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Production error distribution in sheet metal industry

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1. Introduction

Constructions based on fabricated sheet metal parts are used in a wide range of different types of products. Typically, these constructions can for example be found in consumer goods (e.g. white brand products), means of transportation (e.g. cars and elevators), mechanical engineering (e.g. machine cabinets and covers) and electronic equipments, such as telecommunication cabinets and computer housings. One typical sheet metal component based product, a computer housing, is featured in Fig. 1.

Fig. 1 Computer housing

An increasing market turbulence and customer demands compels manufacturing companies to manufacture high-quality and customized products within short lead-times and at condescending expenses. These competition requirements are important for customer loyalty and long-term survival but they can eat deep into profits. The solution for stable profits and long-term survival, therefore, lies in the continuous development of manufacturing resource performance and the elimination of threats amongst them. Improved production efficiency and flexibility are the keywords for most manufacturing companies.

Surveys in Finland [1, 2] have shown the need to invest in the new AMT (Advanced Manufacturing Technologies) in the Finnish sheet metal industry in the 1990's. The need to produce growing amount of customized products within short lead-times and at condescending expenses mainly for the electronics and telecommunication industry has driven the metal fabricating industry to find new ways of improving production through advanced manufacturing technology. In this run the focus has been on hard technology and less attention is paid to the professional skills of the workforce [3].

However, the selected way has lead to a situation, where appreciable portion of profit within reach is wasted due to production errors [4]. By reducing production errors the whole production flow can be made more effective and profitable. Reducing production errors is not possible however without understanding the prevailing situation. Therefore it is important to analyze the whole production flow so, that production activities can be focused correctly. A systematic production performance measurement is therefore needed when development activities are considered

1.1 Objective and scope

The production flow of the sheet metal part based constructions is inspected in this paper. The main objective of this paper is to analyze the production flow error distribution in the production flow of the sheet metal based constructions. Terms error and production error in this paper means a deflection from a planned production flow where the customer demands are not met. Because of that deflection various repairing operations are needed.

This paper is a part of quality related research program ("LELA") [5] carried out by Lappeenranta University of Technology between December 2000 and August 2002 and it is based on the field study carried out in three Finnish case factories which produce sheet metal part based constructions, mainly for electronics and telecommunication-related industry. It is most relevant to the sheet metal part fabricating industry which produces sheet metal part based constructions for electronics and telecommunication industry. This paper concentrates on the manufacturing function of a company and the focus is in well known, high-grade Finnish based "state of the art" companies.

1.2 Case factories

All three case factories are well known Finnish based factories. It is generally accepted that these factories represent advanced activities in their manufacturing operations. Factories A and C are parts of larger consolidated companies. All case factories manufacture products for global distribution. The turnover of the consolidated companies is representing quite a remarkable part of the annual Finnish turnover in sheet metal fabricating industry. Branches of manufacturing activities and production flow details in case factories are listed below.

Factory A manufactures electromechanical locks. These electromechanical locks contain many sheet metal components, e.g. lock body, front shield and counterparts. The production flow of sheet metal components used in the locks includes many work phases. A punch press and a laser-combination machine are used in the fabrication of blank parts. The production flow includes also many manually operated phases. These manually operated phases include grinding phases of visible surfaces, heat treatment in some lock components, inserting different inserts, special work phases and final assembly. Surface treatment processes are used extensively. The production strategy in Factory A is medium volume production.

Factory B manufactures sheet metal parts based constructions for electronics, telecommunication and automotive industry. Mass production methods, such as automated eccentric presses, are used extensively in the production and most of the bending and fabrication of blank parts-phases are done by these eccentric presses. The production flow includes some manually operated phases, such as the riveting. Surface treatment processes are also used extensively. The production strategy in factory B is a high volume production.

Factory C manufactures custom outdoor and indoor enclosures for telecom applications such as wireless base stations, switching systems and network access equipment. The production includes wide range of sheet metal part based constructions. The production flow includes many automated work phases, such as punch press operations. Many work phases are still operated manually. These manually operated work phases include press brake phases, joining phases and grinding phases. Surface treatment processes are also used extensively. The production strategy in factory C is a medium volume production.

