UNB Off-site Construction Research Centre

Canadian Society for Civil Engineering

Transforming Construction with Reality Capture Technologies:
The Digital Reality of Tomorrow

August 23-25, 2022, Fredericton, New Brunswick, Canada

KEY RESULT INDICATORS (KRIS) AND KEY PERFORMANCE INDICATORS (KPIS) FOR MAINTENANCE MANAGEMENT

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Abstract: Maintenance management is an important process in the operation phase of any asset because it can impact the serviceability and useful life of the assets. In addition, maintenance management constitutes a substantial proportion of operational asset costs. Establishing a suitable set of (i) key result indicators to evaluate maintenance management and (ii) key performance indicators (KPIs) to improve maintenance decision making is essential for monitoring primary aspects of maintenance functions. While many KPIs have been defined for evaluating maintenance management and subsequently used for identifying root causes of deficiencies, there are potential areas for improvement in defining their relation with KRIs and supporting maintenance decisions. This paper aims to identify the KRIs and KPIs related to maintenance management by conducting a literature review and exploring the use of performance measures in maintenance management from organizational and algorithmic perspectives. The identified KRIs and KPIs are then analysed and categorised based on their purpose and content. In addition, primary data from interviews of industry practitioners is collected to identify the challenges of measuring maintenance performance in practice. The findings of this study show the lack of quality and reliable data, and automated data collection are the main issues in measuring KPIs for maintenance management. In addition, it was found that communication with the clients to understand their needs and update the KPIs based on their requirements and objectives over time could improve the effectiveness of the maintenance monitoring systems.

Keywords: Key Performance Indicator (KPI); Key Result Indicator (KRI); Maintenance, Performance Measures; Asset Management

1 INTRODUCTION

Maintenance is an important process for preserving the optimal value of various types of assets, such as buildings, infrastructures, equipment, and facilities, throughout their lifecycle. Lee et al. (2012) and Yalcinkaya and Singh (2014) emphasised the importance of maintenance management in the operation and maintenance (O&M) phase, as 80% of an asset's lifecycle costs could belong to this phase. In today's competitive business environment, adopting novel maintenance management techniques can highly increase the productivity of organisations and direct them to meet their performance requirements at the lowest possible cost.

The most common asset maintenance approaches are failure-based maintenance, time-based maintenance, and condition-based maintenance. These approaches are prone to a wide range of inefficiencies, unavailability in addition to poor quality and unreliability of assets. Emerging new technologies in the industries, recent studies have focused on the prediction of failures and adopting predictive approaches for maintenance management. Predictive maintenance (PdM) relies on intelligent equipment monitoring using sensors, Internet of Things (IoT), and Artificial Intelligence (AI). PdM intends to reduce costs by preventing failures, unscheduled maintenance, and downtime and ensuring that failing parts are replaced when necessary (Kumar et al. 2010). PdM can provide organisations with the answer to two questions: 1) why did it happen? (i.e., pattern) and 2) what will happen and when (i.e., forecasts)?

Adopting new approaches for maintenance management, the asset managers need to know 'how efficient and effective their approach is, in improving their maintenance system'. To answer this question, effectively measuring the performance of maintenance management in terms of its timeliness, correctness (less redundancy), and completeness is essential.

Parmenter (2015) argued that many organisations choose and monitor incorrect Key Performance Indicators (KPIs). He introduced four types of performance measures:

1. Key Result Indicators (KRIs) tell you 'how' you have done in a perspective or critical success factor.
2. Result Indicators (RIs) tell you what you have done.
3. Performance Indicators (PIs) tell you what to do.
4. KPIs tell you what to do to increase performance dramatically.

An initial step in measuring the performance of maintenance management is to establish suitable PIs and KPIs. KPIs are measurable, quantifiable, and numerical indicators that evaluate the performance of an asset and consist of tactical and strategic activities that are crucial for the current and future success of an organisation (Kerzner, 2011). KPIs mainly focus on the specific scope, although they provide information about the whole asset's performance and, consequently, the organisational productivity. KPIs play an important role in improving timely decision-making as they are assessed and measured daily or weekly and assist managers in achieving the pre-set goals. Defining the right KPIs can provide organisations with opportunities for improvement and lead them to reduce downtime, costs, crew inefficiency, and waste (Parida, 2006). KRIs intends to provide information regarding whether the organisation is attaining its desired outcomes in long-term planning (assessed monthly or quarterly). KRIs may include information about customer satisfaction, net profit before tax, the profitability of customers, employee satisfaction, and return on capital employed, which are ideal for the board (i.e., the people who are not involved in day-to-day management) (Parmenter, 2015).

