Sustainability and Performance Indicators Landscape

Minna Lanz[1*], Eeva Järvenpää[1], Hasse Nylund[1], Reijo, Tuokko[1], Seppo Torvinen[1] and Konstantinos Georgoulias[2]

[1]Tampere University of Technology, Department of Mechanical Engineering and Industrial Systems
Tampere, 33101, Finland

[2] Laboratory for Manufacturing Systems and Automation (LMS)
University of Patras
Patras, 26500, Greece

ABSTRACT

The research aims to improve information flow management, by offering more transparent information exchange methods, tools and technologies. While the main target is towards new kind of information and communication technologies (ICT) and systems, the work starts by defining a set of Performance Indicators (PIs) and Sustainability Metrics that are needed in the factory floor and management levels. Today performance indicators and sustainability metrics are measured in various manners in manufacturing companies. Some of the metrics and indicators are suitable only for company level while others are more specific and visible in the factory floor. The paper will categorize the metrics and indicators according its relevance to factory levels (such as operator, cell/line, company and society) and by their measurability and preciseness. Analysis is carried out with a network analysis tool for showing clusters of most important metrics.

1. INTRODUCTION

In past decades, institutions in general are increasingly interested and involved in defining sustainability and social responsibility. In addition, social and political pressures have led to the creation of new regulations and policies that support new business opportunities around global sustainability. Considering sustainable manufacturing, a large number of indicators have been proposed and currently being researched Lanz. However, comparison of metrics has always been difficult due to the fact that there exist a lot of different interpretations for indicators and how these are measured or computed. Understanding the effects of the factors or indicators and their interrelationship can be used for system performance and profitability development.

Peltokorpi et al (2013) stated that several previous approaches to analyzing and developing the performances of manual assembly systems have been undertaken, advisedly or unknowingly, with inadequate information to handle a socio-technical system. In a socio-technical system, introducing any form of technology or initiative will have ripple effects on the surrounding subsystems consisting of personnel, work processes and the immediate work environment boundary, meaning that no new introduction of practice can be seen as occurring in a static environment. Instead of understanding this interlocked complexity of the assembly environment, many efforts today are concentrated on separate subsystems or problems to be solved from one constrained viewpoint. In field of production, particularly, the technical and economical measures have been dominant. However, they only offer measurability of what can be measured in numbers, without connection to softer (less prominent and not as strictly measured) indicators.

Considering the information flow in the mechanical engineering and manufacturing industry the role of metrics and indicators is becoming more and more important. It is expected that in future the machinery will be part of the Industrial Internet of Things. This means, that the information flow does not only include substance information, but heterogeneous and real-time signals from various sources. Due to the combination of content and context information, understanding the level, type and reliability of information becomes a great challenge.

* Minna Lanz: Tel.: (00 358) 408490278; E-mail: minna.lanz@tut.fi

Currently information systems have more and more dominant role in manufacturing industry. On one end there are ERP systems and on the other end there are production machines and systems. Both of these have lately evolved thanks to the general advances in automation technology, information technology and the expansion of internet technologies. However, these systems have been developed from different perspectives and for different motives. The knowledge flow that should pass through these systems does not exist. The systems were built as stand-alone systems. Recently companies have come up with different methods to close these knowledge flow gaps. The straightforward way, and perhaps most used way is to use printed work orders to be attached to material/part lots. Due to these short-cuts for managing the knowledge flow, level of manual non-productive and non-value-adding work tends to rise too high.

On the other hand, the challenge is not only in the ICT sector. The second important challenge is in the human realm. Those who actually contribute to the information flow and who operate according to the available information. In manufacturing the balance between cost efficient automation and using human capacities in an intelligent way will determine the choice for processes and factory locations. The recognition is growing that conscious efforts are needed to design factory processes at what used to be considered high labour-cost work places. To do this in a sustainable way, manufacturing performance should be radically increased by smart and semi-automated machinery. Future knowledge workers should integrate with smart manufacturing technology by means of dynamic interaction and optimal levels of physical and cognitive automation.

