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Improving the Road Construction Supply Chain by Developing a National Level Performance Measurement System: the Case of Estonia

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Abstract**—**Transport and logistics are the lifeblood of societies. There is a strong correlation between overall growth in economic activity and growth of transport. The movement of people and goods has the potential for creating wealth and prosperity, therefore the state of transportation infrastructure and especially the condition of road networks is often a governmental priority. The design, building and maintenance of national roads constitute a substantial share of government budgets. Taking into account the magnitude and importance of these investments, the expedience, efficiency and sustainability of these projects are of great public interest. This paper provides an overview of supply chain management principles applied to road construction. In addition, road construction performance measurement systems and ICT solutions are discussed. Road construction in Estonia is analyzed. The authors propose the development of a national performance measurement system for road construction.

Keywords**—**ICT in road construction, key performance indicators, quality performance measurement, road construction supply chain.

I. Introduction

THE continuous development and maintenance of essential public infrastructure is an important ingredient for sustained economic growth. At a national level, transportation investment boosts productivity and economic potential. It contributes by making freight flows more efficient and reliable whilst doing the same for personal and business travel increasing also mobility and quality of life. Modern infrastructure networks create more productivity amongst businesses and individuals across the geographic landscape. "Any congestion, or lack of capacity, must be viewed as a bottle-neck not just to traffic, but to productivity and economic growth itself." [1].

Estonia is situated on the eastern boarder of the European Union having only 633 km of land border (Russia, Latvia) and a 3,794 km long coastline. Estonia's geographic position has long been used to the advantage, during the 11th century Estonia's capital Tallinn was part of the vibrant economic alliance of trading cities known as the Hanseatic League. As a major thoroughfare, Estonia's location has fostered the creation of efficient transportation links and distribution chains for goods and services to serve Estonian, European and international companies.

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The Estonian transportation and logistics sector is comprised of a combination of transportation services, transit trade, distribution centers and value-added logistics.

Transport contributes considerably to Estonian export revenues and its balance of trade. Prior to the recent economic crisis, the Estonian transport and transit sector accounted for approximately 14.4% of the Estonian Gross Domestic Product (GDP) [2]. In 2008-2009, the Estonian export and transport sector was the first to recover strongly and was the locomotive driving GDP growth, with export volumes doubling in the IV quarter of 2010. In 2010, the transport sector accounted for more than 12% of Estonian GDP, and in 2011, the transport sector employed *circa* 50,000 people (over 8% of the work-force) [3].

The rapid economic growth in the beginning of this century led to transportation shortages and congestion problems and increased the demand for road quality improvement. With the help of European Union (EU) funds the Estonian government has given high priority to road development, investing particularly in the construction of high-quality roads. The amount assigned for road infrastructure development for the period 2008-2013 was 737 mil. EUR. The annual budget of the Estonian Road Administration (ERA) is approximately 300 mil. EUR which constitutes approximately 30% of state investments into the real sector.

Taking into account the magnitude and importance of these investments, the expedience, efficiency and sustainability of these projects are of great public interest. In this paper the authors give an overview of road construction supply chains, performance measurement systems, the development of related Information and Communications Technology (ICT) and current practices in Estonian road construction management. The aim of the paper is to determine if there is a need to develop and implement a national level performance measurement system that gives feedback of road construction investments throughout the lifecycle of the road.

II. Road Construction Supply Chain

The supply chain has been defined as ''the network of organizations that are involved, through upstream and downstream linkages, in various processes and activities that produce value in the form of products and services" [4]. Road Construction Supply Chain (RCSC) is deemed an integrated approach for road construction projects to resolve common problems and to address common deficiencies in construction management. Road construction management embodies many challenges and restrictions due to the temporary and complex nature of road construction projects. The construction of one road generally involves the management of numerous separate projects with responsibilities divided among several independent contractors whose involvement often includes separate phases of the lifecycle of the entire project. Efficient collaboration among all contractors throughout the road construction lifecycle is crucial to enhancing construction management performance [4].