Due to the lack of a standardised set of KPIs and KRIs for maintenance management, this research aims to identify and classify these indicators through conducting a literature review and exploring the use of performance measures in maintenance management. The challenges that organisations are facing in measuring KPIs and KRIs are identified through interviews with industry practitioners. In the upcoming sections, the related literature is reviewed, followed by the research methodology and findings, with a conclusion presented at the end of the research.

2 LITERATURE REVIEW

2.1 Data Analytics for Maintenance Management

British Standard (BSI, 1993) defines maintenance as "a combination of any actions required to retain an item in, or restore it to, an acceptable condition". Assets are composed of different components that form complex systems, and failure in some components can result in catastrophic consequences. For decades, many organisations have suffered from the weaknesses inherent in their maintenance approaches, which have resulted in crucial deficiencies in their performance (Ansari et al., 2019). Some organisations consider the maintenance of assets as a cost burden (Sherwin, 2000; Tsang, 2002) while maintenance improvement could lead to significant savings for the organisations. To improve maintenance, first, maintenance managers need to plan a suitable maintenance approach/strategy for their systems. Then, they need to monitor maintenance activities, which requires collecting and analysing data to measure maintenance performance. Comprehensive information about the maintenance history and integrating this information into work processes can improve maintenance management performance. Karim et al. (2016) proposed a concept, "Maintenance Analytics" (MA), consisting of four interrelated time-lined phases that demonstrate how technological revolutions such as the Internet of Things (IoT) boost data and information availability. The MA phases are 1) Maintenance Descriptive Analytics, 2) Maintenance Diagnostic Analytics, 3) Maintenance Predictive Analytics, and 4) Maintenance Prescriptive Analytics. The Maintenance Descriptive Analytics aims to answer the question, "What has happened?". To achieve this, accessibility to data associated with the system operation and the time frame related to each specific log is highly important. The Maintenance Diagnostic Analytics aims to answer the question, "Why has something happened?". In this phase, descriptive analytics analysis can frame the analytics; therefore, the data used in Descriptive Analytics needs to be available and reliable. The Maintenance Predictive Analytics aims to answer the question, "What will happen in the future?". To predict failure and faults, accessibility to business data such as planned maintenance is necessary. The Maintenance Prescriptive Analytics aims to answer the question, "What needs to be done?". The hypothesis of prescriptive maintenance is: "Do not just predict problems, prescribe a solution" (Padovano et al., 2021).

Maintenance decision-making and effective business performance are highly dependent on maintenance data and data analysis. To achieve the optimal state of a complex asset, a large amount of data needs to be recorded, mined, and analysed. However, poor data quality and raw data transformation have remained the main challenges for measuring maintenance performance (Lukens et al., 2019). Therefore, many organisations are seeking to adopt new technologies for automating data collection and data analytics. Karim et al. (2016) proposed a generic knowledge discovery process that includes: Data Acquisition (collecting relevant data); Data Transition (communicating the collected data); Data Fusion (gathering and combining data from various sources); Data Analysis/Mining (investigating data to extract information and knowledge); and Information Visualization (visualising information for easier interpretation and supporting maintenance decisions) as shown in Figure 1.

Figure 1: A generic knowledge discovery process adapted from Karim et al. (2016).

2.2 Maintenance KPIs and KRIs

Parmenter (2015) identified seven characteristics of KPIs; they must

- Be non-financial measures,
- Be assessed regularly (24/7, daily, or weekly),
- Be clearly defined for staff for measurement and required actions to be taken,
- Be measured by a specific individual or team,
- Have considerable impacts on the key success factors,
- Have positive effects on the performance, and
- Be acted on by the management team.

On the other hand, KRIs are the summary of many activities and progress in an organisation and are ideal for reporting the accomplishments to a board. KRIs are generally assessed on a monthly, quarterly, or annual basis, although shorter timeframes can be used, and they can be both financial and non-financial measures. Table 1 summarises the main characteristics of PIs and RIs identified by Parmenter (2015).