Now if we consider the future operations and systems from the metrics and indicators point of view. The starting point would be to visualize the role, type and reliability of an indicator and a metric. The visualization of operations allows the generation of realistic feedback mechanisms, which in other hand are believed to increase the motivation factory workers and productivity of the factory. Velaction [18] stated that above all the key performance indicators must be measurable. Secondly the indicators must be relevant towards company goals and meaningful (both in a sense of understanding where the indicators are measured or calculated and how they are communicated). Behind every indicator there has to be known actions that either increase or decrease the value. They also stated that few indicators are enough, since behind every indicator there exist several measures, actions and counteractions. And finally according to Velaction [18] the key performance indicators must be public and thus reviewed by the personnel.

2. Social, Technical, Economic and Ecological measures within manufacturing industry

Bell and Morse [1] summarized that measuring the sustainability itself, especially social sustainability, is relatively futile exercise of measuring the immeasurable. A lot of research exists where it has been attempted to capture and quantify sustainability. They stated that most approaches do not work, or worse end up measuring things that cannot be measured and not things that can be measured. They came into the conclusion that sustainability is not a “thing” that can be measured, however as an element of circularity appears inevitable: sustainability becomes defined by the parameters that can be measured.

2.1. Social Sustainability indicators

Social sustainability is of key importance to the future of European manufacturing. Human capital is the main enabler of the Factories of the Future. Human skills and engagement to manufacturing will determine the manufacturing development of Europe, in the decades to come, within the global market competition. Promoting excellence in manufacturing emerges as a strategic goal in the years to come, both for industry and society [9]. Sustainability of the human capital, in Europe, is subject to the global economic conditions. Retirement age and employment systems need to be adapted, while the societal impact of manufacturing on local environments ought to be taken into account, in terms of energy demands, life quality, natural resources and safety. The nature of the future workplace in factories will determine the engagement of young talents in future manufacturing.

Vallance et al. [17] stated that “inter and intra-generational equity, the distribution of power and resources, employment, education, the provision of basic infrastructure and services, freedom, justice, access to influential decision-making and general ‘capacity- building’ have all been identified as important aspects of the development paradigm”[17]. The Stiglitz report [15] proposed novel approaches for measuring quality of life from an objective perspective, considering health, education, personal activities, political voice and governance, social connection, environmental conditions, personal insecurity, economic insecurity, but also from a subjective perspective and including inequalities. Considering the wide quantity and variety of existing indicators, research addresses the challenge of creating sound methodologies to select, use and evaluate the most appropriate sets, according to the different contextual aspects and social settings. At the micro level, several efforts have been developed to design frameworks, methodologies, and indicators to measure sustainability at a company level [7]. For example, G4 from

Global Reporting Initiative (GRI) defines wide criteria for social, economic and ecological indicators and measures [4] Measuring a standard set of indicators is becoming a trend among big industrial players to measure their sustainability from social and environmental aspects. The power and impact of G4 criteria lies in the relatively large user group.

2.2. Technical Sustainability indicators

The performance measures, realized as performance metrics, are used to maintain current and develop future behaviour and characteristics of the environment, both on real and virtual existences. Analysing the performance measures can offer great value for the decision-making based on the selected strategy and values of a manufacturing company [13]. Figure 1 represents views of performance measurement and metrics. The performance measurement is divided into manufacturing process monitoring, manufacturing flow efficiency, and competence of the company. When introducing different measures for companies it has to be noted that different people in a manufacturing company are responsible for different areas of manufacturing and therefore are interested in different performance metrics measured. The other challenge is that some of these metrics in use are measured while others are calculated with different formulas.

