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Maintenance Informatics Dashboard Design for Through-Life Engineering Services

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Abstract

This article introduces maintenance informatics dashboard design approach for visualising maintenance, repair and overhaul events on a timeline. This paper presents a proposed methodology for aggregate visualisation techniques and a 2D graphical plot method as well as a summary of events on a timeline. In this paper, these events are occurrences which are classified and categorised into levels. The occurrences are accumulated over time as historical information and represented in a visual format over a timeline based on an entity relationship diagram. The information modelling technique with respect to data visualisation is emphasised. The result is a single-page-view of maintenance activities. The maintenance activities of aircraft engines are visualised to ease the accessibility of getting accurate and relevant information for making better maintenance decision. The result can be used to gain insight of the root cause of the events from inception to end of life of the engine.

Keywords: Through-life Engineering services; timeline; visualisation; information modelling; summarisation; engine events

1. Introduction

Visualisation is changing the way information is presented in through-life engineering perspective [1]. Through-life events can occur at a precise point-in-time or an interval-in-time [2]. These events experienced by an asset or an object as well as times of occurrences can be envisioned on a timeline. The timeline is a graphical concept display of historical events from the aerospace, manufacturing and operations domains.

Point-in-time refers to the date of the event in time. The interval-in-time relates to an event with a given start and end date typically used to inform maintenance decision between periods A and B. There is also a downtime or lag in operation of the engine in-service. The duration of the occurrence is also often captured to give quick feedback to decision makers. The swift alternative decision to scheduled condition-based maintenance can be provided on time.

Information modelling of engine event histories is discussed to demonstrate the data organisation displayed in a concise and accurate way. The modelling of information for visualisation has become essential in the through-life perspective because of the increasing amount of data that cannot that be viewed on a single screen. In order to achieve this, the entity-relationship diagram (ERD) is required to capture relevant attributes that will be used to describe the semantics of engine past events to support temporal queries, information presentation and representation [3].

This paper reports on an abstract model to display maintenance activities. This article illustrates how historic engine information is represented in an interactive timeline

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display based on levels and a group of events. This paper introduces a summarising technique to fuse complex semantic information into single data points, thereby representing multiple points on a timeline as a 2D graphical plot [4],[5]. This paper reports a new hybrid visualisation technique to view events on a timeline. An information modelling strategy is utilised to model historical engine events. This article illustrates multiple assets with levels on a timeline as a single view. This work can be introduced to show manufacturing and design events on a timeline. This paper reports aggregate attributes as detailed information.

2. Related Work

Karam [6] used timelines extensively in electrical engineering to represent electrical signals, the most common timeline display generator being the oscilloscope (and its relatives such as logic analysers). Karam discussed three major processes used in the timeline display generation. The event interpretation - deriving information about a system given a record of its actions (a trace of events); rendering activity- the display of derived information on a timeline; and display presentation - the organisation of the screen (the set of timelines) for suitable viewing.

Kumar et al. [7] represented timeline in a familiar means of demonstrating the relationship amongst historical events. The point and click restructuring capability help the user to prepare a better mental model of the content of a document. Kumar explored the use of interactive documents as interfaces to historical data, starting with the basis of the popular representation of a timeline.

Allen [8] showed that timelines could be an effective aid for understanding relationships amongst events which deliver several types of cognitive advantages for a user, such as inform, show context, encapsulate and link. Allen introduced semantic zooming with the view to scale the space in 2D. The semantic zoom relates to pinch-to-zoom. The interface and functionalities are described in the implementation section.

Alonso et al. [9] produced timelines on novel organisers for digital libraries of the historical information. It is a challenging and time-consuming nature to get an overview of the historical information on youths. Alonso et al. determined and compared the LifeLines graphical data representation to the tabular data representation commonly used in computer applications.

