

Developing Road Performance Measurement System with Evaluation Instrument

Kati Kõrbe Kaare, Kristjan Kuhi, and Ott Koppel

Abstract—Transportation authorities need to provide the services and facilities that are critical to every country's well-being and development. Management of the road network is becoming increasingly challenging as demands increase and resources are limited. Public sector institutions are integrating performance information into budgeting, managing and reporting via implementing performance measurement systems. In the face of growing challenges, performance measurement of road networks is attracting growing interest in many countries. The large scale of public investments makes the maintenance and development of road networks an area where such systems are an important assessment tool. Transportation agencies have been using performance measurement and modeling as part of pavement and bridge management systems. Recently the focus has been on extending the process to applications in road construction and maintenance systems, operations and safety programs, and administrative structures and procedures. To eliminate failure and dysfunctional consequences the importance of obtaining objective data and implementing evaluation instrument where necessary is presented in this paper.

Keywords—Key performance indicators, performance measurement system, evaluation, system architecture.

I. INTRODUCTION

ROAD networks are important lifelines for modern societies. Social prosperity and economic development are directly related to mobility and accessibility of communities and are, therefore, highly dependent upon the existence of high quality road networks. Currently, roadways are the dominant mode of transport, particularly in developed countries [1].

Trend towards greater public accountability and transparency in decision making has been an important characteristic of transportation planning, decision making, and organizational management during recent years [2]. One way of accomplishing that has been through the use of performance indicators. When monitored they, provide decision makers with some sense of whether their decisions are improving road network performance, quality and organizational productivity of the road authority. Through the monitoring of such indicators, officials, legislators, and the general public can

follow the continuing efforts of transportation agencies to improve the performance and quality of the road network.

Performance measurement is understood as an instrument for improving the efficiency, effectiveness and objectivity of developments or projects, organizations and services. Performance measurement can enhance the transportation planning, programming, and budgeting process. Good planning and effective programming are necessary, but not sufficient in themselves proper feedback about performance during the lifespan of roads is also expected by policy makers and the public. They want to know what transportation agencies have done and are doing to address mobility, reliability, quality and safety issues.

Performance measurement provides data and analysis that validate the accuracy of transportation planning forecasts and affirms that decisions are leading to promised results. As public agencies face demands for greater public accountability, performance measurement and reporting help answer those demands. In order to make performance measurement a useful tool for improvement the gathered knowledge, must be carefully tied to the agency's mission and strategic goals regarding the development of road networks.

Performance measurement in the transportation sector has been applied in many different ways depending on the goals set by the country's governing body or transportation agency. Therefore in the road sector we have examples of performance being measured from various perspectives and for different reasons. Three most common approaches are: to assess the efficiency of road network, to assess current and future technical conditions of road infrastructures or to evaluate road agency efficiency with respect to provided services [3].

Road authorities collect and retain extensive datasets related to their services and the life-cycle of their infrastructure. It is important to note, that proper data collection, analysis, refinement and presentation is a prerequisite for using it and for reporting to a broader audience. Development of appropriate performance indicators is required for linking transportation and infrastructure data for road management. After the phase of data gathering and analyses and before implementing any changes for improvements an evaluation audit may be required to avoid making false or incorrect conclusions.

P. Smith [4] has presented that many of the expected distortions arising from reliance on performance indicator schemes, and concludes that they may have significant dysfunctional consequences. But at the same time he is against abandoning the performance audit in public sector. In this paper authors present the idea of including evaluation process to avoid dysfunctional consequences and suggest that great

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attention should be given to the incentives implicit in any strategic control scheme, and that the style with which the scheme is applied will have important bearings on its effectiveness.

The use of performance management system (PeMS) in conducting operational analysis, planning, and evaluation studies is described here. The database provides managers and officials with a uniform, comprehensive assessment of road network performance and furthermore engineers can base their operational decisions on knowledge of the current status of the network.

