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# PRIORITISING ENGINEERING CHANGE PROPAGATION RISK ESTIMATES

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## ABSTRACT

It is essential to assess the effects of change rigorously before a change is implemented, yet design engineers are faced with the problem that an exhaustive analysis of all product parameters affected by change proposals is simply impractical. In this paper, we describe a criticality-based approach to ordering predicted risks. This enables design engineers to concentrate their efforts on the components which are critically disposed to the effects of proposed changes. Using a diesel engine as an example, we show that components which have the most noteworthy risk of causing significant redesign if affected by a change are not always of the highest priority when evaluating effects of change.

*Keywords: Change propagation, Risk management, Risk chart, Risk Prioritisation Number*

## 1 INTRODUCTION

Change is core to the development of complex products; successful implementation of change requests depends partly on the understanding of the design issues that are associated with a proposed change. Risk assessment is widely considered to be an integral part of good management practice [1] and it can also be used when assessing the consequences of design change [2]. However, unless these risk evaluation techniques are carefully deployed, they can lead to a false sense of security.

Design engineers are faced with the problem that in order to carry out change processes effectively, they need to thoroughly analyse the possible effects of change. Depending on the approach taken for such assessments, a thorough evaluation process can be very time consuming. One possible reason is that each component interacts, sometimes in an unintended manner, with many other components within the product. The components which are affected by the initial change also have a tendency to further propagate the effects of change to other components extending the amount of assessment necessary for a single change. As such, methods which draw attention to the main components that are disposed to the effects of change are useful to designers. The idea of analysing the consequences of change proposals exhaustively is inefficient as well as impracticable. To this end, there is the need for prioritisation techniques for supporting design managers in identifying risk cases of utmost concern.

In previous studies on change assessment, it has been shown that there are benefits to assessing the design effort associated with making a change [2]. Such assessment of design effort when used as criteria for ordering risk estimates enable designers select solution proposals which requires lesser effort to implement. However, there have been reported cases of change to components which have lead to high implementation cost even though such components do not require significant redesign effort. For example, an unexpected change to an oil filter may be expensive in terms of its effects of existing stock. As a result, in addition to assessing the design effort involved with changes propagating between components, it is also important to identify components which are critically disposed to the effects of change even when the estimated design effort is within acceptable limits.

