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Measuring performance of linear assets considering their spatial extension

C. Stenström and A. Parida

Abstract

Purpose – In this study, linear assets performance are examined regarding analysis and presentation, considering both the technical asset and the user context, to simplify cognitive tasks of planning and decision-making.

Design/methodology/approach – Linear, or continuous assets, such as roads, railways, electrical grids and pipelines, are large, geographically spread out technical systems. Linear assets are comprised of system, subsystem and component levels. Thus, asset managers are involved with each level of the linear asset; asset management has strategic, tactical and operational levels. A method is developed to link together the technical and organisational levels and to measure asset performance considering their spatial extension. Geographical location and time are used as independent variables.

Findings – For performance measurement of linear assets, it is found that the spatial extension is an equally generic dimension as time is for technical assets in general. Furthermore, as linear assets actually are combinations of linear and point assets; separate analysis of these assets is a prerequisite. Asset performance has been studied in a case study in terms failures and cost; the results indicate that the method visualise poor, as well as good, performance in an easy to interpret manner. Besides, the results indicate that other parameters related to dependability can be presented in a similar way.

Practical implications – This study highlights the importance of including the spatial/geographical extension of linear assets in infrastructure managers' performance measurement. It is believed that the method can make planning and decision making more effective by pointing out improvement areas in technical assets, in a way that is intuitive to both technicians and managers.

Social implications – As infrastructure managers are improving their analysis and visualisation of performance, the public's interest of following the information increases, which in turn contributes to the connection between infrastructure managers and the public.

Originality/value – The presented method and case study analysed performance in function of both the technical and organisational levels, including the spatial component. It is believed that the method for analysing and visualising performance of linear assets is distinctive.

1 Introduction

Maintenance costs can represent a significant portion of the business cost in asset-intensive organisations. Non availability and downtime of an asset will have impact on the asset capacity, product/service quality and cost of production. Performance measurement and condition monitoring is a multi-disciplinary process; it provides critical support to heavy and capital-intensive industries by keeping assets, e.g. machinery and equipment, in a safe operating condition. Furthermore, in a global business environment, asset utilisation and performance optimisation can assist asset managers (AMs) to remain competitive.

The advancement in information technology (IT) has had a significant impact on the asset management information system; we are now better able to determine an asset's health status, thereby supporting good decision-making and simplifying cognitive tasks. Technological advancements, including embedded and wireless sensors, automated controls and data analysis

management, have led to new and innovative methods in asset health monitoring. Further, rapid growth in networking systems, especially through the Internet, has overcome barriers of distance, allowing real time data transfer to occur easily from different locations (Toran et al. 2000). With the emergence of intelligent sensors to measure and monitor the health state of a system and its components and with the gradual implementation of information and communication technologies (ICT) in organisations, the conceptualization and implementation of eMaintenance are becoming a reality (Parida 2006; Muller et al. 2008).

Corporate strategy dictates how to achieve business objectives and create value for stakeholders, but without a comprehensive description, executives cannot easily communicate the strategy amongst themselves or to their employees (Kaplan and Norton 2004). Accordingly, the management of an organisation must convert the corporate strategy and objectives into specific objectives for each of the organisation's various hierarchical levels. For example, to meet the objectives, an asset must obviously perform at a certain level. The appropriate performance must be defined and disseminated to the relevant stakeholders and a reliable measurement system set in place. The latter is a necessity, as without assessment, it is not possible to attain the desired objectives. A number of asset performance measurement frameworks have been developed, such as the "Balanced Scorecard" (Kaplan and Norton 1992) approach, to ensure that all operation and maintenance activities of assets are aligned with an organisation's strategy and objectives (Parida and Chattopadhyay 2007). However, linear assets, such as roads, railways, electrical grids and pipelines, are especially problematic as they stretch over large geographical areas, are continuously operated, and comprise many levels, each featuring different stakeholders.

The study begins by discussing the importance of performance measurement and data quality. It then presents a method for measuring performance and dependability of linear assets, followed by a case study for verification. The aim is to include both the asset context, with its spatial extension, and the user context, to ease planning and decision-making; see Figure 1. The strategic, tactical and operational contexts correspond to long-, medium- and short-term planning.

Figure 1: Visualisation of technical asset and user context.

