ABSTRACT

In today’s global product development environment, the design of large scale systems is completed by distributing design tasks to various subsystems that are located in different parts of the world. Though such a process reduces the product development time (due to concurrent completion of design tasks), there also exists the possibilities of errors due to information communication and handling among the distributed subsystems. Errors in information communication get amplified when there exist a large number of subsystems with high coupling between them. Causes for errors in design information communication include loss of design information emails, corruption of attachments that include product data, duplication of files at multiple locations, different software being used to complete the same design task, etc. All these factors contribute to delays in the product development process. In this paper, a new approach for design information communication that utilizes Really Simple Syndication (RSS) feeds is proposed. Most information providing websites provide their users with RSS feeds that include the latest available news. In this paper, the same process is incorporated for design information communication within decentralized design through the use of a web-based design environment. The design of a golf driver head by two subsystems is used as a case study.

1. INTRODUCTION

In common industry practices, errors and mistakes can occur at many fronts. With the advent of globalization, the locations of different components of a product design corporation are distributed all over the globe. Designers in these decentralized scenarios communicate with each other via email, telephone or video conferencing. Most of the data and information is primarily transferred as attachments to email along with some usage of regular mail, faxes or in-person delivery of design information. In this environment, errors and mistakes can occur due to several events – emails get lost, attachments get corrupted, multiple versions of the same file exists at both ends of the communication, different software versions might render attached files unreadable and different software solutions can be used for the same task. Therefore, there exists a need to develop a better method for information and data communication between geographically distributed subsystems that can overcome these issues.

The internet has become the medium for data and information communication between geographically distributed systems and people. Today there exist web based frameworks for data communication in media studies [1], law [2] and engineering [3-5] to name a few. Web-based frameworks and IT tools have also been extensively used for the design of complex engineering products and processes. In particular, there exists significant research in the use of IT based methodologies for information communication in decentralized/collaborative design environments employing multiple, distributed designers. Wu et al developed the VE4PD information framework based on web services and agent based technology to manage information in a Collaborative Product Development process that extends through the entire lifecycle of the product [6]. Chu et al have developed tools for viewing, manipulating, providing mark-ups and modifying CAD files within a web browser [7].

Karlsruhe’s Virtual Documentation tool (KaViDo) is a web-based system for collaborative research and development [8]. KaViDo aids designers in recording and documenting the
product development process, manage the competences of distributed “experts” and assists in exchanging user experiences during product design. XML is used to exchange data between KaViDo and other applications. PRE-RMI is another platform independent framework that integrates distributed and heterogeneous software resources to support computationally intensive activities in the product design process [9]. PRE-RMI is coded in Java and uses Java’s RMI messaging system.

WebBlow is a multi-agent environment for Multidisciplinary Design Optimization (MDO) problems that uses multiple software agents, the Internet as well as XML [10]. WebBlow uses XML for data management on the server side as well as for message exchanges between software agents. Parashar et al present an XML based data architecture for MDO problems that combines optimization and analysis data [11]. In addition to the aforementioned frameworks, there exist a large number of platform independent, web-based frameworks for information communication between distributed designers that can be found in the literature [12-19]. In many of the above frameworks, a common feature that exists is the use of XML as a method for data and information communication.

The primary advantage of the use of XML is that it enables storage and communication of data and information in a text based format which is platform and software independent. Additionally, the extensible property of XML allows the users to prescribe any schema based on their needs and applications. However, this strength of XML is also its primary disadvantage as an information communication medium in decentralized design. This is because different designers and disciplines have different schemas used to represent the data. Several researchers have worked towards developing standardized XML schemas that can be used for distributed design [11, 20]. However, there exists a lack of consensus since proposed schemas might not be suitable for all different design scenarios.

In this paper, a new methodology for information communication that leverages the latest developments in Information Technology (IT) is presented. The methodology proposed in this paper is based on the use of Really Simple Syndication (RSS) feeds. RSS feeds are now commonly seen on all information and news providing websites. These feeds are comprised of the latest information that the host website is providing and are dynamically updated with every piece of breaking news. Users subscribe to these feeds from multiple sources that are then aggregated in a single location (for example, Google Reader, Windows Vista). RSS feeds eliminate the need for a user to visit multiple websites several times to obtain the latest information since the latest information is autonomously updated for the user subscribed via the RSS feeds. RSS feeds are developed using a universally accepted standardized XML schema.

This paper presents an approach for design information communication within decentralized design through the use of RSS feeds. This approach is compared to the use of the traditional email approach for information communication. Other methods for information communication include faxes, in-person delivery of design information and discussions in meetings. Though the web based approach is not explicitly compared to these other methods, the disadvantages of the email approach listed in this paper also hold for these methods.

