Innovative Approach To Variation Mapping In Craft-based Textile Manufacturing

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Abstract. This paper proposes a simple and practical method that facilitates capture of the most significant sources of variation within a craft-based textile manufacturing operation. With the aim of reducing waste in such processes and improving the consistency of the fabric finish, this research work establishes a method that helps indicate the degree to which variation sources contribute to the variability noticed in finished woven fabric. This is achieved by a methodology that is based on the combined use of process modelling theory, specifically the integrated definition for function modelling (IDEF) and process expert knowledge.

Keywords. Variation, IDEF0, Textile Manufacturing.

1. Introduction

One of the biggest challenges within manufacturing is process variation, more so in textile manufacturing [1]. In craft-based manufacturing of garments made from natural animal fibers, the inherent variability of the raw material, production process and environmental conditions makes the achievement of high consistency in the final product, an enormous challenge [2]. The different ways in which expert dyers, carders, spinners, weavers and fabric finishers make decisions to compensate for the varied raw material and process conditions also contributes to the final product variability.

These variations result in waste, in form of rework, scrappage, penalties from customers etc. This variation also has some other less tangible but equally important effects. These include, the adverse effect on brand perceived quality, customer confidence and so on. In such a highly saturated and competitive industry, these issues could be detrimental to textile businesses.

This paper thus presents a practical yet innovative method for capturing the process variations that exist within a textile manufacturing regime. It demonstrates a novel way of identifying the critical process variations that contribute to product variability within the production process. This work also practically outlines the initial steps required to eliminate and/or control variation within craft-based textile manufacturing, to reduce waste and improve product consistency. At the same time, it provides a framework by which traditional textile manufacturers can identify the best part of their production process in which to deploy new technology and systems.

A case study on the proposed method is also provided based on a manufacturing process for woven cashmere fabrics.

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2. Review of Literature

Within the context of quality and process control, it is impossible not to mention Shewhart; his pioneering work on control chart and its prevalent use in Statistical Process Control (SPC). The common or underlying theme in his work and other related literature on the application of SPC for quality improvement is that all processes exhibit some level of unusual behavior which is attributable to the inherent process variation.

The SPC tools, particularly control charts, help indicate the unusual behavior within a process that indicates the presence of variation [5]. They however, don't reveal the cause of the variation nor the impact it is having on subsequent processes within the overall manufacturing system [5].

Lean Six Sigma, the highly proven systematic approach applied within manufacturing and service processes for process improvement also incorporates some of the SPC tools and techniques [6]. Although, the lean six sigma approach further relies on the use of various analytical tools like Ishikawa diagrams, FMEA, RCA etc. to find the cause of process variation-related problems.

The DMAIC methodology used within the context of lean six sigma is designed to reduce process variability and the occurrence of defects by introducing apposite controls. This methodology is understood to be most effective when used for an appropriately defined process of reasonable scope, which makes it easier to manage.

It has been recognized that attempting to simultaneously consider a multi-stage manufacturing process through the DMAIC method, introduces unmanageable levels of complexity to the task. For instance, given a quality improvement project intended to identify one process (out of the entire manufacturing process), whose process variation and defects contribute to the final product variability, a Lean Six Sigma approach would be ideal for driving the required process improvement that will reduce product variability.

Conversely, if the management of a large multi-stage manufacturing setup intended to look at their end to end manufacturing process, to identify the key processes that contribute to a specific phenomenon further down their manufacturing process (for example, the variability in the fabric finish), they would need to employ a more pragmatic method.

The pragmatic method employed would have to be a consistent framework that initially captures the complexity of the entire process, but that funnels these – based on set criteria – into finite, manageable and critical sub-processes that impact the predefined end-process phenomenon. These identified sub-processes can then be the targets for process improvement projects using Lean Six Sigma tools and techniques.

