PROCESS ANALYSIS OF AUTOMOTIVE PARTS USING GRAPHICAL MODELLING

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Abstract

Recently graphical modelling is being studied as a useful process analysis tool for exploratory causal analysis. Graphical modelling is a presentation method that uses graphs to describe statistical models of the structures of multivariate data.

This paper describes an application of this graphical modeling with two cases from the automotive parts industry.

One case is the unbalance problem of the pulley, an automotive generator part. There is multivariate data of the product from each of the processes which are connected in the series. By means of exploratory causal analysis between the variables using graphical modeling, the key processes which causes the variation of the final characteristics and their mechanism of the causal relationship have become clear.

Another case is, also, the unbalanced problem of automotive starter parts which consists of many parts and is manufactured by complex machinery and assembling process. By means of the similar technique, the key processes are obtained easily and the results are reasonable from technical knowledge.

1. Introduction

This paper describes an applied study of graphical modelling as causal analysis by two process analysis case studies.

·Graphical modelling is a form of multivariate analysis that uses graphs to represent models[1]. Graphs are widely used for cause and effect diagrams(one of QC seven tools), association charts(one of new seven tools for TQC), and path analysis in SQC because they are easy to understand as a visual aid. These methods by graph consist of characteristics and prior knowledge of variables and factors. On the other hand, graphical modelling presents the structure of data by using exploratory and conversational PC program from data information. By means of adding technical reviews to the result, we can appreciate deeply the structure of data and attain new knowledge, and contribute to process control and KAIZEN.

[1] Edwards,D., "Introduction to Graphical Modelling", Springer-Verlag, 1995

2. Case study 1 — Pulley's unbalance problem

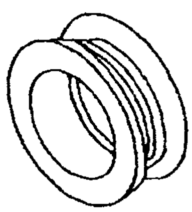
The pulley is an automotive part used for connecting the generator to the engine with a belt. A pulley production line is composed of some elementary processes which are connected in series. There are two purposes in case study 1.

(a) To obtain the key process with the factors of the variation of the unbalance.

(b) To create a hypothesis of unbalance causal mechanism by exploratory causal analysis.

2.1 Outline of process and data

The pulley's appearance and manufacturing process are shown in Figures 1.



→ Pre-forming → Forming→ Normalizing→ Flanging→ Cutting →
1 2 3 4 5

Fig. 1 Pulley manufacturing process

Numbers in Fig. 1 show stages to obtain data of each process. The data is the characteristics of the unfinished products of each process. The data, n=38, is resultant characteristics of each processes. Balance accuracy and balance direction are the final characteristics(objective variables) in this case study. Variables, A1 through Y2, are shown in Table 1 . The suffix letter A through Y , shows the priority in the processes which are connected in series. For example, depth A is measured in each process and suffix number shows process transition, A1 through A5 . This group of variables e.g. A1 through A5 is named characteristics series. B and D, C and E are one pair characteristics of balance accuracy and balance direction.

Table 1 21 Variables

Characteristics \ Process	Pre-forming	Forming	Normalizing	Flanging	Cutting
Bottom thickness	A1	A2	A3	A4	A5
Outer diameter deflection	B1	B2	B3	B4	
V-form deflection					C5
Direction of Outer diameter deflection		D2	D3	D4	
Direction of V-form·deflection					E5
Cup depth	F1	F2	F3		
Flange diameter				G4	
Weight	H1				

Final characteristic	Balance accuracy Y1	Balance direction Y2

2.2 Analysis using graphical modelling

It would not be wise to analyze all 21 variables shown in Table 1 at once. It is especially desirable to analyze as follows:

STEP 1 Grasp the relation of neighboring characteristics series.

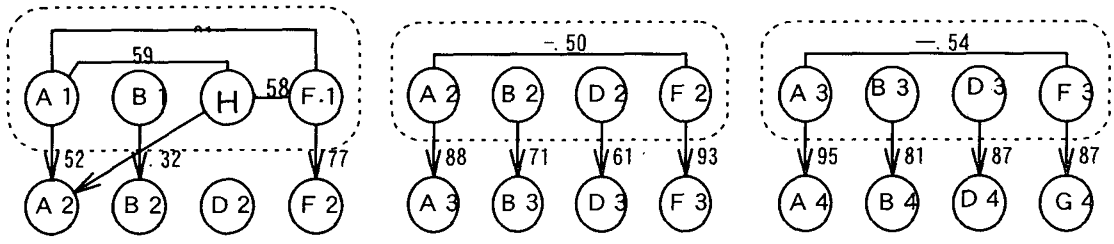
STEP 2 Find out characteristics series and variables which contribute to final characteristics, Y1 and Y2.