2 Performance measurement

Organisations are using scorecards to manage their strategy over the long term in a number of critical processes (Kaplan and Norton 1996), such as the following:

1. Clarifying and translating vision into objectives and strategy
2. Communicating and linking strategic objectives with performance measures at different hierarchical levels
3. Planning and setting targets linked with key performance indicators (KPIs) and aligned with strategic initiatives
4. Enhancing strategic and performance feedback and learning

Organisations must align their performance measurement system with their strategic goals, objectives and desired performance (Kutucuoglu et al. 2001; Murthy et al. 2002). A challenge in performance measurement is determining how to measure the asset in question; some are difficult to measure as they are intangible and qualitative in nature. As per Murthy et al. (2002), maintenance management must be carried out in both strategic and operational contexts. The organisational structure generally comprises three levels; the strategic or top management level, the tactical or middle management level, and the functional/operational level (Parida and Chattopadhyay 2007). Two major strategic requirements of a successful performance assessment are the following (Figure 2):

1. Cascading the objectives down from the strategic level to the operational level
2. Aggregating performance measurements from the operational level up to the strategic level

Figure 2: Strategic maintenance performance measurement process (Parida et al. 2003).

Based on key performance indicators (KPIs), results are visualised in key result areas (KRAs), and critical success factors (CSFs) are the factors required for achieving the objectives of the KRAs (Figure 2).

The strategic objectives, which are often contradictory, are formulated based on the requirements of the stakeholders, both internal and external. The organisation's capacity and resources are considered from a long-term point of view and are matched with each other. The strategic objectives are then cascaded down through the tactical level to the operational level operators. Following the breakdown of objectives, the operational level is measured and aggregated to evaluate whether the organisational objectives have been achieved. Thus, the adoption of appropriate processes is vital to successfully align performance measurement to overall objectives.

3 Methodology

Linear, or continuous assets, such as roads, railways, electrical grids and pipelines, are large, geographically spread out technical systems. However, linear assets commonly comprise point assets as well, like stations for service or energy transformation. Therefore, linear assets can be divided into linear and point assets; this distinction is required in data analysis if the technical density per unit of length differs between linear and point assets.

A central term in maintenance and asset management is dependability, a collective term used to describe availability and its influencing factors: reliability, maintainability and maintenance support (Figure 3). Simple measures of these factors are: measures of uptime for availability, failure frequency for reliability, active repair time for maintainability and logistic time for maintenance support. Such indicators are fundamental to performance measurement, and thus used in this study.

Figure 3: Dependability, adapted from International Electrotechnical Commission (IEC 1990).

Technical systems can be divided into system, subsystem and component levels, and organisations can be divided into strategic, tactical and operational levels. As the operational level includes a large number of components and a human can only process and follow a limited amount of information; data aggregation is a requirement. As the data need is different for senior managers, managers and supervisors, indicators must be aligned for ease of communication and planning. If we consider a linear asset, such as a railway, stretching throughout a country, the monitoring can be aligned and divided as illustrated in Figure 4 and Table 1.

Level	Performance is measured for
Strategic	Network
	Network's classes and/or areas
	Network's technical systems
Tactical	Lines
	Lines' technical systems
	Nodes
	Nodes' technical systems
Operational	Sections, subsections and stations
	Sections' technical systems, subsystems and components
	Subsections' technical systems, subsystems and components
	Stations' technical systems, subsystems and components

Table 1: Linear asset divided into organisational levels.

Figure 4: Illustration of linear asset divided into organisational levels using the Swedish railway network as an example.

A good performance measurement system does not necessarily require a high level of precision; it is more important to know the indicators' trends, i.e. how the current value compares to historical values (Kaydos 1991). Common independent variables to measure trends over are: time, produced products, and transported weight or distance. A major difference between linear assets and other assets is the spatial/geographical component. In linear assets, the spatial component can be seen as equally generic as time is for all technical assets. Therefore, we analyse performance over space and time.

In summary, the method suggested for measuring dependability of linear assets, considering their spatial extension, is built on the following three prerequisites:

- Analysis and performance is presented as a function of two variables, i.e. the spatial extension and a second generic variable
- Analysis distinguishes between the linear parts and the point parts
- Analysis includes the organisational and technical asset levels (Table 1)

4 Case study

A case study has been carried out on railway infrastructure to verify the methodology. Analysis of other linear assets, such as electrical grids and pipelines, will not yield the same result, but the method for assessing performance is similar.