The rest of the paper is divided as follows: Section 2 provides technical background on RSS feeds and the proposed methodology of using RSS feeds for engineering design. The problem of designing a golf driver head by two subsystems, namely the business and engineering subsystems is formulated in Section 3. Section 4 presents the design solution using a traditional approach of using emails and attachments for information communication. The concept of RSS feeds is implemented for the golf club design problem in Section 5 through the development of a web based interface between the subsystems. Section 5 also provides the system implementation of the developed web based interface. Section 6 compares the converged results obtained through both the traditional and IT approaches of design information communication. The paper concludes with closing remarks in Section 7.

2. RSS FEEDS

RSS feeds are created using a standardized XML schema. In this paper, Really Simple Syndication or RSS 2.0 is implemented. A generalized schema of RSS 2.0 is shown in Figure 1.

```
<?xml version='1.0' encoding='UTF-8'?>
<rss version = '2.0'>
  <channel>
    <title> Title of Feed </title>
    <link> Link to Host </link>
    <description> Description of the feed </description>
  </channel>
  <item>
    <title> Title of the news item one </title>
    <description> Description of the news item one </description>
    <link> Link to the news item one </link>
  </item>
  <item>
    <title> Title of the news item two </title>
    <description> Description of the news item two </description>
    <link> Link to the news item one </link>
  </item>
</rss>
```

Figure 1: Generalized RSS 2.0 Schema

In Figure 1, the root element is specified by the <rss> tag, which informs the parser of the feed that the document is a RSS feed. Nested within the <rss> element is the <channel> element. The <title>, <description> and <link> elements are required for <channel> elements. These elements provide the basic information about the feed; <title> corresponds to the name of the channel. It usually refers to the title of the webpage where the information is being updated. The element <link> stores the URL to the website corresponding to the channel. The <description> element contains a phrase or a sentence describing the channel. In addition to these three required
elements, there exist several optional channel elements that are available within RSS 2.0 [21].

A channel can contain any number of <item> elements. Each new piece of information or news is stored in an item. Like a channel, an item can have several elements. Though there exist no required elements within an item, at least one of <title> or <description> needs to be present.

For complex engineering systems, the growth in computational speed has enabled the generation of large amounts of design information in relatively small amounts of time. In a design scenario comprising of a large number of distributed subsystems with many coupled design variables, communicating such large amounts of design information is not a trivial task. This paper proposes the use of RSS feeds as a medium for design information communication within distributed systems. The primary advantages of using RSS feeds are:

- The RSS schema is easily portable for engineering design needs. Each item element in an RSS feed can be set to correspond to an individual piece of design information. For decentralized design problems each design variable is stored within an individual <item> element. The title sub element refers to the name of the design variable and the description sub element stores the value of the design variable.
- The link sub element can be used if the desired information communicated is a data file, graphic, picture, report or presentation. For example, if one subsystem needs to communicate a screenshot or link of a CAD model to another subsystem, it can link the screenshot using the link tags to the RSS feeds. The subsystem subscribed to the RSS feed can then click on the link at its end and view the image. This prevents the existence of multiple files at the two communicating ends.
- The schema for RSS feeds are universally accepted standards set by the World Wide Web consortium [22]. Therefore, designers from different design subsystems do not require specifying specialized XML schemas for communication of their design information.
- Analogous to bloggers subscribing to feeds from several different news organizations, designers within one subsystem can subscribe to the feeds of multiple subsystems. Using this approach, information about a design change made by one subsystem can be immediately communicated to all affected subsystems and digested. The use of RSS feeds provides a practical medium for realizing the goals of concurrent engineering. Additionally, a subsystem can broadcast multiple RSS feeds if the information communicated to one subsystem is not to be communicated to another.
- RSS feeds are easily setup to read from databases that might store generated design information. This enables automating the entire process of information communication when using the internet for data communication.
- By utilizing a standardized XML schema, the individual subsystems do not need to communicate any additional information such as style sheets that are otherwise needed for the interpretation or display of the data stored in a regular XML file. All subsystems are familiar with the structure of the schema and the desired information can be easily obtained from the RSS feeds.

The schema used for design information is henceforth referred to as Engineering-RSS feeds or E-RSS. Figure 2 shows a generalized schema for E-RSS feeds.

```xml
<?xml version="1.0" encoding="utf-8" ?>
<rss version="2.0">
  <channel>
    <title>NAME OF SUBSYSTEM</title>
    <link>LINK TO SUBSYSTEM</link>
    <description>DESCRIPTION OF SUBSYSTEM'S ROLE</description>
  </channel>
  <item>...
    <title>NAME OF DESIGN VARIABLE</title>
    <description>VALUE OF DESIGN VARIABLE</description>
    <link>LINK TO DESIGN INFORMATION</link>
  </item>

  "ADD MORE ITEMS FOR EACH DESIGN VARIABLE/DESIGN INFO-----"
</rss>
```

**Figure 2: Generalized Schema of E-RSS Feeds**

As seen in Figure 2, information about the subsystem is stored in the initial <title>, <link> and <description> elements. The subsequent <item> elements comprise of communicated design variable information. The <title> element within each <item> comprises of the design variable name and the <description> element stores the latest modified value of the design variable.