Noticeable is that the production flow in each case factory is different. Also different fabricating methods are used and batch sizes and annual production figures are different in each case factory. A common factor for every factory is mechanical constructions based on sheet metal parts and used in electronics and telecommunication industry.

1. 3 Literature revive

Very few papers can be found in literature about the production flow of constructions based on fabricated sheet metal parts and a literature review exposed no written papers handling the production flow of constructions used in electronics and telecommunication industry. Bitzel et al. [6] describes the sheet metal process flow in general in their book and the production chain of a sheet metal parts based cross member of a flatbed laser machine is described as an industrial example. Berkhahn and Miyakawa [7] show general sheet metal fabrication processes in their paper. They also show examples of sheet metal parts used in a machine tool. The process flow of elevator car constructions is shown in a paper of Kanamouri et al. [8]. One example of the described sheet metal process is shown in Fig. 2 [7].

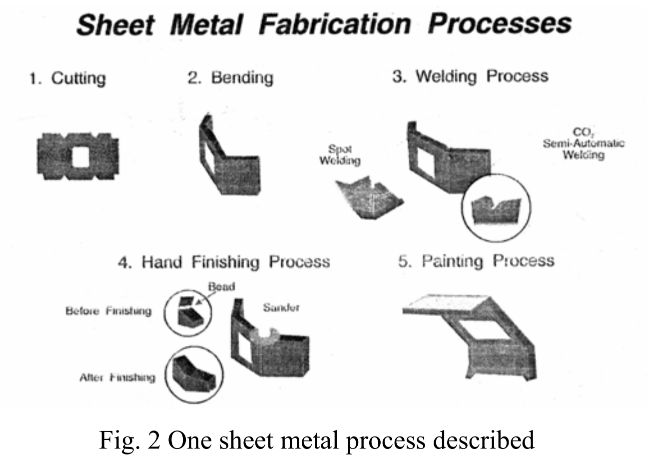

Fig. 2 One sheet metal process described

Ollikainen [9] has also listed production activities in sheet metal part fabricating industry in his paper. According to Ollikainen these activities include NC-programming, part fabricating operations (2D-parts, bending, joining, assisting work phases), surface treatment operations (pre-treatments, surface treatments, after-treatments), assembly operations, packing and transportation arrangements and warehouse operations.

Noticeable is that in literature review no written papers could be found about production error distribution in the production flow of constructions based on fabricated sheet metal parts.

2. Methods

The aim of the field study was to collect data from the production error distribution in the production flow of the sheet metal part based constructions. No existing model for a similar or comparable field study could be found in published papers. Therefore own study methods had to be developed.

First, background information was collected from the case factories and a production flow partition was done. Secondly, special production error charts were formulated based on the collected production information and production flow partition. At this point every case factory was asked to select some products to be tracked in this field study and training occasions were arranged to every person to be involved in the collection of production error data. After a short training period a production error data collection was arranged for the selected products by workers in each case factory. After all, all completed production error charts were collated and production error databases were generated.

2.1 Production chain partition used in field study

In this paper the whole production flow has been shared into functional phases based on background information collected from case factories. These functional phases have then been shared into work phases. These functional phases and work phases cover all manufacturing actions in studied case factories and the partition is featured in Table 1.

Table 1

Production chain partition used in field study

Functionalphase	Work phase
1 Fabrication of blank parts	11 Mechanical cutting
	12 Punch press
	13 Deep drawing
	14 Forming
	15 Laser cutting

Table 1 (continuation)

Functional phase	Work phase
2 Bending	21 Press brake
	22 Bending automatic
	23 Folding machine
	24 Eccentric press
	25 Hydraulic press
3 Joining	31 Welding
	32 Spot welding
	33 Riveting
	34 Other joining method
4 Surface treatments	41 Cleaning
	42 Pretreatment
	43 Surface treatment
	44 Painting
	45 Printing
5 Unspecified work phases	51 Threadning
	52 Forming
	53 Marking
	54 Grinding
	55 Countersinking
	56 Nut inserting
	57 Assembly of non-sheet metal parts
	58 Bonding
	59 Hardening
	60 Heat treatments
	61 Deburring
7 Assembly	71 Welding
	72 Riveting
	73 Screwing
	74 Spot welding
	75 Bonding
9 Assisting work	91 Transportation
	92 Handling
	93 Packing
	94 Transportation arrangements
	95 Warehousing

3. Results

The field study took place in three Finnish sheet metal part fabricating based factories during the time period May 2001 – October 2001. The number of the parts traced in the field study was 732724 pieces and a total of 84011 production errors were reported.