4.1 Data collection

Operation and maintenance data have been collected from the Swedish Iron Ore Line (Malm-banan), managed by the Swedish railway infrastructure manager Trafikverket (Swedish Transport Administration). The line is a 400 km, 30 tonne axle load, mixed traffic line stretching from

Boden to Riksgränsen, the boarder of Norway. The line consists of three sections in series called 111, 113 and 118. See Figures 4 and 5.

Figure 5: Illustration of the Swedish Iron Ore Line (Malmbanan) and its sections. See also Figure 4

The aim of this study is to develop and verify a method for measuring performance and dependability of linear assets, considering both organisational levels and the assets' spatial extension. Therefore, the case study is focused on failure data to avoid the additional complications of data quality; this is not a concern for occurred failures as long as each registered failure is considered a failure. However, further parameters and cost modelling is considered in an extension of the case study in Section 10.4.3. Further information regarding the data collection in railways can be found in Stenström et al. (2012) and Stenström et al. (2013).

The data from Trafikverket constitute infrastructure related corrective maintenance work, i.e. failure data. The corrective maintenance consists of urgent inspection remarks reported by the maintenance contractor, as well as failure events and failure symptoms identified outside the inspections, commonly reported by the train driver, but occasionally reported by the public. The failure data span 12 years, from 2001.01.01 - 2012.12.31. The analysis is carried out for the three railway sections in series, i.e. railway sections 111, 113 and 118. The reported number of failures on these railway sections for the time frame is 22 207, including infrastructure failures (the substructure, superstructure, signalling and electrification), animals in track, snow/ice and wheel impacts.

Analysis at the strategic level requires data of a whole network and is therefore not feasible. Thus, the case study analyses performance in terms of failures at the tactical and operational levels. However, the strategic level analysis is similar to the tactical level.

4.2 Results

As noted, the method is studied by analysing railway infrastructure performance in terms of failures, and is carried out at both tactical and operational levels. Failures are analysed as a function of time and space; time is generic for most organisations and space is generic for linear assets.

According to Table 1, the railway lines, nodes and their systems are to be analysed. However, failures as a function of time for these groups are presented analogously, and the spatial context is

a greater concern at the operational level; thus, one railway line is analysed. For the operational level, analysis is carried out for the subsections, stations, systems, subsystems and components as given in Table 1.

4.2.1 Tactical level

The performance of the Swedish Iron Ore line in terms of failure frequency appears in Figure 6. The high numbers of failures and stabilisation around 2006 are due to rail breakage (ageing) and a major rail reinvestment. In 2009, a new process and computer system for failure reporting was subsequently implemented and is thought to have impacted the number of failures reported. However, changes in contracting, maintenance policy, additional wayside detectors and more traffic are further factors to consider. The Swedish railway network consists of about 50 lines; full scale analysis would enable comparison for best practices, i.e. benchmarking. As noted, this analysis is concerned only with railway sections 111, 113, and 118 of the Iron Ore line.

Figure 6: Failures on Swedish the Iron Ore Line, including railway sections 111, 113 and 118.

4.2.2 Operational level

Results from analysis per section is shown in Figure 7, which is comparable with the results found at the tactical, or line level, but railway section 111 accounts for most of the failures, while the best performing is railway section 113. These figures suggest a need for further study of the causes. A possible reason may be that more iron ore is transported on railway section 111 compared to the other two railway sections.

Accordingly, further analysis of subsections, stations and items is carried out for railway section 111; these comprise 16 subsections and 16 stations; see Table 2.

The spatial extension is important at the operational level; thus, failures are presented as a function of time and space. As Figure 8 shows, subsections 1, 5 and 12 have many failures, mainly because a wayside detector for wheel impacts is located in subsection 1, there were 49 incidents of animals entering the track for 2006-08 in subsection 5, and subsection 12 had many traction power plant failures.

Likewise, consistency over time can be visualised by fitting a curve to Figure 8 and viewing the result as a contour plot, i.e. from a top view; see Figure 9 produced by using interpolation in MATLAB. Figure 9 reveals that subsections 1 and 12 are high in failures over time, and subsections 10 and 14, 16 are low in failures over time. The fit in Figure 9 may present the consistency more clearly than the bar chart in Figure 8, but such a fit makes sense as both time and railways are continuous. It can also be easier to track the performance of each subsections,

Figure 7: Failures per railway section.