The primary objective of supply chain management is to meet customer (in this case the national transportation authority or state) demands through the most efficient use of resources. This would include the optimal management of distribution capacity, inventory and labor. In theory, a supply chain seeks to match demand with supply and do so with the minimal inventory [5].

In road construction first the decision making process to invest in a highway is complex and time consuming. The same applies to the duration of the planning and constructing and especially the operation and useful time. Project development generally comprises several phases requiring a diverse array of specialized services and the involvement of numerous participants (see Fig. 1). There are so many independent parties including state or local authorities, developers, engineers, general contractors, subcontractors, consultants, supervisors, suppliers, and maintenance agencies in a road construction project that the construction project should be systematically broken down and all parties should cooperate with each other to implement the project [4].

Most of the projects are road maintenance and rehabilitation works that should be performed to maintain the service levels of the national and local roads. These types of road construction works will be conducted by central and local governments periodically and, therefore, will potentially require similar specifications and skills from similar suppliers and sub-contractors. Also if new road construction is undertaken, the type of works is considered linear that would require similar tasks performed by similar resources for each defined section. For this kind of characteristic of project, i.e., consisting repetitive operations, the implementation of supply chain management is reasonable and beneficial.

It has been identified that there are three models of RCSC based on the owner's involvement, i.e. RCSC nominated by owner; RCSC created by owner, and RCSC managed by owner. The three models have different levels of owner involvement in the construction project supply chains, whereas concurrently managing their value chains [5].

Therefore to run a successful project in RCSC the following aspects must be taken into account [6]:

1) Integrated and incentivised supply chain - integrating the supply chain with its specialist knowledge, incentives for innovative ideas to give best value solutions.
2) Maintaining a competitive and sustainable supply chain - maintaining a good quality supplier base motivated and incentivised to work with the road administration.
3) Early creation of delivery team - early contractor involvement for more scope in innovation, better risk management, and forward planning of work programs and resources.
4) Clear points of responsibility, no unnecessary layers of supervision - clarifying roles and responsibilities to reduce contractual interface problems, eliminating resource wastage from unnecessary layers of supervision.
5) E-procurement - to make tender processes, communications and performance measurement more efficient.
6) Selection of suppliers on the basis of best value - identifying the aspects of quality which add real, affordable value, using reality checks to confirm quality submissions and promises.
7) Partnership approach based on long-term relationships - moving from short-term project partnering arrangements to long-term relationships for retention of skills and better resource and work programming.
8) Fair allocation of risks - risks will be allocated to the party best able to manage them and the road administration will accept risks where suppliers are prepared to work in partnership to manage them and control the consequences.
9) High quality design - design solutions will be based on whole life value.
10) *Performance measurement with continual improvement targets* - establishing benefits in the form of cost and

