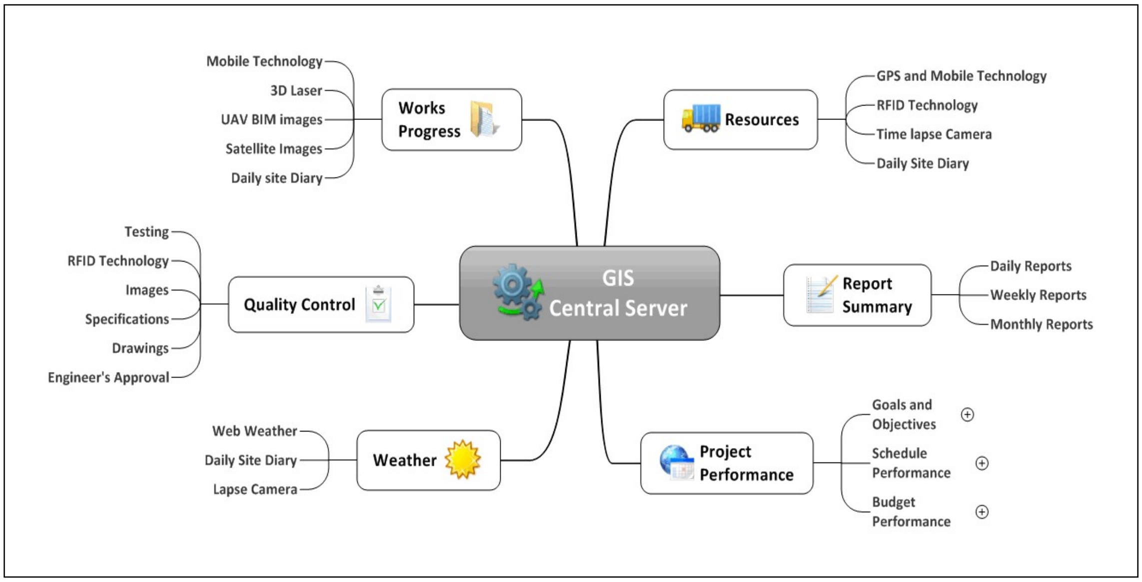

Figure 22: Examination of project progress issues

Following the findings of research works regarding the causes of delay at the international level and the results of the questionnaire survey research described in this thesis, the innovative tool that has been designed can provide:

- Efficient and transparent record keeping and sharing to all the involved parties of a project,
- Achievement of more effective project management and works progress monitoring and control,
- Early warning for possible delays allowing for timely decision making,
- Delay prevention,
- Dispute avoidance, and
- Cheaper dispute resolution procedures.

Information regarding a project will be input into a central portal and the parties of the project will be able to extract information via various reports depending on the information requested. The main reports that are aimed to be produced are the following:

- Site conditions report: In the case a conditions report is required for a particular day or period of time (Figure 23) the central server may use the information provided by the time lapse camera (images), the collected weather reports, the site reports, the GNSS-based positions reports, and potentially RFID data in order to generate a report made of information about the weather, the resources on site and the plant and machinery pattern on site.
- Works progress report: If a works progress report is required by a particular day or period of time (Figure 24), the central server may use the information provided by the time lapse camera (images), the works schedule, the laser scanner 3D images, the UAV camera images, the RFID reports and the satellite images to provide as output a report consisted of information about the completed works until the requested date.
- Works quality report: By using information input by testing results, specifications, engineer's approvals and images, an output quality report can be produced.
- Bad Weather and effect report: In the case the contractor claims that for a particular period there was disruption and delay at works because of bad weather conditions, a weather report and the actual effect on the works could be produced with the information input via the site daily reports, the time lapse images and the weather report.