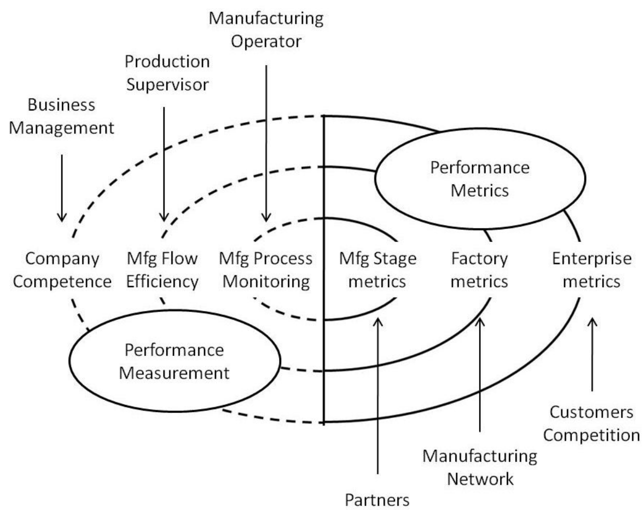

Figure 1. Performance measures [13].

2.3. Economic Sustainability Indicators

Economic sustainability seeks to secure both short and long term profitability and economic viability. This requires both competitive and sustainable factors where competitive refers to the ability to operate profitably in global markets before factors of sustainability can be considered. For manufacturing companies, the ability to produce and provide products that meet the needs of customers in a profitable way plays a key role in economic sustainability. Most of the performance metrics related to economic sustainability are related to costs with the aim of cost-reduction without compromising customer satisfaction and causing unwanted environmental effects. Typical indicators in this category are related to material and energy costs as well as cost of labor and the use of the machinery. Material costs include direct material costs that can be calculated from different inventories such as raw material, work in progress, and finished goods. Indirect material costs include auxiliary materials such as packaging material. Energy costs can be divided similarly to costs that can be pointed to use of the machinery as well as energy used in e.g. air conditioning, heating, cooling, ventilation, and lightning [13].

2.4. Ecological Sustainability Indicators

The sustainability in a sense of ecological sustainability consists of broad definitions for sustainability. The focuses in the field of sustainable development mainly focus on waste and carbon emissions, conserving energy, conserving natural resources, and reducing business impact on ecosystems [8]. The Organization for Economic Co-operation and Development's (OECD) project on sustainable manufacturing and eco-innovation aimed to accelerate sustainable manufacturing by diffusing knowledge and providing industry with a means to measure its progress in a simple and comprehensive way. According to the National Council for Advanced Manufacturing (NACFAM) perspective, there are two distinctions in the way sustainable manufacturing is referred. First, sustainable manufacturing includes the manufacturing of sustainable products, and second, sustainable manufacturing includes the manufacture of all products produced using sustainable practices. The former includes manufacturing of renewable energy, energy efficiency, green building, and other green and social equity-related products [8]. The G4 defined various measures for withdrawal types and sources of water, emissions, power consumption and possible pollution of environment [4]. Unfortunately for the manufacturing companies the ecological sustainability indicators measure the progress of full factory, not performance of smaller units. Thus the sustainability indicators cannot be easily adapted to the development activities and because of that the development speed tends to be slow.

3. SUSTAINABILITY METRICS LANDSCAPE

3.1. LANDSCAPE INTENTION

The main idea of this work was to map different important metrics and compare those in human-friendly manner. The task represented in this paper:

1) Maps indicators into comparable table,
2) Visualizes the information, and
3) Draws relationships between the metrics

The selection of metrics has been done based on their appearance in literature and from metrics appearances in interviews among companies [6]. This metrics landscape is the first version, and will be updated during its life-time based upon suggestions from academy and industry.

3.2. RESEARCH METHODOLOGY

In order to define and understand the meaning Social, Technical, Economic and Ecological Sustainability and how it relates to the field of manufacturing industry, a multi-stage literature study was carried out. Literature was sought out on many levels, including scientific and general audience literature. The second part of research is based on conventional quantitative and qualitative analysis of indicators. Evaluation and elimination of sole indicators will be carried during the evaluation. The focus is in European manufacturing industry thus some of the indicators are expected to be irrelevant (or have small relevance in Europe).