Given the understanding of RSS feeds and the proposed E-RSS schema, the next section introduces a case study for which a web based framework is developed. Design information is communicated within this web based framework by employing E-RSS feeds. The case study is the design of a golf driver club head by two subsystems within a corporation.

### 3. CASE STUDY PROBLEM FORMULATION: GOLF DRIVER CLUB HEAD DESIGN

In the previous section, a review of the use of IT resources in engineering design frameworks is presented along with background information on RSS feeds. The previous section also proposed the use of RSS feeds as a medium for design information communication in distributed design systems. In this section, the design of the club head of a golf driver by two decentralized subsystems is introduced. The two subsystems are the *Business subsystem* and *Engineering subsystem*. It is assumed that both subsystems are entities of the same company but geographically located in different places. Both subsystems have their own individual goals and control different design variables but their individual decisions affect the solutions of the other subsystem. Additionally both subsystems are subject to design constraints set by the United States Golf Association (USGA).

It is hypothesized that the two subsystems follow a sequential iterative design approach where the business subsystem makes
its decisions and passes marketing information to the engineering subsystem. The engineering subsystem then makes its own decisions and communicates its solutions back to the business subsystem. The process continues until convergence is achieved. The schematic of this decentralized design scenario is shown in Figure 3. The formal problem statements for the two subsystems are given next.

**Business Subsystem:**

The goal of the Business Subsystem is to maximize the market share captured by the designed driver. Market share is evaluated as a function of the selling price, weight of the driver and Moment of Inertia (MOI) about the center of gravity of the driver. It is assumed that the market share depends on only these three attributes since this is the commonly provided product information for golf drivers in sporting goods stores. The business subsystem selects the appropriate material to be used for manufacture of the club head and sets the price at which the club should be sold. The weight of the club head is determined by multiplying the density of the selected material with the volume of material used. Material volume is determined by the engineering subsystem. The MOI at the center of gravity is a function of the selected material density (business decision) and design configuration (engineering decision). The material choices for the business subsystem along with the corresponding densities are given in Table 1. The list of choices is obtained from [23].

<table>
<thead>
<tr>
<th>Material Name</th>
<th>Density (gm/cc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc Alloy</td>
<td>7.049</td>
</tr>
<tr>
<td>Aluminum Alloy</td>
<td>7.702</td>
</tr>
<tr>
<td>Aluminum</td>
<td>2.74</td>
</tr>
<tr>
<td>Titanium</td>
<td>4.5</td>
</tr>
<tr>
<td>Titanium Alloy</td>
<td>4.85</td>
</tr>
<tr>
<td>431 Stainless Steel</td>
<td>8.03</td>
</tr>
<tr>
<td>17-4ph Stainless Steel</td>
<td>7.85</td>
</tr>
</tbody>
</table>

**Table 1: Material Choices for Driver Head**

In order to determine the overall market share model, regression based models of market share as a function of the three attributes are independently developed next and combined using a weighted sum approach. The regression models are developed using data on price, weight and MOI from existing drivers that are sold in sporting goods stores.

**Market share vs. Price:** In order to come up with this function, the overall price range for existing drivers was determined. It was found that there exist drivers as cheap as $30 and as expensive as $800. Using this as the attribute range, it is assumed that there exists a section of the total market that purchases drivers within this entire range. For example, it is assumed that 2% of the total market comprised of professionals that are willing to purchase an $800 driver. At the same time, 2% of the market is comprised of beginners who would only pay $30 for a driver. For the intermediate price range, data is generated to determine a model for market share as a function of the driver price. This data is generated by investigating the prices on available clubs in sports stores. The regression model is given in equation (1).

\[ MS(P) = -0.000000002P^4 + 0.000004P^3 - 0.0025P^2 + 0.5199P - 10.763 \]

where \( MS \) represents market share and \( P \) represents price. The predicted model is plotted in Figure 4 along with the generated data and is explained below.

![Figure 4: Market Share Vs Price](image-url)

The blue (thin line) curve represents the generated data while the black (thick line) curve represents the regression model fitted using Excel. The obtained \( R^2 \) value is also shown in Figure 4. It is acknowledged that this value is relatively low compared to the desired value of 1. However, this was the best fit obtained among all available regression models in Excel.

The first peak on the blue curve in Figure 4 represents most average to better-than-average golfers in the market who would be willing to buy drivers in the $150-$200 price range resulting in a high market share. This was assumed based on investigation of the available clubs in sports stores. It was found that this was the most common price range for drivers.

