10TH INTERNATIONAL DESIGN STRUCTURE MATRIX CONFERENCE, DSM'08
11 – 12 NOVEMBER 2008, STOCKHOLM, SWEDEN

ASSESSING DESIGN STRATEGIES FROM A CHANGE PROPAGATION PERSPECTIVE

Edwin C Y Koh, Rene Keller, Claudia M Eckert and P John Clarkson
Engineering Design Centre, University of Cambridge

Keywords: Design Strategies, Change Propagation

1 INTRODUCTION

The use of design strategies in product development has received huge attention from academia and industry [1]. Some of the strategies include embedding flexibility in product platforms [2] and making components more modular to allow component re-use [3]. While there are numerous guidelines on how to implement design strategies (for example [4]), one of the main challenges is to decide on the appropriate strategies for different components. For example, there is a need to distinguish which components should be standardised for high volume production and which components should be made flexible to absorb and implement future changes. This paper describes how we can provide recommendations and identify misalignments in design strategies by classifying components according to their change propagation characteristics. Earlier work on component classification for design strategies has been described by Koh et al. [5]. The focus of this paper is to describe the data collection process and the interpretation of the results generated.

2 A DIESEL ENGINE CASE STUDY

A case study, involving 7 interviews and a two day model building workshop, was carried out in a Swedish automotive company to assess if their existing design strategies are suitable from a change perspective. The analysis uses the Change Prediction Method (CPM) as described by Clarkson et al. [6] to analyse product components according to their change propagation likelihood, impact, and risk. These change propagation values are elicited from experts and computed based on components connectivity captured in Dependency Structure Matrix (DSM) (see [7] on DSM). The following sections describe the data collection process and discuss the results generated from the initial work.

2.1 Data collection

The data collection process can be described by the following steps – (1) Decide on the product to be analysed. (2) Decide on the appropriate level of component breakdown. (3) Identify linkages between components. (4) Assess the likelihood and impact of change propagation for each linkage. (5) Elicit relevant component information (e.g. lead-time).

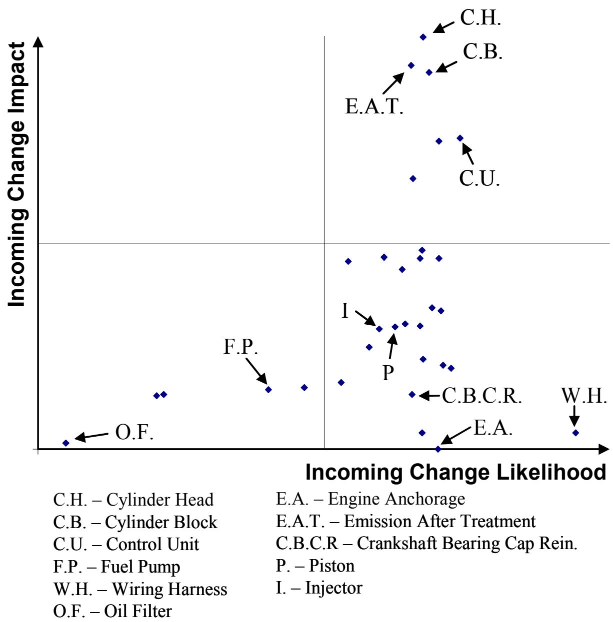
Based on several discussions between two senior staffs (managers) from the company and the first two authors, a heavy duty diesel engine was selected with 32 components identified to represent the entire diesel engine. The 32 components were chosen based on two criteria – having a manageable amount of components and keeping the right level of details to facilitate meaningful analysis. This was followed by the identification of linkages between components and the assessment of their change propagation likelihood and impact. A 3-dimensional Computer Aided Design (CAD) model of the engine was available to assist the staffs in recalling the linkages. By analysing the components in a DSM, 179 direct linkages between the 32 components were identified. These linkages were further classified into Mechanical and Proximity, Thermal, Liquid-flow, Electrical, and Control linkage types. A direct linkage between two components can be made up of more than one linkage type. In total, 132 Mechanical and Proximity linkages, 22 Thermal linkages, 44 Liquid-flow linkages, 6 Electrical linkages, and 7 Control linkages were identified. Subsequently, the two senior engineers provided an indication of the propagation change likelihood and impact as they analyse each linkages. The scale used was 'Low', 'Medium', and 'High'. Information such as redesign cost and lead time were also elicited using the scale of 0 (Low) to 5 (High). In addition, components were classified into 'in-house' and 'supplier' parts. It should be noted that since the company is part of a multi-company organisation, a 'supplier' part can come from within the organisation. The components were also further classified into ‘platform’ and ‘non-platform’ parts. Platform parts can be seen as components that are identified for standardisation. The entire data collection process took less than one day.