BS EN 15341:2019 classified indicators into two categories: 1) indicators measuring the technical performance of the assets (e.g., safety, reliability, and availability), and 2) indicators measuring the performance of the maintenance sub-processes such as preventive maintenance process, corrective maintenance process, spare part provisioning process, human maintenance resources process, etc. (BSI, 2019). The identified KPIs/KRIs from the literature are presented in the finding section.

Table 1: Difference between KRIs and KPIs adapted from Parmenter (2015)

Result Indicators	Performance Indicators
Can be financial and non-financial	Non-financial measures (not expressed in dollars, pounds, euros, etc.)
Measures mainly monthly and sometimes quarterly	Measured frequently (e.g., 24/7, daily or weekly)
As a summary of progress in an organisation's critical success factor, it is ideal to report progress to a board	Acted on by the CEO and senior management team
It does not help staff or management because nowhere does it tell what you need to fix	All staff understand the measure and what corrective action is required
Commonly, the only person responsible for a KRI is the CEO	Responsibility can be tied down to the individual or team
A KRI is designed to summarise activity within one CSF	Significant impact (e.g., it impacts on more than one of the top CSFs and more than one balanced scorecard perspective)
A KRI is a result of many activities managed through a variety of performance measures	Has a positive impact (e.g., affects all other performance measures in a positive way)
Normally reported by way of a trend graph covering at least the last 15 months of activity	Normally reported by way of an intranet screen indicating activity, the person responsible, and past history so that a meaningful phone call can be made

3 METHODOLOGY

This study used a qualitative approach to collect information from primary and secondary sources. First, an extensive literature review was conducted to explore different types of maintenance performance metrics in different sectors and the use of data analytics in maintenance management, as presented in the literature review and findings sections. To collect the primary data, semi-structured interviews were carried out with subject matter experts to collect information about KPIs present in the organisations, their maintenance approach, and challenges for developing KPIs. The collected data from interviews are analysed and presented in the findings section.

To investigate how findings from literature related to the use of KPIs in practice, interviews were conducted with a number of experts from the smart asset management work field. Companies with different roles in the smart asset management supply chain and innovation processes were selected to gain a broad perspective on factors that affect the use of KPIs in practice. All companies selected are based in the Netherlands.

Interviewee 1 (I1) is a CTO of a technology provider that enables organisations to use 3D point clouds for smart asset management. The company focuses on providing LiDAR equipment for the production of 3D scans and algorithms to analyse the 3D scans. Due to the relative newness of the technology, this company particularly focuses on the front end of innovation processes, as their clients primarily experiment with their product rather than implementing it as part of the core maintenance activities.

Interviewee 2 (I2) is a company's CEO that enables SME manufacturers to transform into industry 4.0 readiness. They provide physical solutions to generate, stream, gather and visualise data from machinery and additional documents. Their customers typically have an urgency to implement smart asset management in order to keep up with their competitors. As such, I2 focuses on adopters of industry.

Interviewee 2 (I3) is a business consultant at the digital asset management department of one of the largest asset management companies in the Netherlands. This organisation has over 150 years of experience in asset management and, at the time of writing, five years of experience in smart digital asset management. Clients of this company are typically related to public infrastructure owners that follow structured public asset management guidelines. Their products and services are mainly focused on implementation and actual delivery.

The questions involved the types of their maintenance approach (time-based maintenance, condition-based maintenance, predictive maintenance, prescriptive maintenance), their portfolio of projects, the types of KPIs they use and how they measure these KPIs. There was extra focus on the difficulties in defining and measuring KPIs. Further questions were about new technologies, their implementation and future-proofing the systems.

4 FINDINGS

4.1 Findings from Literature Review

This section focuses on the KPIs found in the literature for different purposes.

