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Design Trade-Offs in an Interactive Industrial Symbiosis Platform

Jennyfer Lawrence Taylor, Melanie Ayre, Sarah King, Cecile Paris

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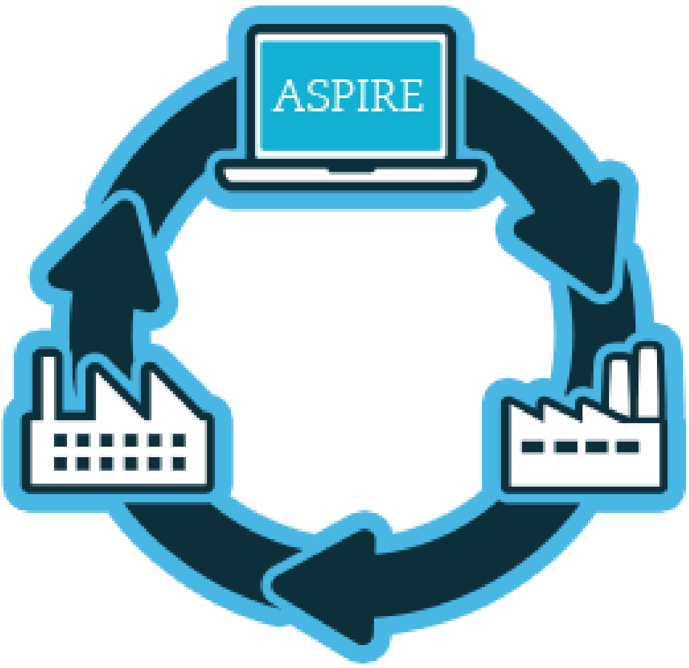

Contents

1 Abstract

The ASPIRE interactive platform improves the sustainability of the Australia's manufacturing sector by systematically identifying opportunities for exchange of resources such as wastes and by-products between firms, leading to successful industrial symbiosis outcomes (e.g., reduced operating costs and landfill waste). Stakeholders including small to medium enterprises (SMEs), designers, and business advisers demonstrate widely differing conceptual models of resources, necessitating design trade-offs. This paper explores different conceptual models of industrial resources, and identifies design trade-offs arising from those differences. It then evaluates the impact of these design choices on the users' ability to effectively describe their resources via an interactive web interface and receive meaningful waste management connections. This study highlights the challenging nature of interaction design in an industrial resource space, and the importance of understanding how users make sense of the world to ensure that design interventions meets their needs.

2 Introduction

Industrial waste management presents economic and environmental challenges to Australia's manufacturing sector. Australia has the highest material use in the Asia Pacific Region [29] and produces globally significant levels of waste [24]. SMEs represent 90% of its manufacturing sector [2], but waste remains a low priority, with SMEs being major contributors to landfill where they currently send 50% of their waste [25]. Given their high representation across the economy, SMEs are an ideal target for a strategy to drive resource efficiency and reduce waste to landfill though industrial symbiosis (IS), addressing the issue of increasing waste management costs [10].

Researchers, government, and industry networks have been leveraging Information and Communications Technology (ICT) to facilitate IS projects, where waste from one organisation's production processes is used as input to another to reduce waste disposal costs and environmental impact [16]. This project builds on previous Australian efforts in the mineral industry [3], and online resource exchange tools [15]. We deployed an interactive system that suggests potential waste management 'connections' between SMEs based on resource inputs and outputs (e.g., pallets, polystyrene).

A significant challenge in the design of an IS system is the taxonomic characterisation of resources [16, 28]. In Australia, there is no standardised waste classification system [23], and semantic approaches through resource ontologies remain in the early stages of development [28]. Moreover, IS stakeholders hold differing conceptual models of what constitutes a 'resource' and how these resources should be described and communicated to others. Design trade-offs were therefore necessary to enable users to accurately describe their resources, while finding a common ground to facilitate meaningful conversations with others. This qualitative study explores these conceptual models and design trade-offs through the following research questions:

- Do IS stakeholders differ in their conceptual models of resources?
- What design trade-offs result from these differences?

- What is the perceived impact of these trade-offs on users' ability to effectively represent their resources on the platform?

This case study addresses the specific challenges of interaction design in an industrial resource management context, particularly in developing a resource model. We illustrate some of the design decisions enabling us to successfully reconcile these competing perspectives and effectively manage trade-offs. This example also highlights the importance of understanding user conceptual models to ensure that design interventions deliver their intended benefits and support user adoption of these systems.