2.2 Method of analysis

The data collected was subsequently analysed by the Change Prediction Method (CPM) tool developed in the Cambridge Engineering Design Centre. The CPM tool analyses direct and indirect change propagation between components and is capable to classify components according to their change characteristics. To proceed with the analysis, the ‘Low’, ‘Medium’, and ‘High’ scale used for propagation change likelihood and impact were converted to numerical values. In order to verify that the results are insensitive to numerical conversion, four sets of input scales were used to analyse the results. The scales are {0.1; 0.5; 0.9}, {0.1; 0.5; 0.7}, {0.3; 0.5; 0.7}, and {0.3; 0.5; 0.9} to represent {Low; Medium; High}. The results generated by the four sets of input scales were subsequently analysed by the Kendall Tau rank correlation method [8] and were found to be insensitive to the choice of input scale. By classifying the components according to their change propagation characteristics, different rankings and plots can be generated for analysis.

2.3 Results and Discussions

Figure 1a shows a Product Variant Portfolio (PVP) plot of the components with respect to their incoming change likelihood and impact [5]. The incoming change likelihood indicates the aggregated probability that a component can be affected due to changes in other components while the incoming change impact indicates the aggregated effort required to change the component if a change is required. In this analysis, the incoming change impact considers the average proportion of redesign work required, the average redesign cost, and the component lead-time.



(a)

Impact Rank	Part name	Source	Platform Parts	
			Current	Recomm-endation
1	C.H.	in-house	Yes	Yes
2	E.A.T.	supplier	No	No
3	C.B.	in-house	Yes	Yes
4	C.U.	supplier	Yes	No
⋮	⋮	⋮	⋮	⋮
17	P.	supplier	Yes	No
18	I.	supplier	Yes	No
⋮	⋮	⋮	⋮	⋮
25	F.P.	supplier	No	Optional
26	C.B.C.R.	supplier	Yes	No
⋮	⋮	⋮	⋮	⋮
30	W.H.	supplier	No	No
31	O.F.	supplier	No	Optional
32	E.A.	supplier	No	No

(b)

Figure 1. (a) Product Variant Portfolio (b) Component data listed according to change impact

As described in Koh et al. [5], components that fall within the top-left region of the PVP have low likelihood of change propagation but will incur high amount of redesign effort if a change is required. Therefore, components that fall within this region should be standardised. If a change is required, the connectivity between these components and the rest of the product should be reduced to further decrease the likelihood of changes propagation. Components that fall within the bottom-right region of the PVP have high likelihood of change propagation but require low amount of effort if a change is required. Therefore, if a change is required, these components can be redesigned as flexible components. This is to reduce the impact of future changes as these components are very likely to be changed. Components that fall within the bottom-left region have low likelihood and impact of change propagation. These are the least critical components and platform strategies are optional. On the other hand, components which fall within the top-right region are likely to be changed and would require high redesign effort. In an ideal case, no component should fall within this region. Recommendations on the appropriate design strategies can be made for these components by extending the analysis to take into account their outgoing change risk. Detailed explanation can be found in Koh et al. [5].

Figure 1b shows an excerpt of the classification result with components listed according to their incoming change impact. It can be seen from the result that the component with the highest incoming change impact is the cylinder head. In addition, the 'in-house' components are ranked 1st, 3rd, 6th, and 12th on the list. Although it is unclear at this point whether the placement of 'in-house' components at the top half of the list is a cause or an effect, three possible scenarios can be suggested. Firstly, there might be a conscious effort to keep components with high change impact in-house so that the company has more control over its operation. Alternatively, the outsourcing of components to suppliers can reduce the impact of change as part of the changes is carried out by the suppliers. Lastly, the change impact values for 'supplier' components might be systematically underestimated as the staff in charge of the external supply chain did not take part in the change impact analysis. If the result is proven to be systematically underestimated, it provides an indication that more needs to be done to let the engineering staffs understand the full impact of their engineering changes.