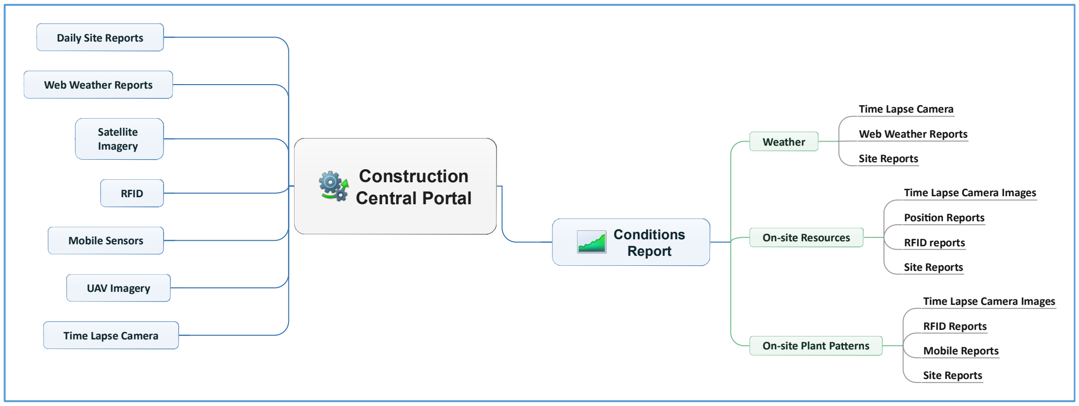

Figure 23: The methodology of producing a conditions report

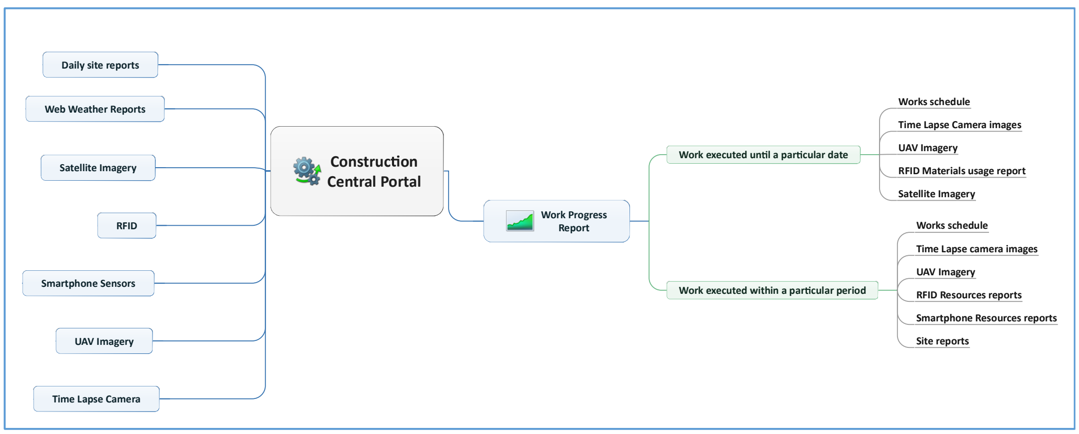

Figure 24: The methodology of producing a works progress report

The methodology designed and presented is a modern and technologically advanced approach of record keeping and reporting. It can provide efficient, unbiased and transparent record collection, and automatic communication of the results to all interested parties within the framework of a project. This is a crucial element towards more effective project management and decision making for delay and dispute avoidance and, if needed, a more effective and cheaper dispute resolution procedure.

Additionally to the traditional and smart methods of site information recording the modern technologies that will be used for data input to the central portal as explained above, an objective of the proposal is the development of a group of novel techniques productivity monitoring of construction machinery with the use of sensors found on smartphones.

Based on the accumulation of information and data, and considering the intended target groups and purpose of the Portal, the appropriate platform and tools can be developed through the employment of Information and Communication Technologies (ICTs).

A three-tier architecture can be adopted and latest development tools must be used. The Construction Management Portal shouldconsist of the following Pillars: (a) the project's Portal, (b) the Construction Management Application and (c) the Web GIS Application. More specifically: The activities of this task aim to the user-friendliness of the Portal, platform and tools, adding complexity and deepening the level of information and data retrieved depending on its intended target group.

The **project's Portal** will be implemented with the use of a Content Management System (CMS) and will act as the gateway. The CMS will incorporate features and functionality such as Pages Management, Content Management and Search functionality, as well as functions such as News and Announcements, Useful Links, Document Library (documents, images), Events and Calendar, Contact forms, Frequently Asked Questions, etc. User group and role management will be integrated within the CMS administration. Project's Portal will be used also for dissemination purposes.