3 Background

There have been a number of attempts to design ICT systems to facilitate the development of IS [1,6,13,16,27,28] and web-based waste exchange networks [12,14,15]. These efforts to facilitate IS using digital tools build on the globally successful regional examples of IS from Kalundborg, Denmark [5,7], Ulsan, South Korea [4], Australia [3], and NISP, UK [22]. However, many ICT interventions have not been successful and are no longer available. This is likely due to issues such as a lack of industry awareness, the passive nature of waste exchange databases, and information confidentiality [9]. A more recent active waste exchange in our region is the Waste Not tool [15], but information on the site dates back to 2011 [17], showing a lack of activity.

Our system extends beyond these 'passive' systems, where information is posted by 'sellers' online for potential 'buyers'. Instead, our platform's algorithm actively matches companies based on potential resource exchange opportunities. This additional step improves opportunity identification and, in theory, the likelihood of a successful resource transfer. Since 'useful' matches are defined in terms of resource exchange, a common resource model is required for the system to understand resources and their relationships, and for users to accurately describe their resource and assess the value of a potential connection. However, the development of industrial resource ontologies and waste reporting frameworks has proven complex for many reasons, e.g., they require details not known to a waste producer, or they do not permit description of mixtures and semi-products [28].

3.1 Resource Model Design

Our initial resource model was populated through meetings with diverse SMEs, a paper-based, open-question survey, and a review of waste classification hierarchies. Paper and digital prototypes underwent user acceptance tests with SMEs and business advisers to refine the resource list. The initial implementation is a three level hierarchy displayed as an alphabetised list with text-match searching (Figure 1).

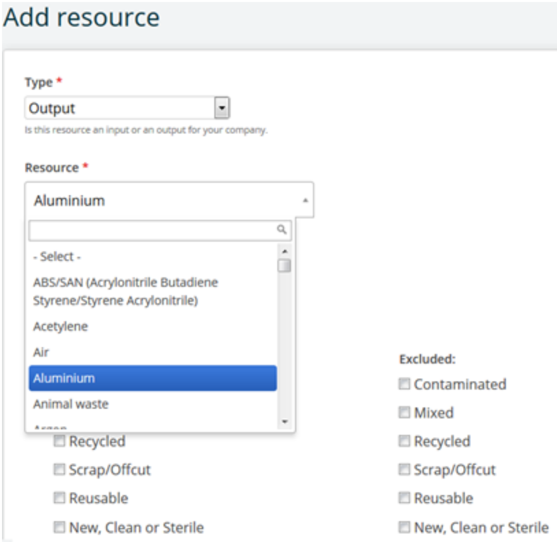

Figure 1. The "Add resource" section of our platform

The current resource model is organised around resource inputs and outputs, with 182 entries that allows users to identify resources at different levels of specificity according to their needs (e.g., Plastic → PS (Polystyrene) → EPS (Expanded Polystyrene)). Higher level groupings are based upon a mixture of resource properties including material, industrial domain, and final product. "Attribute" checkboxes enable users to communicate additional characteristics of their resources, such as 'contaminated', 'mixed', and 'scrap'. Additionally, 'Service Level Options' specify approximate value (a confidential field used by the model only), a minimum and maximum quantity, and production frequency (Figure 2). A photograph with a free text caption can also be uploaded.