Figure 8: Failures per subsection and year of railway section 111.

Subsection ID	Station ID	Name of subsections and stations	S&Cs [No.]	Length [m]
1		Kiruna malmbangård - Krokvik		4832
	1	Krokvik	6	
2		Krokvik - Rautas		9039
	2	Rautas	3	
3		Rautas - Rensjön		8869
	3	Rensjön	3	
4		Rensjön - Bergfors		7778
	4	Bergfors	3	
5		Bergfors - Torneträsk		8907
	5	Torneträsk	4	
6		Torneträsk - Stenbacken		8477
	6	Stenbacken	6	
7		Stenbacken - Kaisepakte		7929
	7	Kaisepakte	3	
8		Kaisepakte - Stordalen		10612
	8	Stordalen	3	
9		Stordalen - Abisko östra		8974
	9	Abisko östra	12	
10		Abisko östra - Abisko turiststation		912
	10	Abisko turiststation	0	
11		Abisko turiststation - Björkliden		6562
	11	Björkliden	3	
12		Björkliden - Kopparåsen		7164
	12	Kopparåsen	4	
13		Kopparåsen - Låktatjåkka		6742
	13	Låktatjåkka	0	
14		Låktatjåkka - Vassijaure		1130
	14	Vassijaure	4	
15		Vassijaure - Katterjåkk		4088
	15	Katterjåkk	0	
16		Katterjåkk - Riksgränsen		1767
	16	Riksgränsen	0	

Table 2: The subsections and stations of railway section 111.

e.g. as seen by comparing subsection 5 in Figures 8 and 9. However, a drawback of Figure 9 is that the total cost per subsection and year cannot be seen.

When the stations' (point assets) performance is analysed for the switches and crossings, at system, subsystem and component levels, station 1 shows many failures at the system level (Figure 10). Station 1 has 6 switches and crossings; remarkably, station 9 has 12 switches and crossings but performs better in terms of failures. It can also be seen that the connector component is going from many failures to near zero failures for the last three years.

4.3 Considering further variables; cost modelling

In the case study results, performance is studied in terms of failures to allow emphasis on the method. Nevertheless, considering only one parameter may not verify the usability of a method. Other variables which are interesting to study in a similar way are the logistic time, active repair time and train delays. In the case of the railway line studied, about one fourth of the failures led to train delays; thus, plotting the train delay, or cost, instead of the failures would yield different results. Therefore, we follow up the case study with cost modelling. For details, see Parida et al. (2013).

Figure 9: Contour plot by fitting a curve to the bar chart in Figure 8. Year 1:12 corresponds to 2001:2012.

(a) Failures of S&Cs.

(b) Failures of S&Cs' switch controls.

(c) Failures of switch controls' connectors.

Figure 10: Failures of switches and crossings (S&Cs).

4.3.1 Methodology and data quality

Besides complementing with train delay data, the data set used for modelling of cost is the same as before. Railway section 111 includes 1 0171 failures during the 12 years period. Important data for calculating cost of corrective maintenance are found to be: train delays, logistic time, repair time and spares cost. Thus, corrective maintenance cost is the sum of these four cost objects.

Train delay data is registered by the signalling system and therefore assumed to be of satisfying quality. But some failures are causing very large delays, like tear down of the overhead contact wire for delivering power to the train. Therefore, the percentage that causes the longest delays can be considered as outliers and is preferably analysed separately in a more detailed analysis.

The maintenance time data is registered by personnel and therefore the accuracy and precision is somewhat unknown. However, about one fourth (28 %) of the failures are causing train delays; it is assumed that the maintenance team travel to the failure location as soon as possible and carry out active repair efficiently. Therefore logistic time and repair time is estimated upon train-delaying failures. Furthermore, we found that the data is highly skewed, and thus, the logistic time (t_{LT}) and active repair time (t_{RT}) data points are limited to $5 \leq t_{LT} \leq 120$ minutes and $5 \leq t_{RT} \leq 240$ minutes with consideration to how long most failures should take to rectify. In this study we used the median for the LT and RT, nevertheless, the log-normal mean can be used, but with care as it is sensitive to outliers. Lastly, 2.7 % of the failures were found to be missing the geographical location and therefore discarded. Corrective maintenance cost (C_{CM}) is then calculated according to:

$$C_{CM} = N(\bar{n}_P C_P (2m_{LT} + w_{RT}) + \bar{C}_S) + C_D \sum_{i=1}^N t_{D,i} \quad (1)$$