It can also be seen from Figure 1b that components such as pistons are platform parts. This means that the rest of the engine will be designed around these standardised parts. However, it can be seen from Figure 1a that the piston falls within the bottom-right region of the PVP, suggesting that it has a high likelihood of change propagation and should be made flexible. Such misalignments in design strategies sparked discussions among several senior management staffs to reevaluate their platform strategies.

3 CONCLUSION

This paper describes how component classification in terms of change propagation characteristics can be used to provide recommendations and identify misalignments in design strategies. A diesel engine case study was described in this paper to illustrate the data collection process, and the generation and interpretation of the results. Initial findings suggest that the effective use of component classification can help companies identify misalignments in design strategies. More research is required to take supply chain and manufacturing switch cost into account.

REFERENCES

[1] Simpson, T. W., Marion, T., de Weck, O., Holtta-Otto, K., Kokkolaras, M. and Shooter, S. B. Platform-based design and development: Current trends and needs in industry. In *ASME IDETC/CIE'06*, Philadelphia, Pennsylvania, 2006.

[2] de Weck, O. and Suh, E. S. Flexible product platforms: framework and case study. In *ASME IDETC/CIE'06*, Philadelphia, Pennsylvania, 2006.

[3] Smith, J. and Duffy, A. Modularity in support of design for re-use. In *ICED'01*, Glasgow, 2001.

[4] Martin, M. V. and Ishii, K. Design for variety: developing standardized and modularized product platform architectures. *Research in Engineering Design*, 2002, 13(4), 213-235.

[5] Koh, E.C.Y., Keller, R., Eckert, C.M. and Clarkson, P.J. Component classification: a change perspective. In *9th International Design Structure Matrix Conference, DSM'07*, Munich, 2007.

[6] Clarkson P.J., Simons C. and Eckert C.M. Predicting change propagation in complex design. *ASME Journal of Mechanical Design*, 2004, 126(5), 765-797.

[7] Browning, T. R. Applying the Design Structure Matrix to system decomposition and integration problems: A review and new directions. *IEEE Transactions on Engineering Management*, 2001, 48(3), 292-306.

[8] Kendall, M. G. *Rank correlation methods*. 1962 (Charles Griffin & Company Limited).

Contact: Edwin C.Y. Koh
Engineering Design Centre, Cambridge University
Trumpington Street
CB2 1PZ, Cambridge, United Kingdom
Phone: +44 1223 766955
Fax: +44 1223 332662
e-mail: cyek2@cam.ac.uk

10TH INTERNATIONAL DSM CONFERENCE

Assessing Design Strategies from a Change Propagation Perspective

Edwin C Y Koh, René Keller, Claudia M Eckert,
P John Clarkson

Engineering Design Centre
University of Cambridge
United Kingdom

Technische Universität München

MANAGE COMPLEX SYSTEMS
FOLLOW THE FLOW OF INFORMATION!

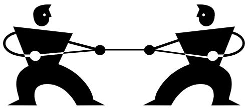
Index

- Introduction
  - Design Strategies
  - Engineering Change Propagation
  - Modelling of Change Propagation
- Diesel Engine Case Study
  - Data Collection
  - Change Propagation Analysis
  - Evaluation
- Summary

Technische Universität München

Design Strategies

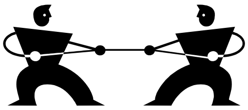
Economic of scale (Standardised)



Easy to change (Flexible)

Which component?

In-house



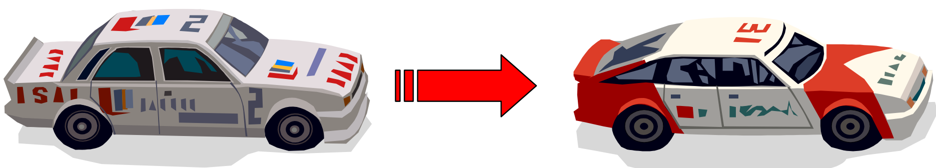
Out-source

Which component?

- *Business*
- *Legislation*
- *Engineering*

How does engineering change propagation affect these decisions?