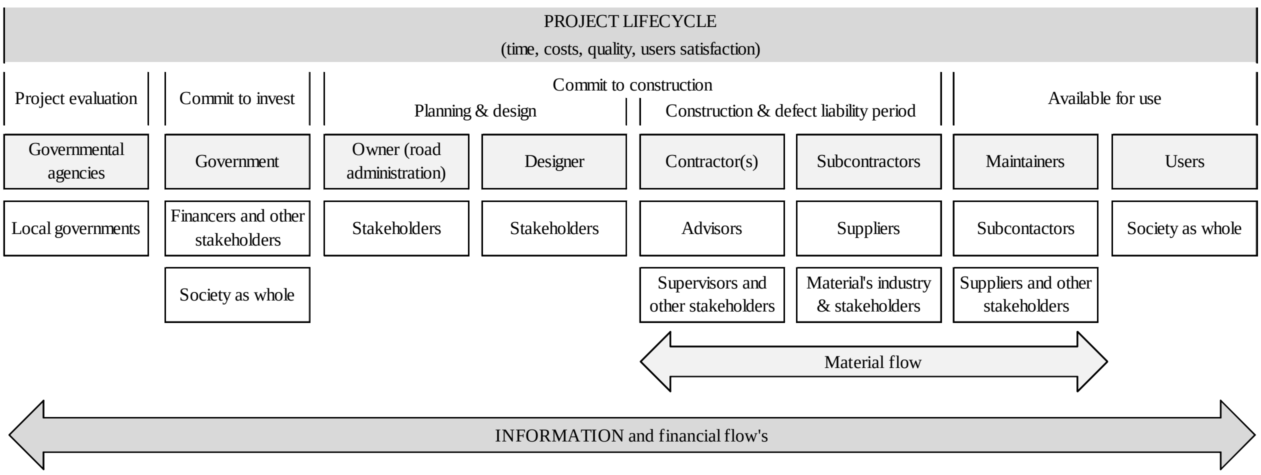

Fig. 1 Supply chain and project stages in road construction industry (based on [7]-[10])

time-savings, reduced defects and accidents, and improved whole life value and satisfaction with the project.

The principles of supply chain management and performance management require that all significant activity throughout the supply chain be measured.

III. Performance Measurement in Road Construction

Performance measurement is the selection and use of quantitative measures of capacities, processes, and outcomes to develop information about critical aspects of activities, including their effect on the society. Performance measurement estimates the parameters under which programs, investments, and acquisitions are reaching the targeted results.

The main reason to adopt Key Performance Indicators (KPI-s) as performance metrics is to put strategy into operation. It has the ability to turn a sector's strategic plan into numbers that can be used to guide performance throughout the supply chain. Like in many management measures and approaches effectiveness will be dependent on the emphases placed on the approach by the government (see Fig. 2).

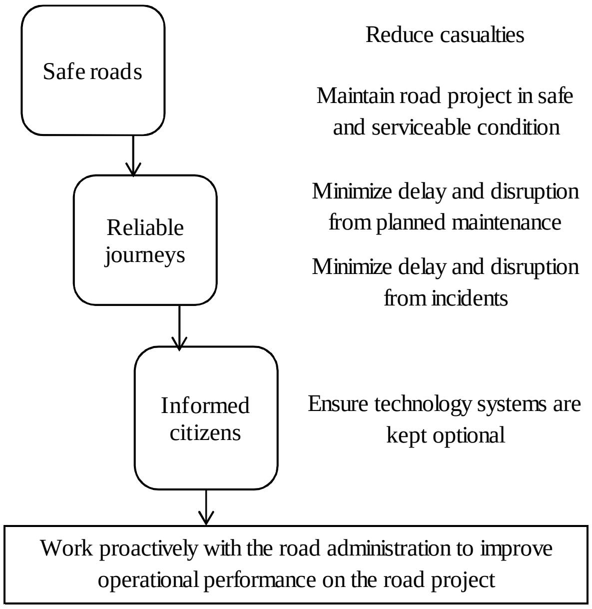

Fig. 2 Linkage between road administration goals, performance measures, and KPI-s (based on [6])

Both road construction business and national road authorities need a performance measurement system with KPIs to avoid being accused to focus on "the bottom line" and "on the short term". The use of KPIs gives a more balanced view of a sectors performance and a more holistic view of progress [11]. In the road construction sector KPIs can be applied to road programs evaluation, planning and organization management in the following ways [12]:

1) In process management, to measure the success of individual processes or groups of processes.
2) In benchmarking, to establish "best practice" or "superior performance" processes in order to improve performance of the road administration.
3) To aid the development or improvement of the functions or specific engineering tasks of the road administration.
4) In management-by-results, to set targets and evaluate the achievement of goals and objectives.