II. PROJECT PERFORMANCE MEASUREMENT

A. Literature Overview

Performance measurement has been widely promoted by governments for more than 20 years, for the express purpose of increasing management's focus on achieving results. It was introduced in Canada in the mid-seventies. At the beginning of such reform managers were advised to identify and report "performance indicators". In the last decade, interest has grown in the art and science of performance measurement, particularly as it applies to road and transportation systems. The topic is well documented in the literature with significant treatises from many organizations around the world, including the U.S Federal Highway Administration (FHWA) and the Transportation Research Board (TRB), the Organization for Economic Cooperation and Development (OECD), Austroads (Australia) and the Transportation Association of Canada (TAC) [1], [5]-[9].

Literature does not show agreed upon definitions and connections between performance indicators, performance measures and performance information [6]. The research and practice reports provide perspectives as to why performance measurement is important and what is typically measured. Integrating performance information into budgeting, managing and reporting has become a common component of good public and not-for-profit management [4], [10]-[11].

The theoretical models of Rogers, Prochaska & DiClemente and Gladwell provides a valuable framework for understanding why the use of performance measures is stalled (the circle of unaccountability) and for generating ideas about concrete steps that could be taken to accelerate adoption. Six steps are recommended:

- (1) raise public awareness,
- (2) redesign measures and reports,
- (3) make the delivery of information timely,
- (4) require public reporting,
- (5) develop and implement systems to reward quality, and
- (6) actively court leaders [12].

The recommended six steps are interconnected; action on all will be required to drive significant acceleration in rates of adoption of performance measurement and reporting. Coordination is necessary to ensure these steps are taken and that they work in concert with one another [12].

Collected performance information may be used as an input in performance measurement as well as in evaluation. The main difference between performance measurement and

evaluation is that the first is a frequent, almost ongoing activity intended to improve the performance, often of an activity, service or organization, whereas evaluation is carried out on an either *ad hoc* or regular basis, with the purpose of independently questioning the relevance, quality and even appropriateness of a project, solution, service, policy or program [8].

Therefore, performance measurement tracks the network and its parts throughout the lifecycle. Whereas authors propose that evaluation should be an integrated part of the road network performance measurement system.

B. Importance of Evaluation in Performance Measurement

In road network performance measurement, evaluation should complement and support the system. Evaluation and performance measurement share many of the same features with regard to structuring and planning, obtaining data, analyzing and evaluative judgment (see Fig. 1).

Differences as said in previous sub-chapter lie in the scope, depth, multiplicity and frequency of the tasks to be carried out rather than in kind. One may even argue that good performance measurement systems may help to highlight the themes and questions that evaluation studies should cover. Indeed, monitoring and evaluation studies should be seen as closely interlinked and complementary; monitoring providing data for evaluation and thus constituting one of several data sources, and evaluation being the necessary add-on to monitoring in order to focus on causality and deeper explanations conducted from time to time to qualify monitoring data.

Literature states that evaluation studies and performance measurement are highly complementary forms of knowledge production [10]. Evaluation tools can remedy a number of the shortcomings of performance measurement when applied in performance management and also contribute to research-based policy development. Improved technology has enabled monitoring and reporting systems to collect outcome data on a regular basis and thus measure performance in a more balanced and focused way.

Institutions sometimes draw conclusions from performance indicators and implement changes based on raw observations and output measurements and lead to unwanted outcomes. This automatic transformation into performance information has caused many performance measurement systems to fail [5] and therefore it is important to involve data analyzes and evaluation process into performance measurement.

Failure of PeMS is often described from organizational point of view. Bourne [13] has stated that there are three main blocking factors to implementation of the measures that refer to the road network performance measurement:

- the effort required;
- the ease of data accessibility through the IT systems;
- the consequences of measurement.

The measures may therefore prove inaccurate and these cannot be used to track the pathway to strategy execution. Information from performance assessment that should necessitate adjusting activities, do not bring this effect. Even

improvement activities are undertaken these are not based on the facts collected by the system. [13].

