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Procedia CIRP 17 (2014) 201 – 206

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Variety Management in Manufacturing. Proceedings of the 47th CIRP Conference on Manufacturing Systems

Complexity analysis for problem definition in an assemble-to-order process: engaging emic and etic perspectives

Victoria Townsend[a]*, Jill Urbanic[b]*

[a]Industrial and Manufacturing Systems Engineering, University of Windsor, Windsor N9B 3P4, Canada
[b]Mechanical, Automotive, and Materials Engineering, University of Windsor N9B 3P4, Canada

* Corresponding author. *E-mail address: townsenv@uwindsor.ca; jurbanic@uwindsor.ca*

Abstract

This research regards assembly systems as complex sociotechnical systems, wherein knowledge workers are operators of and within the system. To ground the research empirically, an exploratory case study is used, which focuses on complexity and problem analysis in the redesigning of a high variety assemble-to-order process. The influence of product variety on the assembly process is first examined using an etic approach by applying ANOVA methods to production data to test the impact of product type (268 unique assemblies) and product platform (8 unique product platforms) on the variability in productivity. In the case study, 53.59% of the productivity variability is accounted for by product variety (or 20.77% by product platform). To inquire into other influences on complexity and problems in the assembly process, work, and system, a sociotechnical emic approach is engaged with interviews of 8 knowledge workers in 6 different roles. Using emic coding, 26 areas of concern arise for the assembly process and associated work with three problem areas (process, layout, and training). These codes are mapped to the assembly process stages and visualized as nodes, then analyzed using graph theory and an adapted usability curve. From this analysis, 8 critical problem foci are identified, to further inform the problem analysis and redesign of the assembly system. The emic approach helps to uncover relationships and interactions contributing to complexity that were concealed in the etic analysis. The emic methodology used in this research lends itself to generalizability to examine problem analysis when an integrative sociotechnical approach may prove useful.

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Sociotechnical process analysis and design; participation in engineering design; knowledge workers; emic coding

1. Introduction

In the literature, relationships between product variety and assembly processes have been studied with various perspectives on complexity, summarized in 2011 by Hu et al. [1]. These perspectives include defining complexity indices based on analyzing physical product attributes with handling and insertion [2]; using information entropy analysis in product structure planning, basic assembly process planning, and assembly technology planning [3]; and determining sequence planning relative to choice during operation [4] – to name a few that interface with the human system. More broadly, manufacturing system complexity has been discussed [5] and interfaced with the human system operationally [6].

While this literature is broad in scope, there is a very narrow body of literature addressing the sociotechnical system (STS) relationships between product variety, assembly processes, and complexity. STS approaches are grounded in the principle that knowledge workers are not just system users; they are operators of and in the system [7, p. 70]. Hence, a STS approach differs from a human interface approach by regarding knowledge workers as *active,* versus *passive,* in assembly processes; this has considerable effect on system change, uncertainty, and interactions – fundamental features of complexity [8, p. 793]. Hu et al. express this view when they correlate human systems with efficiency and versatility for managing assembly complexity: "many assembly operations are so complex that human assembly

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doi:10.1016/j.procir.2014.01.079

workers are the most efficient solution. In some cases, manual operations are the only options" [1, p. 726]. Further, Fisher et al. stipulate "the way that human skills are organized" as one of three core building blocks of flexibility for responding to product variety in assembly systems [9, p. 125]. With empirical evidence, Fisher et al. determine that "the way that human skills are organized" is an enabler of hardware and software (the other two building blocks), while also offering a broader scope of versatility [9, p. 126]. Though the significance of the human system is clear, the literature is unclear about *how* the social and technical aspects of the system can be intentionally integrated systematically, theoretically, and pragmatically into a win/win synthesis to address assembly complexity with product variety.

Bley et al. advocate that one means of achieving this integration with assembly systems involves synthesizing participative approaches with work typically performed separately by specialists, industrial engineers, in the act of rationalizing assembly processes with customer demands and economic constraints [10, p. 498]. Their call to action appeals for "a new synthesis between participative and specialized rationalization that has to be more than the actual coexistence of both approaches" [10, p. 498].