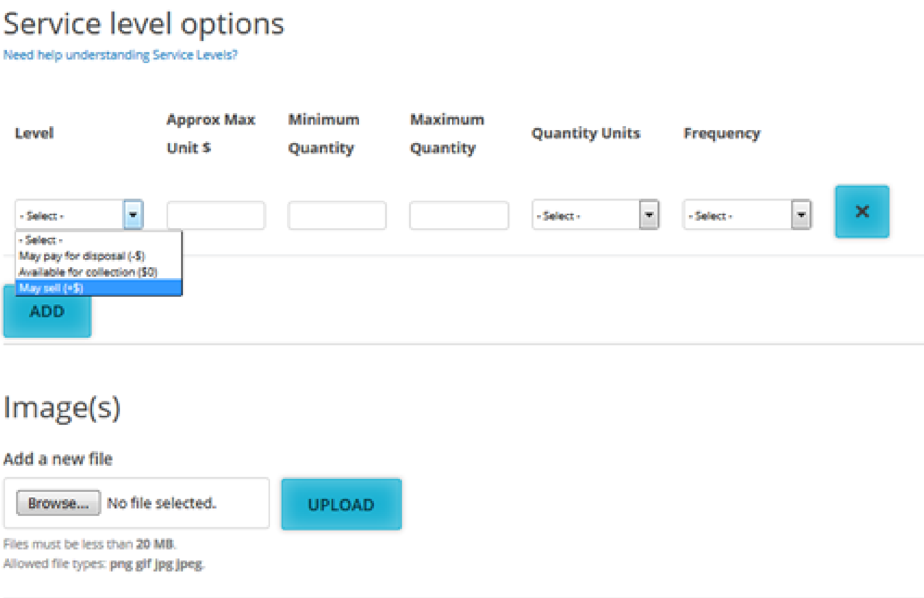

Figure 2. Service level options and image upload

4 Methodology

We undertook a grounded theory-style qualitative study examining the "social phenomenon" of resource conceptual models [8]. We leveraged "multiple forms of data" [11] from semi-structured interviews, workshops, and card sorting using a small, non-random sample of participants. An inductive, "open coding" process [18] was undertaken to analyse the data, where a coding framework was constructed and refined based on emerging themes. By analysing the relationships between the codes, we manually paired codes together that were related or stood in opposition (e.g. flexibility and prescriptivity), which indicated the presence of key design trade-offs in the data.

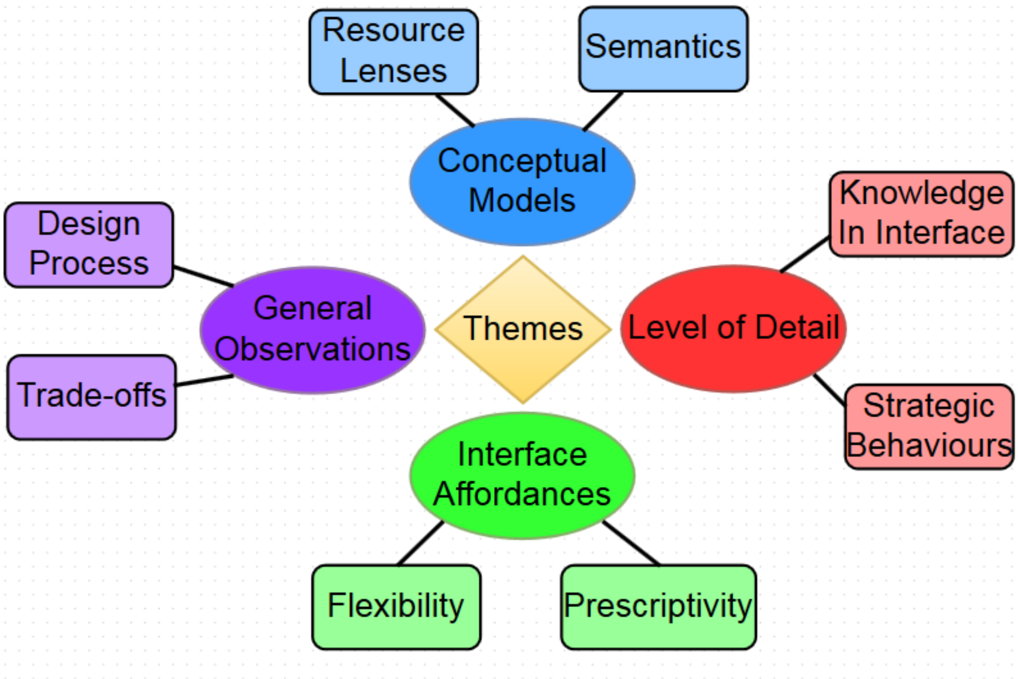

Figure 3. Coding framework

4.1 Interviews

We conducted individual, semi-structured interviews with 3 designers, 2 business advisers, and 2 SMEs to understand their perspectives on the resource model and design trade-offs. The notion of 'conceptual models' [21] provides a theoretical lens for exploring users' understandings of resources. A semi-structured approach allowed us to prepare questions concerning themes such as "resource semantics", with the flexibility to pursue unanticipated lines of enquiry through improvised follow-up questions [26].

4.2 Workshops

Two focus-group style workshops were facilitated by system designers to "assess user needs and feelings" [20] about the resource management interfaces and gain general usability feedback. Each two hour session comprised a mixture of 8-10 people including designers, business advisers, and SME users. Participants were guided through the process of registering their resources, with individual and general group discussion addressing topics such as the choice of language, layout, and level of detail in the interface.