Contrary to performance measurement, evaluation can question the very relevance and appropriateness of the development, program, project or solution and as such identify unintended as well as expected and planned results. It can further explore the reasons for the documented results. In this sense, evaluation has a deeper heuristic and penetrating nature than performance measurement.

The tool to collect data mirrors the different roles of evaluation and performance measurement. Evaluation, besides being used for management and accountability purposes, is also used to determine causality. In performance measurement, the production of data is carried out through routinized processes, whereas in evaluation studies data collection is customized to the needs of the single study only, data collection is structured specifically to test hypotheses or the question of attribution.

Therefore evaluation studies need to be designed in a way that provides the best possible evidence to answer the attribution question. The key consideration for performance measurement is to generate data on indicators that drive performance through changing the behavior of those involved. The analyses made aim to improve in performance measurement and finding reasons providing the necessary changes is done by evaluations.

As has been stated, performance data feeding back into the program organization needs to be analyzed in order to identify the contextual evidence that may explain good or poor performance. It is thus important that performance data is reported on the basis of balanced assessment. Evaluation audits are a tool to help in creating such assessments.

Performance measurement has a wider scope, lesser depth and they gather data collection is continuous. Evaluation audits are supporting measures of the PeMS and good PeMS helps to highlight themes and questions that evaluation studies

should cover.

C. Data availability in Road Authorities: the Example of Estonia

The Road Administration Agency in Estonia currently does not have a compound broad-based system for Road Network Performance Measurement. There is a demand to receive feedback information about life-cycle performance about specific road construction projects or even in detail about specific road sections. There are currently three larger databases in use:

- Road Register;
- Pavement Measurement System (PMS), that gathers information about International Roughness Index (IRI) and other technical details;
- Smart Road database – comprising information about traffic, safety, traffic signs, traffic restrictions *etc.* [15].

Information from these databases is not available to the stakeholders without substantial effort and further processing. Therefore the aim of this research is to list current problems with feedback from road construction projects and network performance and to identify all potential stakeholders. Using a recommended list of key performance indicators a united platform of performance measurement system is presented [15].

There is no one measure, or one set of measures, that could be identified as the “best” for all cases. Furthermore, although there are many common issues to be considered, there is not just one good way to develop a set of performance measures or establish a PeMS. In each case, the performance measures used must depend on the specific conditions of an agency, its goals, its resources, and its audience. In case of Estonia the authors have suggested focusing on measuring technical data to get feedback in improving quality and sustainability.

