Manufacturing performance system for SMEs: A prioritization of KPIs with fuzzy analytic hierarchy process

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ABSTRACT

In today's increasing competitive global market, large and successful manufacturing enterprises have implemented the system of key performance indicators (KPIs) which drives the performance toward the business objectives; however, this is not the case for small-medium sized enterprises (SMEs) which have been increasingly important for any national economy, especially in manufacturing sector. Although the KPIs can ideally be constructed in accordance with the concept of SMART (Specific, Measureable, Attainable, Realistic, Time-related) or balanced scorecard, but SMEs that are lack of limited resources and expertise could rarely afford to build such systems with the appropriate definition and measurement of KPIs. Therefore, the paper aimed to provide systematically the system of KPIs adaptable to SMEs, to prioritize the importance of each proposed KPI with the application of a fuzzy analytic hierarchy process (FAHP), and to instruct the comprehensive deployment of the SMEs' manufacturing performance system.

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1. Introduction

In the global context, SMEs have played a key role of tremendous contribution into national economy, development, and political stability. Specifically, SMEs accounted for over 95% of firms and 60% to 70% of employment in OECD (Organisation for Economic Co-operation and Development) economies (Sergei, 2018), whereas the corresponding numbers in Vietnam were about 98% of total enterprises, 63% of employment, 45% of GDP as reported by USAID (2019). The report also emphasizes the quantity did not match with the quality as around 70% exports were dominated by FDI (Foreign Direct Investment) firms and lead firms also co-located with their foreign suppliers without the involvement of local SMEs. This can be explained by the fact that SMEs have not progressed further on the road of developing their supply chain in the age of globalization (Håkon et al., 2004). One of roadblocks on the way of SMEs to develop their supply chain is productivity issues in which the measurement and improvement of manufacturing activities have still remained the main research area (Sergei, 2018). Furthermore, low performance is waste in different forms in terms of energy, raw-materials, downtime, operations, maintenance, and quality (Carl-Fredrik et al., 2015).

As a well-known principle in industries, *what cannot be measured cannot be improved*, which is also represented by the "check" step in the PDCA (plan-do-check-action) methodology used to measure the success of the business (Bruno & John, 2011). The performance measurement systems are widely utilized by large enterprises, but such systems are not well implemented by SMEs as it should be (Piotr, 2017). One of them is the balanced scorecard that has been introduced for the alignment of business strategies with department objectives; however, the method was proven as an ineffective method for the SMEs due to the prominent barriers to strategic performance (Hudson et al., 2001). One of the barriers is accounted for limitation in understanding of how to measure and manage a performance system as well as potential advantages of implementing such performance systems (Garengo et al., 2004), which was also emphasized by a study of KPIs implemented by SMEs in Vietnam (Ta, 2018). Another research pointed out that a lack of resources and expertise is one of the roadblocks for the deployment of such systems (Pham & Bui, 2014).

To overcome the inherent barriers SMEs have been faced, the paper firstly presents the manufacturing performance system that contains a package of simplified KPIs adapted for SMEs based on the literature review, and then prioritizes them to suit with each SME's context by applying the mathematical model of fuzzy analytic hierarchy process, and finally provides implementation guidelines of such system.

2. Materials and Methods

2.1. Development of KPIs

The proper selection of indicators will sharpen performance and expose areas that need attention. *What gets measured gets done* and *if you can't measure it, you can't manage it* are two of the well-known principles (Bernard, 2012). However, numerous enterprises are working with the improper measures, many of them are incorrectly categorized as KPIs. Due to misunderstanding on performance measures, those enterprises have improperly mixed different indicators. Understanding KPIs plays very critical roles in the success of the business as they function like navigation instruments to understand whether the business is on successful paths. They are often categorized by the following types according to Parmenter (2010):

- Key result indicators (KRIs) show how a process can be done in a perspective or critical success factor.

- Result indicators (RIs) indicate what have been done.

- KPIs indidate what needs to be done towards established goals.

KPIs represent a set of measures focusing on the actions to improve the aspects of organizational performance that is the most critical for the current and future success of the organization. Each KPI has seven characteristics including:

(a) Non-financial measures (e.g., not expressed in dollars, yen, pounds, euros, etc.)