1) Literature review: Collection and analysis of metrics
2) Analysis and classification of metrics
3) Modeling of relations between indicators
4) Elimination of sole indicators
5) Analysis of the relationships with network analysis tool

4. RESULTS

4.1. STEP 1 AND 2: METRICS AND CLASSIFICATION

Total amount of processed and selected metrics was 201. The list of collected and selected metrics can be found from (URL: https://docs.google.com/spreadsheet/ccc?key=0AgyZdp7Vd6tedEhjQVhJT0g0dWR3UEs1akZra2pHUmc#gid=0). The metrics were classified and visualized into four categories based on their impact. The categories were Employee, Manufacturing unit, Factory and Society. After this classification the metrics measurability was evaluated and classified into three categories; 1) quantitative (measurable unit), 2) computable (rates, ratios and formula-based) and 3) qualitative levels, illustrated in Figure 3. The collection of metrics were classified according to G4 and other scientific sources into following categories:

Table 1. Classification of metrics [2], [3], [4], [5], [6], [10], [14], [16], [18] and [19].

Classes	Subclasses	Nro.
Economics	Economic performance, market presence, Indirect economic impacts, procurement practices, employment	9
Labor	Employment, labor/management relations, occupational health and safety, training and education, diversity and equal opportunity, equal remunerations for women and men, supplier assessment for labor practices, labor practices grievance mechanisms	16
Human rights	Investments, freedom of association and collective bargaining, child labor, forced or compulsory labor, security practices, indigenous rights, assessment, supplier human rights assessment, human rights grievance mechanisms	12
Social	Anti-corruption, public policy, anti-competitive behavior, compliance, supplier assessment for impacts on society, Individual career, worker wellbeing	24
Product Responsibility	Customer health and safety, products and service labeling, marketing communications, customer privacy, compliance	9
Environment	Material, water, biodiversity, emissions, effluents and waste, products and services, compliance, transport, overall, supplier environmental assessment, environmental grievance assessment, energy	39
Technical	Process flow metrics, quality metrics, financial metrics, productivity metrics, economic)	91

4.2. Step 3 and 4: Relations and Elimination of Sole indicators

The following figure shows the preliminary results of the network analysis.