Like many modern manufacturing processes, the production of woven cashmere fabrics and accessories is a multi-stage manufacturing process. A finite number of production processes that feed into each other are linked. Each production stage produces an output product that is fed-in as an input to subsequent processes. The key stages include; product design, dyeing, yarn manufacture, weaving and fabric finishing. Each of these production stages introduces some level of variation as the cashmere is processed from raw fiber to woven cloth. These process variations are propagated across the series of process stages and result in the product variation in the final fabric [7].

The crux of this research work thus focuses on the development of an innovative method for mapping out the most critical sources of variation (SoV) in woven cashmere fabric production that impact the quality of the fabric's finish. Though the method was designed for a specific textile manufacturing application, the strength of the proposed method is its simplicity and generalizability for similar manufacturing applications.

The literature review showed that substantial work has been done in [5] [7] [8] [9] on variation source identification (VSI). However, this should not be confused with mapping of variation sources, as is being addresses in this paper. The literature found on VSI focused on identifying the specific root cause of the variation from which a measured deviation in a product's quality characteristics must have resulted.

These research works were generally based on the assumption that all the key sources of variation that affect a product's quality characteristics, are known. They then build on this, by proposing methodologies for identifying which of the known sources of variation impacted a given product quality characteristic.

Much fewer literature have focused on determining what these key sources of variation within the entire process are in the first place and how to go about establishing them, and that is where this study comes in.

2.1. Process Mapping

The step of process mapping is a common and necessary step in identifying variation in a process. As such, accurate modelling of the fabric production process is important in developing the proposed variation mapping method in this paper. Capturing the production process 'as-is' and not 'as-designed-to-be' or 'as-thought-to-be' is very important, so as not to misidentify the variations in the process.

Several process mapping techniques and tools exist. This include value stream map (VSM), business modelling notation (BPMN), UML diagrams, data flow diagrams (DFD), role activity diagrams (RAD), integrated definition for function modelling (IDEF) and colored petri-nets (CPN).

The integrated definition for function modeling (IDEF) was used in this study to model the manufacturing process of interest. It is a process modelling technique that can be used for graphical and textual representation of data, information and functions of any process. There are a few iterations of IDEF, but the IDEF0 and IDEF3 are the most popular of the IDEF's iterations for process modelling.

The simplicity of the IDEF0 model, as used in this work, is evident in the fact that it uses one type of box to represent all the activities of a process – to different levels of detail. There are 4 types of arrows in IDEF0. The arrows and their placement on and around the activity boxes in an IDEF0 model are a key part of the IDEF's syntax. This is illustrated in the figure below.

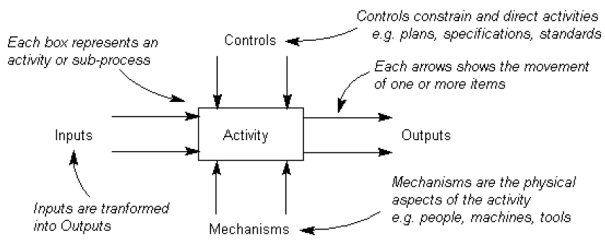

Figure 1. IDEF0 box and arrow syntax. [10]

IDEF0's advantage over many other modelling methods is the flexibility and effectiveness with which it allows analysis of complex systems, with multiple levels of detail [11]. The literature showed that IDEF0 has also been used as the basis for ERP system implantation [12], for extracting key information required for process simulation

[13], for deciding maintenance business process [14] and for database system creation for the optimization of a production process [15].

3. Methodology

The proposed method for the mapping of the sources of variation is as shown in figure 2 below. The proposed method begins with the creation of an IDEF0 representation of the manufacturing process. The model provides the framework for identifying all the SoV in the process. Evidently, a mis-representation of the actual process would seriously impact the accuracy of the identified SoV.

One of the main reasons for which the IDEF0 was selected as the base framework for mapping out SoV is the fact that it provides a consistent structure with which to assess the SoV within each process. Since the IDEF0 notation requires clearly defined inputs, controls, outputs and mechanisms (ICOM) per process, every process can be considered consistently based on their inputs, controls, outputs and mechanisms (ICOM).