(b) Frequent records (e.g., 24/7, daily, or weekly)

(c) What actions taken by CEO and senior management team (e.g., CEO calls relevant staff to enquire what is going on)

(d) What actions taken by staff (e.g., staff can understand the measures and know what to fix)

(e) Measures that tie responsibility down to a team (e.g., CEO can call a team leader who can take the necessary action)

(f) Indicators that have signifiant impacts on performance

(g) Encouragement to appropriate actions for improvements in performance

(h) Patrik & Magnus (1999) also indicated dimensions and characteristics of manufacturing performance measures that are consistent with the above seven characteristics, except for the characteristic of simplicity which is suitable with SMEs' characteristics as well. The simplicity means the measure should be understandable and easy for data collections, calculations and reports.

Therefore, those characteristics should be taken into the selection of performance measures to have proper performance indicators. Overall equipment effectiveness (OEE), one of popular KPIs in manufacturing, is taken as an example to consider its compliance with the characteristics described by Table 1.

By taking the characteristics, Table 2 provides KPIs suggested for SMEs.

Table 1. Overall equipment effectiveness (OEE) and its characteristics

Characteristics	Description
(a)	OEE is an non-financial measure that gives a picture of performance taking availability rate (time utilization), performance rate, and quality rate into account.
(b)	OEE is normally measured in days, months, quarters, or years for showing the performance trend.
(c), (d), (e), (f), (g)	OEE is used by different enterprise levels, ranging from strategic to shop-floor levels. The top managers look at OEE to capture the overall effectiveness of whole factory so that they can make proper decisions, whereas the middle and operational levels find the OEE and its components (availability, performance rate, quality rate) as a directional compass for improvement and problem-solving priorities (Kashif et al., 2018).
(h)	OEE is a bottom-up method in which an integrated force is trained to maximize the equipment effectiveness (Amin & Fredrik, 2015). It is also a well-known application SMEs can make reference or benchmark.

Table 2. Characterized key performance indicators (KPIs) for small and medium-sized enterprises (SMEs)

Characterized KPIs for SMEs (x: the KPI was proposed by the according author(s))	Customer complaints	Supply on Time in Full	Stock loss (obsolete)	Productivity	Overall Equipment Effectiveness	Delivery on Time in Full	Environment, health, and safety (EHS) incidents
	KPI.1	KPI.2	KPI.3	KPI.4	KPI.5	KPI.7	KPI.8
Anagnostopoulos (2010)	x	x		x	x		
Bernard (2012)	x		x		x	x	
Carl-Fredrik et al. (2015)			x		x		
Enoch (2016)							x
Farzad & Kuan (2011)	x				x	x	
Henri et al. (2016)		x		x	x	x	
Kashif et al. (2018)					x		
Mourtzis (2015)	x	x	x		x		
Raymond & Pit-yan (2016)				x	x		
Sergei (2018)					x	x	

There are seven proposed KPIs that are suitable for SMEs to build a foundational manufacturing performance system. Nine out of ten research papers pointed out the OEE as a key performance measure whereas Enoch (2016) strongly proposed the incidents related to EHS as a safety KPIs in the manufacturing sector. They are linked together to create a package of KPIs as a starting point for SMEs regardless of manufacturing business sizes. Besides, the proposed KPIs can be managed by different business departments as the following proposal (Table 3).

By doing that, those enterprises (SMEs) which are lack of expertise and resources can easily set up the performance measurement foundation as well as practice it to get quickly experimental results before mass deployment or implementation of information technology solutions. However, in some special SMEs' business contexts where the SMEs also want to prioritize the KPIs so that they can focus their limited resources on top KPI priorities to the bottom. The solution for this is also the main contribution of the next part that presents the KPI priority with the application of

Table 3. Functional categorized key performance indicators (KPIs)

Functional KPIs	Unit	Business function
Customer complaints	#, %	Sales, marketing
Supply on Time in Full	%	Warehouse, inventory
Stock loss (obsolete)	$, %	Warehouse, inventory, accounting
Productivity	#	Production
Overall Equipment Effectiveness	%	Production, maintenance
Delivery on Time in Full	%	Production, quality, planning
Environment, health, and safety incidents	#, %	Safety, human resource

#, % and $ represent numeric, percentage, and finanial records respectively.

Table 4. Triangular fuzzy scale

Pair-wise Importance Scale								
Absolute	Very strong	Strong	Weak	Equal	Weak	Strong	Very strong	Absolute
9:1	7:1	5:1	3:1	1:1	1:3	1:5	1:7	1:9

fuzzy analytical hierarchy process (FAHP) whose technical inputs are given by the industrial experts.

2.2. The methodology of FAHP for prioritizing KPIs

Every business process has its own management goals and objectives that are ideally written in KPIs in compliance with SMART criteria (specific, measurable, attainable, realistic, and time-related) to avoid the risks that they could be unachievable (Doran, 1981). The evaluation was done by the group of three experts, who have strong experience in the field of operational excellence and production management. They will evaluate and prioritize each KPI based on pair-wise comparison towards SMART criteria.