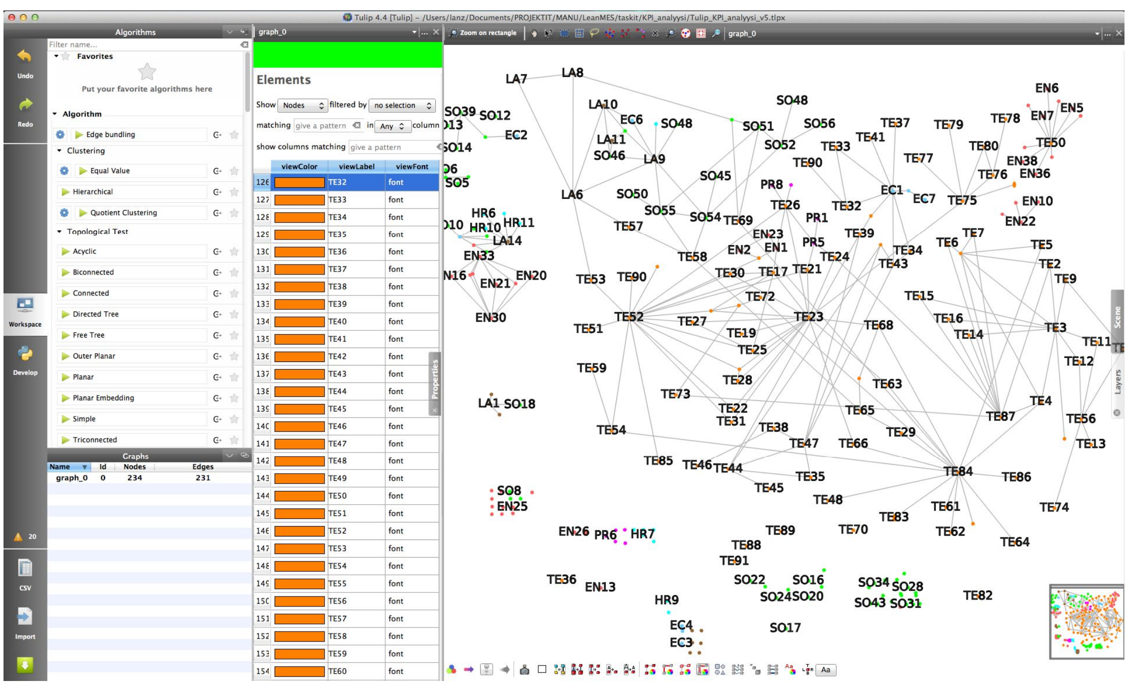

Figure 2. Network analysis and formulation of clusters.

	Employee	Manuf. Unit	Factory	Society
3	LA3, LA7, SO4, SO46, SO49, SO50, SO51, SO52, SO53, SO54, SO55, SO56	TE89	EC3, LA8, LA12, LA15, SO10, SO12, PR3, PR4, PR5, PR6, EN5, EN7, EN11, EN12, EN19, EN26 EN27, EN30, EN31, EN33, TE23, TE24, HR4, HR5, HR6, HR11, EN18	EC2, EC7, SO2, SO6 EN9, EN13, EN22
2	LA4, LA5, LA9, LA11, LA13, TE57, TE58, HR7	TE19, TE27, TE31, TE32, TE33, TE34, TE54, TE56, TE59, TE60, TE61, TE62 TE64, TE67, TE72 TE73, TE81, TE83 TE86, TE88, TE90	TE49, TE87, EC4, EC5, LA1, LA3, LA6, HR10, SO8, SO9, PR1, PR9, EN2, EN4, EN6, EN8, EN10, N15, EN16, EN17, EN21, EN23, EN28, EN29, EN32, EN37, EN39, TE5, TE6, TE7, TE9, TE10, TE11, TE12, TE13, TE14, TE15, TE16, TE17, TE18, TE20, TE21, TE22, TE29, TE30, TE36, TE37, TE41, TE42, TE43, TE48, TE50, TE51, TE52, TE53, TE55, TE63, TE71, EC1, EN20	EC6, EC8, EC9, LA14, HR1, SO1
1	SO45, SO47, HR2	TE85, TE65, TE66, TE68, TE69, TE70, TE74, TE75, TE76, TE77, TE78, TE79, TE80, TE84, TE91	LA10, LA16, HR3, HR9, SO3, SO48, PR2, PR7, EN1, EN3, EN24, EN25, EN34, EN35, EN36, EN38, TE1, TE2, TE3, TE4, TE8, TE25, TE26, TE28, TE35, TE38, TE39, TE40, TE44, TE45, TE46, TE47, HR8, HR12, PR8	SO5, SO7, SO11, EN14

Figure 3. Classification of metrics.

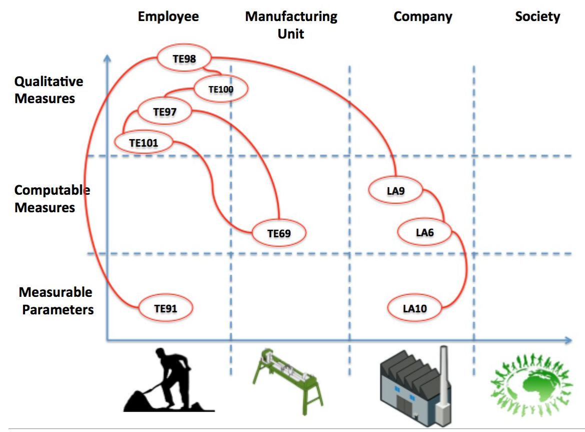

Figure 4. Visualization and network analysis.