The **Construction Management Application** must be mainly a data entry tool enabling the import of data (manual entry and / or via importing file mechanisms). Specific data entry screens must be designed per user category to allow data importing such as construction daily diary information, electronic documentation and photos. Moreover, a mechanism for exporting specific data regarding the progress of the project must be implemented, so as to be used (importing) from commercial project management software (e.g. MS Project). Finally, users should be able to execute pre-designed reports per date in order to view specific information per period of the project.

The purpose of the **Web GIS Application** is to provide the facility to the users to navigate to GIS data through an On-line Web Application. The application will use the Geographical Information Data, extending them through Web GIS capabilities. Various layers of information should be available through this Web GIS Application. The ability to monitor the progress of a project by the use of UAV photos should be available along with other information such as drawings (e.g. Autocad files).

Indicatively, through this Web GIS Application, the user should be able to use the followings tools:

- The table of contents. The user will have the option to select from the "Table of Contents" the service/layer in order to display its content (e.g. thematic map).
- The available backgrounds. The user will have the option to select a Basemap as a background from the ones available.
- The data identification tool. The user will have the ability to display and view detailed information of the available data.
- The navigation tools. Using the navigation tools (e.g. zoom in, zoom out, pan, etc.), the user will be able to navigate on the map.
- The printing maps tool. The user will have the ability to prepare a map using the "Print" functionality.
- The measurement tool. By using the "Measure" tool, the user could make rough measurements on the map.
- The time-slider tool. By using this tool, the user could view layers in a map, and play the map to see how the data changes over time.

A **Relational Database** must be designed and developed in order to manage and host geographic information data and other related non-GIS data, required by the project.

Moreover, the necessary GIS Services could be developed and integrated into the Web GIS Application as to present Geographical Data.

5.6 Excavator Productivity Monitoring Application

Smartphones can identify patterns in the operation of excavators. This ability has been examined for the purposes of this research work as demonstrated above in section 5.4.5. As discussed above, certain construction activities are executed in a cyclic manner (a) excavation, (b) lifting of the soil material and turning towards the truck, and (c) releasing the material in the truck.

In order to examine the use of smartphones for productivity monitoring three smartphones were placed on specific locations on an excavator to detect whether the location of the smartphone could bias the sensitivity of the recorded data due to fluctuations generated by the operation of the machine, the smartphone on the operator cockpit performs the same with the other smartphones positioned on crucial parts of the machine, and whether the collected data, namely 3-axis acceleration, angular velocity, position and gravity readings, could reveal patterns of the cyclic operation of the excavator.

It was observed that this methodology can provide a visual presentation of standard activities of the excavator, such as the activity of the excavator lifting the soil material and turning towards the truck. It was also observed that there is correlation of the results the various smartphones examined. However there was a difference in the acceleration magnitude of one of the smartphones that probably is because of the position of the smartphone (the smartphone placed on the arm of the excavator).

To address the objectives needed to complete the proposed tool for productivity monitoring using smartphone; (a) the developing sophisticated algorithms to quantify the cyclic operation of the construction plant and, hence, compute an estimation of its productivity will be firstly required. Secondly (b) this knowledge will be embedded into a smartphone app that will be used by the excavator operators during their shift to monitor daily productivity in real or quasi-real time. This information will be send and kept in the Construction Central Portal.

Different approaches must be examined to identify the optimal method for the quantification of the cyclic operation. Both supervised and unsupervised classification techniques will be applied on the collected data to detect the event sequence that signify 'cut & fill' operations (events). This will be achieved via robust clustering and processing of the time series of each smartphone sensor (i.e. accelerometer, gyroscope, and GPS/GNSS readings). Data will be further combined by correlating the events with the positions of other types of machinery that are involved in the construction phase, such as trucks. The dataset used in this phase, will be collected by using at least 3 state-of-the-art smartphones, which will be placed on the excavator and trucks. The smartphones will use specific software to perform logging of data at a minimum interval of 10Hz. Additionally, an **advanced inertial measurement unit (IMU)** is proposed to be placed on the excavator to provide a reference dataset to check the integrity of the readings and identify potential biases. The collected information will be used as a tested for the comparison of the classification techniques and end up with the optimal productivity monitoring algorithm. Once this task is completed, the algorithm will be able to be embedded on a specifically designed application (app) for mobile phones. The app should consist of a friendly graphic user interface (GUI) that will allow smooth and seamless use by the operators of the excavator. Furthermore, the app should be developed as cross-platform to support the major mobile operating systems available in the market, namely Google Android and Apple iOS. Additionally, the app should support online and offline data export to supply the Construction Central Portal with required productivity information.