These views from the literature are echoed in the industrial partner problem statement, sharing emphasis on corresponding and inter-related social and technical issues, for an assembly process with high product variety:

At [Company], custom assemblies are designed and manually assembled per the voice of our customers. Since 2003, orders have grown by an average of 25.5% year-to-year. In 2003, 16,373 assemblies were designed and assembled. In contrast, 103,450 assemblies were designed and assembled in 2012. While this growth has created substantial business and employment opportunities, challenges now exist in process versatility (396 unique assembly configurations and products), attaining and maintaining quality standards, and high turnover of temporary employees. In turn, this has created a need to redesign the assembly process. (Excerpt, company letter)

Founded in the above critique of the literature and industrial partner problem statement, this research aims to examine sociotechnical system relationships in problem analysis for a complex assembly system with high product variety. Specifically, etic (outsider) and emic (insider) approaches are utilized to accomplish this aim – the latter highlighting an integrative sociotechnical approach.

2. Methodology

2.1. The etic approach and quantitative analysis

First, statistical analysis is performed on archival production data, a common manufacturing engineering problem analysis practice. Here, relationships between product variety and productivity are tested. The production data consists of 562 data events (unique production runs), from January to September 2013. The reported data is normalized, for confidentiality, such that the reported numbers are a factor of the minimum productivity (minutes/assembly/person). Since the analyzed data consists of continuous data (productivity) and discrete data (product numbers and product platforms), ANOVA analysis is performed. This is considered an etic, or outsider's, perspective on the problem analysis.

2.2. The emic approach and qualitative analysis (interview)

Next, a qualitative approach is utilized, in which "the goal is to understand the situation under investigation primarily from the participants' and not the researcher's perspective. This is called the *emic*, or insider's, perspective, as opposed to the *etic*, or outsider's, perspective" [11, p. 8]. The emic approach engages people in different roles to share their perspectives on the problem via an interview; "In a qualitative study, it is important to obtain as many perspectives on a topic as possible" [12, p. 26]. To engage these multi-perspectives, research study participants are recruited in accordance with research ethics principles, and the study underwent research ethics board review and approval.

Participants are recruited in line with the inclusion principle: a person who works, directly or indirectly, with the assembly process being studied at the company. Participants recruited for the study include: manager, planner, supervisor, customer service manager, lead hand, and builder. The builder and lead hand roles are directly related to the assembly process; the other roles are indirectly related to the assembly process. The purpose of including both direct and indirect involvement towards analyzing the assembly process is to engage the systems perspective, which involves understanding the interactions between the immediate assembly process and the inputs and outputs of the process.

This research paper analyzes the first 7 interview questions. It is important to note that the full interview conducted contains 12 questions as part of a larger study that goes beyond problem analysis, into a participatory design of the process and system with implementation. This paper focuses on problem analysis and definition. Table 1 outlines the interview questions and their purpose, to (I) Assess participant experience with manufacturing systems and design, which helps to define the context and generalizability of the results; or (II) Assess participant perspectives on the current state and ideal state of work and the assembly process (AP), with the tension between the current and ideal states being analyzed as the problem.

Table 1. Interview questions and their purpose

Interview Questions	Purpose
1. How many years have you worked at the [company facility]?	I
2. In addition to your current role, do you have additional experience in manufacturing in other industries or roles?	I
3. Do you have past experience with participating in design, in manufacturing or another setting?	I
4. How would you describe the current AP?	II
5. How would you describe your work with the current AP?	II
6. How would you describe an ideal AP?	II
7. How would you describe your ideal work with an ideal AP?	II

By defining the problem as the tension between the current state and ideal state of work and the assembly process, the research aims to capture aspects of the current state that may be beneficial (the associated questions seek to understand the baseline) and potential for improvement (the associated questions seek to engage idealized design [13]). In this approach, the questions lend themselves to these goals but are intentionally designed to be open and unbiased, i.e. to not assume that there is a problem with the work or process, but to ask the participant if s/he sees any issues or problems. By separating the questions into work and process, the interview also tests Trist and Bamforth's statement made in the sociotechnical systems literature: "Occupational roles express the relationship between a production process and the social organization of the group. In one direction, they are related to tasks, which are related to each other; in the other, to people, who are also related to each other" [14, p. 14].