4.3. STEP 5: NETWORK ANALYSIS

The amount of analyzed indicators was relatively high, and it is expected to increase in future. The visualization allowed more holistic view on the relationships. The clustering showed that EN33, EN30 and LA14 formed a cluster indicating energy spent on transport and supplier environmental assessment, Figure 5. TE50 (Energy consumption), Figure 6, formed a cluster around energy and financial metrics. TE52 (Productivity) in Figure 7, TE23 (Manufacturing Quality), TE84 (Machine Processing time) and TE87 (Delivery Reliability), in Figure 8, had most relationships and are considered as clusters. LA9 (Average training per employee per year) formed a cluster around training, individual career and worker wellbeing, in Figure 4. It has to be noted that most cluster had socio-technical characteristics, meaning that both qualitative and quantitative indicators that are needed to be considered.

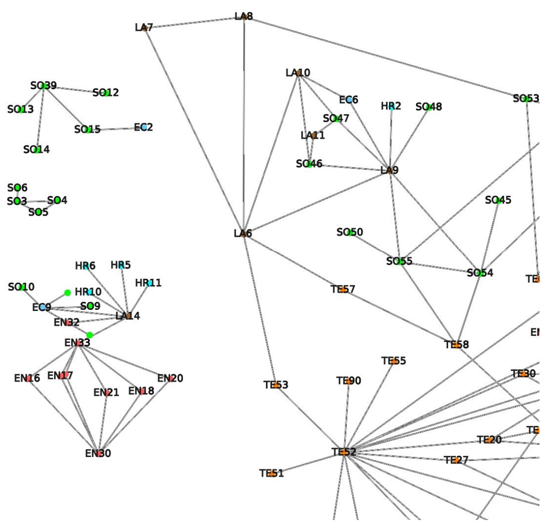

Figure 5. Energy cluster and Training, individual career and worker wellbeing cluster.

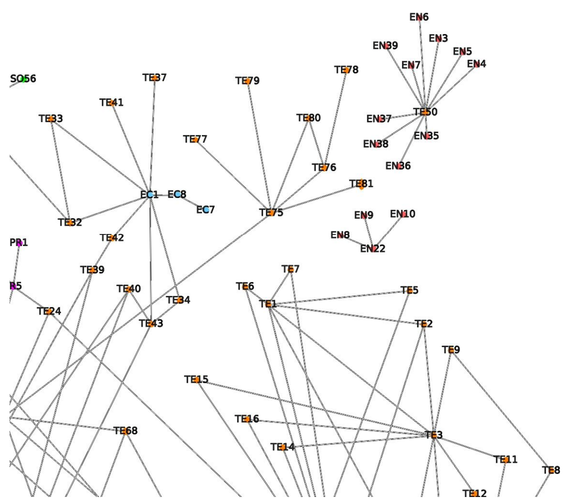

Figure 6. Energy Consumption.

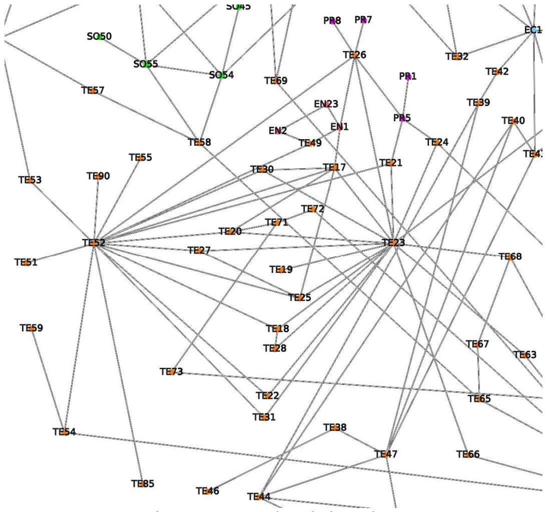

Figure 7. Productivity cluster.