The pair-wise comparison can be done by the analytical hierarchy process (AHP) proposed by Arash & Mahbod (2007). However, the AHP method may contribute to the imprecise judgments of decision makers, which can be improved by the application of FAHP (Aşkın & Güzin, 2007). In addition, FAHP can reduce or even eliminate the fuzziness; vagueness existing in many decisions made by multiple makers (Ali & William, 2018).

Therefore, evaluating each proposed KPI with the SMART principle in combination with FAHP to prioritize them will be a comprehensive package of KPIs that suits with the SMEs' different contexts. The FAHP model is represented by triangular fuzzy numbers that are identified as triple M = (l, m, u) in which l, m, and u stand for the lower, medium and upper values of M, respectively ($l \leq m \leq u$). Its function is defined as (Chang, 1996) :

$$\mu_{\mathrm{M}}(x) = \begin{cases} \dfrac{x}{\mathrm{m}-\mathrm{l}} - \dfrac{\mathrm{l}}{\mathrm{m}-\mathrm{l}}, & x \in [\mathrm{l}, \mathrm{m}] \\ \dfrac{x}{\mathrm{m}-\mathrm{u}} - \dfrac{\mathrm{l}}{\mathrm{m}-\mathrm{u}}, & x \in [\mathrm{l}, \mathrm{m}] \\ 0, & \text{otherwise} \end{cases}$$

Table 4 is used as the measurement scale of the triangular fuzzy model:

The first step in the FAHP process is to structure the hierarchy of KPIs with SMART criteria,which is described by Figure 1.

The pair-wise comparison is conducted on both levels in which level 1 is a pair-wise comparison of SMART criteria with each other in terms of SME's manufacturing performance system evaluated by the three experts. Subsequently, level 2 is also a paire-wise comparison of among KPIs towards each criterion of SMART principle.

Specifically, each expert will be asked to grade the importance of one sub-criterion over another on the same level with respect to the top criterion as the extracted part of the survey provided by Table 5. According to the expert with the survey below, the "specific" criterion is equally important as the "measurable", but less important than the "assignable" characteristic in terms of manufacturing performance system. That means as the construction of manufacturing performance system, the SMEs should consider the "assignable" characteristic of a KPI.

After getting the inputs from the group of industrial experts, the data was analyzed accord-

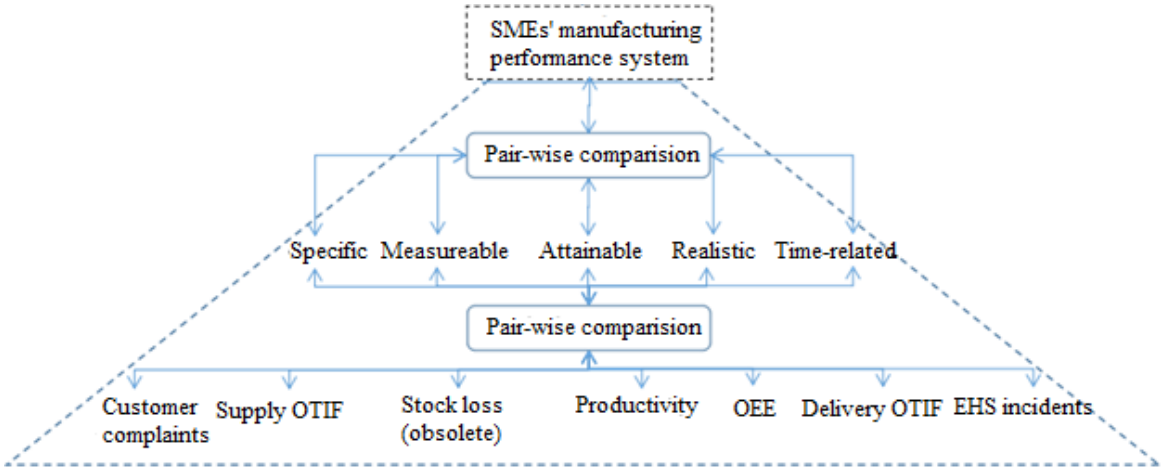

Figure 1. Hierarchy tree for fuzzy analytical hierarchy process pair-wise comparison.

Table 5. An extracted part of the survey

	Specific	Measurable	Assignable	Realistic	Time-related
Specific		1	-2	2	3
Measurable			-2	1	3
Assignable				2	2
Realistic					2
Time-related					

Based on your expertise, please grade the importance of each SMART criterion over others with respect to SMEs' manufacturing performance system based the triangular fuzzy scale.