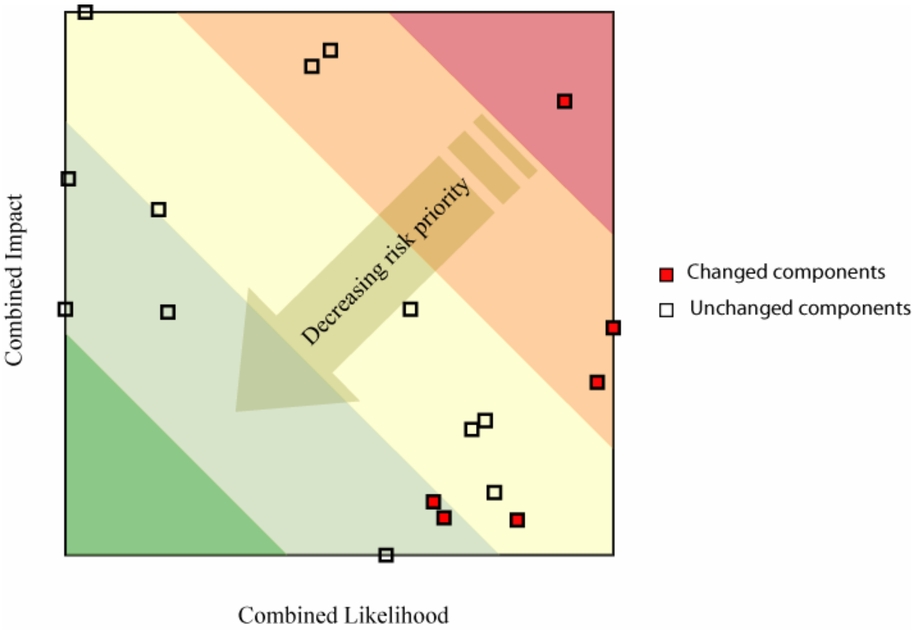

*Figure 1: Using the Risk Matrix to rank effects of change in a helicopter [2]*

The Risk Matrix plot is an established method for prioritising risk estimates [3]. It has been successfully used on a number of occasions when assessing the design efforts associated with making a change [4]. However, in a situation where criticality is a crucial factor, it may not be a sufficient way to order risk estimates. To explain further, consider an example of a case where changes were made to the *Weapons and defensive system* of a helicopter described in an earlier paper [2]. In the example, the entire helicopter was represented as a collection of 19 aggregate systems and assemblies including the *Weapons and defensive system*. Estimates of design effort that may result from changes to the weapons and defensive system affecting any of the other 18 systems were prioritised using a Risk Matrix as shown in Figure 1. Within such a Risk Matrix model, analysis of components affected by a design change are usually read from the top right hand corner of the plot [5]. The adoption of such convention is important to ensure that the effects of change requiring the most significant design effort are considered during change impact assessments. Since the effects of component change on other helicopter parts cannot be analysed exhaustively, it is important to have a cut-off point when assessing probable propagation risk.  The top three risk categories in Figure 1 contain 12 of the 18 aggregate systems in the helicopter model. This translates to almost 70% of tens of thousands of physical components and systems within a helicopter. Assuming, an assessment on such a large percentage of the helicopter were considered reasonably sufficient in alerting designers to the most significant risks, then components within the second lowest risk band in the plot which can also be affected by change may be ignored. Such an event, if unanticipated, typically leads to an  increase in change implementation costs as well as delays in schedules [6]. The Risk Matrix as used in the example above is intended to draw attention to systems which take up the most significant design effort when change propagates. Using such method for risk prioritisation does not prevent components critically disposed to effects of changes from being passed off as insignificant risks and vice-versa.

This paper describes an approach to change assessment that accounts for practical side-effects of changes. This enables the assignment of high-criticality to components affected by change even in cases when estimated potential frequencies of propagation event between component pairs are low. It is based on  findings from previous studies which show that functional objectives of systems almost always implies dependencies between components which make up such system, it also influences how changes propagate between components [7].

## 2 METHOD

This research is based on findings from case studies in two UK companies, one of which is an aerospace company [8] and the other manufactures products for an automotive market [4]. In both studies (carried out in 1999 and 2003 respectively) the Change Prediction Method (CPM) developed by Clarkson et al. described in [2] was used to calculate risks associated with changing components affecting other parts of a product. In this study, prioritisation techniques commonly used in Failure Mode Effects and Criticality Assessments (FMECA) are adopted as a means for ranking the order of risk estimates derived using the CPM tool.

This prioritisation technique involves the generation of a Change Risk Prioritisation Number (CRPN) similar to the Risk Prioritisation Number (RPN) used when assessing "failure modes." This index is derived from a product of change likelihood, impact, and a non-detection index as will be explained in Section 4. The non-detection index is assumed to be a factor indicative of criticality. Estimates of change propagation likelihood and impacts from previous case studies serve as useful inputs for this type of prioritisation technique. In order to obtain estimates for the probability of non-detection of a risky event, theoretical analyses on product properties which contribute to risk of propagation between components were carried out. The findings from the analysis process lead to the formation of heuristics for ranking chances of detecting change propagation between components. It was assumed that the chance of detecting rare cases of changes propagating between components depends on the nature of dependencies between component pairs. This assumption is based on the knowledge that a pair of components may be coupled in a number of ways, for example through the choice of product architecture and/or the function they perform [7].

In order to assess the appropriateness of the CRPN technique for risk ranking, we prioritise the risk of carrying out changes to parts of a diesel engine. Change assessment prioritisation carried out using this CRPN technique is then compared against assessment ranking derived using the Risk Matrix. An example of a case of a change to the lubrication system of diesel engine is used to show the benefits of using CRPN as a technique for risk estimates when evaluating the possibilities of changes propagating between components.

## 3 ASSESSING CHANGE PROPAGATION RISK

In practice, plans for implementing changes are based on incomplete knowledge of possible emergent problems. As a result, techniques for handling uncertainties that help reduce or eliminate unwanted consequences associated with making a change are beneficial for organisations. Risk methods have been used as a way of dealing with uncertainty in various fields of discipline, such as software and healthcare [9]. Within design, these risk concepts have been redesigned to address different design considerations which are characterised by uncertainty, such as safety and performance. Although risk assessment techniques are similar, specifics such as event likelihood classifications pertaining to each form of Risk Matrix vary with its intended use. Yet, in spite of all the variations to the risk assessment methods reported in literature, it should be noted that the CPM is currently the only risk-based tool specifically for identifying, as well as for prioritising, the risk of changes propagating within a product.

### 3.1 CPM tool

The CPM tool was developed to support decision making during change processes. Although the tool is used for to provide an overview of the nature of connectivity in a product, its primary purpose is to enable design engineers to perform what-if analysis of the possible effects of proposed changes. To this end, the tool estimates the risks a change to a component posses on each and every other component within a product.