4.3 Card Sorting

An “open” card sorting activity was an “inductive”, “generative” method of gaining insight into the variation in conceptual models people hold about resources [19]. Twelve participants (primarily research scientists) were provided with 26 cards listing commonly selected second level resources, and asked to organise them into “as many groups as desired” [19], label the groups, and illustrate inter-group relationships. While research scientists were selected given the difficulties associated with accessing SME users for this task, participants were of diverse backgrounds and academic backgrounds and could thus indicate the variability in conceptual models between users.

The qualitative data demonstrates the variety of conceptual models our stakeholders hold about industrial resources. These differences have resulted in design trade-offs concerning a) the degree of flexibility in describing resources afforded by the interface, and b) the level of detail captured in the interface.

5 Results and Discussion

5.1 Differing Conceptual Models of Resources

Analysis of different datasets confirmed that there was substantial variability in conceptual models both within the stakeholder groups, and between the stakeholder groups. As Norman suggests, the same person can even hold different conceptual models of the same thing given different usage circumstances [21]. Card sorting models were heavily influenced by the participants’ background and knowledge of industrial resources. For example, a participant working in the sustainability sector focussed on degree to which resource is sustainable, while an engineer thought about resources in terms of different engineering disciplines (e.g. mineral, chemical, civil resources). Knowing what a resource was made or used for also influenced the ease and granularity of the groupings.

The average number of groups in each diagram was 5-6. Some items could be placed in more than one group, and were swapped between groups during the drawing process or placed between groups (e.g., one participant moved rubber between “natural materials” and “industrial materials”). Factors influencing the definition of groups included: the amount of resource processing required from its natural form or source materials, whether the resource was seen as a waste/by-product or new material, whether the resource was perceived to be domestic or industrial, and whether it was using for “building”/”construction” which is a commonly occurring category.

5.1.1 Resource lenses

The researchers analysed the data to inductively derive a number of different conceptual 'lenses' through which people view and understand resources. Most diagrams incorporated a mixture of more than one lens. A 'material' lens was the most common pattern of sorting the cards, followed by 'process', 'form' and 'sustainability' lenses. The following figures are select examples of card sort diagrams that demonstrate these lenses.

Material lens

Figure 5 demonstrates the grouping of resources by material composition. Nylon and soil are considered outliers that do not belong to any of the formulated groups. Some workshop participants also drew on a materials lens e.g., one user noted the limitations of a basic, non-semantic search for "plastic" in being unable to return a list of resources made of plastic such as a "car bumper".

Form was used as a secondary method of grouping "Construction" resources as "hard" or "soft" (see Figure 5). This is consistent with our mixed resource model that draws on both 'form' and 'material'.

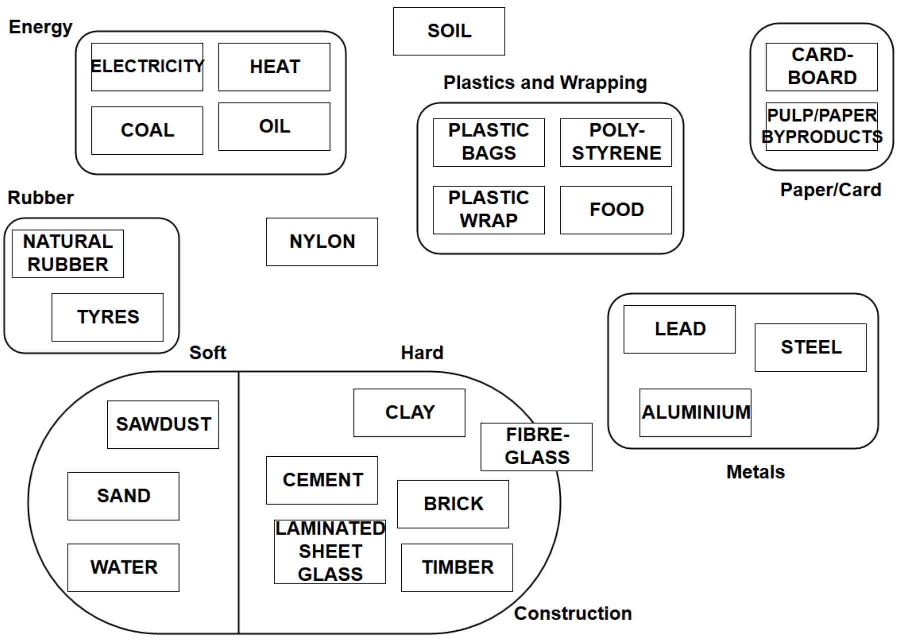

Figure 4. Resources grouped using a material lens

Process lens

Figure 4 linearly arranges resources based on their role in the production process. "Basic Requirements", "Fuel/Power" and "Natural Resources" contribute to "Ingredient Products", which are then transformed into "Primary Products". This view is congruent with the input/output resource model used in our platform.