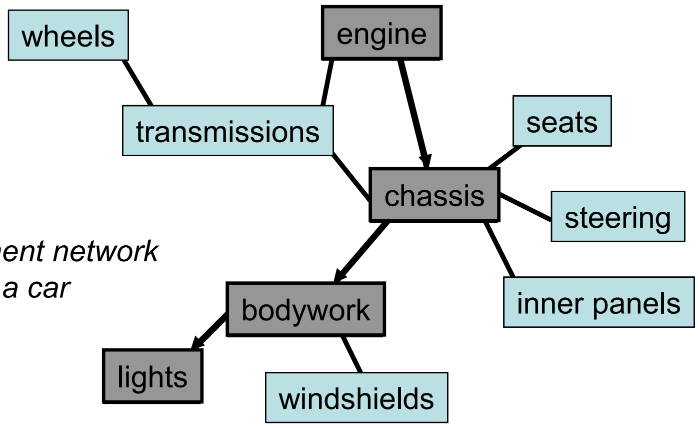
Engineering Change Propagation



- Products redesigned from previous ones
- Change or add features
- Beneficial to keep other parts unchanged

Design with constraints

Engineering Change Propagation



Component network of a car

- Some parts are more likely to be affected
- Some parts have higher change impact

Modelling of Change Propagation

Initiating (columns) / Affected (rows)

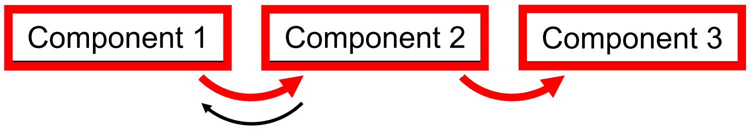
DSM	Comp 1	Comp 2	Comp 3
Comp 1		0.9	
Comp 2	0.5		
Comp 3		0.3	

Modelling of Change Propagation

Initiating

CPM (Affected \ Initiating)	Comp 1	Comp 2	Comp 3
Comp 1		0.9	
Comp 2	0.5		
Comp 3	**0.15**	0.3	

Affected



Direct & Indirect Change Propagation

FOLLOW THE FLOW OF INFORMATION!
MANAGE COMPLEX SYSTEMS

Modelling of Change Propagation

Initiating

CPM (Affected \ Initiating)	Comp 1	Comp 2	Comp 3
Comp 1		0.9	
Comp 2	0.5		
Comp 3	**0.15**	0.3	

Affected

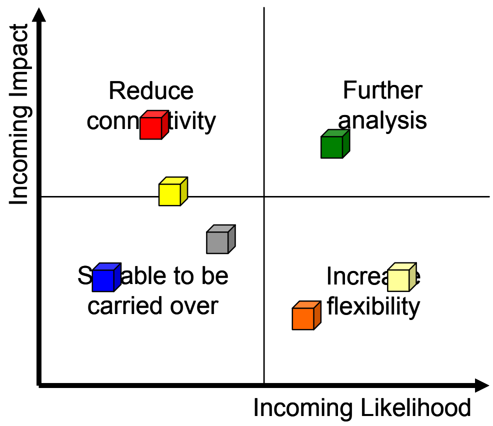
Incoming Change

(Affected by others)

Outgoing Change

(Affect others)

Modelling of Change Propagation



- Classifies components wrt to incoming likelihood & impact
- Recommendations according to quadrants
- Correlate with design strategies