Risk is derived from the product of likelihood that a change to a component affects other components and the resulting consequence a change will have as a factor of the original design effort for that component. The unit for analysing risk is the average proportion of the design work that will need to be redone if the change propagates [2]. It should be noted these estimates generated using the CPM tool are limited to the design work associated with change not how much a component is critically disposed to effects of change.

Risk identification is only a part of risk assessment. Estimates of risk carried out using the CPM analysis have been shown to be a close reflection of consequential design efforts that arise from changes propagating between components. However, in order to be able carry out practical cost-effective assessments of risk, it is important to prioritise assessments and provide risk mitigation measures. A CPM analysis can direct a more detailed analysis; however designers still have to think through the details of each particular change. If the Risk Matrix is used to prioritise estimates from a CPM analysis, then the predicted estimates inherit the assumptions under which the Risk Matrix was conceived. In situations where such assumptions are not explicitly stated, and its implications not understood, the usage of the Risk Matrix as a sole method for prioritising assessments may provide a false sense of security when evaluating the impact of change irrespective of how accurate the CPM design effort risk estimates are.

### 3.2 Risk Matrix

The Risk Matrix (also referred to as risk fever charts) illustrated in Figure 2, is a graphical method that is used to prioritise and manage key sources of risk in a project [5]. It is a simple method to use and its strength lies in the ability to quickly separate high and low risk events. The Risk Matrix method is based on an assumption that the more severe a risk estimate is, the more critical its priority. Depending on the convention adopted for analysis reading the matrix, this assumption implies that risk categories which fall into the top right hand corner of the matrix are of most significant priorities.

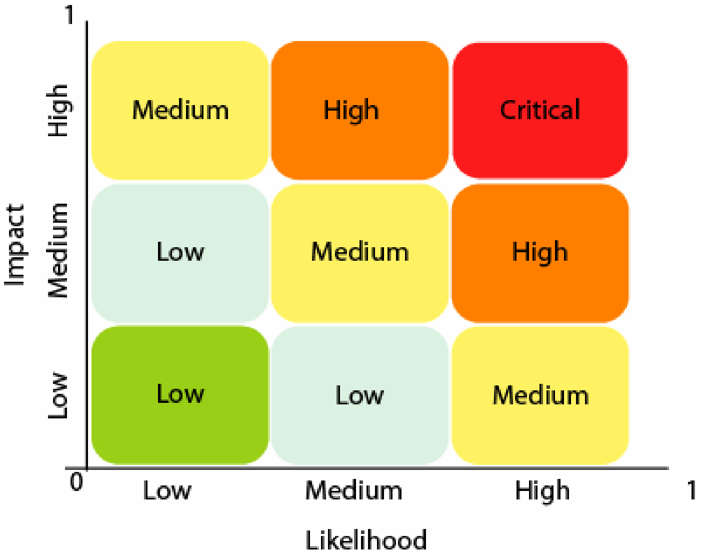

*Figure 2: The Risk Matrix prioritisation technique*

In practice, a fundamental aspect of the Risk Matrix as a prioritisation method is the establishment of a risk acceptability criterion as well as risk mitigation measures. Estimates of risk that do not fall within the acceptable risk limits are subject to further analysis on how to moderate the effects of such risk. Depending on the number of events to be considered during risk assessment, it is not unusual that a low risk event may be isolated from such mitigation analysis. In a situation where such risk is assessed purely on the basis of design effort involved in making a change and not considering the critical disposition of a component to the effects of change, it is still possible to take on a risk beyond that which is desired. Clarkson et al. provide an example of a change project where an unexpected change to just the wheels of a helicopter costs £50,000 [2].

Granted that effects of change to components of complex products cannot be assessed exhaustively, it is important to look beyond the magnitude of design effort when assessing the risk of change propagating between components. An example of change to the weapons and defensive system of a helicopter discussed earlier in Section 1 highlighted the fact that the Risk Matrix approach sometimes associates low assessment priority to components critically disposed to the side-effects of changes. This leads to such components being overlooked during impact assessments.

## 4 PRIORITISING CHANGE IMPACT ASSESSMENTS

Priority of assessment in risk management is typically assigned to events considered significant in terms of an organisation's tolerability for change. Magnitude is one but not the only indicator of how significant a risk is. In product change management, a change request may be classified as immediate, mandatory or convenient [10]. Within such a framework, a change request classified "immediate" will have a higher assessment priority than that of an equivalent magnitude that is classified "convenient" – priority in this case is not based the enormity of the risk. The fact that there is a degree of urgency associated with change should be accounted for when considering criticality of risk. There is a chance that a change event may not even occur, let alone propagate between components. Such tendencies should be taken into account when prioritising the order of change impact assessments.