The reliability of smartphone sensors must also be addressed at this stage by comparing the quality of the smartphone sensors against the IMU readings. This can be carried out by investigating specific statistic indices, such as the unit variance to examine and compare the noise levels for each sample. In this way, a second comparison between the quality of the used smartphones can be carried out, providing valuable answers regarding the impact of the sensor brand, the sensors sensitivity, and the operating system. Consequently, a sample clustering or classification approach must be examined and tested on each dataset to investigate the ability of smartphones to quantify the productivity of the aforementioned types of plants.

5.7 Summary

The current methods for project monitoring, control, delay analysis and dispute resolution are inadequate. The cost of caused delay can be very high and the dispute resolution procedures end up being very expensive or faced with apprehension.

Chapter 5 proposes an integrated novel methodology to address these issues that will be utilizing modern technologies to provide important and useful information, both spatial and descriptive, to a Geographical Information System (GIS) central server, or Construction Central Server in our case, which in turn will be able to provide information reports as output regarding day-to-day and milestone issues related to the project works. The methodology enables the collection of information from traditional means of recording data during a construction project as well as from numerous sensors by means of modern technologies and the generation of reports on significant issues relevant to a project. This novel methodology will provide (a) efficient and transparent record keeping and sharing to all the involved parties of a project, (b) more effective project management and works progress monitoring and control using smart technologies, and (c) an early warning mechanism for possible delays allowing for timely decision making to enable delay prevention. The ability to have transparent access to retrospective detailed project information will promote dispute avoidance and cheaper dispute resolution procedures.

CHAPTER 6: CONCLUSIONS AND FURTHER WORK

6.1 Introduction

Initially, this thesis examined the key elements of the Cypriot construction industry that affect time and completion in projects. Secondly, it suggested an integrated statistical methodology and workflow to identify, both the most important delay causes in construction projects and the practices to avoid or mitigate their effects which are commonly accepted by all stakeholders with imminent applicability. The aforesaid research was carried out via a specifically designed survey, which covered topics, such as delay frequency and duration, Extension of Time (EOT), disputes, project monitoring and programming, and, in great detail, the causes of delay and the measures that can mitigate their effects. Prior to the design of the questionnaire, an extensive literature review was carried out, which shed light to the related research work that has been carried out at the international level. The views of the three main parties (owners, consultants, contractors) regarding the main causes of delay and the practices that can be applied for delay avoidance and mitigation were analysed separately, and the correlation of their perceptions was investigated. As a secondary objective, this thesis proposed a robust methodology that can aid the control of a construction project for delay mitigation and the achievement of easier and cheaper dispute resolution procedures using state-of-the-art geospatial technologies.

6.1.1 Time in in construction projects in Cyprus

The results of this research show that delay is as large problem in Cyprus as in other countries. The majority of the participants in the questionnaire research (56%) stated that delays occurred in more than 40% of times they were involved in a construction project. Furthermore 80% of the participants stated that the average duration of delay they experienced is up to 30% of the original duration of the project.

Regarding programming of the works only 54% of the participants are using the critical path method in their programme planning. Additionally, 57% stated that they update the programmes upon request of the Consultants or the Client, and only the 56% of the sample updates the programme when there is a delay event.

In recording, more than 80% of the participants answered that they use conventional means, such as photographs, meeting minutes and correspondence. Only 57% use works programme updates, 48% prepare progress reports, 26% monitor activities productivity, and 35% monitor the activities' progress.

Almost half of the respondents stated that disputes on EOT duration are never or rarely resolved until the delivery of the project. In the case the disputes are resolved via arbitration the duration is usually less than 3 years, whereas in the case of litigation it will last for more than 3 years.

6.1.2 The Causes of Delay in Cyprus

Based on the overall results, the most important identified sources of delay are the 'changes by the owners' (RII:77.78), 'inadequate programming of works'(RII:71.85), 'mistakes and missing information from consultants' drawings'(RII:69.26), 'difficulties in financing of the works by the contractor'(RII:67.41), 'low productivity by contractor'(RII: 67.41) and 'delayed instructions by consultants'(RII: 67.41).