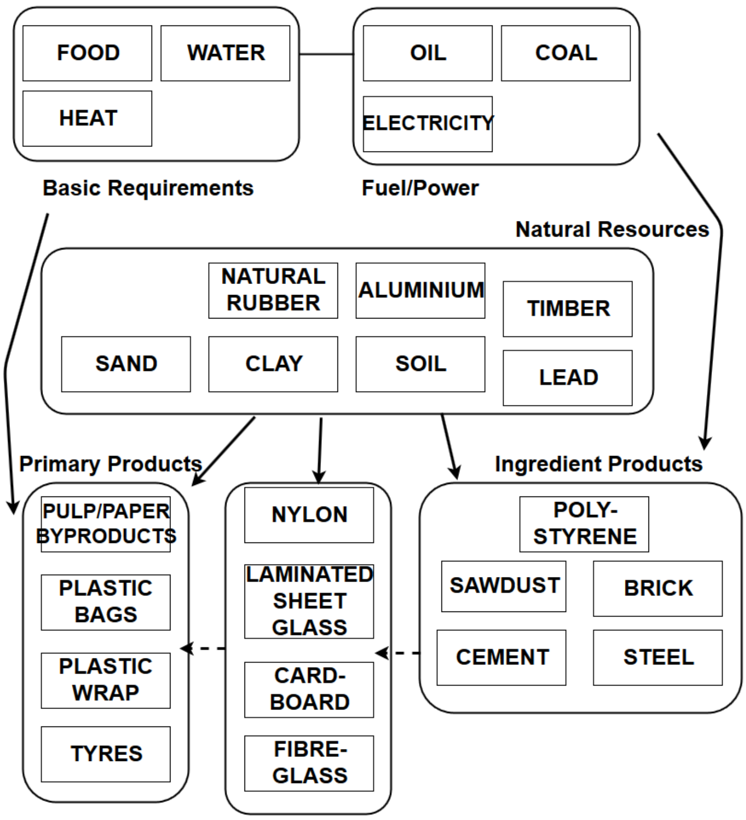

Figure 5. Resources grouped using a process lens

Sustainability lens

Figure 3 organises resources by their environmental impact. For example, electricity and heat can be generated using natural renewable energy sources such as wind power, whereas coal and oil are 'unsustainable' fossil fuels. Items that are not easily biodegradable (e.g., plastic) or produce a high level of emissions (e.g., coal) are also listed at the 'least sustainable' end of the spectrum.