In order to have a precedence order for assessing individual component risks during change impact analysis, it is necessary to have a criterion for assigning a degree of importance to each individual event. In general, selecting a prioritisation criterion depends on the issues considered to be more significant when assessing the impact of changes. Factors such as the number of links to a component or a component's lead time can be used as criteria for prioritising assessments. However, merely considering a single criterion for ordering assessment may lead to the oversight of critical issues that may affect the successful implementation of a change.

In terms of assessing the impact of change, priority should depend on how important a component is to the outcome of a change process. Such a prioritisation scheme may be influenced by magnitude of a risk associated with making a change, as well as other relevant design issues but, ultimately it should rank the more critical risk as being of notable significance.

## 4.1 Risk prioritisation

A risk prioritisation technique common to the automotive and software industries that enables criticality based risk ranking is the assignment of Risk Prioritisation Number (RPN). Commonly used to assess failure modes, the RPN is a core part of the Failure Modes, Effects and Criticality Analysis (FMECA [11]). Similarly, the primary purpose of the CRPN is to assign a measure of criticality to change propagation risk estimates. It achieves this aim by multiplying an additional non-detection variable 'D' to risk estimates 'R' as shown in the Equation 1. This variable is termed a non-detection index due to its manufacturing origin. Slight variations of the term have been adopted for usage in other fields where risk assessments is practiced, such as healthcare [12]. In this paper, it will be argued in Section 4.2 that non-detection index is a factor that can be used to indicate the criticality associated with change propagating between components.

$$\begin{aligned} CRPN &= (L \times I) \times D \qquad (1) \\ &= R \times D \end{aligned}$$

Despite the wide spread usage of this form prioritisation technique in industry, it is not without its own flaws. Bowles [13] observed that there are problems with the CRPN scale as traditionally used. Slight changes in detection indices leads to disproportionate changes in CRPNs. As a result, comparing two CRPNs can be misleading. However, these irregularities in the scale are easily addressed by transforming CRPN to a logarithmic function [14].

The non-detection index is a probabilistic estimate that a risky event that could occur will be predicted. Using such a variable, the CRPN technique enables the assignment of a criticality status to components for a various reasons. As a result, priority is not so much dependent on specifics such as lead times or the number of links to a component, it is simply concerned with if such a risk event will take place or not. This approach to prioritisation enables ordering of risk estimates such that components with tendencies to be affected by a design change are moved up the priority scale irrespective of the estimated design effort.

The formation of a non-detection index is a core part of this prioritisation technique. Guidelines for developing non-detection indices can be found in [15]. A typical scale for indicating chances of detection can range from "remote" through to "high." In order for these qualitative scales to be useful, numerical equivalents are used for risk prioritisation, with the smallest numerical index assigned to the most certain non-detection incidence (i.e. the most obvious component) and the highest numerical index to the most uncertain incidence of detection. In order to apply CRPN as an assessment prioritisation technique to risk estimates derived using the CPM tool, it is important to develop a non-detection index ranking scheme for change.

## 4.2 Risk detection and component dependencies

Whether or not a change propagates depends on the current state of a design [16]. Change assessment as it is currently carried out using the CPM technique is based on connectivity information between component pairs. The method does not account for system interactions in risk estimation. In order that components critically disposed to effects of change are accounted for when ordering risk estimates, it may be useful to consider system-induced interactions between components.

Studies show that the path through which changes propagate between components is partly dependent on the type of relationship between them [7]. System-induced relationships are of associative nature; as such components are bound by a common objective [6]. In this kind of relationship, change may propagate between two components within a system if the overall system goal is not achieved regardless even if there is a direct interaction between component pairs or not. For example, change to the *Defroster* of a car may propagate onto to its *Alternator* if such a change overloads the electrical system even though both components are not directly linked.

Others relationships occur in a pair wise manner [6]. As a result, change may propagate between two component that interact directly irrespective of it they are functional related or not [7]. An example can be seen in the interaction between an *Oil filter* and the *Starter motor* of a diesel engine. Both components are not functionally related, but spatially dependent in some diesel engine designs. An increase in the size of the *Oil filter* probably to improve its filtering capacity in harsh working environments may cause a change to the *Starter motor*. The pair wise dependency between components is a *direct* dependency, while component pairs linked by an associative relationship are *latently* dependent on each other [7].