This outcome is aligned with the main sources of delay identified in the literature. However, two main differences were identified. Firstly, the cause 'delay in payments to contractor' that was one of the most important causes mentioned in the literature review is not considered as one of the most important in by the Cypriot respondents. In this case Cyprus is more in line with the countries with more developed economies since 'delay in payments to contractor' was not mentioned in the studies carried out in USA, UAE, Australia, Hong Kong and Norway. Secondly the 'inadequate programming of works' is considered by the Cypriot respondents as a very important delay cause, whereas in the literature review was not mentioned as many times as other causes of delay. According to the literature review, this perception in Cyprus construction industry is in line with the results of studies carried out in China, Turkey, Egypt, Jordan, Malaysia, Norway and India.

With respect to the origination of delay in projects, the examination showed that there is a high correlation between the perceptions of the owners and consultants, moderate correlation between the consultants and contractors and low between the owners and the contractors. By considering the risk of liability for each delay source, it was concluded that the lower correlation in the delay causes ranking perception is affected by the liability risk for delay under the contract. It is evident that through the years the opinion of each party regarding the real causes of delay has been formed in such way as to hold the other involved parties responsible.

This fact deprives the industry from finding a clear way through practices and policies for delay and dispute avoidance. Evidently, there is a need for setting out a map of practices and measures that will assist in avoiding the causes of delay and mitigating their impact in the undesirable case of occurrence.

6.1.3 Delay Mitigation Measures

The research participants were asked to select 12 out of 18 identified practices they consider that will have the most significant impact on the attempt to avoid and mitigate delays and subsequent disputes in construction projects. They were also asked to rank them in order of significance (i.e. from 1 to 12) giving 1 to the measure they think it will have the greatest impact on delay avoidance and 12 to the one with the least impact.

The top ten practices with the expected greatest impact on delay mitigation and avoidance span across the categories of ‘programming’ (3), ‘communication and cooperation between the parties’ (2), ‘recording and productivity monitoring’ (2), ‘tender-related’ (1), ‘design-related’ (1) and ‘material supply-related’ (1).

Unlike their perceptions regarding the causes of delay, all stakeholder parties had high agreement with respect to the importance of the practices that can be applied for delay mitigation and avoidance. These practical measures as identified by the perception-based statistical analysis used are the following:

- The implementation of procedures for preparation of realistic programme of works with application of critical path method. Additionally, there could be a requirement so that time in projects is managed by planning engineers with adequate academic qualifications and relative experience;
- In the case a delay event occurs there must be a contractual requirement for the programme to be updated and distributed to all parties;
- There must be periodical (weekly, monthly) update of the works programme according to progress of works, with all changes highlighted to all parties.

Extending the implementation of such processes, the culture of regular programme updating must be promoted by educating the members of the construction industry about its importance;

- Design stages completion strategy must be applied to ensure complete design and construction details preparation by the consultants prior the tender period;
- Frequent progress meetings with the participation of all parties must be obligatory during the whole progress of the works;
- There must be introduction of frequent, clear and transparent updating of all involved parties for the works progress;
- Monitoring of the progress and productivity of activities with smart modern technologies (UAVs equipped with high resolution cameras, mobile sensing techniques, digital photogrammetry, image processing, laser scanning, RFID, BIM techniques for 3D documentation, and time-lapse camera) for early warning in the case there is reduced productivity or progress of works can be applied;
- A methodology that will detect unrealistic tenders by contractors must be applied. Also, the contractors' financial condition during contractor selection must be examined so that it is confirmed that the contractor selected is in a position to complete the project. Furthermore, education of the contractors about the consequences of non-realistic tendering is required.

These are the practices and measures which all three parties agree that will have the most significant impact on the attempt to mitigate the risk of delay. It is evident that the application of such practices can be applied immediately without acceptance issues by all major stakeholders. Ergo, they have the required acceptability and applicability for immediate appliance.

6.1.4 Smart Tool for Productivity Monitoring

As a secondary objective, this thesis proposed the methodology design of a smart tool that can aid the control of a construction project for delay mitigation and enable easier and cheaper dispute resolution procedures using state-of-the-art geospatial technologies.