The Organisation for Economic Co-operation and Development (OECD) carried out an extensive study in 2001 [12], which aimed to assess the applicability of the KPIs in improving the management of road administration. The 15 indicators that were field-tested included: average road user costs; level of satisfaction regarding travel time and its reliability and quality of road user information; protected road-user risk; unprotected road-user risk; environmental policies/programs; processes in place for market research and customer feedback; long-term programs; allocation of resources to road infrastructure; quality management/audit programs; forecast values of road costs vs. actual costs; overhead percentage; value of assets; roughness; state of road bridges; satisfaction with road condition.

It is suggested in the OECD report that ideally agencies need to link their higher level goals with performance measures and individual KPIs. For example, American Association of State Highway and Transportation Officials (AASHTO) strongly promote reform for the entire U.S. highway system centered on supporting the achievement of six key national interests. AASHTO is in the process of developing and establishing these broad agency goals on construction safety, mobility, and stewardship of the entire U.S. highway system. These six key national interests appear to reflect the interests of American society and address the public's major concerns about and views of the transportation system. If the reform is accepted and implemented, AASHTO believes that every highway agency in the United States will be capable of and held accountable of producing results that reflect and work toward realizing these goals. For the system to be effective, has been established as the driving force behind performance management [13].

Also in Great Britain, to deliver on its aims and objectives, the Highways Agency has established seven key program-level performance measures:

1) Reliability – Implement a program of delivery actions that tackle unreliable journeys on the strategic road network.
2) Major projects – Deliver on time and budget the program of major schemes on the strategic road network.
3) Safety – Deliver the Highways Agency's agreed proportion of the national road casualty reduction target.
4) Maintenance – Maintain the strategic road network in a safe and reliable condition, and deliver value for money.
5) Carbon emissions – Contribute to national and international goals for reducing carbon dioxide emissions by lowering the Highways Agency's emissions.
6) Customer satisfaction – Deliver a high level of road user satisfaction.
7) Efficiency – Deliver the Highways Agency's contribution to the Department for Transport's efficiency target [6].

A major concern of transportation agencies throughout the world is to develop a method to effectively and efficiently maintain roadway infrastructure. Over the last two decades, an outcome-based initiative known as Performance-Based Road Maintenance (PBRM) has produced results that are signify-

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cant. In contrast to traditional techniques that specify materials or methods to perform maintenance work, the PBRM system specifies the desired outcome.

In order to successfully run, monitor and evaluate supply chain and performance of a project it is important to have accurate, comparable and reliable information. The Highway Development and Management Tool (HDM-IV) has been used to combine technical and economic appraisals of road projects, to prepare road investments programs and to analyze road network strategies [14]. The performance management system should ideally compare the results presented by HDM-IV with the performance of the road during its lifecycle.

Recent development in technologies enables the organization to avail information easily and also the rapid developments have decreased the cost of information. These technologies are essential to gather information to manage and evaluate the supply chain [15].

IV. ICT Solutions

Today due to very rapid developments in new technologies as RF location-based solutions (LBS) using Global Positioning Systems (GPS), cellular triangulation, accelerometers and radio frequency identification (RFID) technologies over public and private data networks and with the use of ICT solutions it is now possible to measure the performance of road networks simply, quickly and cost effectively.

The impact of ICT on many different aspects of economy and RCSC management has been discussed also with the help of the conceptual models [16]-[19]. However, only recently empirically grounded models have been presented that have found a positive and significant impact of ICT on labor productivity and economic growth. One of the major transformations in the rapidly evolving digital economy occurs in the supply chains. ICT in general, and ICT in Supply Chain Management, is argued to enable great opportunities, ranging from direct operational benefits to the creation of strategic advantage.

Although the road construction industry has been slow to implement automation, new technologies and ICT, especially when compared to other industries such as manufacturing and service, the nature of the construction industry is changing and adoption of new technologies is required to survive and prosper in an increasing global economic system with fewer resources, complex projects, and fierce competition. As such, many construction companies have already begun implementing ICT and reported significant benefits in its use [18].