The interviews are recorded (with consent from participants). They are then transcribed, verified, and coded using emic coding. Emic codes (problem perspectives) arise out of the data as defined by the participants.

2.3. The emic approach combining qualitative and quantitative analysis

The interview codes are then analyzed relative to the assembly process and scope of the research study; visual analysis is engaged, resulting in a mapping of codes to the assembly process and associated work in a complex web that resembles graph theory. The codes are considered nodes and analyzed using graph theory, with a matrix of magnitude for code occurrence and a matrix of adjacency for relationships between codes. A weighted adjacency matrix is formed as a product of the adjacency and magnitude matrices. The weighted adjacency matrix captures not only each code's relationship with other codes but also the significance of those relationships relative to the code web as a whole.

Specific problem analysis foci are identified through a plot of weighted adjacency versus magnitude. This approach is analogous to the usability plot proposed by Nielsen [15] who "suggests that each usability problem should be plotted on a two-dimensional graph where one axis of the graph corresponds to problem severity and the second, to the number of people in the targeted user population who are likely to be a affected by the problem" [16, p. 515]. This is analogously translated here by considering the code's weighted adjacency value as the problem severity (the code's relationship to other codes, i.e. its integrality to the code web) and considering code magnitude as the number of people affected (the code's occurrence). From this analysis, an emic problem statement is formed based on a format used in design thinking [17].

3. Results

3.1. Etic results of production data analysis

The ANOVA tests use the following nomenclature.

Statistical Nomenclature

DF	Degrees of freedom
SS	Sum of squares
MS	Mean squares
F	F-statistic (signal to noise ratio)
P	P-value or probability value
R-Sq	R-squared value (% of variation in Y explained by X)
H_o	Null hypothesis
μ	Mean productivity [minutes/assembly/person]

A one-way ANOVA test is performed for productivity versus product number using a 95.0% confidence level to test the null hypothesis in (1). In this data set, there are 268 unique product numbers (final assemblies), of which 154 are manufactured only once in the data set time frame of 9 months. These are excellent conditions to test the impact of product variety on the productivity for a manual assembly process. Results are shown in a box-plot (Figure 1) and a standard ANOVA analysis table (Table 2).

$$H_o: \mu_{product\ 1} = \mu_{product\ 2} = \cdots \mu_{product\ 268} \quad (1)$$

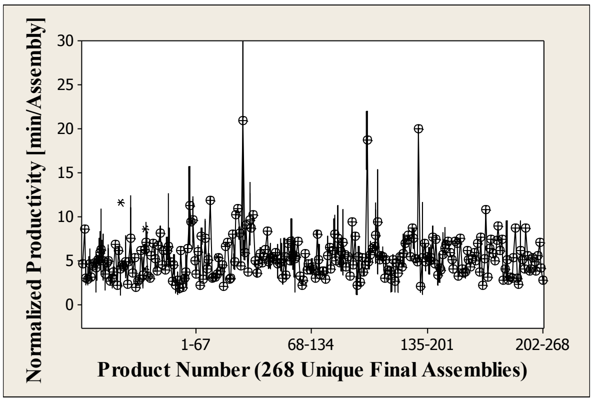

Fig. 1. ANOVA boxplot on productivity versus product number

Table 2. ANOVA table on productivity versus product number

Source	DF	SS	MS	F	P
Product Number	267	3900.6	14.6	1.28	0.021
Error	295	3377.5	11.4		
Total	562	7278.1			
R-Sq = 53.59%					

Table 2 indicates that the p-value is 0.021, which is <0.05; therefore, the null hypothesis is rejected. Thus, not all of the productivities are the same for every product (though there may be some means that are statistically similar). This is not surprising; however, the R-Sq value is interesting in stating that only 53.59% of the variation in productivity can be explained by the different product numbers. To further explore this, product families are tested based on common platforms using the same analysis set-up with the null hypothesis in (2). Results are shown in a box-plot (Figure 2) and a standard ANOVA analysis table (Table 3)

$$H_o: \mu_{platform\ 1} = \mu_{platform\ 2} = \cdots \mu_{platform\ 8} \quad (2)$$