3.1 Production error distribution by work phases

The production error distribution by the work phases in each factory studied is presented in Table 2. Figures shown in the table are presenting the percentage distribution of all production errors in each factory. In some cases figure “0.0” is used. This figure does express that a production error exists but the share is zero. Blank cell in table expresses that no production error exists in that work phase.

Code <26> in the work phase column signifies indefinable notes in the production error charts. Code <76> in the work phase column is added to signify the general assembly work phase in assembly phase of an electromechanical product.

Table 2

Production error distribution by work phases, %

	Work phase	Factory A	Factory B	Factory C
11	Mechanical cutting		17.0	0.5
12	Punch press	16.3		45.1
13	Deep drawing		0.3	
14	Forming			
15	Laser cutting	1.8		
21	Press brake	0.2	1.8	31.8
22	Panel bender			
23	Folding machine			
24	Eccentric press	0.2	61.7	0.5
25	Hydraulic press			
<26>				0.2
31	Welding		1.9	
32	Spot welding			
33	Riveting	1.9	6.0	0.2
34	Other joining method			
41	Cleaning		0.6	
42	Pre-treatment			
43	Surface treatment	4.2	3.5	
44	Painting		1.9	
45	Printing			
51	Threadning		1.6	
52	Forming		0.2	
53	Marking		0.1	
54	Grinding	0.3	1.4	13.5
55	Countersinking	2.7		
56	Nut inserting			
57	Assembly of non-sheet metal parts		0.2	2.5
58	Bonding		0.2	
59	Hardening	43.5		
60	Heat treatments			
61	Deburring	0.3	1.2	
71	Welding			
72	Riveting		0.0	
73	Screwing		0.0	
74	Spot welding			
75	Bonding			
<76>		28.6		
91	Transportation		0.4	
92	Handling			5.7
93	Packing			
94	Transportation arrangements			
95	Warehousing		0.0	
	Total	100	100	100

4. Analysis

When factories A and C are examined, it can be observed that the production strategy in both factories is medium volume production and the production flow is a mixture of automated production machinery and manually operated work phases. Factory B differs from factories A and C. The production strategy in factory B is high volume production and the production flow is highly automated.

4.1 Most problematic functional phases and work phases

The three most problematic functional phases in factory A are emphasized in Fig. 3. In the figure we can see that production errors are mainly caused in "*5 Unspecified work phases*" in Table 1 (46.8% of all production errors) and in "*7 Assembly*" (28.6% of all production errors). The third problematic functional phase is "*1 Fabrication of blank parts*" (18.1% of all production errors). A total of 93.5% of all production errors is caused in the three most problematic functional phases. Manually operated work phases are mainly performed in unspecified work phases and in assembly. This indicates that manually operated work phases are the most sensitive sources for production errors in factory A.

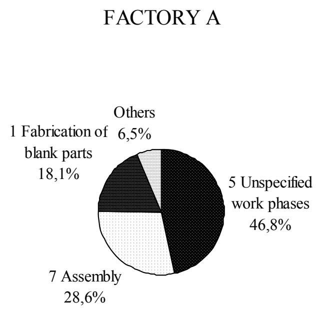

Fig. 3 The most problematic functional phases in factory A

The three most problematic work phases in factory A are presented in Fig. 4. In the Figure we can see that production errors are caused mainly in "*59 Hardening*" (43.5% of all production errors), "*<76> Assembly*" (28.6% of all production errors) and in "*12 Punch press*" (16.3% of production errors). See Table 2. A total of 88.4% of all production errors are caused in the three most problematic work phases. Work phases hardening and assembly are mainly operated manually. This supports the observation made above, that manually operated work phases are the most sensitive sources for the production errors in factory A. Also, the punch press related production is very sensitive source for production errors in factory A.