The second peak in the blue curve represents the market for $300 clubs. Since a significantly higher number of commercially available clubs with this price tag were also found, it was assumed that the market for this price was higher than that for prices in the range between $200 and $300. Next,
the model for market share as a function of club head weight is developed.

**Market Share Vs Weight:** Using a preliminary version of the driver head CAD model developed by the engineering subsystem, the appropriate range for the weight of the club head is determined. The CAD model provides the volume of material that would be used for manufacturing the club. The material volume is multiplied by the density of different materials to obtain a range for club head weight. Based on this, the range of possible weights for the club head was identified to be between 200 gm and 350 gm. Additionally, it is assumed that market share reduces as the weight increases. For example, it is assumed that 100% of the market share is captured with a club whose head weight is 200 gm while 0% of the market share is captured with a weight of 350 gm. This forms the bounds for the model of market share as a function of club head weight.

In addition to the bounds, it is also assumed that the market share function does not vary linearly with respect to the weight. The function is such that for small increases over 200 gm in club head weight, the market share does not decrease significantly. However, as the weight increases towards 350 gm, the market share reduces significantly. Using these guidelines, a model of market share as a function of club head weight is developed using regression. This is shown in equation (2) and plotted in Figure 5.

\[
MS(Wt) = -0.0045Wt^2 + 1.7787Wt - 79.449 \tag{2}
\]

A quadratic function is used to model the change in market share with changes in club head weight. An \( R^2 \) value of 0.9766 is obtained for the regression model in turn validating the choice of the quadratic function.

![Figure 5: Market Share Vs Club Head Weight](image)

The model for market share as a function of MOI at the center of gravity is presented next.

**Market Share Vs MOI:** The primary goal in the design of a driver is to provide as large a “sweet spot” as possible since this is most forgiving on hits that are off center. For this purpose, designers traditionally increased the size of the head and developed new composite materials that were light weight. However, the USGA has constrained the total volume of the club head to not exceed beyond 460 cc thus restricting the possible increases in size of the club face [24].

In recent times, there has been a significant change in the design approach for golf drivers. For new drivers, it is seen that the center of gravity is moved such that a higher MOI is obtained. A higher MOI implies greater stability which in turn translates to the club being more forgiving on off-center hits.

With these new developments in driver design, the USGA has now set limits on the MOI. According to the USGA, drivers MOI cannot exceed 5900 gm-cm\(^2\). This results in the addition of an extra constraint in the design of golf club drivers. However, from a business perspective, more market share will be captured by designing clubs with higher MOI, with the USGA constraint serving as the upper bound.

In order to develop a model of market share as a function of MOI, data is generated for market share as MOI is increased from 0 gm-cm\(^2\) to 5900 gm-cm\(^2\). The lower bound for MOI is set to 0 gm-cm\(^2\), implying a non existent driver. For the market share model, this implies that if there is no club, there will be no buyers. As the MOI increases, the number of buyers of the club increases non-linearly. For small increments in MOI towards the lower end of the range, the market share does not increase significantly resulting in a flat curve. As the MOI increases over 4000 gm-cm\(^2\), there is a steep increase in market share. Most commercially available drivers have a MOI around 4500 gm-cm\(^2\).

These trends are utilized in the development of the market share model. The market share model as a function of MOI is mathematically shown in equation (3).

\[
MS(MOI) = -3 \times 10^{-13} MOI^4 + 2 \times 10^{-9} MOI^3 + 3 \times 10^{-6} MOI^2 - 0.0046 MOI + 0.4342 \tag{3}
\]

The generated data and regression model are plotted in Figure 6. The \( R^2 \) value for the regression model of equation (3) is 0.996, implying the fit curve is close to the actual data. This is plotted in Figure 6.

![Figure 6: Market Share Vs MOI](image)

Given the formulation of the market share as a function of the three attributes, a simple weighted sum approach is used to determine the total market share as the three attributes are individually varied. This total market share formulation is shown in equation (4).

\[

\]
where \( w_1, w_2 \) and \( w_3 \) are relative importance or weights for the three attributes. It is noted that the weighted sum approach is limiting but is used for this problem for simplicity.

The goal of the business subsystem, as stated previously, is to maximize market share. The tasks for the business subsystem include determining a material, calculating the weight of the club head by multiplying the material density with the volume obtained from engineering, setting the appropriate attribute weights and determining the maximum attainable market share. The Engineering Subsystem sub-problem is explained next.

**Engineering Subsystem:**

The goal of the Engineering Subsystem is to minimize the material used for the club head while ensuring structural integrity. The engineering subsystem makes modifications to the CAD model. The design modifications are subject to USGA constraints on MOI and total head volume. For this case study, the PRO/ENGINEER CAD software from PTC is used for solid modeling. Additionally, PRO/MECHANICA is used to perform FEM stress analyses. As part of PRO/MECHANICA analyses results, it is possible to determine the weight of the model as well as the MOI at the center of gravity.