STEP 3 Obtain the key process where final characteristics result.

STEP 4 Create a hypothesis of the mechanism about final characteristics variance.

2.2.1 Step 1

To grasp the relation of neighboring characteristics series, first we considered prior process data to be explanatory variables, and the following process data to be objective variables and analyze them by using graphical modelling. An analysis of these data is shown in Fig. 2.



dev=15.538, df=21 p-value0.795 dev=20.682, df=18, p-value=0.601 dev=26.680, df=23, value=0.270

Fig. 2 Chain independence graph (STEP 1)

We observed that there are strong positive partial correlations between the same characteristics series and between F3 and G3. Also there is negative partial correlation between bottom thickness A series and cup depth F series. We observed the following from above:

(a) There was already a relation in the pre-forming process between bottom thickness A series and cup depth F series and the relation goes through the following processes.

(b) If we combine A series and F series into one group series, these A series and F series, outer diameter deflection B series and direction of outer diameter deflection D series are independent of each other.

(c) The F series includes flange diameter G4, and F series are F1, F2, F3 and G4 in Step 2.

We can easily explain the above with technical knowledge.

2.2.2 Step 2

To find out the characteristics series and variables which contribute to the final characteristics, balance accuracy Y1 and balance direction Y2 from the result of Step 1, we observed Y1 and Y2 to be objective variables and the final characteristics of each series A5, B4, D4, G4, C5 and H1 to be explanatory variables. We analyzed them by using graphical modelling and illustrate the result in Fig. 3.

We have some observations from Fig. 3.

(a) The main variables which influence the variance of Y1 are C5 and B series, especially C5 is large.
(b) The main variables which influence the variance of Y2 are E5, D series, F series and G4, especially E5 and D4.
(c) There are no variables which influence both Y1 and Y2. Therefore we analyzed these data Y1 and Y2 separately.

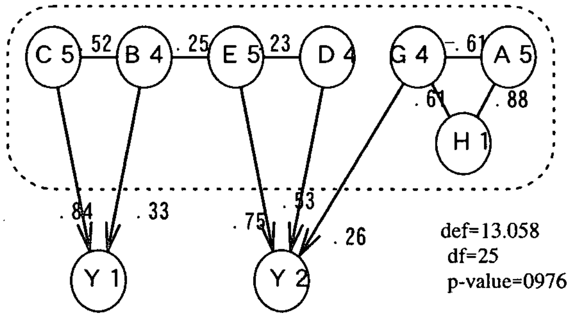


Fig. 3 Chain independence graph (STEP 2)

We conclude the following from the above observations.

(d) According to the partial correlation coefficient between Y2 and G4(one of F series) −0.26, we do not consider the F series as factors of Y2.
(e) We considered the selection of outer diameter deflection B series, B1, B2, B3, B4 and V-form deflection C5 as balance accuracy Y1's factors, and direction of outer diameter deflection D series, D2, D3, D4, E5 as balance direction factors of Y2.

2.2.3 Step 3

From some selected characteristics series and variables in the results of Step 1 and Step 2, we explored the mechanism about variance of balance accuracy Y1 and balance direction Y2 which are synthetic characteristics. A chain independence graph about balance accuracy and direction by using graphical modelling one by one are shown in Fig. 4a and 4b.