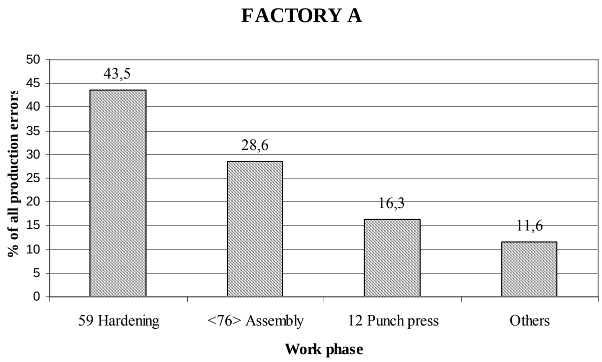

Fig. 4 The most problematic work phases in factory A

The three most problematic functional phases in factory B are emphasized in Fig. 5. In the figure we can see that the production errors are mainly caused in "*2 Bending*" (63.5% of all production errors) and in "*1 Fabrication of blank parts*" (17.3% of all production errors). The third problematic functional phase is "*3 Joining*" (8.0% of all production errors). A total of 88.8% of all production errors is caused in the three most problematic functional phases. The mass production methods are used extensively in the bending. The joining is operated mainly manually. This indicates that the mass production methods are the most sensitive sources for the production errors in factory B.

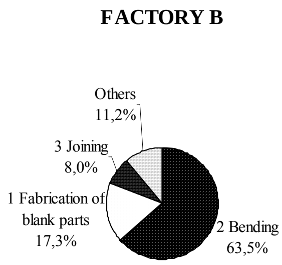

Fig. 5 The most problematic functional phases in factory B

The three most problematic work phases in factory B are presented in Fig. 6. In the figure we can see that production errors are mainly caused in "*24 Eccentric press*" (61.7% of all production errors) and in "*11 Mechanical cutting*" (17.0% of all production errors). A total of 84.7% of all production errors in factory B is caused in the three most problematic work phases. This supports the observation made above; that the mass production methods are the most sensitive for the production errors in factory B.

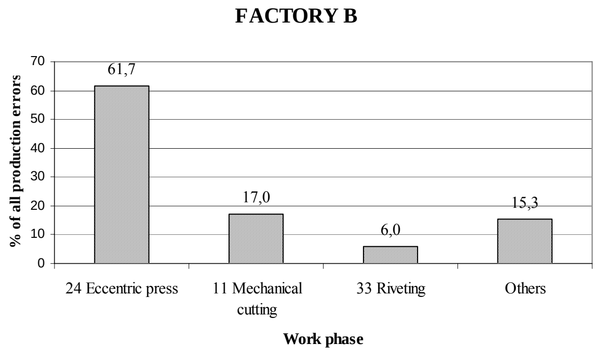

Fig. 6 The most problematic work phases in factory B

The three most problematic functional phases in factory C are emphasized in Fig. 7. In the figure we can see that production errors are mainly caused in "*1 Fabrication of blank parts*" (45.6% of all production errors), in "*2 Bending*" (32.5% of all production errors) and in "*5 Unspecified work phases*" (16.0% of all production errors). A total of 94.1% of all production errors in factory C are caused in the three most problematic functional phases.

The three most problematic work phases in factory C are presented in Fig. 8. In the figure we can see that production errors are mainly caused in "*12 Punch press*" related operations (45.1% of all production errors), in "*21 Press brake*" related operations (31.8% of all production errors) and in "*54 Grinding*" (13.5% of all production errors). A total of 90.4% of all production errors in factory C is caused in the three most problematic work phases. The result indicates that in factory C there are problems related with both the automated work phases and manually operated work phases. It can be said that the most sensitive work phases for the production errors are the punch press related operations and the press brake related operations.