For World Class Maintenance (WCM), which is defined as "the maintenance practices that enable a company to achieve a competitive advantage over its competitors in the maintenance process" (Wireman 2003), Schjølberg and Baas (2003) identified eight KPIs as follows:

- Total maintenance cost/asset replacement value, which describes if the company has too high maintenance costs
- Average inventory value of maintenance materials/asset replacement value, which is used to evaluate if the inventory value of maintenance material is too large
- Time for preventive maintenance/total time for maintenance, which indicates the time portion of preventive maintenance
- Total maintenance cost/total turnover, which describes the cost of maintenance compared to the turnover of the company
- Time for critical corrective maintenance/total time for maintenance, which indicates the time portion for critical corrective maintenance
- Planned and predictive time for maintenance/total time for maintenance, which describes the amount of time in maintenance organisation used for proactive work in terms of planned and predictive maintenance
- Actual operation time/required operation time, which shows the operational availability in production
- Overall equipment effectiveness (OEE), which equals Availability rate x Performance rate x Quality rate

One of the sources of data that can be used for measuring KPIs is maintenance work orders (MWOs), which are used when tracking and solving any maintenance–related issue (Brundage et al., 2018). These data could include time/date elements, human elements, machine/facility elements, and some raw text describing the maintenance issue (Brundage et al., 2018). Table 2 shows some of these elements and the KPIs that can be calculated using time elements.

Table 2: Elements of MWO data and related KPIs adapted from Brundage et al. (2018)

Time Elements	Human Elements	Machine Elements	Raw Text Elements	Calculated KPIs
Machine Down Time-stamp	Maintenance Technician	Machine Name/ Manufactory	Description of Problem	Time between Failure
Machine Up Time-stamp	Operator	Machine Type/ Location	Description of observed Symptoms	Time to Repair
Maintenance Technician Arrives Time-stamp, Problem Found Time-stamp	Skill or Craft	Part in Process	Description of Cause	Time to Diagnose
Part(s) Ordered Time-stamp, Part(s) Received Time-stamp		Necessary Part	Description of Solution	Lead Time for Part

Maintenance of healthcare facilities could be a critical process because the failure of some systems, such as heating and cooling systems, could result in catastrophic disruptions in the healthcare services. Shohet (2006) developed four types of KPIs for strategic healthcare facilities maintenance, including 1) Organisation and Management, 2) Asset Development, 3) Performance Management, and 4) Maintenance Efficiency. Specifically for maintenance efficiency, three KPIs were developed:

- Annual maintenance expenditure AME per square meter built (excluding cleaning, energy, and security expenditures),
- Annual maintenance expenditure per "output" unit (patient bed), and
- The maintenance efficiency indicator (MEI) indicates the investment in maintenance in relation to the facilities' performance.

4.2 Findings from Interviews

The findings from the interviews with the three interviewees are presented in this subsection. Company I1 focuses on innovation's front end and uses 3D point clouds for smart asset management. They provided insights on how and why their customers demand limited input for their business cases. Requests for quotations for I1 generally come from sandboxed innovation departments that have the budget to experiment with LiDAR scanners and the point cloud technology. Therefore, they have requested a set of KPIs related to the business value in a limited number of their projects. If requested, the KPIs focus on (i) technical results from point cloud scans and (ii) processing time.

Company I2 is an industry 4.0 enabler that distinct two types of clients (i) early mature SMEs aiming to gain insights from experimenting with their machine data and (ii) digital mature SMEs that have specific objectives and generally aim at data-driven improvements. Their first type of client does not define KPIs at the start of the project. Typically, these clients define their KPIs as soon as data is available in their databases. As part of their projects, an important process is to analyse and assess the data on its value such that a business case can be made for productivity improvement. This assessment is important, as the I2 has experienced that the realm of possible KRIs/KPIs is larger than what companies can understand and use in practice. According to I2, the projects typically focus on general machine productivity improvements, which implies that the KPIs of I2's clients also relate to general productivity and machine efficiency rather than the maintenance KPIs, as shown in the tables above.

Their second type of clients aims to improve their processes using a data-driven approach. These clients typically have a set of KRIs/KPIs and steering mechanisms to be implemented when the required data becomes available. These companies have shown to use KPIs typically related to Table 2. It should be noted that the metrics of this type of I2's clients do evolve over time, i.e., during the projects and afterward. I2 explicitly mentioned the gap between theoretical and practical approaches in defining KRIs/KPIs.