Plaisant et al. [10], [11] created LifeLines to provide a general visualisation environment for personal histories. LifeLines were implemented to present a personal history overview on a single screen, offer direct access to all comprehensive information from the overview with a single or double mouse click. It makes critical information or alerts visible at the overview level. In the visual display of quantitative data, Tufte [12] described timelines as a common and powerful form of graphic design such as data maps and time series. Kocherlakota [13] argue that techniques be designed for the automated, unsupervised analysis and exploration of raw data, followed by the generation of effective abstracts based on the analysis.

The remaining sections of the paper are as follows: Section 3 describes the methodology for graphing the timeline, section 4 defines the information modelling technique, section 5 describes the implementation of the events timeline application, section 6 is the case study, section 7 presents the results and discussion, and section 8 is the conclusion with future work.

3. Methodology

The proposed new Summarisation of Engine Events (SUMEE) methodology utilises an aggregate visualisation technique and 2D graphical plot method to design and provide a summary of events on a timeline.

This methodology observes both scientific and information visualisation [14]. The scientific visualisation is the interactive visual representation of data to strengthen insight and information visualisation is the interactive visual representations of abstracts to increase knowledge [15]. Scientific visualisations are used to clarify familiar observations, while information visualisations are utilised for finding out interesting pattern. The scientific visualisation relates to the real world and the information visualisation is abstract in nature. The goal of the visualisation is for characterisation, prediction, gaining insight and decision making.

The physical object under investigation is an engine with related activities of events and time being represented in an abstract view form in the maintenance domain. The relationship between information and scientific visualisation is the activities and engine object. The hybrid visualisation will incorporate multivariate attributes of independent and dependent variables on a 2D graphical plot. The document of the event description contains complex and detailed information. The information is the activities which have been observed and documented by service engineers which tell the stages of the story of the impact on the asset. This information can contain pictures as visual evidence that such an event happened at a point in time of an interval of time. It keeps track of the activities and life of the asset to understand the way it degrades based on the operating conditions.

This paper focuses on the knowledge building phase of the semantic decision and inference relevant attributes to the on-demand information in a database, but not discussed in detail since the work relates to the application. In this case, the semantic fusion refers to the integration, representation and visualisation of the engine events in a single view as a large menu where users can easily access underlying information. In the context of decision fusion visualisation relates to temporal or parametric content or links to relational databases [16]. In Figure 1, the concept of the timeline visualisation is presented.

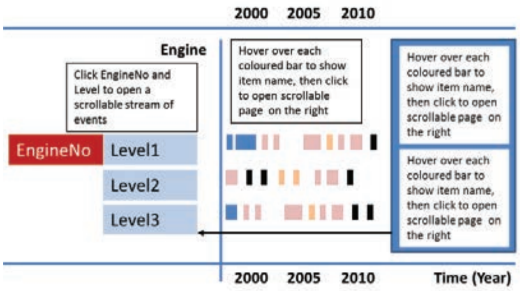

Figure 1 Initial design of timeline visualisation

- **Visualisation Technique**

Information visualisation concentrates on the use of computer-supported tools to derive new insights and knowledge visualisation emphases on transferring insights and creating new knowledge. A combination of information and knowledge visualisation was explored. The technique powers the presentation of interactive documents. Also, the technique alters the spatial presentation of the document. A user can experiment with the technique on electronic documents to convey the document semantics.

In this paper, the SUMEE methodology utilises an aggregate technique (groups of related events), summarisation (facet) rule (levels and key), data map, time series and 2D graphical plot methods to visualise the engine events on a timeline. The authors introduce helicopter and fisheye views:

i. Helicopter view: A graphical helicopter view is a data map which incorporates a time series statistical method. The data map illustrates the point of the state space with regards to its dependent variable. Its view looks meaningless. It was chosen because large data sets can be neatly presented on a page view in terms of single square dot as a time point and collection of squared dots as a stream or continuous data of time intervals. These square points are colour coded which makes the graph attractive and draws the user attention.

ii. Fisheye view: A graphical fisheye view is a focus-based technique, which allows concentration of one specific region on the screen while keeping the context visible [7]. When a user points, hovers or clicks at a point or interval-in-time, detailed aggregate information is revealed.