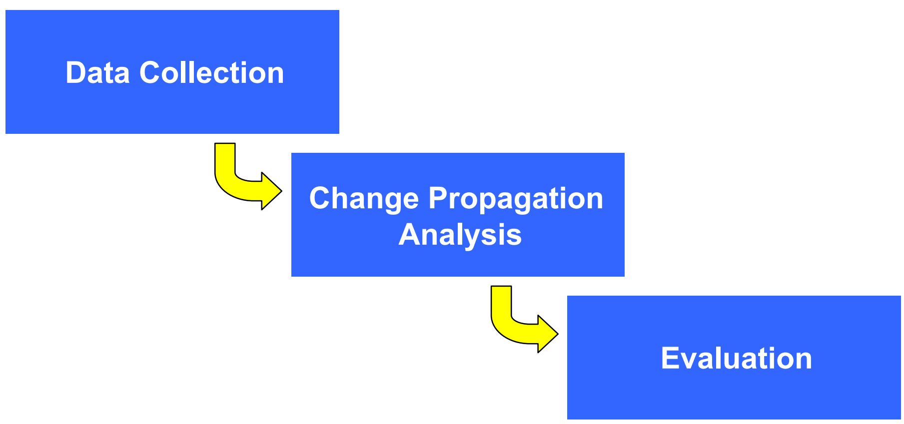
Impact ~ Effort to change

Likelihood ~ Probability of change

~ Component

Diesel Engine Case Study

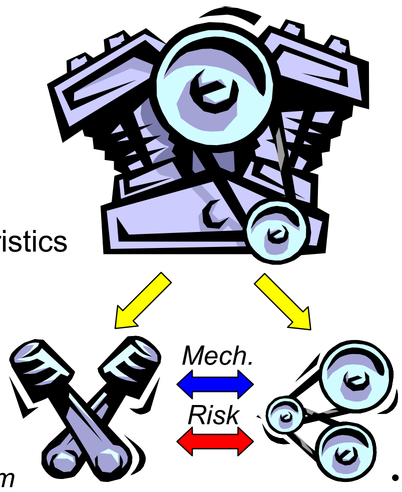
Objective:
Assess current design strategies with a change propagation perspective



Data Collection

Two-day model building workshop:

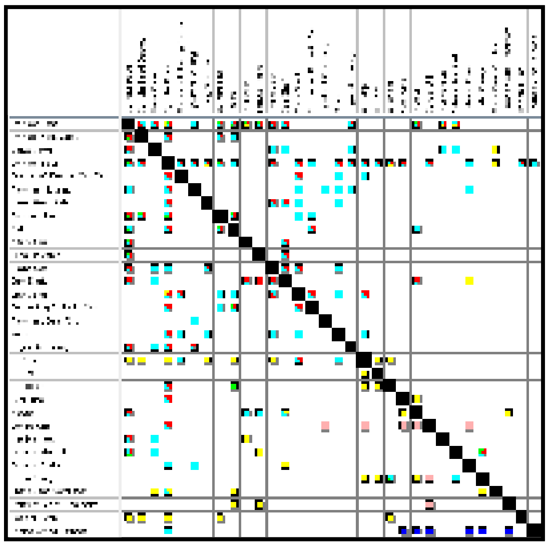
- Decide on the product
- Component breakdown
- Linkages between component
- Change propagation characteristics
- Component information



Data Collection

Data Summary:

- Heavy Duty Diesel Engine
- 32 Components
- Mech., Elec., Thermal, Liquid, Control
- Likelihood and Impact {L;M;H}
- Lead-time, Redesign cost, etc…

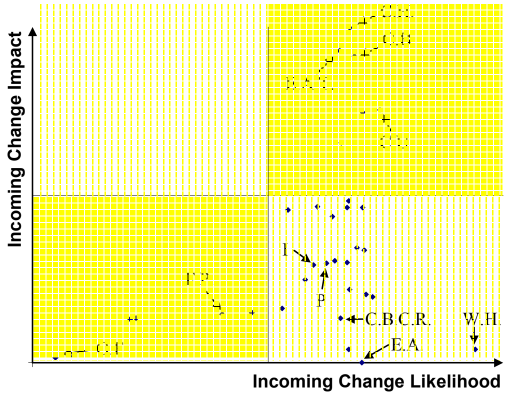


DSM of a Diesel Engine

MANAGE COMPLEX SYSTEMS

FOLLOW THE FLOW OF INFORMATION!

Change Propagation Analysis



C.H. – Cylinder Head
C.B. – Cylinder Block
C.U. – Control Unit
F.P. – Fuel Pump
W.H. – Wiring Harness
O.F. – Oil Filter

E.A. – Engine Anchorage
E.A.T. – Emission After Treatment
C.B.C.R – Crankshaft Bearing Cap Rein.
P. – Piston
I. – Injector