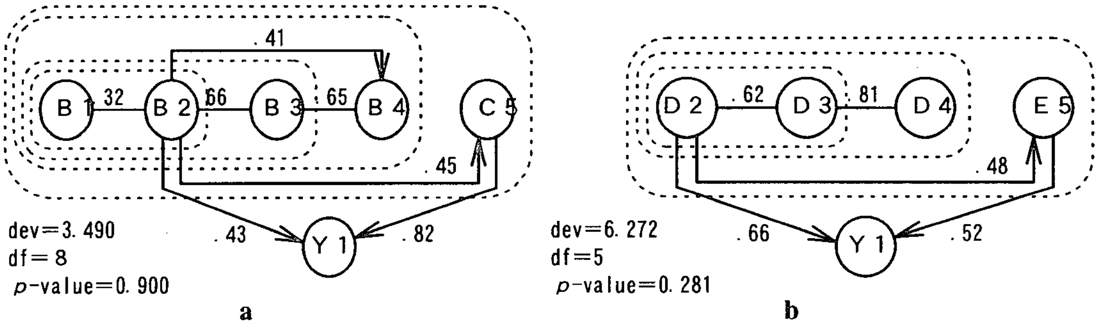


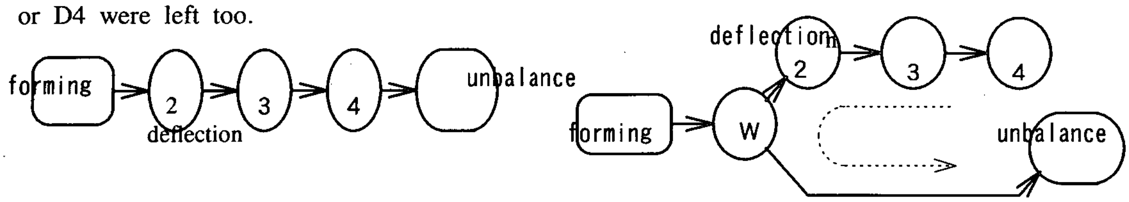
Fig. 4 Chain independence graph (STEP 3)

We have some observations from Fig. 4.

(a) There is no edge from B1 to Y1, and the partial correlation is not so strong between B1 and B2.
(b) There are edges from B2 to Y1 in the deflection amount characteristics series, and from D2 to Y2 in the deflection direction characteristics series.
(c) There are no edges from B4 to Y1 and from D4 to Y2.
(d) There are edges from C5 to Y1 and from E5 to Y2.
(e) There are edges from B2 to V-form deflection C5, and from D2 to direction of V-form deflection E5.
(f) There are no edges from B4 to C5 and from D4 to E5

At first, these observations led to Hypothesis 1 that the cause of outer diameter deflection depends on the forming process and outer diameter deflection causes unbalance. See Fig. 5a

But if Hypothesis 1 were concluded perfectly, edges from B4 to Y1 in Fig. 4 a and from D4 to Y2 in Fig. 4b should be drawn. Because Fig. 4a means that there is some relation from B1 to Y1 even if B3 or B4 were left. Fig. 4b means that there is some relation from D2 to Y2 even if D3 or D4 were left too.



a Hypothesis 1 **b** Hypothesis 2

Fig. 5 Hypothesis

Here another Hypothesis 2 is proposed that the forming process makes characteristics W concerning both outer diameter deflection and unbalance. In other words, there is no relation between outer diameter deflection and unbalance under Hypothesis 2. See Fig. 5b

Now Hypothesis 2 is also explained from correlation coefficient matrices. We observed Hypothesis 2 from the viewpoint of balance accuracy matrix R1 and balance direction matrix R2.

R1=

B1	B2	B3	B4	C5	Y1
1.000	0.324	0.237	0.334	0.294	0.287
	1.000	0.683	0.737	0.606	0.732
		1.000	0.824	0.427	0.517
			1.000	0.541	0.615
				1.000	0.891
					1.000

R2=

D2	D3	D4	E5	Y2
1.000	0.619	0.600	0.571	0.843
	1.000	0.868	0.357	0.611
		1.000	0.243	0.532
			1.000	0.748
				1.000

From R1 and R2, each correlation coefficient between balance accuracy Y1, balance direction Y2 and deflection variables is as follows:

$r(B2,Y1) > r(B4,Y1) > r(B3,Y1)$, $r(D2,Y2) > r(D3,Y2) > r(D4,Y2)$

But if Hypothesis 2 were concluded perfectly, that is to say, then each correlation coefficient could be written as follows:

$r(B4,Y1) > r(B3,Y1) > r(B2,Y1)$, $r(D4,Y2) > r(D3,Y2) > r(D2,Y2)$

R1 does not show and explain Hypothesis 2 clearly, but we can deny it from the viewpoint of R1 and R2 together. Further we tried to make another model by adding V-form deflection and its direction.

From observation (d), we can understand the V-form process or end & inner diameter cutting process is another key process and V-form deflection leads to unbalance. That is to say, we concluded that V-form deflection is one reason of unbalance besides the characteristics W. And from the observation of (e) and (f), we can observe the causal and effect between the forming process, outer diameter deflection and V-form deflection. One direct reason of the V-form deflection is not outer diameter deflection but the characteristics W. And from R1 and R2, we can understand the above, too. We also include the characteristics W as a common cause of unbalance and V-form deflection from these results. Then we added V-form deflection which is the key as well as the characteristics W to Hypothesis 2 . Consequently Hypothesis 3 is proposed.