Table 6. Average consistency ratio (CR) of first level

Average of consistency ratio (CR)	Specific	Measurable	Attainable	Realistic	Time-related
SMEs' manufacturing performance system			0.037		
Key performance indicators	0.080	0.077	0.077	0.088	0.097

ing to the procedure proposed by Amy et al. (2009) with the testing results of consistency in the response of the experts (Table 6). The consistency ratio for both levels show the suitability of the FAHP model for the data inputs due to its value is below then the CR validation value of 0.1. Therefore, the following weights for each KPI with respect to SMEs' manufacturing performance system indicate the KPI prioritization by which the SMEs can focus their limited resources on the implementation instead of mass deployment.

Table 7 shows the result of FAHP analysis indicating the rank of KPI importance from the point of views given by the experts. The most high-ranking KPI is OEE whose calculated weight is 0.223 whereas that of *stock loss* is the lowest one with the weight of 0.036. Based on the result, SMEs should kick off the implementation of those KPIs according to the prioritization that suits their business context. By measuring OEE, the efficiency and effectiveness of a manufacturing workstation, including one or more operators and machines, are identified. Based on the current workstation performance, the improvement actions can be brainstormed and focused on weaknesses represented by the lowest percentage of OEE components (availability, performance, and quality). There are also some popular lean techniques to increase OEE, such as single minute exchange of dies (Andreia & Alexandra, 2010), or design of experiment (Anand & Nandurkar, 2012). These methods will bring significant insights of improvement opportunities for manufac-

Table 7. Key performance indicator (KPI) ranking with respect to small and medium-sized enterprises' manufacturing performance system

KPI prioritization	Description	Weights
1	Overall equipment effectiveness	0.223
2	Customer complaints	0.198
3	Productivity	0.196
4	Delivery on time in full	0.155
5	Supply on time in full	0.149
6	Environment, health, and safety incidents	0.043
7	Stock loss (obsolete)	0.036

turing performance.

Another source for exposing the opportunities for improvements is the *customer complaints* which require the SMEs to have the analysis of failure or root cause for the problems in accordance with the corrective actions. The standard procedure should follow ISO 9001 standards as minimum requirements and the reports must be recorded as the lessons learned to avoid the repetitive problems or noncompliance.

With the measurement of *productivity*, its trend not only shows how much the SMEs should put effort for improving the productivity but also alarm how the customer order can be achieved by capacity investment or continuous improvements. At the end of the day, the productivity matters the most due to the fact that the output rate per production time unit or headcount shows how well the manufacturer minimizes its resources to maximize the output, which in turn satisfies the customer order by delivery in time on full qualified products.

What the customer needs is not just only the full quantity with agreed cost but the order must be available at the right place at the right time, where the concept of just in time (JIT) was born (Gupta & Garg, 2012). Its KPI should be measured in percentage, frequently monitored, and set up target of 100% orders are *delivered on time in full*. Additionally, Kanban which is one of the JIT tools can be adapted by SMEs to improve the KPIs by enabling both internal and external delivery processes to work smoothly with least waste, least work in progress (WIP) and lead time (Abdul et al., 2013).

By looking back to the upstream supply chain, the requirements of SMEs to their sub-suppliers are quite similar with the customers' point of view. Not only must the quality be met, but the sub-suppliers have to *supply the input materials on time with the right quantity and quality*. Their performance should be managed in form of percentage with the frequent data records of the supply compliance and process audit. By doing that, the production schedule can be guaranteed without negative effects due to lack of materials or non-compliance material quality.

Not to mention SMEs' operational performance, the increasing awareness of EHS across the large international enterprises pushes the prominent requirements of EHS compliance on SMEs (Kim, 2007). Therefore, in order to increase the chance of joining the global supply chain SMEs need to meet EHS compliance standards required by sourcing enterprises. The KPI of EHS incidents is an approachable starting point for those who are lack of resources in pursuing the international standards, like ISO 140001 for environment or OHSAS 18001 for occupational health and safety, to name just a few.

Finally, the *stock loss* points out the lack of material flow management in which both input materials and finished products could be lost or obsoleted, resulting in major financial loss. Due to lack of resources in implementing the management software, like enterprise resource planning, the KPI is easily implemented for SMEs in combination with frequent accounting audits during a year. By keeping the data on track, the SMEs will be alarmed to have immediate corrective actions before stock major losses.