Where (note that these notations differ from the notations given in the front matter of this report; see Study C for further maintenance cost modelling):

N	=	Number of failures
n_P	=	Number of personnel in the maintenance team
C_P	=	Monetary cost per personnel [t^{-1}]
m_{LT}	=	Median logistic time [t], i.e. median of t_{LT}
m_{RT}	=	Median repair time [t], i.e. median of t_{RT}
C_S	=	Average monetary cost of spare parts
t_D	=	Train delay time [t]
C_D	=	Monetary cost of train delay [t^{-1}]

Similar methodologies for modelling maintenance costs have been presented by Nissen (2009) on switches and crossings, and by Patra et al. (2009) on railway track life cycle cost analysis.

4.3.2 Results

The results are given recalling Eq. 1 and assigning values to the constants. Number of personnel in the maintenance team (n_P) is set to two, cost per personnel (C_P) equals € 100 /h, train delay (C_D) equals € 53 /min (Nissen 2009), and spare parts cost (C_S) equals € 100 per failure.

In Figure 11 it can be seen that three subsections had especially high costs. In subsection 1, 14 wheel impact detections in year 2010 resulted in 2 953 minutes train delay. Subsection 5

experienced a fire accident in a signalling facility and a power outage in year 2007, resulting in 1849 and 1366 minutes delay, respectively. The same subsection had and overhaul and conversion of interlocking in year 2008 that gave 1 934 minutes train delay. For the relative contribution of train delay, logistic time, repair time and spare parts costs, see Parida et al. (2013).

Figure 11: Corrective maintenance cost of the subsections of railway section 111.

5 Discussion

The method presented is built on three prerequisites: analysis and performance are presented as a function of two variables, i.e. the spatial extension and a second generic variable; analysis distinguishes between the linear parts and the point parts, and it includes both organisational and asset levels.

In the first part of the case study (Section 10.4.2), performance is analysed in terms of one variable, i.e. failures, to allow focus on the method. In the second part of the case study (Section 10.4.3), cost modelling is introduced, aggregating cost of train delay, maintenance time and spare parts, to further test the method and make comparison. It is found that the number of failures and the cost of failures yield different results, which could be expected. Nevertheless, it further emphasise on how the performance of linear assets can be visualised for ease to interpret and facilitate decision making. Regarding the results, Figures 8 and 11 shows that subsections 1 and 5 performed poorly in both the number of failures and in cost. In subsection 1, the large number of failures and cost both originate from wheel impact detections; however, the large cost is from 2010 and could therefore be studied in more detail. Regarding subsection 5, the failures and cost are of different reasons; large number of failures is to a large extent owing to many animals entering the track, while cost is due to a few major malfunctions. To yield further results, the largest train delays can be plotted separately, e.g. one plot of cost considering delays up to the 98th percentile and another plot considering the 2 % outliers.

The case study concerns railways; analysis of other linear assets, such as electrical grids and pipelines, will not yield the same results, but the method for assessing performance is similar.

6 Conclusions

This study presents a method for assessing performance and dependability of linear assets with consideration to their spatial extension; for linear assets, space is an equally generic dimension as time is for assets in general. The method also considers the asset structure and organisational levels. As linear assets actually are combinations of linear and point assets; separate analysis of these assets is a prerequisite.

Asset performance has been studied in a case study in terms failures and cost. The results indicate that the method can visualise performance at different technical and organisational levels in a manner that is easy to interpret.

The high number of failures in the case study can be traced to a number of factors: aging rails and a subsequent rail reinvestment in one railway section (Figure 7), many wheel impact detections in a subsection (Figure 8), many animals entering the track in certain years in another railway subsection (Figure 8), a power converter plant in a third subsection (Figure 8), and a connector going from many failures to near zero failures for the last three years in the switch control subsystem of the switches and crossings (Figure 9). Furthermore, high corrective maintenance cost can be traced to rail breakage, fire, interlocking failures and wheel impact detections (Figure 11).