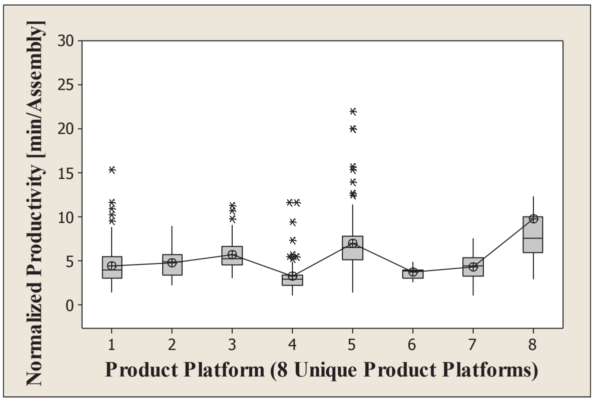

Fig. 2. ANOVA boxplot on productivity versus product platform

Table 3. ANOVA table on productivity versus product platform

Source	DF	SS	MS	F	P
Product Platform	7	1511.6	215.9	20.78	0.000
Error	555	5766.5	10.4		
Total	562	7278.1			
R-Sq = 20.77%					

Table 3 indicates that the p-value is <0.001, which is <0.05; therefore, the null hypothesis is rejected. Thus, not all of the productivities are the same for every product platform (though there may be some means that are statistically similar). This is not surprising; however, the R-Sq value is interesting in stating that only 20.77% of the variation in productivity can be explained by the different product platforms.

What this analysis lends itself to is the following question: if product variety itself only accounts for 53.59% of the productivity variation, and product platforms even less so with 20.77%, then the problem of responding to product variety in this assemble-to-order process has influences beyond that of analyzing product complexity and its relationship with the assembly process and manufacturing system. These other influences on complexity in the assembly system need to be understood; consequently, in this research study, knowledge workers who experience this complexity every day in their work with the assembly process are asked to participate in sociotechnical problem analysis.

3.2. Emic results of interview analysis

The first 3 questions of the interview help to define the context of the study relative to each participant's past experience with manufacturing systems and design. The first question asked each participant, "How many years have you worked for the [company]?" The resulting mean is 13.38 years, with a range of 0 (temporary employees) to 40 years.

The second question asked each participant, "In addition to your current role, do you have additional manufacturing experience in other industries and/or roles?" 4 participants cited additional experience exclusively within the company (Supervisor, Packager, Lead hand, Picker/packer, and Receiver). 2 participants cited additional experience exclusively outside of the company (Material handler, Sorter, Food industry). 1 participant cited additional experience within and outside of the company (Packager, Automotive industry). Participant experience thus spanned 7 additional roles and 2 industries.

The third question asked each participant, "Do you have past experience participating in design, in manufacturing or another setting?" Results are shown in Figure 3.

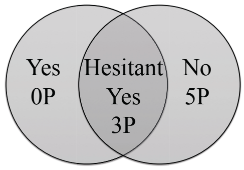

Fig. 3. Participant (P) past experience with design

In question 3, it was anticipated that participants might describe design experience with their home, hobby, etc. All of the participants (P) initially answered "no" to this question. After probing, 3 participants answered "yes" hesitantly, with design experience including: "coming up with new ways to do things;" deciding to purchase new equipment or retrofit existing equipment; university computer aided design course; high school construction course; and "assess[ing] whether you need to automate versus not automate"

Questions 4 – 7 asked each participant to describe the current and ideal assembly process and his/her work with both. By emic coding of the transcripts, 26 codes emerged as participant-defined areas of concern (cf. code nomenclature).