- Direct dependency is typically as a consequence of the choice of architecture chosen for a product. This type of interaction occurs in a pair-wise manner. Changes may propagate between component pairs if there are insufficient margins to accommodate effects of the design changes within a chosen architecture.
- Latent dependency on the other hand arises due to interactions between components. A set of components associated to a system's functionality are all directly linked but not necessarily in a physical manner. Change to one such component may propagate to any other components that contribute to achieving such functionality.

It is important to note that not all component pairs with a direct dependency between them are physically connected to each other. An example of such interaction is a dependency that arises due to thermal flows between the engine and the bonnet of an automobile. It is also important to note that not all direct dependencies are intended. Ulrich and Eppinger [17] describe the nature of connectivity between component-pairs as either fundamental or incidental depending on the intentions of the designer. Incidental interactions are those which are not intended but arise as a result of a chosen solution principle.

In previous studies on change propagation, it was found that there are many reasons for unexpected proliferation of change and in a lot of cases, oversight plays an important role towards the non-detection of propagating changes [18]. There are other contributory factors leading to this condition where critical dependencies are not foreseen during change impact analysis, for example the specialist nature of many design engineers technical background make them unaware of the implications of decisions they make on other parts of a product. In general, latent dependencies are more hidden and less obvious to the observer than direct dependencies.

Studies also showed that there can be more than one set of dependencies between any pair of components [7], in other words a component part may be directly interacting due to one type of relation and latently interacting as a result of another type of relation. For example, in some designs of diesel engines, the oil filter is separate, completely from the sump. Both components have a latent dependency between them arising from the lubrication system. In another design, the oil filter is literarily bolted onto the sump creating a direct dependency between them. The existence of the direct dependency as a result of the choice of architecture does not make the latent functional dependency invalid. As such, in the second design, the components are coupled both directly and latently. An assessment of structural dependency only (such as bolt sequence) between such a pair of components may or may not draw attention to the possibilities of changes propagation through latent links. Yet while this may be true, the chances of non-detection of possibilities of propagation may not be as high as a scenario where dependencies are purely latent. These findings form the basis of the formation of a non-detection index for risk prioritisation.

## 4.3 Developing a risk detection index

CRPN like other risk based methods is developed out of the practical need to solve problems of uncertainty. The formation of a detection index is a core part of the CRPN as a prioritisation technique. It can be obtained subjectively or through the use of some objective criteria. In order to take advantage of the relative correctness in risk estimates generated using the CPM tool when deploying the CRPN technique, it is important to have a consistent criteria for assessing probability of non-detection of propagation between components. In traditional RPN usage, the detection ranking is typically a subjective judgment of the designer. This approach is subject to various sorts of bias [19]. Estimates on how a change may propagate are influenced by factors such as technical background and operational experiences rather than just the current state of the design. Thus in addition to the inherent difficulty associated with detecting change, there is also an issue of an individual's ability to identify and estimates the change.

In this paper, we try to avoid the issue of the designers' subjectivity based on the understanding that the nature of component dependencies is essential to change propagation. From the findings from our study, it can be assumed that the types of relationships between a pair components is not only indicative their criticality to effects of change, but also can be indicative of chances of non-detection. With this in mind, we develop a ranking for non-detection which is illustrated in Table 1. It is based on our findings from previous research on the role of dependencies in change proliferation. The only type of associative relationship considered in this study is functional dependence between components. As such, components are associated with each other if they belong to the same functional system. Guidelines put forward in [15] form the basis of this ranking scheme. Non-detection in this case is a probabilistic estimate that a risky event that could occur will not be predicted. The scale used for this table is limited to high, medium and low respectively to conform to the scales used with CPM tool.

*Table 1: Change effect detection evaluation criteria 'D'*

| Description of detection criteria | Example | Non-detection Ranking | Dependency type |
|---|---|---|---|
| If the component pair are associated by a functional goal but are not directly linked with each other. | A change to the *Defroster* of a car causing a change its *Alternator* | Moderately High | Latent |
| If the component pair are not associated by a functional goal but are directly linked. | A change to the *Oil filter* propagating to an adjacent component such as the *Starter motor* | Moderate | Direct |
| If the component pair are associated by a functional goal as well as being directly linked with each other. | Change may propagate from an oil filter to a bolted on sump either through the structure or as a result of the lubrication functionality. | Moderate | Both direct and latent |
| The are no relationships between both components | A request for change to parts within independent modules | Low | None |

## 5 AN EXAMPLE OF CHANGE

In order to assess the use of CRPN as a technique for prioritising critical risks when carrying out change, the method was applied to several scenarios involving changes to a diesel engine. The analysis of these change scenarios was carried out based on a previous extensive case study of change processes in a leading UK automotive company [20]. A model of a diesel engine developed with 7 engineers, containing 41 components, was reused to determine relevant connections between components in the engine. The model consisted primarily of pair-wise direct dependencies between components. Estimates of change likelihood and impacts collected during the study were used for change impact risk estimation in the CPM tool.