At this stage, the next step for SMEs to successfully implement the performance system is to brainstorm a comprehensive road map in which the suitable tools for data collection, performance tracking and displays, report interpretation, communication flow across the staff levels must be determined. The final part will show some guidelines that fits SMEs' context.

Figure 2. Two-way communication flow of performance system.

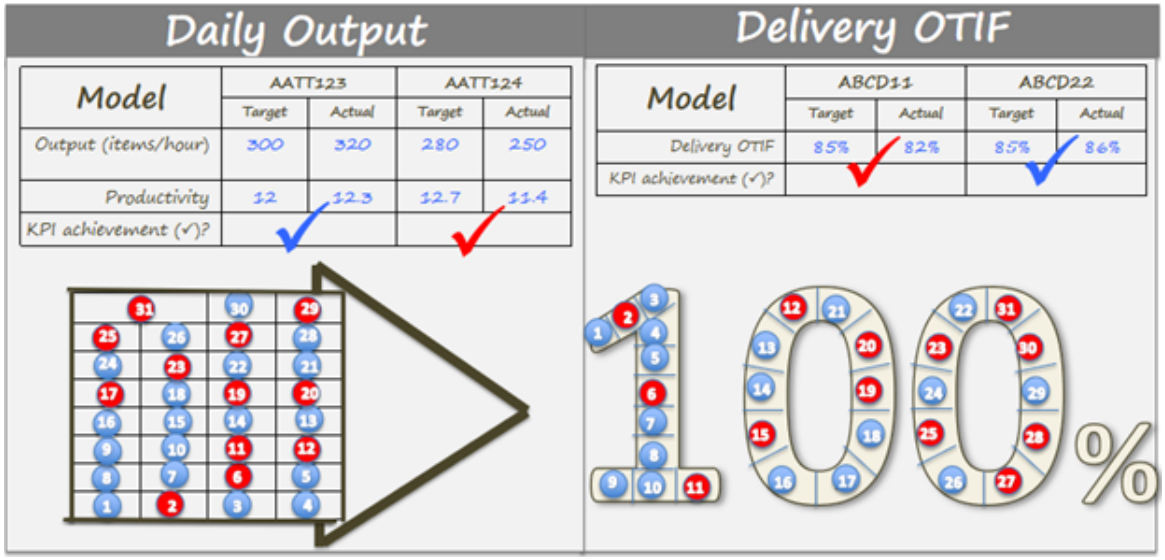

Figure 3. Visual record and display for key performance indicator (KPI) communication.

3. Results and Discussion

No matter what system SMEs are going to implement, the commitment from the managerial levels plays a decisive role on the success. The commitment must be translated into business actions from the top management levels to operational ones; specifically, the performance management system has to be communicated to the entire organization as the two-way communication flow (Figure 2).

Figure 2 shows that the commitment can be proved as frequent meetings throughout the organization by grouping different cross-functional or working levels together so that they can feel the importance of work, keep on track the progress, as well as increasing the responsibility of the staff. During the meetings, the KPIs are the main topics for discussion on how improvements can be made, which will also improve unintendedly the employee morale due to the scene of free-speaking ideas.

To make the communication flow smoothly, the SMEs should have tools for supporting the record of data as simplification as possible as it comes to operational levels, like operators who normally don't have many opportunities to learn and use the complex procedure or system. Therefore, the

most approachable way is to apply visual display with some cost-effective accessories like the table or handbook as Figure 3.

As can be seen by the figure, the simple visual method does not require any special understanding in technical terms (Nguyen et al., 2017), but indeed it communicates easily to all about the performance status. Described by Figure 3, the staff will be notified as the failure in the corresponding KPI with the red-highlighted dots whose numbers inside indicate the days of the month. Based on the alerts, the supervisor and its responsible members will brainstorm the root causes and then preventive actions. Finally, these activities must be recorded in document and the best solution is to follow the ISO 9001 standards in a real sense.

4. Conclusions

To enhance the competitiveness and join the global value chain, SMEs have no ways but make their operations themselves toward excellence. One of the critical steps is to develop and implement the performance system. By taking account the inherent weakness of SMEs who are mostly lack of resource and expertise to deploy such systems, the paper provides seven important KPIs to measure its manufacturing performance. Besides, the paper takes one step further to prioritize these KPIs based on the industrial experts' experience with high quality outcome by applying the FHAP. Therefore, the SMEs should consider firstly OEE as a key KPI for the experiment if needed and then apply the rest in order to avoid spending much effort.

Last but not least, the system should be deployed in a practical approach with the commitment from top management by conducting clear and quick-win meetings across working levels to make sure all the staff are on the same page.

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Conflicts of interest

The authors declare no conflicts of interest.

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