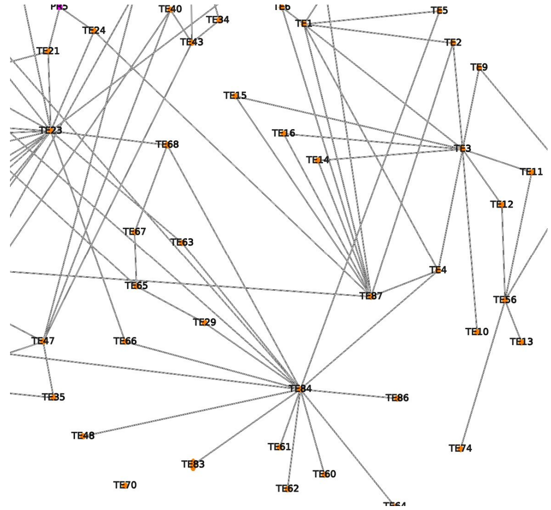

Figure 8. Machine Processing cluster.

5. SUMMARY

Collecting, sorting and connecting the indicators in formal manner formed first version of Sustainability and Key Performance Indicator Landscape. Example of relationships is showed in the Figure 2. The network analysis combined to the classification of the indicators shows the complex connections between indicators and their measurability (or calculability). The literature review showed that the definition of the indicators varies a lot. The literature review used for collecting the metrics was concentrating on specific and narrow domains. The identified knowledge gap is the lack of holistic approach and visibility of relationships between metrics/indicators. The research work here aims to bridge the mentioned gab and provide a set of interconnected indicators suitable for analyzing performance of a socio-technical system. The second outcome of this network analysis is the vision for possible models for socio-technical systems. As the network analysis illustrated there exist relationships between softer (qualitative) and hard (quantitative) metrics. The multiple relations, measuring/calculation manners and counteractions form highly complex landscape. The complexity hinders companies to select most suitable indicators for their own production scenario. It also shadows the behavior of different departments and affects negatively to measure return of investments in production development activities and in production control. Visualization of the possible cause-effect relationships between quantitative and qualitative indicators allows companies to approach development activities more openly. The possible cause-effect factors between indicators can be used for tracking errors and problems during the process development. It has to be noted, that this work does not allow automatic reasoning to reach targets, however it will help identify the key indicators.

6. DISCUSSION AND FUTURE WORK

This work will be utilized for two separate cases. The case 1 utilizes the sustainability and key performance indicators landscape as an input for Lean Manufacturing Execution System (LeanMES) concept, which ultimate goal is to provide lean, scalable and extendable MES concept for SMEs. The envisioned new type of operation planning and control concept actively supports the human operator by providing needed feedback of his/her operations via selected metrics in a dynamically changing environment. The case 2 utilizes this landscape for creating calculus for social sustainability Assessment Framework. The Assessment Framework can be utilized to create a reference to evaluate sustainability performance of a company. Company's current practices can be used as a baseline and desirable targets can be set. The Assessment Framework helps to identify the main drivers that impact on social and economic sustainability. Based on the company interview by [6], the most important metric seems to be the delivery reliability. The companies are prepared to sacrifice e.g. resource utilization and efficiency, in order to make sure the customers are served on time. Another indicator followed is delivery reliability, which only defines the ratio between on-time and not on-time. In the future the companies want to measure the used time in more detail, in which kinds of activities the resources use time, from what kinds of activities the total lead-time consists of and how the costs are generated in the production. This sets requirements for friendly user interfaces for time recordings and set offs. The social sustainability among interviewed companies seems to be relatively unknown. While all of them measure the work well-being yearly via questionnaires, social sustainability has not been connected to actual work done. The deeper assessment of relationships between indicators will be carried on in LeanMES and SO SMART projects. The list of indictors is expected to change over the time. The future work consists of defining the weight of the relationships in order to show critical paths between different indicators.

ACKNOWLEDGEMENTS

Authors wish to thank FIMECC MANU LeanMES and FP7 SOSMART (GA 608734) consortia for their contribution and support.