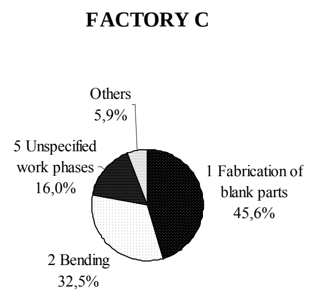

Fig. 7 The most problematic functional phases in factory C

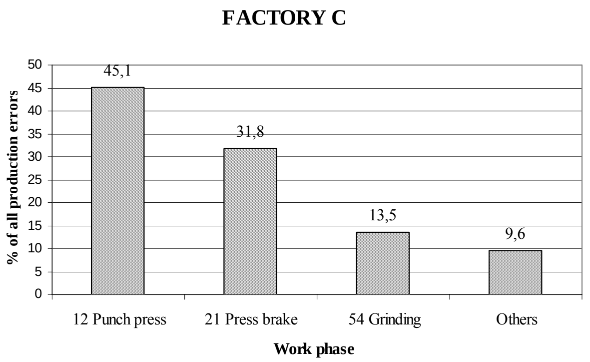

Fig. 8 The most problematic work phases in factory C

4.1 Reliability of results

The production error data collection includes a lot of manual work and human mistakes can happen. However, it is assumed that the amount of missing markings is minor compared to the collected data as a whole. Also, the employees have presumably been motivated enough to collect production error data carefully. This assumption was strengthen in a feedback meeting where it was possible to discuss the results of the field study with shop floor employees, supervisors and designers.

On the other hand, it is supposed that the missing markings are divided evenly between all categories. Therefore, it can be assumed that missing markings have no significance in the final results.

There have been a few insufficiently filled lines in the production error charts. In this case the classification has tried to be done during the analysis phase based on available information and other markings in the production error charts. The amount of unsolved markings is such small that it does not have any effect on the final results.

5. Discussion and conclusions

In the starting point it was unclear where and when the production errors occurred. This indicates that a systematic production performance measurement is needed when development activities are considered. The production error data collected can be used as a tool when the production flow performance and revenue are improved in each case factory. Without knowing the real problematic areas it is impossible to start any improvement activities.

In each case factory the most delicate work phases for the production errors were detected with the methods used in this paper. In each factory three work phases could clearly be found where most of the production errors were caused. These figures were 88.4% in factory A, 84.7% in factory B and 90.4% in factory C. In each case factory this observation can be used when development activities are planned. The development activities can be focused to the real problematic areas, where great improvement is within reach.

From the collected production error data it can be identified that the majority of production errors are caused in manually operated work phases and in mass production work phases. However, no common theme can be found in the production error data collected in production error distribution of the production flow of sheet metal part based constructions in different case factories because the production errors are divided into different work phases in each factory.

The selected functional approach is useful when production errors are studied from a quantitative point of view or when the distribution of production errors is examined. However, this approach does not give information about the effects of the production errors on total costs of the products. Any production error causes extra costs and disturbance into a production system and it can be said that by reducing production errors the whole production flow can be made more effective and therefore, this chosen approach gives proper tools for improvement activities.

If a company really wants to improve the production performance, the measurement of the performance is necessary to be done to understand the prevailing situation. A systematic information collection is therefore needed. It can be used to collect production error information in the shop floor level of a factory. This information can then be used to determine sensitive phases in the production flow and to eliminate production errors in these sensitive phases.