In order to model latent dependencies between components, all 41 components were grouped into systems represented in the columns of a matrix. There were 10 systems in total including fuel, ignition, lubrication and cooling systems. Due to function sharing in engine design, a component may be part of one or more systems.

## 5.1 Example case

In this Section, an example case of a change to the oil filter is used to demonstrate the how the CRPN prioritises risks as compared to risk priority ranking carried out using the Risk Matrix. In terms of component dependencies, the oil filter is directly connected to some components and latently dependent on the some others. The oil filter was chosen because it epitomises the low design effort risk scenario which this prioritisation technique is developed to address.

The oil filter is not a core part of the engine. Yet unanticipated effects of changes to the filter may necessitate further changes to unintended components with significant consequences. Jarratt [4] described an instance in a UK company where changes to filter design from a regular commodity filter to a totally disposable filter with no metal liners led to changes propagating within the engine. Identifying the critical effects of changes to the oil filter enables designers to seek alternative solutions in an attempt to meet design requirements. When prioritising the risk associated with changing the oil filter, it is important to consider components that are critically disposed to the effect of such a change, irrespective of the risk associated with rework if change propagates.

## 5.2 Case risk prioritisation

Following the completion of the model building stage, components critically disposed to effects of change were accounted for by allocating a non-detection index to each component pair. These indices were generated based on the criteria put forward in Table 1. In order that the qualitative scale may have a meaning, numerical indices were assigned to the existing qualitative scale. These indices were restricted to within 0 and 1 to conform to existing conventions used in the CPM tool. Qualitative values of high, medium and low were later represented using 0.3, 0.5 and 0.8 respectively.

Estimates of rework risks that may arise from allowing changes to the oil filter affect any other component within the product was estimated using the CPM tool. These risk estimates were then multiplied to the generated non-detection index to form the oil filter CRPN. The values were transformed onto a logarithmic scale to address irregularities in the CRPN scale [14] and the final values were normalised to enable easier readability.

## 5.3 Contrasts in CRPN and Risk Matrix rankings

The risk estimates ranking as prioritised using the CRPN technique was contrasted against that which is derived using the Risk Matrix priority criteria. The purpose of this assessment is not to show which methods is most effect for risk assessment each of these techniques is suited to different types of analysis. Rather the comparison is carried out as a way of illustrating changes in the ordering of predicted estimates when criticality account for.

The scatter plot shown in Figure 3 is used to assess the differences in rankings derived using each technique. The x-axis of the plot represents the ordering of risk estimates using the Risk Matrix approach and the y-axis represents ordered rankings derived using the CRPN technique. Each point on the graph corresponds to a component that may be affected by a change to the oil filter of a diesel engine. If rankings derived using the CRPN technique were similar to those obtained using the Risk Matrix approach then all the points on the scatter plot should form a straight line. Points above or below the centre line correspond to increases or decreases in the prioritization index allocated to a component when using the CRPN technique.

In Figure 3, the graph shows that risk estimates for each component within the engine fall into one of three distinct thread-lines. In order to aid explanations on how the CRPN technique contrasts with ordering rank derived using the Risk Matrix, a point is highlighted on each thread-line. Point 2 on the middle thread-line shows an example instances where there are no significant differences between rankings derived using either prioritisation technique. However, components on the rankings of components on other thread-lines are either increased or decreased depending on whether or not such component is critically disposed to effect of change to the oil filter. Point 1 is an example of a component functionally related to the oil filter. Its disposition to effects of change to the oil filter is accounted for in the CRPN technique, hence its ranking index is increased. On the contrary, components such as that highlighted on Point 3 of the graph are neither directly nor latently linked to the change causing component. As such, the associated rank of the estimate is reduced accordingly using the criteria set earlier in Section 4.3.