The proposed methodology was designed around a contemporary tool, a Construction Central Portal, that will enable the collection of information from traditional means of recording data during a construction project (site diary, correspondence, programme updates, variation orders, progress meetings´ minutes, drawings´ updates, variation instructions, material testing results and site photographs) as well as from numerous sensors by means of modern technologies (mobile technology, time lapse cameras, UAV technology, RFID technology, laser scanning). The central server will be continuously accepting information from various sources and, depending on the required information; the relevant data will be used to provide the necessary report.

The reporting generated during a project will enable efficient and transparent record keeping and will provide constant sharing between the parties. This will help the parties achieve an effective project management and works progress monitoring and control.

Furthermore, it will be able to act as an early warning tool for possible delays so that with the appropriate decision making the delays will be avoided or mitigated. With transparent sharing of records the parties will know the actual facts and will be able to negotiate easier and more honestly with dispute avoidance more possible. Finally, the availability and clear presentation of records will assist in having quicker dispute resolution procedures.

6.2 Recommendations for Further Work

Delays have significant effects on construction projects on the time of completion as well as the cost of the project. The causes of delay may vary from a geographical area to another. The causes may possibly depend on various factors such as the state of the economy of a country or cultural particularities. Especially in the area of Eastern Mediterranean Europe and the Middle East there is a mixture of construction standards, financial strength and business cultures. In the aforesaid area, construction today is an international business and projects are being constructed by companies from different countries. Major and important projects are being designed and constructed by consortiums of companies and joint ventures from various countries including USA, the UK, Japan, China etc due the project sizes and special requirements. A map of the most important delay factors would be very useful to construction stakeholders interested in working in the area of Eastern Mediterranean and the Middle East. This map can be carried out utilizing GIS systems and the outcome of the literature review of this study.

Countries with important construction sector, e.g. Lebanon, was not found to have such study and thus a common comparative study using the methodology elaborated in this thesis would provide useful conclusions.

The aforementioned suggestion can be further extended to a global approach. In project procurement methods such Public-Private-Partnerships, investors finance projects in foreign countries that may have an attractive investment return but the risk of delay, and thus this return, may be subject to factors variant from the usual in the investors' countries. A world map presenting the most important delay factors would be very useful to investors and stakeholders interested in investing, consulting or constructing at an international level.

The next step for the proposed project control methodology is its implementation. The suggested tool will be a modern and technologically advanced approach of record keeping and reporting. It can provide efficient, unbiased and transparent record collection, and automatic communication of the results to all interested parties within the framework of a project. This is a crucial element towards more effective project management and decision making for delay and dispute avoidance and, if needed, a more effective and cheaper dispute resolution procedure. In addition to the traditional means, smart methods of site information recording using modern technologies will be used for data input to the central portal as explained above.

The development of a novel technique for productivity monitoring of construction excavators with the use of sensors found on smartphones was also demonstrated in this thesis. This productivity monitoring tool must be developed and tested. Furthermore, other types of construction plants that operate in cyclical manner can be examined in the frame of such study. The novel technique described above should be tested on different construction machines also, e.g. a type of piling plant, and cement ground injection plant. The investigation can take place using a similar approach as the one described.

Specifically, the smartphones must be positioned on crucial locations on each machine along with the advanced inertial measurement unit (IMU). Initially, the dataset will be processed to answer the question whether smartphones can identify the cyclical operations performed by the machines. This will be achieved through a thorough statistical analysis of collected sample. In this way, the proper sampling rate must be determined to account for unwanted noise. Furthermore, the automation of cyclical pattern recognition using supervised, unsupervised and ML techniques is the next step with respect to the implementation of the proposed system. Therefore, the question that arises is ‘smart technologies exist, they are here, why not use them?’

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APPENDIX I

Survey Questionnaire

You are invited to participate in research related to the management of construction projects and delays. This research will be attended by professionals in both the private and public sector construction industry. Participants will be asked to complete a questionnaire with questions about managing construction projects, managing delays and resolving disputes over delays. Completion of the questionnaire is expected to take about 1 5 minutes. Your participation is voluntary but extremely important. Your answers will be treated strictly confidentially and the survey data will only be presented in overall results. If you have any questions regarding the search process, please contact us at pm.survey.cut@gmail.com. Thank you for your time and participation. You can start the questionnaire by pressing the Next button below.