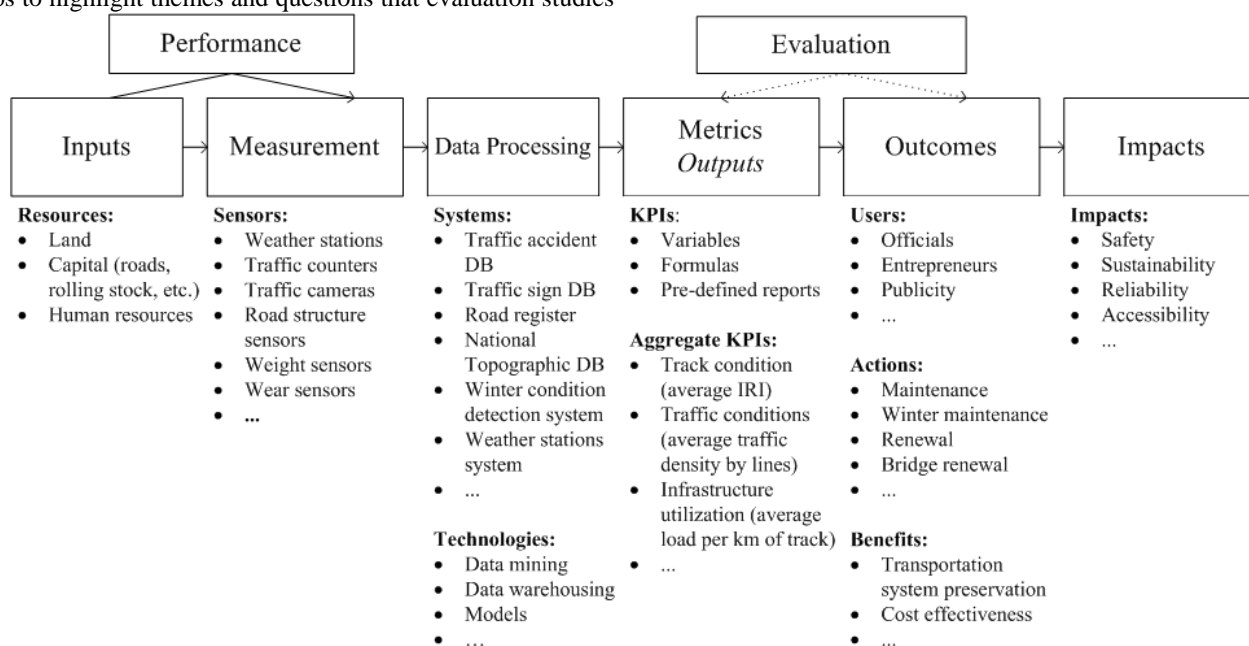


Fig. 1 General Framework of the Road Performance Measurement Process (compiled by author's based on [8], [14])

III. SYSTEM DESIGN

A. General Requirements for the System

To improve performance for the benefit of users, it is critical to implement processes that enable the assessment of operations. Performance assessment methods must be both reliable and credible and must serve as a means of changing how things are done. It is thus advantageous to establish specific performance indicators, methods of analysis and evaluation, as well as structured and quantified quality plans. Some of the major reasons for adopting performance include:

- **Accountability:** performance measurement provides a means of determining whether resources are being allocated to the priority needs;
- **Efficiency:** performance measurement focuses actions and resources on outputs and the process of delivery;
- **Effectiveness:** performance measurement provides a link between ultimate outcomes of policy decisions and the more immediate actions of transportation agencies. It provides a means to evaluate how well we are achieving our goals;
- **Communications:** performance measurement provides better information to customers and stakeholders on progress being made toward desired goals and objectives;
- **Progress:** performance measurement allows periodic refinement of programs and service delivery [16].

B. Performance Metrics

Performance indicators are required for eight different purposes of use: evaluation, control, budgeting, motivation, promoting, celebrating, learning and improvement. Roles of PeMS in road management are:

- The internal efficiency of the road administration.
- The quality of the administration's products and services.
- The outcome for the road transport system.
- The consequences for society.
- Any particular process or learning exercise for a specific engineering task.

Therefore, questions that the PeMS tried to answer are [17]:

- Has the specific road been designed and built to be sustainable during its estimated life span without substantial reconstruction. If reconstruction has occurred has it been due to factors that were not predictable during the designing process?

- Do the current Road Design Guidelines ensure given 15 year durability for new constructed roads that?
- Do the current Road Designing Guidelines rely on proven test results and data?
- Are the financial allocations based on priorities, the funds used rationally and in the most needed areas? How is the evaluation of priorities carried out?
- Does the system take into account the estimated volume of traffic in choosing the suitable design? Does the road comply to the approved design?

A key component of the most successful road projects and programs is a well-defined set of goals and objectives. However, the use of performance indicators goes beyond evaluating the degree to which goals and objectives have been achieved.

The use of performance indicators by a road administration depends on the particular needs for development or improvement in performance (see Table I). The main aspects that influence decisions on the use of performance indicators are:

- The main characteristics of the road transport vision in the country.
- The position of the road administration in the process of organizational reform.
- The specific functions that require development or learning
- The management style of the organization.[5].

C. Data Obtaining Tools

The Performance Management requires physical measurements of different characteristics on field to calculate key performance indicators (KPI-s). Measurement data can be feed into the system in three different ways:

- Directly via environmental sensors.
- Manual measurements on field.
- Via other information management systems.