The completion of the IDEF0 process map allows the development of a database of all the ICOM of each stage of the manufacturing process. The mapping of the SoV then begins with careful consideration of each ICOM factor of the individual processes. This is accomplished by asking two questions;

- Can this factor vary?
- How does it vary?

These are simple questions that the process expert or operators should easily and correctly answer. This exercise, though time demanding, shows that by using this method, all the production processes and their impacting variables can be consistently assessed and yield similar results, given that the process remains unchanged.

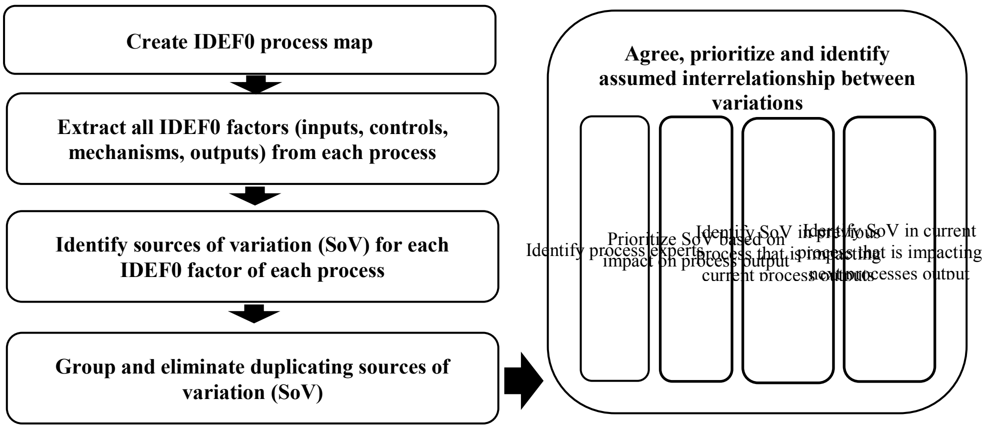

Figure 2. Proposed method for mapping sources of variation in manufacturing process

The result of asking the above questions for each process ICOM factor is a database of all SoV in the end-to-end process. Admittedly, this is likely to be a large database and its manageability is perhaps debatable. Nevertheless, by taking a few more steps this large database of SoV can be reduced, leaving the most critical variation sources.

Another advantage of this method of mapping SoV is that it naturally reveals patterns of how ICOM factors vary across the manufacturing process. On their own, these patterns could be grouped as key sources of variation. Also, depending on the nature of the output from a given process (e.g. information or material), it is usually fed into another process as an input or control. Consequently, in our initial database, there would exist a few duplicates of SoV that appear in one process as an output and in another process as a control or input. These duplicates should be eliminated from the database, which would result in a more manageable list of the SoV within each process.

In the last step of the proposed method, we aim to further reduce the identified SoV so that we can focus on the most critical ones that affect the final product. This is achieved by the following tasks;

- Identify at least 2 process experts per process. This is to help reduce the bias in the outcome of this step. It is believed that between 3 to 5 process experts per process would be optimal for the following exercise.
- Let each process expert prioritize the SoV identified within their process in order of the perceived impact on the outputs of their process. This is the critical step with which the key SoV are determined.
- Get process experts to identify the SoV within the previous process stage that is perceived to most impact the outputs within their own process stages.
- Process experts should then also identify the SoV within their own process stages that most impacts the outputs of the next process stage.

In executing the above exercise, it is very important to provide all the process experts with clear and consistent context, to ensure consistency of answers. This is because it is easy for different process experts to consider the same factors from different perspectives while answering the same question. For example, two process experts from the yarn manufacture process stage in a textile production process might agree that their main output from the process is yarn. Yet, one might be considering the output as the yarn characteristics and features. Whereas, the other might be considering the output as the yarn meterage produced or the yield.

By following the outlined steps above, the most critical SoV for each process will be determined.

4. Case Study

As a case study, we consider the manufacturing process for woven cashmere fabric. To demonstrate the method, it is applied to sub-processes within the fiber dyeing process stage of the manufacturing process.