Code Nomenclature

1	Respond to order volume growth
2	Accurate forecasting
3	Forecasting feedback
4	Steady workforce of builders
5	Efficient staffing of builders
6	Consistent relationship with builders
7	Ease of lead hand and builder communication
8	See builders
9	Training builders
10	Establish builder responsibility and autonomy
11	Ensure quality of final assemblies (no post-inspection)
12	Working with limited room and space
13	Organize and designate position for materials (staging)
14	Improve flow
15	Streamline assembly process, more efficient
16	Flow like an assembly line
17	Assembly line differentiation (contextualized)
18	No need for machines in assembly process
19	Improve build sequence and division of work
20	Builders set pace
21	Determine the right number of builders for tasks
22	Have a partner for builders
23	Working smarter not harder
24	Training for material handlers and lead hands

25	Conflicting flow and work for material handlers with the receiving work
26	Conflict for material handlers – getting supplies and putting away finished assemblies

These 26 codes are each identified by a bubble in Figure 4, with the code number in the middle. The size of the bubble represents the code occurrence; the scale is shown in the legend, for 1 and 2 occurrences. The codes are arranged relative to the 4 main phases of the production process: (1) Initiate the order (receive customer order and initiate work order); (2) Prepare for the assembly process; (3) Perform the assembly process; and (4) Finalize the order (close work order and request customer feedback). These phases represent 4 quadrants in Figure 4. The relationships between the emic codes (code to code) and the production phases (code to quadrant(s)) determine the position for the code in Figure 4. For example, layout (code 12) affects preparing for the assembly process (phase 2) with respect to staging materials (code 13) and also performing the assembly process (phase 3) with respect to improving flow (code 14). Thus, the codes form an interconnected web with each other and the main phases of the production process for problem analysis. Phases 2 and 3 are in scope for this research; phases 1 and 4 highlight context from initiating an order with a customer to finalizing an order. Through this mapping technique, prominent codes emerge not only for their occurrence (bubble size) but also for their interconnectedness (bubble proximity) and thematic relationships (bubble clusters). The latter enables problem focus areas to emerge (bubble shading), which are process, layout, and training.

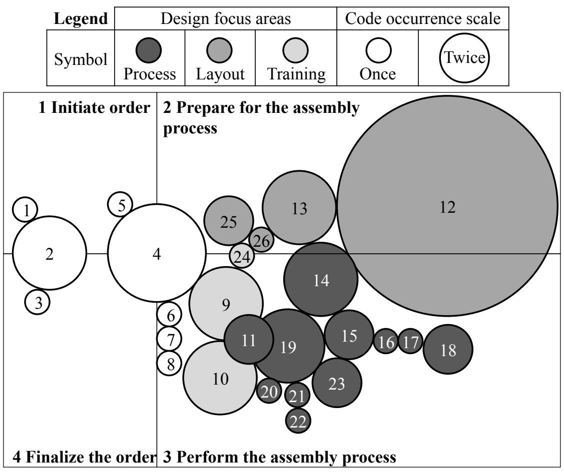

Fig. 4. Map of emic coding to the four main phases of the assembly process

3.3. Emic results of interview analysis combined with quantitative analysis

To further analyze the emic codes from the interview to define specific problem foci, graph theory is applied to the mapping in Figure 4 with the following nomenclature.

Graph Theory Nomenclature

G	Graph (Figure 4), undirected, not complete
N	Nodes (codes), $\|N\| = 26$
V	Edges (relationship, or connecting line between two codes), E {(1,2), (2,3), (4,5), (4,6), (4,9)…}, $\|E\| = 30$
$\mathbf{A}_{ii}$	Adjacency diagonal matrix, where i = $\|N\|$ = 26
$\mathbf{M}_{ji}$	Magnitude row matrix, where j=1, i=26
$\mathbf{W}_{ji}$	Weighted adjacency row matrix, where j=1, i=26
μ_M	Mean value in the magnitude matrix
μ_W	Mean value in the weighted adjacency matrix

Applying this nomenclature to the graph in Figure 4 using equation (3) results in the diagonal adjacency matrix ($\mathbf{A}_{ij}$) in (4) – akin to a design structure matrix (DSM). The sum for each row and column is stated at the end of the row and column; sums greater than the mean are highlighted in grey.