The data collection architecture depends on the data flow characteristics for each type of measurement.

Sensors feed the collection system with constant flow of values depending on the traffic load distribution in time domain on the measured road sections. During peak hours the data flow amount grows equivalently with traffic volume. The backend data collection system hardware and communication channels must be dimensioned accordingly to accept the

TABLE I
 DETERMINATION OF ERA'S PERFORMANCE METRICS (EXTRACT)

Stakeholder	Aggregate KPI-s	KPI-s	Variables	Data Source
Road maintenance department	Road technical condition	Average IRI (International Roughness Index) per km of track	IRI Road section length	PMS Road register
	Infrastructure utilization	Average load per km of track	Rolling stock weight Road section length	Weight sensors Road register
Traffic management department	Traffic density	Average traffic density by lines	Traffic modal split Road sections length	Traffic counters Road register
Traffic safety department	Traffic safety	Traffic accidents per km of track	Traffic accidents and accident classes Road sections length	Traffic Accident Database Road register

sensor data.

Entering manually measured and collected information is typically less computing heavy and affects the system setup minimally. At the same time, there might be also measurements that require more resources for information extraction (e.g. images).

The integration with other Information Management Systems must be taken into account when designing the architecture of the data collection system. It is constructed in a way that supports effortless integration with any number of third party systems in the south-bound interface.

The physical server architecture hosting the data collection depends on the data feeding requirements towards other systems and on the amount of deployed sensors. Prearranged level of operational performance requirements state high availability requirements for the architecture. Load balancing techniques must be used to distribute workload across multiple servers to achieve optimal resource utilization and avoid overload of the computational nodes.

Additional local or regional aggregation layer may be reasonable to introduce when large amount of data in feed into the system. Aggregators do certain amount of data pre-processing in the location where the combined sensor event series are created before sending the values to PeMS. It will reduce the event load to central system. To save computing power and the data transmission channel it is reasonable to do the data format transformation in aggregation node. For the same reason pattern matching techniques for data filtering and aggregation are recommended to add into aggregator.

Information Collector functionality includes the ability to transform process, aggregate, query, store and dispatch sensor data streams. The Complex Event Processing (CEP) platform [18] may simplify the processing of the sensor information. CEP is for querying and analyzing the sensor data stream, dig and publish the conclusion to third systems.

D. System Architecture

Performance data does not tell us why the outcome occurred. Performance systems need to be designed in a way that they do not only gather, store and provide data outcomes (score), but they also need to have built into them opportunities to analyze the details of performance and steps to seek explanations for the outcome data such systems produce [12].

Performance indicator database collects all the measurements and stores them until required for the KPI reporting functionality. When the data is no longer needed, it will be removed from the live data schema and archived. Also the preparation, cleansing and consolidation of the data into different Performance Indicators are done there.

KPI-s are calculated based on the data in the Performance Indicator Database and calculation formulas. KPI formulas may be deterministic or probabilistic. Different authors ([9], [13]) have shown the applicability of Probabilistic Graphical Models (Markov Networks, Bayesian Belief Networks) in road performance index calculation. KPI-s may have multiple (aggregation) levels based on user needs. KPI-s are displayed in the User Interface showing the current situation or as historical trend. Drilldown from KPI value until the specific

performance indicator or sensor value is needed to understand the root causes of different situations (see Fig. 2).