c Hypothesis 3

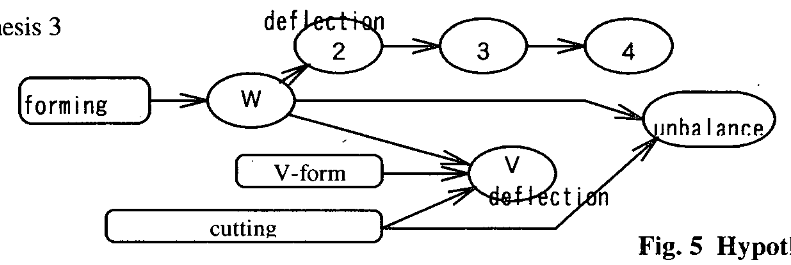


Fig. 5 Hypothesis

2.2.4 Step 4 – Verify the hypothesis by technical knowledge

In this step, hypothesis 3 is verified as the mechanism of unbalance as supported by technical knowledge. We reached the final conclusion of this case study. What is the characteristics W ?

It is considered as uneven wall thickness. The forming die in the forming process (see Fig. 1) can generate uneven wall thickness, and causes deflection B2. The uneven wall thickness can slip upward or downward by the normalizing process. From the above, deflection B3 and B4 are not the cause of unbalance directly. And the slipped uneven of wall thickness can be leveled in height, then the deflection B3 and B4 are not the cause of V-form deflection directly. Besides there may be a little slip at fastening or locking the pulley.

The final conclusion under Hypothesis 3 is as follows:

(a) The key process of unbalance is forming and end & inner diameter cutting.

(b) The unknown characteristics W is interpreted as uneven wall thickness which results in new technical knowledge.

3. Case study 2 — Armature's unbalance problem

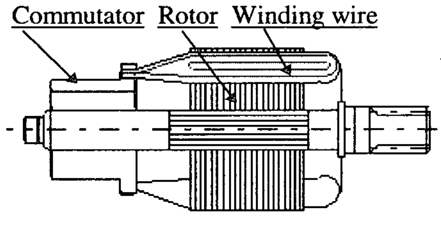
The armature is a rotary device of automotive starting motor. Its unbalance problem is significant for rapid rotation. The armature consists of many parts and its production line is composed of twenty automatic machinery and assembly processes which are connected in series.

The unbalance in each process is accumulated as a final unbalance. All armature need to correct the balance amount in order to satisfy the standards.

The final aim in case study 2 is the disuse of correction process. First we need to find clearly the key process for that aim.

3.1 Outline of process and data

A cross section of the armature and five main manufacturing process are shown in Fig. 6.



A: Rotor →B: Wire winding →C: Assembling commutator

↑ a ↑ b

→D: Powder coating →E: Finishing(Initial unbalance)

↑ c ↑ d

Fig. 6 Armature manufacturing process

The unbalance of finishing process is called the initial unbalance. The unbalance is a vector of amount and angle. See Fig. 7. It is measured up as the dynamic unbalance in the left plane and the right plane. It is widely known as follows:

dynamic unbalance in the left plane(U_L) + ***dynamic unbalance in the right plane***(U_R) = ***quasi- static unbalance***(U_S) + ***associated couple unbalance***(U_C)

It is also widely known that the quasi-static unbalance is the parallel eccentricity component and the associated couple unbalance is the cross eccentricity component. And the added unbalance is calculated as follows:

added unbalance =
unbalance after processing(resultant characteristics) - ***unbalance before processing***

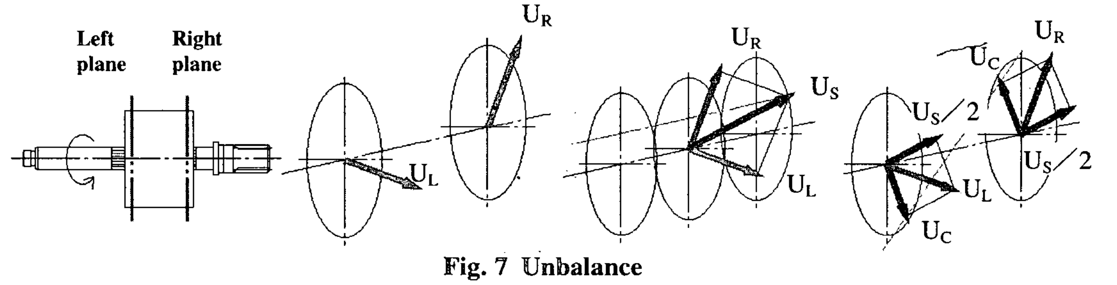


Fig. 7 Unbalance

From the above, the data, n=30, is the resultant unbalance of each process, A through E, and the added unbalance, a through d. See Table 2.