Following the methodology presented in the previous section, figure 3 shows the IDEF0 process map for the dyeing process. Figure 4 then shows the result of following step 2 to step 5 of the variation mapping method shown in figure 2 above. In step 5 of the figure 4 above, by presenting the list of grouped and reduced SoV for the dyeing process to the expert dyers and yarn makers, the key SoV within the dyeing process that impact the dyed fiber and the yarn to be made were identified. These SoV are thus the most likely to affect the final fabric finish and should be the focus of planned intervention.

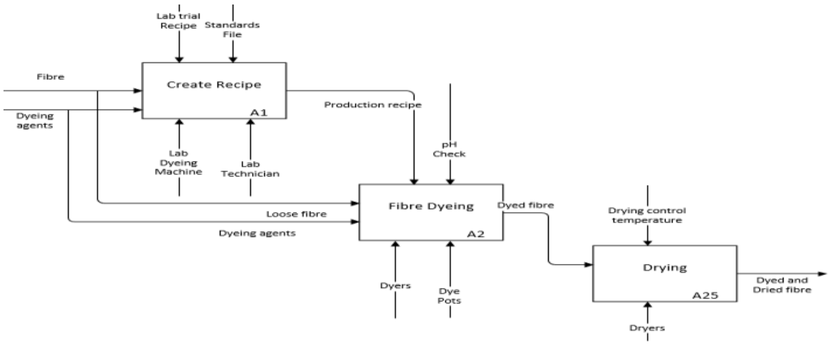

Figure 3. Step 1 of SoV mapping method showing IDEF0 process map for dyeing process.

STEP 2		STEP 3	STEP 4	STEP 5
Process	ICOM Factor	Initial Sources of Variation (Total No. 68)	Grouped & Reduced SoV (Total No. 27)	Process Expert-defined Critical SoV (Total No. 12)
Create Recipe	Input		fibre quality code	fibre length
	Fibre	fibre quality code	fibre length	regain
		fibre length	fibre color	type of chemicals
		fibre color	regain	Total dyeing time
		regain	fibre curvature	number of chemicals
		fibre curvature	mean fibre diameter (MFD)	amount of chemicals
		mean fibre diameter (MFD)	fibre diameter distribution (SD)	type of dyes
		fibre diameter distribution (SD)	coefficient of variation of fibre diameter	Dyeing temperature
		coefficient of variation of fibre diameter	weight of fibre	pH
		weight of fibre	number of dyes	operators reproducibility in measuring dyes and chemicals
	Dyeing agents	number of dyes	number of chemicals	fibre blend distribution
		number of chemicals	amount of dyes	dyeing method
		amount of dyes	amount of chemicals	
		amount of chemicals	type of dyes	
		type of dyes	type of chemicals	
		type of chemicals	Total dyeing time	
	Control		Dyeing temperature	
	Lab trial recipe		spec. of number of dyes	
	Standards file		spec. of number of chemicals	
	Mechanism		spec. of amount of dyes	
	Lab prototype dyeing machines	Total dyeing time	spec. of amount of chemicals	
		Dyeing temperature	spec. of type of dyes	
	Lab technicians		spec. of type of chemicals	
	Output		pH	
	Production recipe	spec. of number of dyes	operators reproducibility in measuring dyes and chemicals	
		spec. of number of chemicals	dyeing method	
		spec. of amount of dyes	dyeing class used	
		spec. of amount of chemicals		
		spec. of type of dyes		
		spec. of type of chemicals		
Loose Fibre Dyeing	Input			
		fibre quality code		
		fibre length		
		fibre color		

Figure 4. Step 2-5 of SoV mapping method for a dyeing process application.

5. Conclusion

This paper has presented a practical approach to mapping the sources of variation in a craft-based textile manufacturing setup. The challenges associated with process variation where discussed and it was shown that a complex multi-stage manufacturing process requires a practical, yet consistent framework for capturing all the sources of variation that contribute to the variability in the final product.