Company I3 primarily focuses on smart asset management of public assets. As a contractor of semi-public organisations such as the Directorate-General for Public Works and Water Management Directorate General, they have to comply with their metrics for maintenance and results to public norms. On an aggregate level, these metrics consist of (i) safety metrics for consumers, (ii) sustainability metrics, (iii) hindrance metrics, and (iv) livability metrics. Norms that indicate the triggers for condition-based maintenance are rigged, tested and refined. I3 mentioned examples of KPIs in relation to maintenance management. For instance, a sustainability metric measures CO2 production. In this case, the KPI can be met by doing less maintenance or choosing techniques that produce less CO2. Another metric is for estimating and adjusting the lifetime of assets based on the current observation (e.g., visual inspection). Their maintenance work processes and documents are all automated and shared with clients, and all decisions are well documented. In their operation, maintenance engineers are the main source of data as they manually fill in forms, add pictures of assets, or update metrics of assets. The used KPIs may change during a discussion with the client to achieve their objectives.

4.2.1 Challenges

The companies were asked about the challenges they have experienced regarding measuring the KPIs/KRIs and the adoption of new technologies for maintenance performance measurement. Company I3 noted that the challenges of KPIs measurement are related to the difficulty of measuring subjective KPIs like "liveability". Such KPIs are hard to define and difficult to relate to steering mechanisms. Another complication is that KPIs often impact each other and that these impacts must be predicted. Also, a cross-correlation of KPIs overview may be plotted against the cost to reveal the effects of steering mechanisms. Company I2 mentioned their experienced issues with the digitisation of analogue and manual working documentation, which is time-consuming and requires significant changes to the work processes. Company I2 and I3 noted that the evaluation of KPIs is a continuous process, which requires adjustments over time.

Company I2 provided insights into the difficulties of evolving from smart asset management to Predictive Maintenance (PdM). The former mainly involves condition-based maintenance metrics where maintenance is applied after sensors pass a threshold value. The latter also includes a prediction of the Remaining Useful Lifetime (RUL) at any moment of the asset's life cycle. Difficulties include the dataset not being of sufficient quality, the limited time horizon of the data, or data points being unreliable. A well-known issue is the unbalance between data of assets in healthy conditions and run-to-failure conditions. This may be solved by either generating data in experimental setups or using synthetic data. Another main issue is the data quality, which is related to the problem of manual data collection. Manual data collection is prone to human error and can cause inaccuracy of PdM models. I3 noted low accuracy of PdM models, which is one of the main reasons that maintenance is often done reactive or condition-based, rather than predictive. Therefore, their used KPIs focus on reactive and condition-based maintenance. According to I2, difficulties in collecting data are often related to non-digital data sources. Company I3 has experienced difficulties with subjective data collected by professionals; therefore, they intend to collect some objective data by sensors to support the professionals, not to replace them, because such data must be evaluated and validated due the possibility of producing invalid data by the sensors.

Asking about challenges regarding computing power, I2 noted that most clients have sufficient computing power for computational data analysis. I3 noted that the cost of computing power is relatively small compared to the other costs of a project, and is not a significant challenge for them.

Asking about employing emerging technologies such as Building Information Modelling (BIM), digital twin, LiDAR, robotics, and thermal cameras to address these challenges, I3 mentioned that the rigid norms for asset management limitedly allow the implementation of new technologies; however, they are still trying to develop and implement such technologies for maintenance management.

5 DISCUSSION

In this study, several KPIs and KRIs have been identified from the literature. From the interviews, it is apparent that the approaches to defining and measuring KPIs differ wildly among companies. I2 focuses on uptime and economic gain for their clients, and the KPIs reflect these concerns. I3 has involvement in infrastructure that involves many people, and the KPIs used are ethical and environmental. The experimental company I1 is focused on implementing new technologies and creating new products and is less involved in KPI measurement. An observation from the interviews is that the use of condition-based maintenance is more prevalent than PdM. This may be due to the absence of quality and reliable data and the lack of automated data collection. That is, the maturity in data collection and digitalisation are key factors in moving towards PdM. The more mature the companies are in both maintenance and digitisation, the more likely the companies are to measure more KPIs.

For identifying effective KPIs, communication with the client is important as the maintenance companies need to meet clients' requirements. Communication can also make it possible to change the measured KPIs and the collected data based on the needs and objectives of the client. In these ways, communication improves both efficiency and effectiveness of maintenance performance monitoring.

In this study, the interviews were conducted with the companies providing maintenance services to clients; therefore, the interviews with their clients could provide more insight into their perspective on monitoring maintenance performance.