The integration of ICT technologies with the GPS technology, through the collection of real-time data to improve management and decision-making functions, contractor companies can revolutionize the way contractors do business. In the Total Jobsite Management Tool (TJMT) cycle, the real-time data produced in the field is collected and transferred to the office. In the office, ICT tools are utilized to convert the raw data into useful information to be used by management for project performance applications such as detecting cost/schedule deviations. The result of this analysis is then used to update the project database, allowing the project manager to take corrective action in the field if necessary.

This real-time GPS data can prove valuable for project management applications by reducing the time required for performance analysis, improving the accuracy and quality of the data, reducing labor costs, reducing duplication, and improving productivity. It is considered a problem that it does not take into account the whole lifecycle of the project and the data that can be gathered could also be valuable in the maintenance process and in controlling the sustainability and durability [18].

Experiments have been performed testing the use of capable smartphones for various purposes for instance traffic management, route planning, safety and conditions of vehicles and roadways, emergency services. The use of other solutions besides localization have been studied, forms of sensing have also been employed in Intelligent Transport Systems (ITS). Accelerometers are used for automotive safety applications such as detecting crashes to deploy airbags and also notify emergency services automatically. Accelerometers and strain gauges coupled with cameras have been used for structural monitoring of the transportation infrastructure [17].

Due to recent rapid developments in RFID use and expansion of mobile device applications the area of road construction and maintenance has tested and started implementing new technologies. All these new ICT solutions can give necessary information to effectively run the construction process, the maintenance and also give necessary data to draw important conclusions regarding whether the goals set in the tender were achieved and sustained throughout the lifecycle. Recent new approaches to use sensor equipped RFIDs in road construction monitoring and measuring concrete and asphalt conditions are very likely to be adopted in the near future also providing information and enabling to get accurate feedback. As a process tracking technology passive RFID technology has significant potential to enhance supply chain control and management in road construction projects.

Brynjolfsson and Hitt [19] state that productivity improvements cannot simply be achieved by working harder but must be achieved by working smarter. The greatest gains in productivity are realized when the new ICT is coupled with other complementary approaches such as new business strategies, new business processes, and new organizational structures – in case of RCSC performance measurement system.

V. Implications for Road Management in Estonia

A. Estonian Road Network and ERA

In terms of infrastructure trade relies on both good rail connections and the road network. The Estonian national transit infrastructure is generally well established. The biggest economical challenge is a good road network, which in Estonia is the area that constantly needs development and improvement. The total length of national roads in Estonia as of January 1, 2011 was 16,000 km, i.e. 28.2% of the total length of the Estonian road network, which was 58,412 km. The length of E-roads (European roads accepted and systematized into international road network by UNECE) in Estonia is only 995 km [20].

The Estonian Road Administration (ERA) is a government agency operating under the auspices of the Ministry of Economic Affairs and Communications (MoEC). It has a management function, it carries out state supervision, applies the enforcement powers of the state and provides public services on the basis and to the extent prescribed by law. In performing its duties the ERA represents the state.

In Estonia road construction and maintenance are influenced and constricted by legal frameworks, political decisions and extreme climate conditions. Political and legal constraints come from being a member of the European Union and having limitations to national level decisions. Procurement regulations are strict and emphasize price as the main criteria. In addition, opportunities regarding collaboration and cooperation between organizations are limited by Competition Regulations.

The ERA has to follow legal acts of the Republic of Estonia and the EU, international treaties which bind the Republic of Estonia, the regulations and orders of the government of the Republic, the regulations and directives of the MoEC and the statutes of the ERA, as well as the relevant regulations of other ministers. The main functions of the ERA are:

1) road management and creation of conditions for safe traffic on national roads;
2) improvement of traffic safety and reduction of harmful environmental impact of vehicles;
3) organization of traffic and public transport;
4) state supervision over compliance with the provisions of legal acts within its area of activity and implementation of the enforcement powers of the state;
5) management of the National Road Databank, the Vehicle Register and the Public Transport Information System;
6) participation in the development of the legislation regulating its area of activity and making recommendations for amendments in the legislation;
7) participation in the elaboration of policies, strategies, and plans in its area of activity and participation in the preparation and implementation of international projects;
8) implementation of state policy and the development of plans in the field of traffic safety and environmental safety of vehicles, and required management of the register of vehicles and other documents prescribed by law [20].