- **2D Graphical Plot Method**

The 2D graphical plot is used to visualise time-dependent information. Time is an independent entity, while the objects used entirely depend on the state space. The plot is illustrated as a vertical and horizontal axis.

The classified related events were represented through a colour coding scheme. The colour scheme provides the timeline plot with a powerful function to help the user to easily and quickly make decisions. The classification enhances the flexibility of the information modelling technique. It simplifies the means by which the algorithm displays multivariate data.

4. Maintenance Information Modelling

Maintenance information can be made possible by spooling relevant semantic data from an ontology or database and represent the data as an object at a point in time or an interval of time. The maintenance information modelling technique is based on two independent variable states (start and end date) and events (cluster-key colour coding).

The data model for the information required to develop the database of the event history is presented in Figure 2. In Entity Relationship Diagram (ERD) is used to represent the understanding graphically and capturing of business information requirements. This technique shows the relationship between each entity, which can be represented as an ontology of taxonomy. The ERD was designed using Microsoft Visio in the perspective of the unified modelling language.

The ERD is a specialised graphic that illustrates the relationships between entities in creating a good database design. The rectangle represents an entity; the diamond shape is the relationship, the oval is the attribute (primary key shown), and the 1-to- M (means one-to-many) as cardinality. This ERD gives an overview of how to the data would be represented and stored in the database.

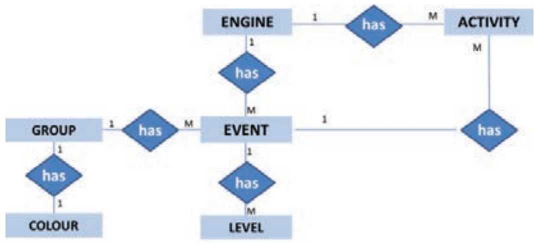

Figure 2 Entity Relationship of events

The descriptions of the entities include:

1. Engine relates to the attributes, e.g. engine number, model and name.
2. Activity relates to location, point of the interval in time such as the start and end dates of the events. It also shows the relationships of repetitive engines and events as well as comments.

3. Events entities are the attributes of the different events and the relationship to level, colour and group.
4. Level describes the attribute of the categorised event in number as integer and description in the text with caption a name.
5. The group entity is the classification of events as key and the representation of the criteria with respect to colour coding.
6. Colour represents the types of coding used to differentiate the group, e.g., blue, green.

Here, general information modelling of event history data is used to build a repository. However, the focus was on engine maintenance records. The design applies to related domains such as manufacturing of aerospace, healthcare, railway, transport and agriculture. Historical events are grouped and exemplified in the data model based on the main colour coding, classify levels and groups the relevant on-demand information for display as output once the mouse is pointing at the data point. The MySQL database was used to store the data, while the Hypertext Preprocessor (PHP) server scripting generates a web interface at runtime to display the attributes.

In this paper, an information modelling technique is used to model the timeline visualisation of engine events, while information architecture supports the visualisation of personal history in the medical application [3]. This modelling technique has become usefully in the aerospace and manufacturing domains, i.e. the representation of events with respect to time will make domain experts knowledgeable, so that, at every point in time events are captured and recorded in the timeline. This modelling schematic will help domain experts know the relevant information to aggregate for presentation on the timeline. The simplification and reduction of the amount of time that the domain experts use in the investigation of events are guaranteed. Information bank should be linked and understand a single language – semantics. The introduction of a semantic technology in this paper will give an edge to how the relevant information is rendered. The semantic data model such as ontology can be crucial in generating interactive visual timeline graphs on the fly.

5. Implementation

The prototype displays objects, attributes and their relationships. The application in PHP remains under development. The implementation strategy in Figure 3 is the system architecture for the proposed prototype design.