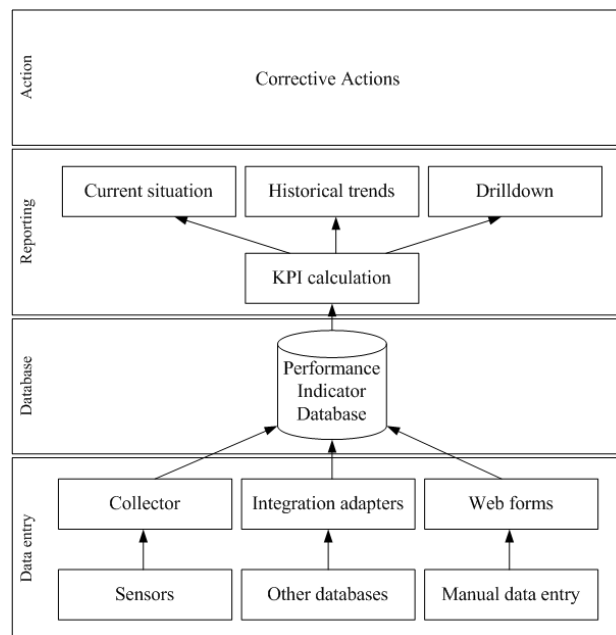


Fig. 2 PeMS architecture

Corrective actions will be taken in response the KPI shows deviation from the norm. The architecture enables systematic investigation of the root cause of the non-conformities to prevent their occurrence, recurrence or minimize the effect on the road performance.

Access control to the data collection system is controlled via security levels – an information consumer is only able to consume the data on the level to which it has been provided access, e.g. some users may only have access to aggregate and pre-processed data, while other users have access to data at the sensor level. The data access mechanisms stay the same, no matter what level access or to what data is requested and granted.

IV. ROLE OF PERFORMANCE MEASUREMENT SYSTEM IN THE DECISION PROCESS

There is a significant role of performance measurement outcomes in strategic processes carried out by the transportation agencies. They are listed as following:

- Resource allocation.
- Monitoring programs/projects/whole network.
- Strategic planning.
- Reporting to the elected officials.
- Reporting to the internal management.
- Reporting to citizens (and media).

One of the lessons that many countries and institutions (including Estonian Road Administration) have learned is the need for modesty. The difficulty of developing and using performance information, as exemplified by these challenges, should be recognized by all. Further, the role of performance information is one of informing decisions not determining

them. There is a real need to educate the users of such information on how to use the information and on its possible interpretations and limitations. The need for experience and management skills will always remain at the center of public sector management [10].

The importance of sensible and informed use of performance information may be especially pertinent for budget decision-makers. There may be a temptation to use evidence of poorly performing programs but to ignore or question performance information about well-performing ones. Misuse here will send quite strong messages. Performance information will normally not be comprehensive, will contain some uncertainty; its role should always be seen as informing [19].

Performance measurement systems with accurate data are needed both when agency's face reducing of budgets or increases in funding. They can be used effectively to establish the need for increased funding with policy makers and the public. Performance measures provide valuable information to communicate with policy makers on transportation funding needs. Performance measures provide an important mechanism to communicate planning and programming results to decision makers and the public.

The PeMS should also help to addressing the overall need or rationale for why any decisions are made and to be a tool to help the agency to do the best possible job given the circumstances, resources and constraints, consistent with the overall mandate. Performance measurement is needed for the network to function as a whole. Performance management should be an ongoing activity for road network agency. The use of performance measurement information will help set agreed-upon performance goals, allocate and prioritize resources, inform road network operators to either confirm or change current policy directions to meet those goals, and finally, report on the success of meeting the goals set.

In order to make performance measurement a useful tool for improvement the gathered knowledge, must be carefully tied to the agency's mission and strategic goals regarding the development of road networks [4].

V. CONCLUSION

Given the large amount of road transportation users globally, governments and road authorities are expected to plan and offer road networks with safe, convenient and efficient transportation services as well as adequate accessibility to communities.

This paper proposes system architecture of a road network performance measurement system that has the ability to gather knowledge from qualitative databases and if necessary uses data evaluation audits. With these additional steps the authors try to eliminate dysfunctional consequences and wrong conclusions that lead to a performance measurement system to fail.

The aim of this system is to produce results that improve the networks sustainability, durability and effective maintenance throughout the life cycle. This model of road network performance measurement provides a systematic framework where identifiable problems within specific stages in the area

of road network performance are addressed, analyzed and solutions suggested. The primary focus is not the financial incentive but more on the continuous and responsive learning from feedback to gather knowledge for decision and policy process.