References

1. **Varis, J.** Flexible Automation in Sheet Metal Industry (Joustavan konepaja-automaation mahdollisuudet levytuotetuotannossa in Finnish).-Lappeenranta University of Technology, 1988.
2. **Ollikainen, M.** Advanced Manufacturing Tecnologies in Sheet Metal Technology (Levytuotetuotannon automaatioasteen nostaminen uusilla levytyökoneilla, oheislaitteilla ja laitejärjestelmillä in Finnish). -Lappeenranta University of Technology, 1990.
3. **Ollikainen, M., Varis, J.** The Utilization of Workforce Potential in the Finnish Sheet Metal Industry. Research Report 31.-Lappeenranta University of Technology, 2001.
4. **Ollikainen, M.** Origins of production errors and significance of employee empowerment in reducing production error amount in sheet metal fabricating industry. Acta Universitatis lappeenrantaensis 147. -Lappeenranta University of Technology, 2003.
5. **Ollikainen, M., Varis, J. and Kälviäinen, H.** Quality Control in Sheet Metal Industry (Levytuotetuotannon laadunvalvonta – LELA in Finnish). Research Report EN 38.-Lappeenranta University of Technology, 2003.
6. **Bitzel, H., Borscherd, J., Muller, J., Neidhart, F., Parey, K., Rau, A., Riecke, S., Schmidt, A., Trentmann, G., Vorländer, G. and Zimmermann, K.** The fascinating world of sheet metal.-TRUMPF GmbH + Co, 1996.

7. **Berkhahn, G., Miyakawa, N.** Developing a unit-Based production system.-The Fabricator, 1993, v.23, No10, p.22-27.
8. **Kanamori, Y., Kojima, K., Okazaki, T. and Hashigushi, N.** A FMS to process elevator's sheet metals.-IEEE Symposium on Emerging Technologies & Factory Automation, v3, 1995, Proc. of the 1995 INRIA/IEEE Symposium on Emerging Technologies and Factory Automation. Part 3 (of 3), Oct 10-13 1995, Paris, France, p.375-380.
9. **Ollikainen, M.** Improvement of the operations is a customer-oriented sheet metal component production. -Lappeenranta University of Technology, 2000.

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GAMYBOS PAKLAIDŲ PASISKIRSTYMAS METALO LAKŠTŲ PRAMONĖJE

R e z i u m ė

Straipsnyje pateikti metalo lakštų gaminių bazinių detalių gamybos srautų kokybės tikrinimo rezultatai. Pagrindinis straipsnio tikslas – išanalizuoti gamybos srautų paklaidų pasiskirstymą metalo lakštų konstrukcijose. Straipsnio rezultatai grindžiami studija, atlikta trijuose Suomijos metalo lakštų gaminių elektronikos ir telekomunikacijų gamybos įmonėse. Kiekvienoje įmonėje gamybos paklaidos buvo fiksuojamos atsakingiausiose operacijose, bet iš kokybės tikrinimo rezultatų nebuvo nustatytos bendros paklaidų atsiradimo priežastys. Tačiau surinkti duomenys rodo, kad daugiausia gamybos paklaidų atsiranda rankinio darbo operacijose bei masinės gamybos stadijose. Gauti rezultatai gali būti naudojami planuojant naują gamybą.

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PRODUCTION ERROR DISTRIBUTION IN SHEET METAL INDUSTRY

S u m m a r y

Production flow of the sheet metal part based constructions is inspected in this paper. The main objective of this paper is to analyze the production flow error distribution in the production flow of the sheet metal based constructions. This paper is based on a field study carried out in three Finnish case factories which produce sheet metal part based constructions, mainly for electronics and telecommunication-related industry. In each case factory the most delicate work phases for the production errors were detected but no common theme can be found from the collected production error data. From the collected data it can be however identified, that the majority of production errors are caused in manually operated and in mass production work phases. In each case factory this observation can be used when development activities are planned.

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РАСПРЕДЕЛЕНИЕ ПРОИЗВОДСТВЕННЫХ ОШИБОК В ПРОИЗВОДСТВЕ МЕТАЛЛИЧЕСКИХ ЛИСТОВ

Р е з ю м е

В статье представлены результаты проверки качества производства базовых деталей из металлического листа. Основная цель статьи – провести анализ распределения ошибок производства в конструкциях из металлического листа. Приведены результаты проверки качества на трех финских предприятиях по производству изделий электроники и телекоммуникации. В каждом предприятии производственные ошибки фиксировались в ответственных операциях, но не были определены общие причины возникновения ошибок по результатам проверки качества. Однако на основе полученных данных определено, что наибольше количество производственных ошибок возникает в операциях ручного производства, а также на стадии массового производства. Полученные результаты можно использовать, выполняя планирование нового производства.

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