One of the main tasks of the ERA is road management and creation of safe traffic conditions on roads. To achieve that aim, it is essential to get feedback from road users. Since 2002, the ERA has conducted surveys of the drivers` satisfaction with the driving conditions on national roads.

Measurements of road surface roughness (according to the International Roughness Index, IRI) have been carried out and inventories of defects on paved roads have been made since 1995. The load bearing capacity (Falling Weight Deflectometer, FWD) of the roads has been measured since 1996 and rut depth since 2001. These four indicators of road surface condition together with the traffic volume are the main indicators of the Pavement Management System (PMS). Data about the condition of road surface is a part of the data in the National Road Databank and is publicly available. Two kinds of software – Estonian Pavement Management System (EPMS) and HDM-4 are used for analyzing the condition of road surface (priority, need for repairs, cost-benefit analysis etc.). EPMS is specially developed software in Estonia for analyzing the condition of road surfaces and HDM-IV is a internationally known software for cost-benefit analysis.

The diagrams of changes in the amount of defects during the years 2006–2010 show a constant decrease until 2010. On main roads, which have been best financed, the defects have decreased as a result of the construction of new pavements. On basic and secondary roads, where less new pavement has been constructed, defects have decreased mostly due to increased surface dressing. IRI graphs show improvement for all road types, although at a lower speed. The average IRI value for the whole network of paved national roads improved in the years 2006–2010, as financing of construction, repairs and maintenance of pavements remained on the same level and repair sites were rationally chosen. The IRI of main roads is considered satisfactory, but the same cannot be said about basic and secondary roads, and improvement is slower than expected. For the road user that means less driving comfort on basic and secondary roads and greater indirect costs [20]-[22].

The severe climatic conditions in Estonia with sometimes several melting-icing cycles per day call for new ICT solutions in road monitoring. The use of wired loop detectors is not suitable due to shifting and subsiding effect of melting-icing cycles causing unsustainable failure of these solutions. By contrast, recent tests using RFID detectors have given positive feedback and have proven to be sustainable [23].

B. Improving Road Construction Performance Monitoring in Estonia

The developed road construction projects are monitored and supervised very tightly during the construction process and also during the liability period. After the end of liability period regular surveillance of the road conditions as described before is carried out in a well regulated way, but without any feedback and comparison to the initial analyses, including meeting the profitability calculations and durability of materials and comparing estimated repair span to the actual need during the lifecycle (see Fig. 3).

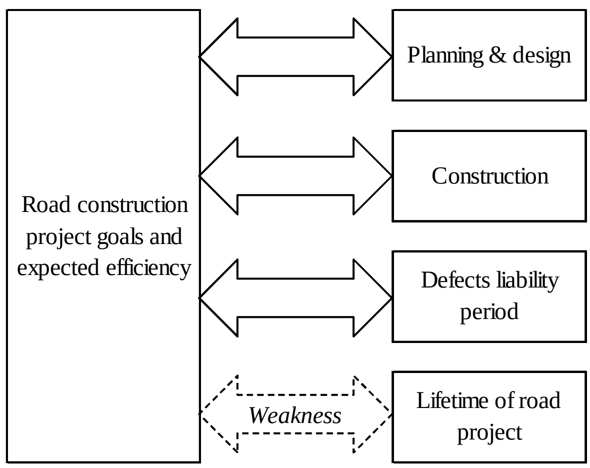

Fig. 3 Current practice of road construction projects evaluation in Estonia

The literature recognizes that in the road construction project performance measurement is more complex than merely measuring cost, time and quality [24]. Internationally, road authorities are becoming more of asset managers. As a result, road project delivery is enabling more integrated services, requiring broader know-how from service providers [25].