The engineering subsystem obtains information about the material to be used from the business Subsystem and performs FEM analyses to determine stresses, deflections, weight and MOI of the modeled club head. Based on the determined weight, the engineering subsystem makes design modifications and repeats the FEM analyses to determine feasibility. For the FEM analyses, a force that corresponds to the impact of hitting golf balls needs to be applied to the CAD model. The normal force of golf balls is approximately 9kN [25]. The CAD model along with the acting loads and applied constraints are shown in Figure 7. The constraints are considered appropriate since the model is designed to withstand the impact of hitting the ball which in turn results in no deviation on the upper and lower surfaces.

Given the decentralized design schematic for the design of the club head in Figure 3 as well as the models for the two subsystems, it is now possible to simulate the sequential iterative design decision making process and determine a design for the club head. This is presented in Section 4.

**4. CASE STUDY: TRADITIONAL SOLUTION**

In the previous section, the problem description of the business and engineering subsystems is presented. Figure 3 includes the individual optimization problem formulations of the two subsystems. In this section the iterative process to determine a club design is simulated. In order to perform this simulation, two people are asked to play the roles of business and engineering respectively. They are provided with the above models and are asked to make respective decisions. Both people in this simulation are experienced mechanical engineers familiar with engineering design concepts and tools as well as occasional golfers. As per the schematic of Figure 3, the person playing the role of the business subsystem goes first in the sequential iterative process followed by the engineering subsystem.

The design process simulation is carried out using the traditional approach of information communication. That is, designers communicate via email where all data is included either in the body of the email or as an attachment. The outcome of the first iteration of this process is discussed and results for all subsequent iterations are tabulated in Table 2.

**Iteration 1:**

The Business Subsystem assumes the following values of MOI and material volume:

\[
\text{MOI} = 5040.6 \text{ gm-cm}^2 \\
\text{Material Volume} = 30.7cc
\]

The business subsystem selects these values since they represent the ideal configuration of the engineering subsystem variables from the business subsystem’s perspective. A high MOI and low material volume translates to high market share. Based on these values for MOI and material volume, the business subsystem determines the price, attribute weights and material type that results in the highest possible market share. These variable values are given below.

\[
\text{Price} = 200.00 \\
\text{Weight for attribute Price} = 0.3 \\
\text{Weight for attribute MOI} = 0.3
\]
**Weight for Attribute Driver Head Weight** = 0.4
Selected Material: Titanium Alloy (density 4.85gm/cc)

The maximum attainable market share is:

**Maximum Market Share = 75.64%**

The value for material volume is very low while the value for MOI is less than the USGA constraint. It can be expected that the low material volume would be infeasible with respect to the engineering subsystem (structural failure). The engineering subsystem would consequently make design decisions and determine feasible values.

The information is communicated via email to the engineering subsystem with the excel file used for market share calculations attached to the email. The engineering subsystem then determines the minimum material volume and maximum MOI possible. In order to determine the design corresponding to the minimum volume and maximum MOI, the engineering subsystem starts with a previously developed CAD model and manually modifies the CAD model to determine the satisfactory design configuration. These manual modifications include changing the thickness of the club head and modifying the overall design shape. The thickness is modified to obtain a lighter driver head while also ensuring safety with respect to stresses. The overall design shape is modified to obtain a higher MOI about the center of gravity.

For every change made, the FEM analysis is repeated to determine the feasibility of the modified design. This entire process is computationally expensive since it is not automated. It is acknowledged that this is not a realistic replication of industry practices; however, the goal of this case study is not to develop a new driver head but to study the method for information communication between the subsystems. These values for material volume and MOI obtained by the engineering subsystem for this iteration are:

**Minimum Material Volume = 73.64cc**
Minimum MOI = 5823.57 gm-cm

This information is communicated back to the business subsystem via email that then recalculates the market share. The email sent by the engineering subsystem to the business subsystem includes 2 attachment files: one is a screenshot of the CAD model and the other is a screenshot of the stresses and deflections in the developed CAD model. The time between the start of the process by the business subsystem to receiving an email from the engineering subsystem was a total of 2 days; this time duration included time for the multiple FEM analyses to run as well as the waiting time for one subsystem while the other completed its tasks.

With the new values for MOI and material volume, the new market share was 36.93%, a significant drop. The consequent modifications made by the business subsystem are presented in Table 2.

<table>
<thead>
<tr>
<th>Iteration No.</th>
<th>Material</th>
<th>Material Density (g/cc)</th>
<th>MOI (g*cm²)</th>
<th>Volume of Material (cc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Titanium Alloy</td>
<td>4.85</td>
<td>5823.57</td>
<td>73.64</td>
</tr>
<tr>
<td>2</td>
<td>Aluminum</td>
<td>2.74</td>
<td>INF</td>
<td>INF</td>
</tr>
<tr>
<td>3</td>
<td>Titanium</td>
<td>4.5</td>
<td>5504.83</td>
<td>72.97</td>
</tr>
</tbody>
</table>

**Table 2: Sequential Iterative Solution Process with Email Communication**

In Table 2, INF refers to infeasibility of the design based on the selected material. The final choice of Titanium as the material for manufacture of the driver head seems valid since most of the drivers available in the market today are made of titanium.