Next

Exit Survey

PROJECT MANAGAMENT AND DELAYS IN CONSTRUCTION WORKS

INTRODUCTION

Status of organization to which I represent:

O Client Representative / Client

O Contractor

O Designer / Consultant

Main business of the organization/ company I represent (you can choose more than one option):

□ Building Projects

□ Civil Engineering Projects

DELAYS

Total value of works that have occupied your company / office / department over the last ten years (€):

O up to 5 million

O 5 - 10 million

O 1 0 - 20 million

O >20 million

State the percentage of projects you were involved in that faced delay in completion:

O 0 - 20% of projects

O 21 % - 40% of projects

O 41 % - 60% of projects

O 61% - 80% of projects

O >80% of projects

State in percentage the delay duration with respect to original duration of projects:

O 0-10% of original contract duration

O 11 -20% of original contract duration

O 21-30% of original contract duration

O B1-40% of original contract duration

O 41-50% of original contract duration

O >50% of original contract duration

State the Extension of Time duration agreed in respect to the actual duration of delay:

O 0-10%

O 11-20%

O 21-35%

O 36-50% O 51-65%

O >65%

DISPUTE RESOLUTION

The disputes that occur in relation to the delays during a project are examined and negotiated or resolved before the completion of works and project delivery.

O Always

O Usually

O Rarely

O Never

In the cases there was Arbitral Award issued what was the duration of the Arbitration Proceedings?

O1 – 12 m

O13 – 24m

O25 – 36m

O> 36m

O Other

Arbitral Award is enforced without the intervention of Courts.

O Always

O Usually

O Rarely

O Never

In the cases there was Court Decision issued what was the duration of the Court Proceedings?

O 1 – 12 m

O13 – 24m

O25 – 36m

O> 36m

O Other

PROJECT MONITORING AND WORK PROGRESS RECORDING

The methods used to record the progress of a project during a project include (you can choose more than one option):

O Updating of works schedule

O Photos

O Meeting Minutes

O Progress Reports regular preparation (e.g. weekly, monthly)

O Correspondence

O Activities productivity monitoring and sharing

O Programme activities progress monitoring and sharing

PROGRAMME OF WORKS – DELAY ANALYSIS

The time that the programme of works is usually submitted by the Contractor:

O Prior the commencement of works

O Within a week after the commencement of works

O Within three weeks after the commencement of works

O After a significant period after the commencement of works, usually when there is a need to EOT claim

O After completion, usually when there is a need to EOT claim

O Never, unless it is requested by a project party (e.g. Consultant, Client)

Preparation of programme of works (you can choose more than one option):

O By hand

O Using Excel software or similar

O Using Microsoft Project or similar

O Using Primavera P3, P6 or Suretrack software

O Using Power Project software

Usually the programme is prepared using critical path method:

O Yes

O No, but there are various "links" between various activities

O No, and there are not any "links" between activities

O I do not know

Usually the programme of works is updated by the Contractor (you can choose more than one option):

O The programme is never updated

O In specific periods (eg weekly, monthly)

O When it is requested by a project party (e.g. Consultant, Client)

O When there is an event that causes reduction in productivity

O When there is an event that causes delay

Do you use delay analysis methodology?

O Yes O No

If 'Yes' which delay analysis methods do you usually use (you can choose more than one option):

O as planned vs as-built

O as-planned impacted

O as-built-but-for

O time-impact analysis

In the case EOT is claimed how often is justified using delay analysis?

O Always

O Usually

O Rarely

O Never

BIM TECHNOLOGY

State the level of BIM usage in the projects you are involved in:

O BIM technology is not being used at all

O BIM technology is used for 3D visualization of architectural design only

O BIM technology is used for 3D visualization of the architectural and structural/ civil works only

O BIM technology is used in design for in a holistic approach including the architectural, structural/civil works and the electromechanical works

O BIM is used during design and construction

Do you believe that the 3D presentation of a variation during construction would be beneficial?

O Yes

O No

Do you believe that the use of 3D presentation of claims due to variations would be beneficial?

O Yes

O No

CAUSES OF DELAY

Below there are 20 causes of delay in construction projects.

Please characterize the level impact and severity of each cause separately as follows:

(1) very high level (of impact),

(2) high level (of impact),

(3) average level (of impact),

(4) low level (of impact), and

(5) very low level (of impact).