6 CONCLUSION

This study focused on identifying the most common KPIs and KRIs for mentoring maintenance performance through literature review processes. In addition, this research provided insight into measuring maintenance performance from the industry practitioners' point of view and identified the main challenges in measuring KPIs. The lack of quality and reliable data was identified to be prime challenges in accurately measuring KPIs. Automated data collection is another challenge that could be addressed by employing new technologies such as digital twin, robotics, and sensory data from LiDAR and thermal cameras.

The findings of this study generate a guideline for organisations to decide on the most suitable and effective indicators for improving the performance of their maintenance management system. In future research, the use of suggested technologies such as digital twin and robotics can be investigated, and their benefits and challenges can be identified to further help organisations in achieving their maintenance performance targets.

7 REFERENCES

Ansari, F., Glawar, R. and Nemeth, T., 2019. PriMa: a prescriptive maintenance model for cyber-physical production systems. International Journal of Computer Integrated Manufacturing, 32(4-5), pp.482-503.

Brundage, M.P., Morris, K.C., Sexton, T., Moccozet, S. and Hoffman, M., 2018. Developing maintenance key performance indicators from maintenance work order data. In International manufacturing science and engineering conference. Vol. 51371, pp. V003T02A027

BSI, 2019. BS EN 15341:2019. Maintenance - Maintenance Key Performance Indicators British Standards Institute, London, UK.

BSI 1993. BS 3811-Glossary of Maintenance Management Terms in Terotechnology. British Standards Institute, London, Uk.

Gackowiec, P., 2019. General overview of maintenance strategies–concepts and approaches. Multidisciplinary Aspects of Production Engineering, 2.

International Electrotechnical Commission (IEC), 2016. IEC 62264-3:2016 Enterprise-control system integration – Part 3: Activity models of manufacturing operations management. International Organization for Standardisation

Karim, R., Westerberg, J., Galar, D. and Kumar, U., 2016. Maintenance analytics–the new know in maintenance. IFAC-PapersOnLine, 49(28), pp.214-219.

Kerzner, H., 2017. Project management metrics, KPIs, and dashboards: a guide to measuring and monitoring project performance. John Wiley & Sons..

Khalifa, M. and Khalid, P., 2015. Developing strategic health care key performance indicators: a case study on a tertiary care hospital. In Proceedings of the 5th International Conference on Current and Future Trends of Information and Communication Technologies in Healthcare (ICTH 2015), Procedia Computer Science, Berlin, Germany. Vol. 63, pp. 459–466.

Kumar, S., Dolev, E., Pecht, M., 2010. Parameter selection for health monitoring of electronic products. Microelectronics Reliability 50, 161168. doi:10.1016/j.microrel.2009.09.016.

Lee, S. K., An, H. K., and Yu, J. H., 2012. An extension of the technology acceptance model for BIM-based FM. In Construction Research Congress 2012: Construction Challenges in a Flat World, pp. 602-611.

Lukens, S., Naik, M., Saetia, K. and Hu, X., 2019. Best practices framework for improving maintenance data quality to enable asset performance analytics. In Annual conference of the phm society Vol. 11, No. 1.

Padovano, A., Longo, F., Nicoletti, L., Gazzaneo, L., Chiurco, A. and Talarico, S., 2021. A prescriptive maintenance system for intelligent production planning and control in a smart cyber-physical production line. Procedia CIRP, 104, pp.1819-1824.

Parmenter, D., 2015. Key performance indicators: developing, implementing, and using winning KPIs. John Wiley & Sons.

Schjølberg, P., Baas, C., 2003. Kartlegging av vedlikehold og driftssikkerhet i norsk industri 2002, vol NTNU 200302. Instituttet, Trondheim.

Sherwin, D., 2000. A review of overall models for maintenance management. Journal of quality in maintenance engineering. Vol. 6 No. 3, pp. 138-164.

Shohet, IMM, 2006. Key performance indicators for strategic healthcare facilities maintenance. Journal of construction engineering and management, 132(4), pp.345-352.

Tsang, A.H.C., 2002, Strategic dimensions of maintenance management. Journal of Quality in Maintenance Engineering, Vol. 8 No. 1, PP. 7-39.

Wireman, T., 2003. Maintenance Management and Regulatory Compliance Strategies. Industrial Press, New York

Yalcinkaya, M., and Singh, V., 2014. Building information modeling (BIM) for facilities management – literature review and future needs. IFIP Advances in Information and Communication Technology, 1-10.