An emerging challenge for road administrations is to define goals and objectives pertinent to current community views, and to devise creative ways to respond to contemporary problems. Key issues facing road transport system and road administrations today include [12]:

1) Decreasing road budgets.
2) Demand for greater transparency in road administration performance.
3) Separation of the production and administration roles of road administrations.
4) Adoption of customer focus rather than an "expert knows best" attitude.
5) Demand for greater efficiency in all operations, leading to better results and quality.
6) Demand for more co-ordination and co-operation across the transport sector.
7) Demand for performance improvements to be implemented more rapidly than in the past.
8) New management aspects and the demand for an open and broad understanding of the mobility problems facing society.
9) Demand for more data and more efficient data management.

Currently in Estonia (as well in many other countries) the ERA is operating in two different areas regards road networks: a) road development and construction; b) daily road maintenance. Through a performance measurement system it would be possible to link these two areas more closely together and form a effective supply chain.

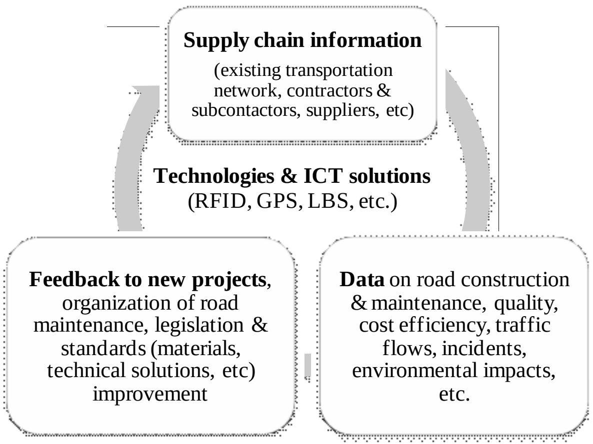

Fig. 4 Effective information flow cycle in Estonian road construction supply chain

Estonia with its innovative ICT solutions, small area and population, has implemented many successful e-developments. Therefore Estonia is an ideal place to implement a new ICT based lifecycle performance measurement system in road construction projects. Every project can get the necessary attention to draw conclusions because the size of the road construction projects is small enough to be manageable (see Fig. 4).

VI. Conclusions

Road network development projects in Estonia are tendered on a case-to-case bases and the legal framework supports to use price as the most important criteria in decision making. ERA focuses on the project outcome and compares roads in compliance with the requirements stipulated in construction projects during the liability period. It also gathers sufficient data on the current conditions of roads from maintenance and repairmen point of view but does not evaluate and give systematical feedback on the road development project lifecycle from the supply chain point of view.

Currently there is no national level system for assessing the performance and sustainability of road investments throughout their lifecycle and through the supply chain. It should be considered in the new Estonian Transport Development Plan to add a set of KPI-s and a system of measuring them due to the lack of performance measurement methods and pre-defined KPI-s in public procurement for roads.

KPIs suggested by the OECD should be analyzed and that a set be developed and implemented on a national level. This has the potential of supporting the development of a performance measurement system that through feedback loops can contribute to the improvement of the RCSC. It can also generate information that can be used to avoid inaccuracies and lack of performance in new projects.

Taking into account new developments in ICT, the amount of data currently available and gathered in databases and the cost of managing and acquiring that data, the authors of this article conclude that establishing a performance measurement system will not produce extra cost. Also new developments in RFID, GPS, mobile technologies and ICT should be studied and in case proven to be reasonable implemented to increase efficiency and reliable feedback on the performance of both RCSC and sustainability and quality of materials.