IDEF0 was presented as a structured and consistent process modelling tool for mapping the production process of such craft-based textile manufacturing processes. With the IDEF0 as the foundation of the variation mapping method, the authors showed that the input, control, mechanism and output factors of each process stage can be consistently assessed to identify the sources of variation within each process. The tacit process expert knowledge can then be systematically applied to reduce the identified sources of variation for the process to the most critical sources of variation that affect the final product.

These critical sources of variation identified provide a firm basis for focused analysis and intervention towards reducing the variability in the final product. The sources of variation identified can also guide decisions to restructure the manufacturing process or decisions on where to invest in new technology.

References

[1] R. . Nayak, A. . Singh, R. . Padhye and L. . Wang, "RFID in textile and clothing manufacturing: technology and challenges," *Fashion and Textiles,* vol. 2, no. 1, p. 9, 2015.

[2] X. Tao, Smart fibres, fabrics and clothing, Cambridge: woodhead Publishing , 2001.

[3] I. H. Ibrahim and C. . Chassapis, "An interactive variation risk management environment to assess the risk of manufacturing variations," *Internatnal Journal on Interactive Design and Manu.,* vol.11, no.3, pp. 597-608, 2017.

[4] T. H. Morton, "24—Composition tolerances in the manufacture of two-component textile fabrics part i: factors contributing to composition variation," *Journal of The Textile Institute,* vol. 68, no. 6, pp. 199-208, 1977.

[5] J.-P. Loose, S. Zhou and D. Ceglarek, "Variation source identification in manufacturing processes based on relational measurement of key product characteristics,"*Journal of Manufacturing Sci. and Engineering,* vol.130, pp.1-11, 2008.

[6] I. . Alhuraish, C. . Robledo and A. . Kobi, "The effective of lean manufacturing and six sigma implementation," , 2015. [Online]. Available: http://ieeexplore.ieee.org/document/7380197. [Accessed 8 5 2018].

[7] A. . Bazdar, R. B. Kazemzadeh and S. T. A. Niaki, "Variation source identification of multistage manufacturing processes through discriminant analysis and stream of variation methodology: A case study in automotive industry," *journal of engineering research,* vol. 3, no. 2, pp. 1-14, 2015.

[8] J. Liu, J. Shi and S. Hu, "Engineering-Driven Factor Analysis for Variation Source Identification in Multistage Manufacturing Processes,"*J of Manuf. Sci. & Engineering-transactions of the Asme,* vol.130, no.4, p.041009, 2008.

[9] X. Zhou and P. Jiang, "Variation source identification for deep hole boring process of cutting-hard workpiece based on multi-source information fusion using evidence theory," *J Intell Manuf,* vol. 28, pp. 255 - 270, 2014.

[10] Syque,"Changing-Minds," 19-01-1998. [Online]. Available: http://syque.com/quality_tools/tools/Tools19.htm. [Accessed 08 05 2018].

[11] J. C. Hernandez-Matias, A. Vizan, A. Hidalgo and J. Rios, "Evaluation of techniques for manufacturing process analysis," *J Intell Manuf,* vol. 17, pp. 571-583, 2006.

[12] O. B. Kwon and J. J. Lee, "A multi-agent intelligent system for efficient ERP maintenance," *Expert Systems with Applications,* vol. 21, no. 4, pp. 91-202, 2001.

[13] T. Perera and K. Liyanage, "Methodology for rapid identification and collection of input data in the simulation of the manufacturing systems," *Simulation Practice and Theory,* vol. 7, no. 1, pp. 645-656, 2000.

[14] A. Gabbar, H. Yamashita, K. Suzuki and Y. Shimada, "Computer aidedRCM-based plantmaintenance management system," *Robotics and Computer Integrated Manufacturing,* vol. 19, no. 5, pp. 449-458, 2003.

[15] L. L. H. Howard, "The development of a database system to optimise manufacturing processes during design," *Journal of Materials Processing Technology,* vol. 134, no. 3, pp. 374-382, 2003.