Author's point of view are, that the adoption and use of performance measures by transportation agencies can foster understanding, accountability, trust, support, and collaboration with decision makers and the public as well as improvement in the quality of road networks.

REFERENCES

- [1] M. Karlaftis, and K. Kepaptsoglou, "Performance Measurement in the Road Sector: A Cross-Country Review of Experience", *International Transport Forum, Discussion Paper no. 10*, 48 pp., Oct. 2012.
- [2] D. MacDonald, C. Yew, R. Arnold, J. Baxter, R. Halvorson, et al, *Transportation Performance Measures in Australia, Canada, Japan, and New Zealand*. Washington, DC: U.S. Department of Transportation, 2004.
- [3] R. Haas, G. Felio, Z. Lounis, and L. Cowe Falls, "Measurable Performance Indicators for roads: Canadian and international practice", in *Annual Conference of the Transportation Association of Canada*, Vancouver, 2009, 23 pp.
- [4] P. Smith, "Outcome-related Performance Indicators and Organizational Control in the Public Sector", *British Journal of Management*, Vol. 4, Issue 3, pp. 135-151, Sept. 1993.
- [5] *Performance Indicators for the Road Sector. Summary of the field tests*. Paris: OECD Publications, 2001.
- [6] B. Perrin, "What is a results/performance-based delivery system? An invited presentation to European Parliament", *Evaluation*, Vol. 17(4), pp. 417-424, 2011.
- [7] G. J. van Helden, A. Johnsen, and J. Vakkuri, "The life-cycle approach to performance management: Implications for public management and evaluation", *Evaluation*, Vol. 18(2), pp. 159-175, 2012.
- [8] C. A. Karl, *Tools that Impact Network Performance: Measurement and Evaluation Tools*. Sydney: Austroads Incorporated, 2007.
- [9] M. A. Ismail, R. Sadiq, H. R. Soleymani, and S. Tesfamariam, "Developing a road performance index using a Bayesian belief network model", *Journal of the Franklin Institute*, no. 348, pp. 2539-2555, 2011.
- [10] M. L. Aldridge, K. D. Kramer, A. Aldridge, and A. O. Goldstein, "Improving Data Quality in Large-Scale, Performance-Based Program Evaluations", *American Journal of Evaluation*, no. 3, pp. 426-436, Sept. 2009.
- [11] J. Mayne, "Challenges and Lessons in Implementing Results-Based Management", *Evaluation*, Vol. 13(1), pp. 87-109, 2007.
- [12] R. S. Galvin, and E. A. McGlynn, "Using Performance Measurement to Drive Improvement: A Road Map for Change", *Medical Care*, Vol. 41, Issue 1, pp. 1-48-1-60, Jan. 2003.
- [13] Z. Li, *A Probabilistic and Adaptive Approach to Modeling Performance of Pavement Infrastructure*. Austin: The University of Texas, 2005.
- [14] W. Santosa, and T. B. Joewono, "An Evaluation of Road Network Performance in Indonesia," *Proc. of the Eastern Asia Society for Transportation Studies*, Vol. 5, pp. 2418-2433, 2005.
- [15] *Annual Report 2011*. Tallinn: Estonian Road Administration, 2012.
- [16] *Road Network Operations Handbook*. La Defense Cedex: World Road Association, 2003.
- [17] National Audit Office of Estonia, private communication, Aug. 2012.
- [18] E. Wu, Y. Diao, and S. Rizvi, "High-Performance Complex Event Processing over Streams", in *SIGMOD'2006*, Chicago, 2006, pp. 407-418.
- [19] K. Kõrbe Kaare, and O. Koppel, "Improving the Road Construction Supply Chain by Developing a National Level Performance Measurement System: the Case of Estonia", *International Journal of Social and Human Sciences*, no. 6, pp. 225-231, 2012.