Though the decentralized design process converges on an expected choice for material type, the goal of this paper is not to study the solution of the design process but rather the medium for information communication between the designers. Some observations with regards to the method of information communication are summarized in Table 3.

<table>
<thead>
<tr>
<th></th>
<th>Total number of emails sent between the two subsystems</th>
<th>Total number of files attached to the emails</th>
<th>Total number of days to complete the design process (time for communication)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
<td>7</td>
<td>4</td>
</tr>
</tbody>
</table>

**Table 3: Communicated Information Between Decentralized Designers**

In addition to the information provided in Table 3, it is important to note that all the work was carried out during working days. Designers were unable to do any modifications over the weekend since the necessary files were at work and could not be accessed from home. This is important because in the next section, a web based design platform is introduced which allows designers to perform modifications in any location. Information in this web based platform is communicated through E-RSS feeds introduced in Section 3. The web based platform also provides designers with the ability to perform computations that do not require specialized software remotely. Additionally, through the use of a database, design information during every iteration is stored and easily accessed at any given time. The web based design framework using E-RSS feeds is presented in Section 5 next.

**5. CASE STUDY: E-RSS SOLUTION**

In the previous section, the iterative solution for the design of a golf driver head problem is presented as a case study. The subsystems communicated with each other through email and used attachments for the transfer of necessary files. In this section, a new medium for design modification and information communication through the use of the internet is presented. This web based design platform comprises of the following three segments for system implementation:
• Database management (Programming Language: MySQL)  
• Information Communication (Programming Language: XML for E-RSS feeds)  
• Web Design (Programming Language: PHP)

The three segments for the design of the club head are individually discussed next.

5.1.1. Database Management:
A database is a collection of tables used for the storage and retrieval of data and information. For the club head design problem, each subsystem creates, maintains and updates its own database. The business subsystem database comprises of three tables as shown in Figure 9.

The elements in Figure 9 correspond to the three tables that make up the database – Business, Materials and Weight Model. The entries under each table name correspond to the names of the fields or columns of the individual table. The Business table is the main table for the business subsystem. Each entry in this table corresponds to the solutions for each iteration. This table stores the volume of material and MOI information obtained from the engineering subsystem.

![Figure 9: Business Subsystem Database](image)

Additionally, this table also stores the local decisions such as price of the club, the weights for the three attributes (price, MOI and club head weight) as well as the calculated value of market share. Material information is stored in the Materials table and connected to the Business table through the “Material ID” field. The Weight Model table stores the coefficients of the market share versus club head weight function (equation (2)).

This model is given an independent table because it is assumed that the designer would be required to modify equation (2) based on the club head weight information obtained from the engineering subsystem. The other two models (equation (1) and equation (3)) are hard coded into the web based framework and assumed to not undergo any changes as the design process progresses.

The engineering subsystem database is comprised of only a single table called “Engineering” as shown in Figure 10.

![Figure 10: Engineering Subsystem Database](image)

The Engineering table stores the name and density of the material selected and communicated by the business subsystem. Additionally, the information generated locally, such as volume of material and MOI are also stored in this table. It is seen from Figure 10 that there exists two more fields namely “Design Figure” and “Stress Figure”. These fields store the names of uploaded screenshots of the CAD model and results of the FEM analyses when a feasible solution is reached. The uploaded files are stored on the server hosting the websites and their names are stored in the Engineering table.

The aforementioned tables are all developed and hosted within a MySQL server. MySQL is selected as the system for database management for its compatibility with PHP, which is the scripting language used to develop the subsystem websites. The medium for design information communication using RSS feeds is presented next.

5.1.2. Information Communication:
The previous section explains the database design for the two subsystems that iterate to determine the design for a golf driver head. As discussed in Section 3, E-RSS feeds are used for communicating design information between subsystems. Using the schema provided in Figure 2, E-RSS feeds are generated by each subsystem at the completion of each iteration. An example E-RSS feed for the business subsystem after iteration 3 from Table 2 is provided in Figure 11.

```xml
<?xml version="1.0" encoding="UTF-8" ?>
<rss version="2.0">
  <channel>
    <title>Business Subsystem News</title>
    <link>http://webaddress/BusWebPage.php</link>
    <description>Latest decisions from Business Subsystem</description>
    <language>en-us</language>
    <item>
      <title>Selected Material</title>
      <description>Titanium</description>
      <link>http://webaddress/BusWebPage.php</link>
    </item>
    <item>
      <title>Material Density</title>
      <description>4.5 gm/cc</description>
      <link>http://webaddress/BusWebPage.php</link>
    </item>
  </channel>
</rss>
```