The initial idea of the application conceived span from Tufte [12] visual display of quantitative information on the graphical excellence of how complex big datasets can be communicated with clarity, precision and efficiency. The graphical design excellence should show the data, induce users to think about the substance and not the methodology or graphic design, make large data sets coherent and present much information in a short space, reveal the data at the several and reasonable level of detail that are relevant to users for decision making. The design displayed in Figure 1 is a data map and time series illustrated in Tufte's work. This work helps to demonstrate substantive maintenance content instead of the methodology and technique. It is also used to display big datasets with the real variability of multivariate data.

The use of maintenance records was explored. A web-based user interface describes a single-screen overview of in-service information using timelines. Hovering the data point provides more details; key colour code illustrates grouped events; click on the engine number to reveal the complete information on specific levels.

- ***Interactive User-Interface Attributes***

The single phase view of the timeline visualisation improves the means of condensing a vast amount of information to reveal relevant data when there a mouse over on the point or the interval of the state space (time). This SUMEE timeline visualisation is a prototype developed using a combination of languages, e.g. PHP, and JavaScript.

a. **Drilldown functionality:** The drill down functionality is a collection of events were grouped into specific categories. The categories are colour coded to differentiate the various data points on the graph when a user clicks the drop-down menu.
b. **Key Colour Coding (KCC):** Key is indicated with a colour coding based on group events (aggregate) referencing irrespective of the levels, and is used to show severity, e.g. red means disruption, green relate delivery.
c. **Levels of Events:** The levels of events refer to the classification of events based on certain criteria defined by a domain expert, e.g. Events>>Level 1>Delivery, Disruption; Level 2>Repair, Overhaul. The levels may be called facets [3]. Level 1 relates to availability of the product to operators. Level 2 is infrequent occurrences – troubleshooting performed on engine. Level 3 relates to maintenance health status – standard daily/weekly activities.
d. **State space (time) Axis:** Indicates the horizontal representation of the latitude in terms of time e.g. the year 2011.
e. **Engine Axis:** This shows the engine number as an attribute, which is dependent on the state space. It is the vertical representation of the longitudinal line to demonstrate the location of the point of occurrence. The plot is a square.

f. **Events:** The events attribute is the various terms which a domain expert would use to describe the impact of the availability of an engine to be an in-service e.g. overhaul. Examples of the terms which can lead to an overhaul in a bird strike, foreign object damage, crack, wear, corrosion, deformation [17].
g. **Mouse over:** When there is a mouse over to the data point, the information pops up to give relevant on-demand detail in the state space.
h. **Mouse click:** A mouse click on the engine number reveals a stream of data relating to a specific level.
i. **On-demand information:** these are the relevant information which the user would require for decision making. The on-demand information includes engine number, the level of the event, duration, start and end dates, image, and comments which are revealed when a user does mouse over or click.
j. Relationships: This represents the mapping of the latitude of time and the longitudinal events

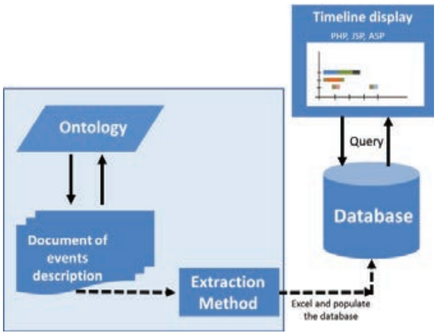

Figure 3 System Architecture

The events ontology and description are available information for creating the database but were not discussed in this paper. This article is about describing the methodology for timeline single page view of historical maintenance activities.

6. Case study

The gas turbine is a heat engine that burns fuel to convert its energy into useful work. The useful work is a fast moving jet of air that propels an aircraft forward. It also powers a driving a load in different applications for example, an electrical generator, a compressor for a gas pipeline, a ship propeller or a water jet. The purpose of this case study is to visualise the event histories regarding time (in years). The product can be used by domain experts (service engineers) to visualise and navigate summarised history of events on a timeline for better maintenance decision making.

Engines experience various events in-service. The in-service events in a complex engineering system were documented during the service maintenance. The investigation of the in-service event in the vast amount of the maintenance information document to identify relevant keywords is a challenge. In this paper, this case study has created an avenue to deliver a visualisation tool to overcome this issue. The research questions include:

i. How these events should be grouped based on the key identifiers?
ii. How would these events be classified into levels?
iii. How would the events be represented in a timeline?