Table 2 Variables and Processes

Variables \ Processes	A	a	B	b	C	c	D	d	E
Dynamic unbalance in the left plane									
Dynamic unbalance in the right plane									
Quasi- static unbalance									
Associated couple unbalance									

3.2 Analysis using graphical modelling

The acquired data was homogeneous and series connection characteristics and it had a multicollinearity. Consequently we analyzed it by graphical modelling instead of multiple regression analysis. Hereafter we illustrate the results of the quasi-static unbalance and the associated couple unbalance as a part of this analysis.

First, the chain independence graph with all of nine processes is shown in Fig. 8.

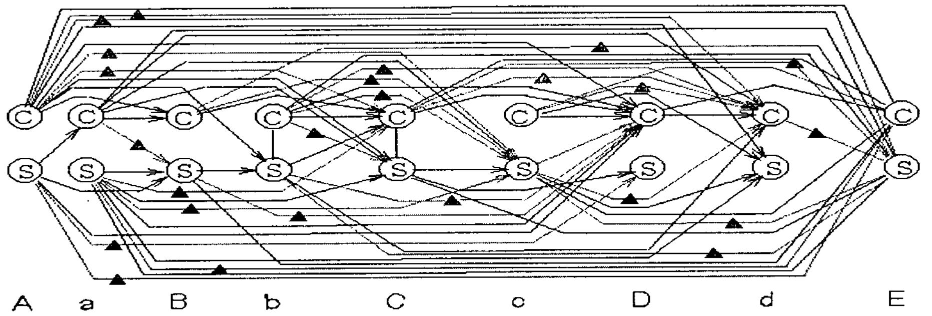
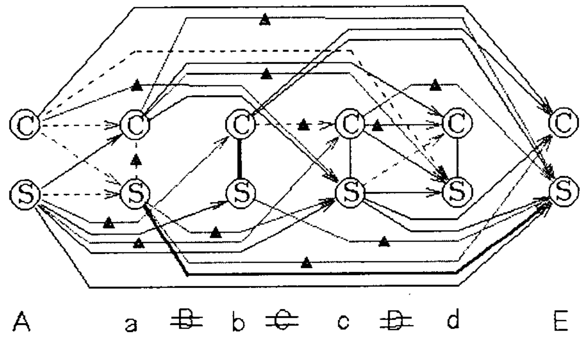


Fig. 8 Chain independence graph

The graph was so complicated that we could hardly understand. Naturally the results by multiple regression analysis was also complicated.

Next we analyzed the resultant data, A through E, and the added unbalance, a through d, separately. See Fig. 9. (▲ mark shows partial correlation coefficient is minus)



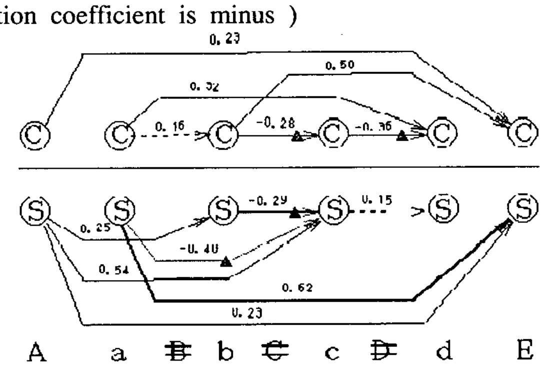


Fig. 9 Chain independence graph **Fig. 10 Chain independence graph**

The plus and minus sighs of partial correlation coefficient were contradictory to the technical knowledge as the relation of cause and effect.

Further we reached the reasonable results by analyzing each component, the quasi- static unbalance and the associated couple unbalance. See Fig. 10. From Fig . 10 we concluded that the rotor assembling and the winding wire processes cause the quasi- static unbalance and the rotor assembling and the commutator assembling cause the associated couple unbalance. The dynamic unbalance is also caused to the same results. We could verify that results above were confirmed by the technical knowledge from the eccentricity and uneven wall thickness.

4.Conclusions

We here analyzed the unbalance problems of the pulley and the armature by using graphical modelling. The pulley problem is a simple case study and we can understand the key process and the interpretation which result in new technical knowledge. The other, armature problem is a complex but the chain independence graphs indicate the lucid relation of cause and effect.

These case studies show that using graphical modelling is especially useful in exploratory causal analysis for the process data in series. It also reveals new technical knowledge.

Reference

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2.Kuzuya et al., "Process Bottleneck analysis of Transfer Line by graphical modeling Technique", JSQC 57 Symposium,1997