![Figure 11: E-RSS Feed for Business Subsystem](image)

As seen in Figure 11, the information communicated by the business subsystem to the engineering subsystem, namely
material name and material density, is stored within two “item” elements. The link element within the item element stores the web address to the website that displays the business subsystem’s current decision. The corresponding E-RSS feed of the engineering subsystem after iteration 3 is shown in Figure 12.

```xml
<?xml version="1.0" encoding="UTF-8" ?>
<rss version="2.0">
  <channel>
    <title>Engineering Subsystem News</title>
    <link>http://webaddress/EngWebPage.php</link>
    <description>Latest design configuration from Engineering Subsystem</description>
    <language>en-us</language>
    <item>
      <title>Feasibility of Current Design</title>
      <description>Feasible</description>
      <link>http://webaddress/EngWebPage.php</link>
    </item>
    <item>
      <title>Club Head Material Volume</title>
      <description>72.97cc</description>
      <link>http://webaddress/EngWebPage.php</link>
    </item>
    <item>
      <title>Moment of Inertia</title>
      <description>5504.83gm sq.cm</description>
      <link>http://webaddress/EngWebPage.php</link>
    </item>
    <item>
      <title>Club Head Figure</title>
      <description>This is a figure of the latest design</description>
      <link>http://webaddress/EngModelFig.jpg</link>
    </item>
    <item>
      <title>Club Head Analysis Figure</title>
      <description>This is a figure of the latest design analysis</description>
      <link>http://webaddress/EngStressFig.jpg</link>
    </item>
  </channel>
</rss>

Figure 12: E-RSS Feed for Engineering Subsystem after Iteration 3

For the E-RSS feeds of Figure 12, all information communicated by the engineering subsystem, namely feasibility, material volume, MOI and screenshots of the CAD model and FEM analyses, are stored within individual “item” elements. For the item elements storing the feasibility, material volume and MOI information, the link elements contain the web address to the website displaying the engineering subsystems current decision. The link elements within the figures items (Club Head Figure, Club Head Analysis Figure) contain the web address to the location of the actual figures on the local host server. The web addresses within the link elements are generically referred to as “http://webaddress/”.

With the database model and E-RSS feeds setup for the two subsystems, these tools can now be brought together under a web based design framework for the design of the golf driver head. Each subsystem designs its own website using PHP scripting utilizing its individual databases. Additionally, each subsystem subscribes to the E-RSS feed of the other subsystem and parses the information contained in the feed for display on its local website. The details of the subsystem websites is presented next.

5.1.3. Website Functionality and Layout:
The development of the web based decentralized design platform involves bringing together the developed subsystem databases for local data storage and retrieval, E-RSS feeds for non local data and tools to perform local computations online. For the golf club head, an independent website is developed for each of the two subsystems. The salient feature of these websites is that design information from non local subsystem E-RSS feeds is immediately and automatically parsed and available on the main webpage. Additionally any evaluation/analyses affected by the non local design information can also be automatically updated with the latest non local modifications.

With the web based design platform developed for both subsystems, it is now possible to simulate the sequential decision making process for the design of the golf driver head. This is discussed in the next subsection.

5.2. Design Process Simulation Using E-RSS Feeds

For this simulation, the business subsystem makes the first decision by assuming values for material volume and MOI. The engineering subsystem then follows with its decision.

In order to perform the simulation, the web addresses were distributed to the two people who played the role of each of the subsystems respectively. The person playing the role of the business subsystem was different from the one earlier, while the person playing the role of the engineer was the same. The simulation using the web based platform took three iterations, similar to the traditional email approach.

The business subsystem set a desired price and determined the material type by exhaustively sampling the material choices and obtaining the choice that maximized market share. The engineering subsystem modified the thickness and overall shape of the club head in order to obtain designs that reduced the volume of material used as well as increased the MOI about the center of gravity. Table 4 shows the design decisions of the two subsystems for the three iterations.

<table>
<thead>
<tr>
<th>Iteration No.</th>
<th>Material</th>
<th>Material Density (g/cc)</th>
<th>MOI (g-cm²)</th>
<th>Material Volume (cc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Titanium</td>
<td>4.5</td>
<td>5504.83</td>
<td>72.97</td>
</tr>
<tr>
<td>2</td>
<td>Aluminum</td>
<td>2.74</td>
<td>INF</td>
<td>INF</td>
</tr>
<tr>
<td>3</td>
<td>Titanium</td>
<td>4.5</td>
<td>5504.83</td>
<td>72.97</td>
</tr>
</tbody>
</table>

Table 4: Sequential Iterative Process Using Web-Based Design Framework

As seen in Table 4, the final selected material is again Titanium. In this simulation, the business subsystem selected Titanium in the first iteration and passed that information to engineering. Upon receiving the response on material volume
and MOI from engineering, the business subsystem selected aluminum in order to maximize market share, similar to the person in the simulation of Section 5. This was determined to be an infeasible choice by the engineering subsystem that resulted in the business subsystem returning to Titanium.

Since the simulation of the decentralized design process resulted in the same solution as that presented in Section 5, the question that arises is, what is the value of the developed framework? In order to answer this question, the goal of developing the web-based framework is revisited. As stated earlier, the objective of this paper was not to improve the solution of the decentralized design process but rather to improve the method for information communication within the design process.