The hypothesis results from the data mining of a large set of information. How to capture, represent and picture the information merely in a concise manner becomes of paramount importance. Service engineers and policy makers would prefer to have a prior knowledge of historical events that an engine has undergone, but this is very unlikely, if possible, it will take an enormous amount of time and manpower to go through the document, databases and web pages. In the light of this, the through-life performance of the asset right from the inception through in-service, maintenance, repair and overhaul (MRO) and finally, end of life (EOL) needs to be tracked [18]. The essence is to feedback to design and manufacture for better maintenance decision making, continuous improvement, the behaviour of engine components by cause of diverse flight conditions.

7. Results and Discussion

The result in Figure 4 represents the information on the timeline, the summarisation rule and 2D graphical plot method initiated using an object-oriented scripting language. These languages automatically extract relevant data from the database designed based on the ERD. The goal is to support the representation of gas turbine event histories accumulated over time. An overview of the event timeline is presented as a single page view, users can hover at a point in the graph to see relevant detailed information, and users can click on a specific engine number to unveil a collection of events relating to a specific level. In this paper, a number of techniques have been utilised to achieve the event timeline visualisation.

While time provides a strong underlying dimension, it does not solve the problem of selection and structuring information as a coherent whole. There are many open and challenging challenges ranging from effective formatting to the generation of descriptions of the events presented. The visualisation tool can be of an immense benefit to designers and manufacturers for better decision making. This application is unique to the maintenance domain. The timeline visualisation has the capability to represent data as a scatter plot and linear form depending on the size of the data.

The visualised data help designers and engineer to predict route with the most maintenance of specific components and engines, and the downtime of engines at different locations. The number of maintenance location that use more spare parts and incurring a high cost. Engines running long hauls and short hauls can be assessed. The informatics present policy makers with a single page view of relevant maintenance data that can aid the design and manufacture of future products. Policy makers can decide to include new groups and levels into the system to assess risk.

The events timeline visualisation in Figure 4 shows the engine numbers and the levels of classified events on the left hand side of the dashboard. The different colour relates to the grouped events. The colours: black signifies installed maintenance, blue represents inspection, green is for delivery, grey illustrates instruction manual, red represents disruption and yellow is for overhaul. The timeline contains difference years and the drill down menu to filter only specific events. The dashboard shows events and when any colour is clicked the information relating to that engine is viewed. When the engine number with level is clicked, the stream of through-life engine maintenance information is opened (see Figure 5).

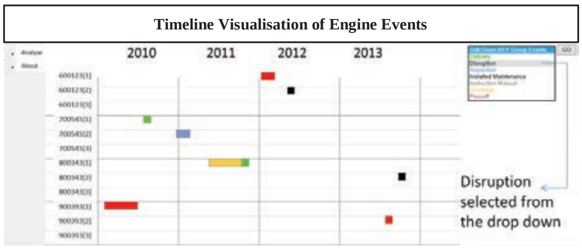

Figure 4 Events timeline visualisation

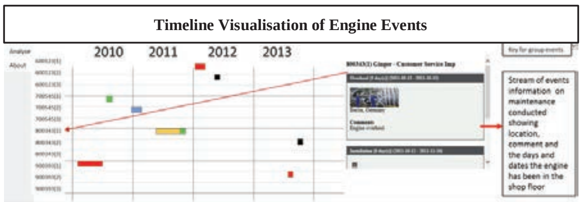

Figure 5 Stream of activities on events timeline visualisation

8. Conclusion

This paper presents a novel work in through-life engineering services perspective with a focus on the aerospace maintenance domain. The visualisation supports spare part management, tracking the activities of gas turbine engine parts and keeps a trial for audit purposes. The visualisations proffer insights, expectations, sentiments, and predictions. The lifespan estimation of components is being investigated.

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