Incoming Change Risk – how components are affected

Outgoing Change Risk – how components affect others

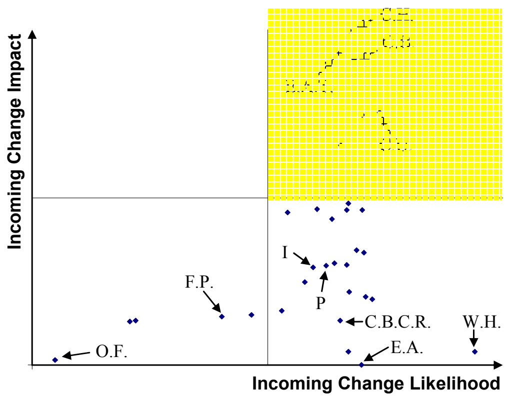
Risk = Likelihood x Impact

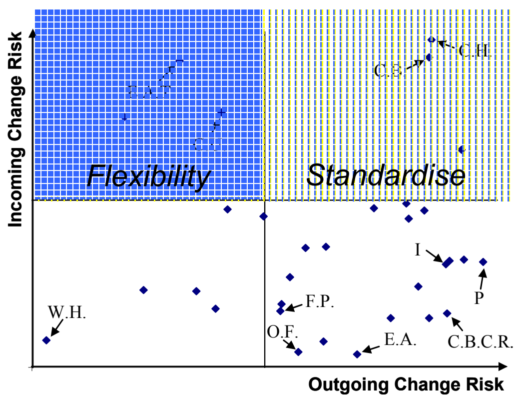
Technische Universität München

MANAGE COMPLEX SYSTEMS

FOLLOW THE FLOW OF INFORMATION!

Change Propagation Analysis





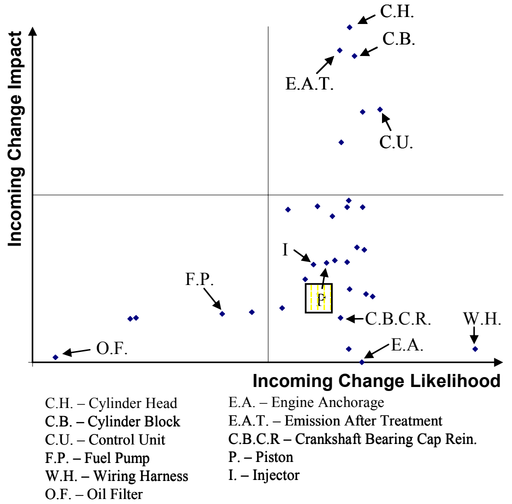
C.H. – Cylinder Head
C.B. – Cylinder Block
C.U. – Control Unit
F.P. – Fuel Pump
W.H. – Wiring Harness
O.F. – Oil Filter

E.A. – Engine Anchorage
E.A.T. – Emission After Treatment
C.B.C.R – Crankshaft Bearing Cap Rein.
P. – Piston
I. – Injector

Risk = Likelihood x Impact

Technische Universität München

Evaluation



Impact Rank	Part name	Platform Parts	
		Current	Recomm-endation
1	C.H.	Yes	Yes
2	E.A.T.	No	No
3	C.B.	Yes	Yes
4	C.U.	Yes	No
⋮	⋮	⋮	⋮
17	P.	Yes	No
18	I.	Yes	No
⋮	⋮	⋮	⋮
25	F.P.	No	Optional
26	C.B.C.R.	Yes	No
⋮	⋮	⋮	⋮
30	W.H.	No	No
31	O.F.	No	Optional
32	E.A.	No	No

Evaluation

Source:

- Multi-company organisation
- In-house: 1st, 3rd, 6th, & 12th

In-house ⟺ *High Change Impact*

Causality

- Outsourcing reduce change impact?
- In-house to maintain control?
- Systematically underestimated?
- Mixture of the above?

Impact Rank	Part name	Platform Parts		Source
		Current	Recomm-endation	
1	C.H.	Yes	Yes	in-house
2	E.A.T.	No	No	supplier
3	C.B.	Yes	Yes	in-house
4	C.U.	Yes	No	supplier
⋮	⋮	⋮	⋮	⋮
17	P.	Yes	No	supplier
18	I.	Yes	No	supplier
⋮	⋮	⋮	⋮	⋮
25	F.P.	No	Optional	supplier
26	C.B.C.R.	Yes	No	supplier
⋮	⋮	⋮	⋮	⋮
30	W.H.	No	No	supplier
31	O.F.	No	Optional	supplier
32	E.A.	No	No	supplier

Summary

- Change propagation analysis based on DSM
- Supporting the assessment of design strategies
- Feasible for industrial application
- Future work – supply chain and manufacturing cost