$$G = (N, E) \tag{3}$$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
1	0	1																									1
2	1	0	1																								2
3		1	0																								1
4				0	1	1			1																		3
5				1	0																						1
6				1		0	1																				2
7						1	0	1																			2
8							1	0																			1
9				1					0	1	1													1			4
10									1	0	1								1								3
11									1	1	0								1								3
12												0	1	1													2
13												1	0	1												1	3
14												1	1	0	1				1								4
15														1	0	1			1				1				4
16															1	0	1										2
17																1	0	1									2
18																	1	0									1
19										1	1			1	1				0	1	1		1				7
20																			1	0							1
21																			1		0	1					2
22																					1	0					1
23															1				1				0				2
24									1															0	1	1	3
25																								1	0	1	2
26													1											1	1	0	3
	1	2	1	3	1	2	2	1	4	3	3	2	3	4	4	2	2	1	7	1	2	1	2	3	2	3	

(4)

Additionally, a row magnitude matrix ($\mathbf{M}_{ji}$) can be created for each code based on the code's occurrence in the interviews, shown in the second row in Figure 5 with values ≥ μ_M highlighted. Applying equation (5) creates a weighted adjacency matrix ($\mathbf{W}_{ji}$) based on the relationship between each code and the magnitude of the related code. $\mathbf{W}_{ji}$ is shown in the third row in Figure 5 with values ≥ μ_W highlighted.

$$W_{ji} = M_{ji} \times A_{ii} \tag{5}$$

Each code's magnitude and weighted adjacency value from each corresponding matrix are plotted on the usability curve (Figure 6) relative to a critical point defined as (μ_M, μ_W) = (2,6). Critical codes are marked with an X in Figure 5.

Code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Mij	1	3	1	4	1	1	1	1	3	3	2	9	3	3	2	1	1	2	3	1	1	1	2	1	2	1
Wij	3	2	3	5	4	5	2	1	10	8	9	6	13	17	9	3	3	1	14	3	4	1	5	6	2	6
Critical									X	X	X	X	X	X	X				X							

Fig. 5. Magnitude matrix, weighted adjacency matrix, and critical codes

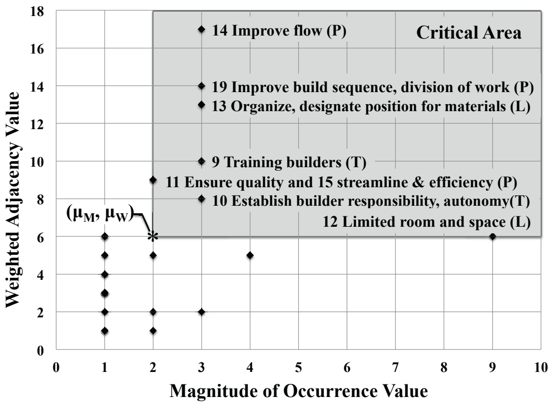

Fig. 6. Critical codes, weighted adjacency versus magnitude occurrence (code's primary relation to P-process, L-layout, or T-training)

The critical codes, or critical problem foci, identified through the graph theory analysis and usability plot in Figure 6 relate to the previously defined problem focus areas as follows: 4 foci relate to process (codes 14, 19, 11, and 15), 2 foci relate to layout (codes 12 and 13), and 2 foci relate to training (codes 9 and 10). In turn, the following emic problem statement is formed: the stakeholders (builders, lead hands, supervisor, planner, manager, and customer service manager) need a re-designed assembly process "that applies to us" with a focus on process, layout, and training because of 8 critical problem foci and the related 26 concern web.

4. Discussion, conclusion, and next steps

This research examines problem analysis in an industrial case study of a high variety assemble-to-order process, with etic and emic perspectives to examine influences on complexity. In an etic approach, production data is analyzed using ANOVA analysis to examine variation in process productivity based on product number (53.6% of variation) and product platform (20.8% of variation). To examine other influences on complexity with an integrative sociotechnical systems view, an emic approach engages knowledge workers with a variety of manufacturing experience to share their experiences and ideas relative to the problem analysis. Though participants in the case study are reluctant to discuss past design experience, clear examples of design experience are found, and this reluctance should be further investigated. The tension between the current and ideal assembly process and work is analyzed as the problem. Across the interviews, participants talked mutually about work and process, very much in keeping with Trist and Bamforth's statement on work as the intersection between social and technical systems [14, p. 14].