REFERENCES

[1] *S. Bell and S. Morse, "Sustainability Indicators – Measuring the Immeasurable?", ISBN-13: 978-1-84497-299-6, published by Earthscan, UK, p. 223, 2008.*

[2] *J. Cottyn, H., Van Landeghem, K., Stockman, K., S., Derammalaere, S.: "A method to align a manufacturing execution system with lean objectives". International Journal of Production Research, 49:14, pp. 4397–4413, 2011.*

[3] *T. Fujimoto " The evolution of a manufacturing system at Toyota". Oxford University Press. p. 380 1999.*

[4] *Global Reporting Initiative "G4 Sustainability Reporting Guidelines", Netherlands, p.95, 2013.*

[5] *ISO/DFIS 22400-2. Automation systems and integration - Key performance indicators (KPIs) for manufacturing operations management - Part 2: Definitions and descriptions. (Final Draft).*

[6] *E. Järvenpää, M.Lanz, R. Tuokko, H. Tokola, and T. Salonen "Requirements for Manufacturing Operations Management and Control Systems in a Dynamic Environment" Flexible Automation and Intelligent Manufacturing, FAIM2014, San Antonio, Texas, US (accepted for publication).*

[7] *D. Krajnc and P. Glavi "A model for integrated assessment of sustainable development", Resources, Conservation and Recycling, Volume 43, Issue 2 , pp. 189–208, 2005.*

[8] *M. Lanz, M. Mani, S. Leong, K. Lyons, A. Ranta, K. Ikkala and N. Bengtsson "Impact of Energy Measurements in Machining Operations", Proceedings of the ASME 2010 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2010 August 15-18 , Montreal, Quebec, Canada, p. 7, 2010.*

[9] *D. Mavrikios, V. Karabatsou, M. Pappas M. and G. Chryssolouris "An efficient approach to human motion modeling for the verification of human-centric product design and manufacturing in virtual environments", Robotics and Computer Integrated Manufacturing, Volume 23, No. 5, pp. 533–543, 2007.*

[10] *O. Mejabi "Framework for a lean manufacturing planning system. International Journal of Manufacturing Technology and Management" Vol. 5, Iss. 5-6, pp. 563–578, 2003.*

[11] *H. Meyer, (Ed.) "Manufacturing Execution Systems: Optimal Design, Planning and Deployment" The McGraw-Hill Companies, Inc. 274 p. 2009.*

[12] *National Council for Advanced Manufacturing http://www.nacfam.org/PolicyInitiatives/Sustainable Manufacturing/tabid/64/Default.aspx/ Accessed April 27, 2010.*

[13] *H. Nylund, M. Lanz, A. Ranta, K. Ikkala and R. Tuokko, "Developing competitive and sustainable performance metrics for an intelligent manufacturing environment" Baric, G. & Dukic, G.(eds.). Proceedings of International Scientific Conference on Management of Technology-Step to Sustainable Production, MOTSP 2010, 2-4 June, 2010, Rovinj, Croatia. 01/2011.*

[14] *J. Peltokorpi, S. Laakso, J. Ratava, M. Lohtander and J. Varis "Relationships of Factors in a Manual Assembly Line Environment", Proceedings of Flexible Automation and Intelligent Manufacturing, FAIM2013, pp. 985–996.*

[15] *J.Stiglitz, A. Sen and J-P. Fitoussi "Report by the Commission on the Measurement of Economic Performance and Social Progress", French Government Initiative, p.291, 2009. URL: http://www.stiglitz-sen-fitoussi.fr/documents/ rapport_anglais.pdf*

[16] *H.O. Unver "An ISA-95-based manufacturing intelligence system in support of lean initiatives" International Journal of Advanced Manufacturing Technology, Vol 65, pp 853–866, 2013.*

[17] *S. Vallance, H.C. Perkins and J.E. Dixon "What is social sustainability? A clarification of concepts", 2011.*

[18] *Velaction Continuous Improvement URL:http://www.velaction.com/key-performance-indicator/ (accessed January 17th, 2014).*

[19] *J.X. Wang,"Lean Manufacturing - Business Bottom-Line Based" CRC Press. p. 257, 2011.*