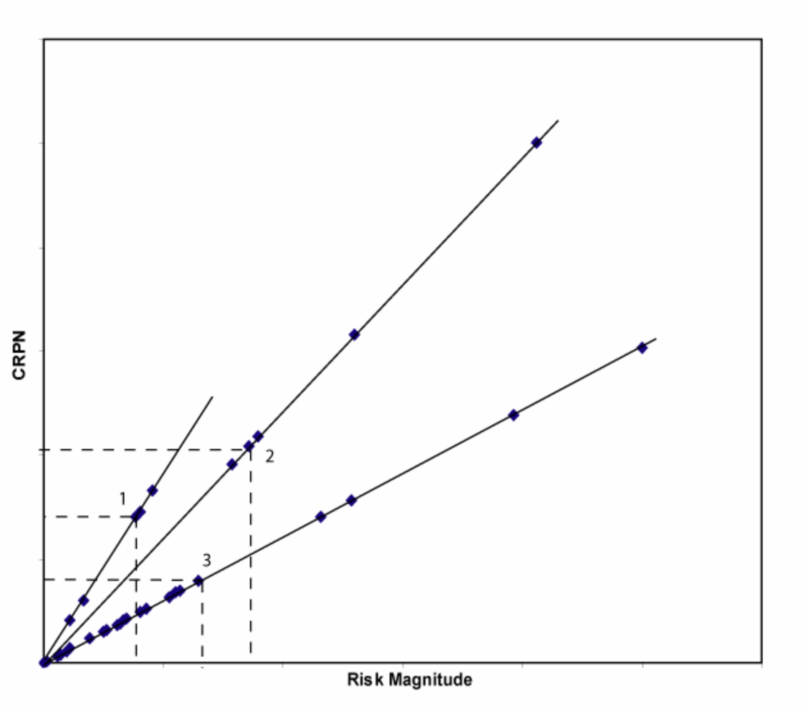

*Figure 3: A plot of CRPN against Risk Magnitude*

From the diagram, it can also be seen that these modifications to each component's ranking index are not dependent on the magnitude of the risk. Thus components which may be critically disposed to effects of change but requiring low design effort can also be accounted for when ordering risk estimates. Contrasts between CRPN and Risk Matrix can further be illustrated in Table 2. Up (↑) and down (↓) arrows were used to mark the relative movement of the component in the CRPN scale.

*Table 2: Comparison of Risk Matrix and CRPN prioritisation rankings*

| **Priority** | **Risk Matrix (magnitude) ranking** | **CRPN ranking** |
|---|---|---|
| 1 | ECM | Wiring harness ↔ |
| 2 | Wiring harness | Fuel filter ↑ |
| 3 | Fuel pump | ECM ↓ |
| 4 | Fuel filter | Fuel pump ↔ |
| 5 | High pressure fuel pipes | Cylinder block assembly ↑ |
| 6 | Cylinder head assembly | Starter motor ↑ |
| 7 | Cylinder block assembly | Low pressure fuel system ↑ |
| 8 | Starter motor | Engine breather ↑ |
| 9 | Low pressure fuel system | High pressure fuel pipes ↓ |
| 10 | Fuel injection assembly | Sump ↑ |
| 11 | Timing case | Cylinder head assembly ↓ |
| 12 | Piston & rings & gudgeon Pin | Oil cooler ↑ |

Due to space considerations, the 40 component long list cannot be displayed in full. The top 12 components that should be assessed as a result of change the oil filter are shown in Table 2. In this order, components with the highest risk magnitudes if affected by change are listed using the Risk Matrix technique. The basic characteristic of the order derived using the CRPN technique in reference to the Risk Matrix can be summarised as shown in Table 3 below.

*Table 3: Assessing the properties of CRPN rankings*

| | | Non-detection Ranking ‘D’ | |
|---|---|---|---|
| | | High | Low |
| Risk estimates ‘R’ | High | Components with high risk magnitude and detection ranking remained relatively high on the both priority ranking tables e.g. *Wiring harness* | Due to low non-detection ranking, such components were ranked to have a reasonably lower priority in the high end of the CRPN scale e.g. *ECM* |
| | Low | Due to high non-detection ranking, components within this category were ranked to have a reasonably higher priority when listed on the CRPN scale e.g. *Engine breather* | Components with an estimated low risk and non-detection ranking were categorised into the lower ends of both priority ranking tables e.g. *Alternator* |

Low risk components such as the sump and the oil cooler occupied positions 19th and 20th of the Risk Matrix ranking. However, the CRPN technique factors in their criticality to the effects of change at hand and assigns such components to positions 10 and 12 respectively. In likewise manner, high risk components such as the cylinder head assembly which are not necessarily disposed to effects of changing the oil filter are assigned a moderately lower rank.