* "very high level " when the cause occurs very often in construction projects and causes severe delay to works

* "high level " when the cause occurs often in construction projects and causes significant delay

* "average level" when the cause of delay occurs often in construction projects and may cause delay

* "low level" when the cause of delay does not occur often in construction projects and may cause delay

* "very low level" when the cause of delay does not occur often in construction projects and it will rarely cause delay to works

Delay to Payments by Client

O Very High Level

O High Level

O Average Level

O Low Level

O Very Low Level

Changes/ Variations by Client during construction period

O Very High Level

O High Level

O Average Level

O Low Level

O Very Low Level

Delay to approval of final drawings

O Very High Level

O High Level

O Average Level

O Low Level

O Very Low Level

Delay to material approval

O Very High Level

O High Level

O Average Level

O Low Level

O Very Low Level

Delay to responses by Client to requests of information

O Very High Level

O High Level

O Average Level

O Low Level

O Very Low Level

Suspension of Works by Contractor

O Very High Level

O High Level

O Average Level

O Low Level

O Very Low Level

Delayed Instructions by Consultants

O Very High Level

O High Level

O Average Level

O Low Level

O Very Low Level

Inadequate experience by Consultants on specialised projects

O Very High Level

O High Level

O Average Level

O Low Level

O Very Low Level

Mistakes and Missing Information form Consultants drawings

O Very High Level

O High Level

O Average Level

O Low Level

O Very Low Level

Delay to responses by Consultants to requests of information

O Very High Level

O High Level

O Average Level

O Low Level

O Very Low Level

Difficulties in Financing of the works by the Contractor

O Very High Level

O High Level

O Average Level

O Low Level

O Very Low Level

Problems between Contractor and his Subcontractors

O Very High Level

O High Level

O Average Level

O Low Level

O Very Low Level

Problems between Contractor and his Suppliers

O Very High Level

O High Level

O Average Level

O Low Level

O Very Low Level

Bad communication

O Very High Level

O High Level

O Average Level

O Low Level

O Very Low Level

Inadequate programming of works

O Very High Level

O High Level

O Average Level

O Low Level

O Very Low Level

Low productivity by Contractor

O Very High Level

O High Level

O Average Level

O Low Level

O Very Low Level

The involvement of a large number of parties

O Very High Level

O High Level

O Average Level

O Low Level

O Very Low Level

Bad weather

O Very High Level

O High Level

O Average Level

O Low Level

O Very Low Level

Accidents

O Very High Level

O High Level

O Average Level

O Low Level

O Very Low Level

Works required by public authorities (Electricity, Water, Telecommunication)

O Very High Level

O High Level

O Average Level

O Low Level

O Very Low Level

MEASURES FOR DELAY CONTROL AND AVOIDANCE

From the following measures for delay control and avoidance, choose the twelve (1-12) that you think that if implemented, they will make the most significant contribution; starting with 1 as the measure you think that if applied to a construction project it will have the greatest contribution to avoidance and control of delays, up to 12 as the least contributing:

Preparation of realistic programme of works with critical path method	
Periodical (weekly, monthly) update of the works programme according to progress of works, with all changes highlighted to all parties	
In the case a disruption event occurs the programme to be updated and distributed to all parties	
In the case there is a delay event, immediate EOT award	
Immediate and final resolution of any disputes occur during a project	
Frequent progress meetings with the participation of all parties	
Monitoring of the progress and productivity of activities with smart modern technologies for early warning in the case there is reduced productivity or progress of works	
Use of alternative more productive methods and machinery in the case there is reduced productivity as compared to the planned	
Better materials supply management and control from the beginning of the project	
Realistic tender preparation by contractors with consideration to all real costs	
Improvement of communication with the contractual use of a Project Manager	
Introduction of frequent, clear and transparent updating of the parties for the works progress	
During the contractor selection attention should be given to the relevant experience of the companies	
Complete design and construction details preparation by the Consultants prior the tender period	
Use of alternative methods of procurement such as Design and Build	
Use of international design standards with specific design stages and deliverables	
Introduction of applicable quick dispute resolution methods, including the updating and improvement of Arbitration Law (CAP. 4)	
Introduction of compulsory Indemnity Insurance for Consultants	