References

[1] J. C. Taylor, *Road funding: time for a change*. Midland: Mackinac Center for Public Policy, 2007.
[2] A. Saarniit, "Share of transit in Estonian economy," *Bank of Estonia's Kroon & Economy*, no. 1, pp. 43–48, Apr. 2006.
[3] *Statistics Estonia*, http://www.stat.ee/, Sept. 2011.
[4] R. M. R. Mazlan, and K. N. Ali, "Relationships between supply chain management and outsourcing," unpublished.
[5] R. D. Wirahadikusumah, and M. Abduh, "Reinforcing the role of owners in the supply chains of highway construction projects," in *Proc. of the First Makassar Int'l. Conf. on Civil Engineering (MICCE)*, Makassar, 2010, pp. 1321–1328.
[6] *Procurement strategy review*. London: Highways Agency, 2005.
[7] R. Vrijhoef, L. Koskela, and G. Howell, "Understanding construction supply chains: an alternative interpretation," in *Proc. 9th Annual Conf. Int'l. Group Lean Constr. IGLC-9*, Singapore, 2001.
[8] Ge Zhendong, and Su Zhenmin, "A Conceptual Framework for Construction Supply Chain Integration," in *Proc. Int'l. Conf. on Management and Service Science (MASS)*, Wuhan, 2010, pp. 1–7.
[9] *KPI Report for the Minister for Construction*. London: Department of the Environment, Transport and the Regions, 2000.
[10] Jung Un Min, and H. Bjornsson, "CS^2. Construction Supply Chain Simulator," in *CIFE Summer Program*, Stanford, 2002.

[11] M. Axelsen, *Key performance indicators: how they work and how to use them*. Brisbane: Applied Insight Pty Ltd, 2009.
[12] *Performance Indicators for the Road Sector. Summary of the field tests.* Paris: OECD Publications, 2001.
[13] M. Garvin, K. Molenaar, D. Navarro, and G. Proctor, *Key Performance Indicators in Public-Private Partnerships. A State-of-the-Practice Report.* Washington, DC: Federal Highway Administration, 2011.
[14] H. G. R. Kerali, *Overview of HDM-IV.* Birmingham: ISOHDM Technical Secretariat, 2000.
[15] J. M. de la Garza, J. C. Pinero, and M. E. Ozbek, "A framework for monitoring Performance-Based Road Maintenance Contracts," in *TRB's 7th National Conference on Transportation Asset Management*, New Orleans, 2007.
[16] A. Rayati Shavazi, M. Abzari, and A. Mohammadzadeh, "A Research in Relationship between ICT and SCM," *World Academy of Science, Engineering and Technology*, no. 50, pp. 92-101, 2009.
[17] P. Mohan, V. N. Padmanabhan, and R. Ramjee, "Nericell: Rich Monitoring of Road and Traffic Conditions using Mobile Smartphones," in *SenSys'2008*, Raleigh, 2008.
[18] C. L. Perkinson, M. E. Bayraktar, I. Ahmad, "The use of computing technology in highway construction as a total jobsite management tool," *Automation in Construction*, no. 19, pp. 884–897, 2010.
[19] Lung-Chuang Wang, Yu-Cheng Lin, and P Lin, "Dynamic mobile RFID-based supply chain control and management system in construction," *Advanced Engineering Informatics*, Vol. 21, Issue 4, pp. 377-390, Oct. 2007.
[20] *Annual report 2010.* Tallinn: Estonian Road Administration, 2011.
[21] S. Pertens, Lemminkäinen Estonia, Ltd, Tallinn, Estonia, private communication, Oct. 2011.
[22] M. Puust, Estonian Road Administration, Tallinn, Estonia, private communication, Oct. 2011.
[23] Lieutenant colonel A. Kirsimäe, Estonian Police, private communication, Oct. 2011.
[24] D. Bryde, and D. Brown, "The influence of a project performance measurement system on the success of a contract for maintaining motorways and trunk roads," *Project management journal*, Vol. 35, no. 4, pp. 57–65, Dec. 2004.
[25] T. Koppinen, and P. Lahdenperä, *The current and future performance of road project delivery methods*. Tampere: VTT Technical Research Centre of Finland, 2004.