This study highlights the importance of including the spatial/geographical extension of linear assets in infrastructure managers' performance measurement. It is believed that the method can make planning and decision making more effective by pointing out improvement areas in assets, in a way that is intuitive to both technicians and managers. As infrastructure managers are improving their analysis and visualisation of performance, the public's interest of following the information increases, which in turn contributes to the connection between infrastructure managers and the public.

Further research can consider other linear assets, like roads, electrical grids and pipelines, and feature other parameters related to dependability.

References

- IEC (1990). *IEC 60050-191: International Electrotechnical Vocabulary: Chapter 191: Dependability and quality of service*. International Electrotechnical Commission (IEC) (cited on page 4).
- Kaplan, R. S. and D. P. Norton (1992). "The balanced scorecard: Measures that drive performance". In: *Harvard Business Review* Jan./Feb.1, pages 71–79 (cited on page 2).
- (1996). *The balanced scorecard: Translating strategy into action*. English. 1st. Boston: Harvard Business Press, page 322. ISBN: 0875846513 (cited on page 2).
- Kaplan, R. S. and D. P. Norton (2004). *Strategy Maps: Converting Intangible Assets into Tangible Outcomes*. 1st. Boston: Harvard Business School Press, page 322 (cited on page 2).
- Kaydos, W. (1991). *Measuring, managing and maximizing performance*. 1st. Portland: Productivity Press (cited on page 5).
- Kutucuoglu, K. Y., J. Hamali, Z. Irani, and J. M. Sharp (2001). "A framework for managing maintenance using performance measurement systems". In: *International Journal of Operations & Production Management* 21.1-2, pages 173–195 (cited on page 3).
- Muller, A., A. Crespo-Marquez, and B. Iung (2008). "On the concept of e-maintenance: review and current research". In: *Reliability Engineering and System Safety* 93.8, pages 1165–1187 (cited on page 2).
- Murthy, D. N. P., A. Atrens, and J. A. Eccleston (2002). "Strategic maintenance management". In: *Journal of Quality in Maintenance Engineering* 8.4, pages 287–305 (cited on page 3).

- Nissen, A. (2009). "LCC for Switches and Crossings at the Swedish Railway: A Case Study". In: *International Journal of COMADEM* 12.2, pages 10–19 (cited on page 11).
- Parida, A. (2006). "Maintenance Performance Measurement system: Application of ICT and e-Maintenance Concepts". In: *International Journal of COMADEM* 9.4, pages 30–34 (cited on page 2).
- Parida, A., T. Åhrén, and U. Kumar (2003). "Integrating maintenance performance with corporate balanced scorecard". In: *Condition Monitoring and Diagnostic Engineering Management: COMADEM 2003: proceedings of the 16th International Congress*. Edited by O. P. Shrivastav, B. Al-Najjar, and R. B. K. N. Rao. Växjö universitet, pages 53–59 (cited on page 3).
- Parida, A. and G. Chattopadhyay (2007). "Development of a multi-criteria hierarchical framework for maintenance performance measurement (MPM)". In: *Journal of Quality in Maintenance Engineering* 13.3, pages 241–258 (cited on pages 2, 3).
- Parida, A., C. Stenström, and U. Kumar (2013). "Performance Measurement for Managing Railway Infrastructure". In: *International Journal of Railway Technology* 2.4, pages 1–14 (cited on pages 9, 12).
- Patra, A. P., P. Söderholm, and U. Kumar (2009). "Uncertainty estimation in railway track life-cycle cost: A case study from Swedish National Rail Administration". In: *Journal of Rail and Rapid Transit* 223.3, pages 285–293 (cited on page 11).
- Stenström, C., A. Parida, and D. Galar (2012). "Performance indicators of railway infrastructure". In: *International Journal of Railway Technology* 1.3, pages 1–18 (cited on page 6).
- Stenström, C., A. Parida, D. Galar, and U. Kumar (2013). "Link and effect model for performance improvement of railway infrastructure". In: *Journal of Rail and Rapid Transit* 227.4, pages 392–402 (cited on page 6).
- Toran, F., D. Ramirez, S. Casans, A. E. Navarro, and J. Pelegri (2000). "Distributed virtual instrument for water quality monitoring across the Internet". In: *Instrumentation and Measurement Technology Conference, 2000. IMTC 2000. Proceedings of the 17th IEEE*. Volume 2, 652–656 vol.2 (cited on page 2).