The interviews are transcribed, verified, and coded, resulting in a visual mapping of 26 emic codes to the assembly process. The mapping for this case study identifies three problem focus areas: process, layout, and training. By applying graph theory (magnitude, adjacency, and weighted adjacency matrices) to an adapted usability plot, the 26 codes are further refined into 8 critical problem foci. These foci align with the process (4), layout (2), and training (2) problem focus areas. In short, this emic approach and corresponding methodology, developed in this case study, can be generalized to examine problem analysis at the local level of process and work when a sociotechnical approach may prove useful. In this research, the emic approach uncovers a web of connections in the problem analysis, which are concealed in the etic statistical analysis. It is thus posited that through the eyes of knowledge workers sociotechnical complexity interactions can be viewed, which can aid in problem analysis. Future research will include further examination of this emic approach and participation (e.g. in mapping the methodology) into subsequent phases of the design process.

Acknowledgements

The authors thank the research participants and industrial partner for their valued participation in this research. This research has received research ethics board clearance, University of Windsor, REB# 31017.

References

[1] Hu SJ, Ko J, Weyand L, ElMaraghy HA, Lien TK, Koren Y, Bley H, Chryssolouris G, Nasr N, Shpitalni M. Assembly system design and operations for product variety. CIRP Annals - Manufacturing Technology 2011; 60:2, p. 715-733.
[2] Samy S, ElMaraghy HA. A Model for measuring products assembly complexity. Int J Comput Integr Manuf 2010; 23:11, p. 1015-1027.
[3] Fujimoto H, Ahmed A, Iida Y, Hanai M. Assembly process design for managing manufacturing complexities because of product varieties. Int J of Flexible Manuf Sys 2003; 15:4, p. 283-307.
[4] Zhu X, Hu SJ, Koren Y, Huang N. A complexity model for sequence planning in mixed-model assembly lines. J of Manuf Sys 2012; 31:2, p. 121-130.
[5] ElMaraghy W, ElMaraghy HA, Tomiyama T, Monostori, L. Complexity in engineering design and manufacturing. CIRP Annals - Manufacturing Technology 2012; 61:2, p. 793-814.
[6] ElMaraghy W, Urbanic J. Assessment of Manufacturing Operational Complexity. CIRP Annals - Manufacturing Technology 2004; 53:1, p. 401-406.
[7] Vermaas PE, Kroes P, Van de Poel I, Franssen M, Houkes W. A philosophy of technology from technical artefacts to sociotechnical systems. California: Morgan & Claypool; 2011.
[8] ElMaraghy W, ElMaraghy H, Tomiyama T, Monostori L. Complexity in engineering design and manufacturing. CIRP Annals - Manufacturing Technology 2012; 61:2, p. 793-814.
[9] Fisher M, Jain A, MacDuffie JP. Strategies for product variety: lessons from the auto industry. In: Bowman B, Kogut B, editors. Redesigning the firm. New York: Oxford University Press; 1995, p. 116–154.
[10] Bley H, Reinhart G, Seliger G, Bernardi M, Korne T. Appropriate human involvement in assembly and disassembly. CIRP Annals - Manufacturing Technology 2004; 53:2, p. 487–509.
[11] Hancock DR, Algozzine R. Doing case study research: a practical guide for beginning researchers. New York: Teachers College Press; 2011.
[12] Corbin JM, Strauss AL. Basics of qualitative research: techniques and procedures for developing grounded theory. California: Sage; 2008.
[13] Ackoff RL, Magidson J, Addison HJ. Idealized design: how to dissolve tomorrow's crisis...today. New Jersey: Pearson Prentice Hall; 2006.
[14] Trist EL, Bamforth KW. Some social and psychological consequences of the Longwall Method of coal-getting An examination of the psychological situation and defences of a work group in relation to the social structure and technological content of the work system. Human Relations 1951; 4:1, p. 3-38.
[15] Nielsen J. Usability engineering. California: Morgan Kaufmann; 1994.
[16] Lehto M, Landry SJ. Introduction to human factors and ergonomics for engineers. 2nd ed. Florida: CRC Press Taylor and Francis; 2013.
[17] Britos Cavagnaro L. Frame the problem - empathize and define. Stanford University Design Thinking Action Lab MOOC. Online: Jul-2013.