Obtaining the same solution when using both email and the web-based framework as methods for data communication validated that the methods of communication converged to the same solution and that the business subsystem model was accurately programmed in the web-based framework. The solution converged upon by the two subsystems is optimal from the perspective of the business subsystem since there does not exist a different solution that provides a higher market share for the given engineering design decisions.

The engineering subsystem manually changed design dimensions and tested the feasibility of the design for stresses and MOI. However, design dimensions are continuous variables and there could exist a design configuration that further reduced the material volume. This reduction would result in the material volume being of the same order of magnitude as that achieved in the given solution thus not adding significant value to the new design. In the next section, the elimination of information communication errors through the use of E-RSS feeds is discussed.

6. DISCUSSION

In Section 1, it is noted that when communicating design information using traditional approaches such as email, there exist several sources of mistakes. For example, emails get lost, attachments get corrupted, and multiple versions of files exist all over the place. In order to compare the two methods used for information communication, the data presented in Table 3 is presented in Table 5 for the web-based design framework.

<table>
<thead>
<tr>
<th></th>
<th>E-RSS Feeds</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of emails sent between subsystems</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Total number of files attached to the emails</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Total number of days to complete the design process (time for communication)</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 5: Comparison of Information Communication Methods in Decentralized Decision Systems

Based on the information in Table 5, the following inferences can be drawn:

- No emails were exchanged between the subsystems when using the web-based framework. Potential loss of design information present within emails was therefore eliminated through the use of E-RSS feeds.
- When using the web-based design approach, since no emails were exchanged, no files were sent as attachments either. Therefore, errors pertaining to data lost through corrupted attachments and existence of multiple versions of the same file are eliminated when using E-RSS feeds for design information communication.
- It is also seen in Table 5 that the communication time reduced for the web-based framework. This is attributed to the ability of the person playing the role of the business subsystem to work at home without the need for any extra files. Therefore, for design decision tasks that can be performed in a web-based environment, it is recommended to use this resource as it allows the designers to work at locations outside of the office without having to carry additional files or corporate laptops.
- It is recognized that the number of days for completion of the design process is subjective in that it is impacted by weekends, access to necessary resources, and individual work routines. However, the general trend of reduced design time when using E-RSS feeds can be inferred. This is because a significant advantage of using E-RSS feeds is that one designer is not waiting on the non-local subsystem designer for its design information. The latest design modifications are automatically updated within the system and transferred to the subscribed non-local subsystems. This process does not require the designers to “communicate” design information.
- This approach for information communication has its advantages over the use of meetings and faxes as well. While personal interaction in meetings may facilitate consensus building, meetings may add unnecessary time to the design process. In addition, faxes typically take even longer than email and are more limited in their communication capabilities.

Thus, it can be concluded that the presented methodology provides significant potential for improvement of the information communication in decentralized decision systems. In the next section, closing remarks for this paper are provided.

7. CLOSURE

In this paper, the problem of design information communication between decentralized designers of large scale complex engineering systems is addressed. The primary issue in such design systems is the occurrence of errors within communicated design data. Causes for such errors are loss of emails and attachments, existence of multiple versions of design files, use of different software/software versions for the completion of design tasks and delays in communication of design information. In order to eliminate these errors, a novel approach for design information communication using Really Simple Syndication (RSS) feeds within a web-based design framework is proposed in this paper. A universally standardized XML schema called Engineering-RSS or E-RSS feeds is developed for engineering design applications and implemented for a hypothetical golf driver head design problem. Based on the obtained results, it is seen that through the use of these E-RSS feeds within a web-based design environment, it is
possible for subsystems to instantaneously obtain the latest design modifications made by non local subsystems as well as eliminate causes for errors.

The case study presented in this paper is relatively small in terms of complex system design and is purely for illustration of the proposed methodology. As part of future work, a larger problem involving several subsystems with increased coupling of design information needs to be implemented. This would involve generation of multiple local E-RSS feeds that serve different pieces of information to different non local subsystems. Additionally, the process of transferring parsed information from E-RSS feeds to the local analysis system needs to be automated.

ACKNOWLEDGEMENTS

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REFERENCES

[22] W3Schools, 2006, "http://www.w3schools.com/"