## 6 DISCUSSION

In this paper, we have shown a way of prioritising risk estimates. This technique allows high priorities to be allocated to assessment of critical effects of change even when risk estimates are low, as shown in Figure 4. The colours of the bars in the chart correspond to the risk estimates of rework associated with changes from the oil filter affecting such components. The length of each bar shows the degree of change in the assessment index for each component between a risk magnitude-based prioritisation method and the CRPN technique. On this plot, we observe changes in the priority index of components based on each part’s disposition to the effects of changes to the oil filter. The priority index ascribed to some high risk components are reduced while others are modified according to the nature of their interaction with the change initiating component. Such means of selecting change effects for assessments is even more important in cases where design engineers are required to analyse alternative ways to carry out a change to a complex product. For example, consider a situation where the purpose of a design change was to ensure consistent uninterrupted supply of oil to parts of an engine. One solution may be to change the mesh of the oil filter to ensure such full requirement is met; another solution may be to change the capacity of the oil pump. Each of these solution options will most likely create its own series of knock-on effects. The CRPN assists designers in identifying components which are critically disposed to the effects of each solution alternative.

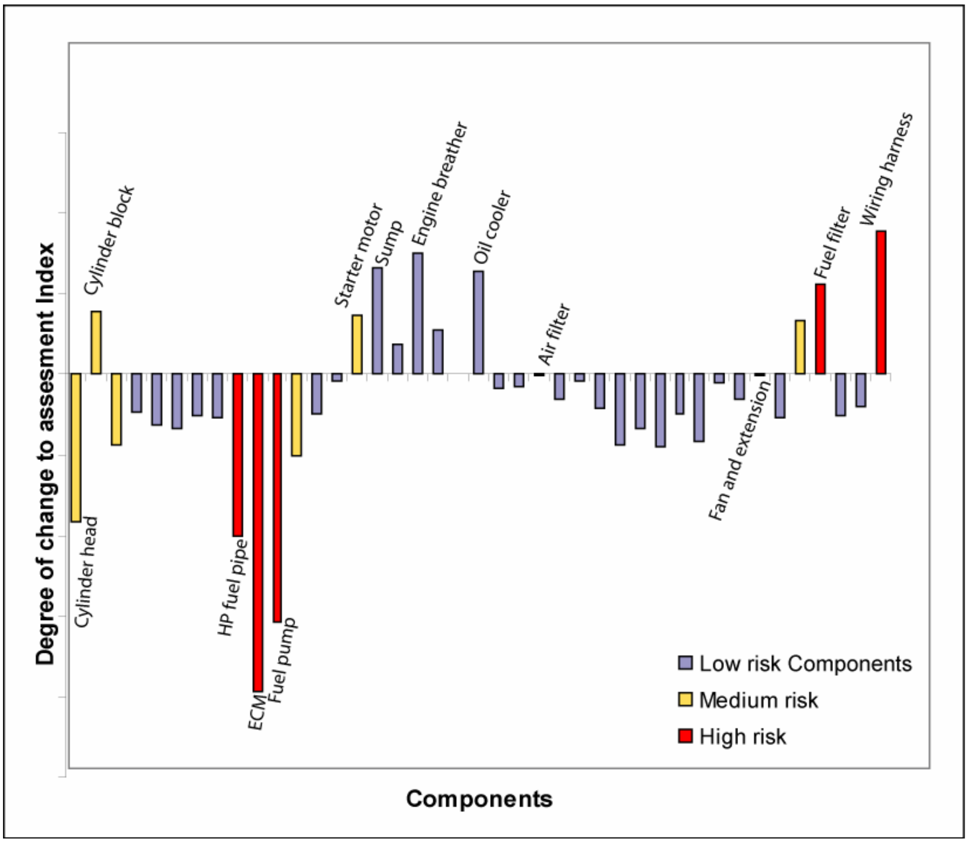

*Figure 4: Reprioritising assessment rank using CRPN technique*

It is important to note that the CRPN technique is not intended to be a substitute to the Risk Matrix. The process of change management is such that designers need to be aware of a high risk components as well as critical effects of change. To this end, the CRPN is intended as an additional prioritisation technique to help guide decision making when carrying out change. This ensures that managers are not only aware of the risks with high magnitudes, but also critical risks as well.

## 7 CONCLUSION

This paper presents a criticality based approach to risk assessments. The technique is based on an understanding that risk rankings are dependent on criteria used for prioritisation. Using the example of a change to an oil filter, it was shown that the CRPN was a more suitable technique for assessing risk on a case-by-case basis. Such a method enables design engineers to concentrate their efforts towards components critically disposed to effects of change when evaluating potential impacts. The technique is intended to accompany the Risk Matrix method of prioritisation as a means of prioritising risk estimates. In a situation where risk ordering is carried out to support strategic decision making, it may be useful to use only the Risk Matrix technique to draw out area require significant design effort, whereas in situation where design engineers are evaluating change impact on a case-by-case basis, it is important to take the added measure of considering criticality of a component to change. This criticality based ordering can be achieved when using the CRPN.

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