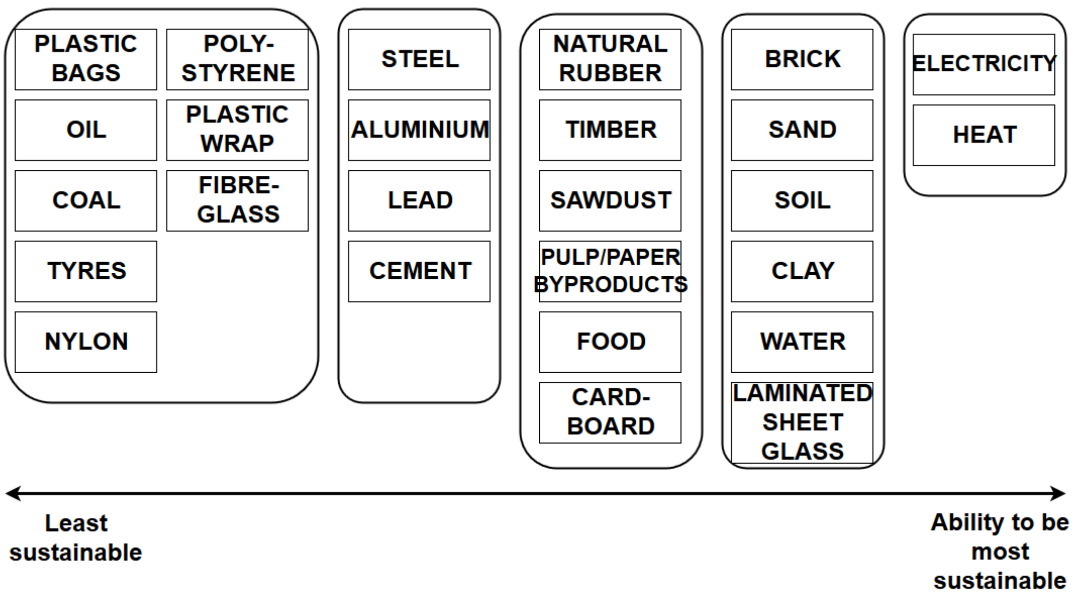

Figure 6. Resources grouped using a sustainability lens

5.1.2 Semantic variation

The semantic variation that occurred when describing resources provided further insight into these differing perspectives of a common domain. The term "resource" itself was considered "ambiguous", with a designer describing a resource as a "material, thing", while a business adviser described it as "an input/output to the business". Workshop participants questioned whether resources encompass both "waste" and "excess product". Determining common resource naming conventions also presented design challenges, as users sometimes referred to the same resource by different names (e.g. "Styrofoam" and "polystyrene"). In another case, an SME user did not realise that "coated/uncoated" paper was presented as "glossy" paper in the attribute list, instead believing that this was missing from the interface. These examples demonstrate conflicts in conceptual model of resources.

5.2 Design Trade-Offs From Conceptual Model Variation

Given the variability in resource conceptual models, the ASPIRE interface is required to reconcile these different perspectives to enable matching by both the mathematical models and human users. Designing the ASPIRE interface has involved making decisions to manage these trade-offs and ensure that users can engage in meaningful conversations with the minimum viable amount of information. Through the data coding process, we identified two key trade-offs involved in the initial design of the platform, and interface refinement following user acceptance testing to address conceptual model differences: prescriptiveness vs flexibility, and low vs high level of resource detail.

5.2.1 Prescriptiveness vs Flexibility

One trade-off in the design process that must be considered as a result of these findings is the level of flexibility users are afforded to describe their resources to potential connections. When listing their resources on the platform, users must select their inputs/outputs from a closed list of options, rather than providing free-text descriptions. While this prescriptiveness facilitates matching and provides a common basis for conversations, it creates tensions due to conceptual model mismatches. Some users found themselves 'translating' between their own conceptual models and the language and concepts used in the system. For example, one SME user used a search engine to find synonyms for a resource they could not locate in the list. The use of a photograph with a free text caption was seen as "very important" to manage this trade-off, allowing users to succinctly provide detailed information about a resource that may not be represented in the drop-down list options.

Managing the flexibility trade-off is also necessary for accurately describing resources since they are highly embedded in their context of use. For example, one SME visualised their waste volume as "how many times we could fill this room", which needed to be converted into standard units for the system (e.g. metres). As another example, the meaning of attribute terms such as "contaminated" is highly dependent on the production environment and the resource itself. One SME manufacturer considered glass contamination to mean chemical contamination, while another spoke about mixed colours or grades of glass as contamination. While attribute descriptions could be provided explicitly through tooltips and explanatory text, the lack of a broadly applicable definition renders flexibility desirable by leaving definitions open to the user's own interpretation. Notably this reinforces the need for business-to-business communication to occur outside the platform (e.g. via telephone).

5.2.2 Low vs High Level of Resource Detail

The level of detail in the interface represents another major trade-off area, with designers aiming for minimum level of detail to foster meaningful conversations between users. This was identified important since existing systems such as search engines provide "too many documents", and labour limitations mean that SMEs require a "user friendly" interface that is "quick to search". One workshop participant even stated that they would rather discuss complex characteristics through a "two minute conversation on the phone" rather than review a multitude of "little messages" in the system. The balance in the level of detail in the resource list is also important for facilitating a broad user base that generates novel, cross-industry conversations. For example, a wooden product manufacturer sought industry specific terms such as "Tasmanian Gum" and "Spotted Wood", whereas the platform resource hierarchy was designed using broader terms such as "hardwood" and "softwood" to balance specificity and general usability.

In the end, the system must still provide enough detail for SMEs to understand and assess their suggested matches. But the level of detail required is highly variable. For one SME, delivery arrangements and reliability of supply were vital details. The resource itself was not the only factor dictating its suitability, but whether there was "enough volume to make it profitable" according to one SME, and how far it needed to be transported before it became "no longer viable". These examples demonstrate the extent to which different users are concerned with different details about the same resource, requiring trade-offs in the information presented for it to be meaningful to a diverse user group.

The specification of required data fields represents another dimension of this trade-off. Presently, the only required resource input fields are the 'Type' (input/output) and 'Resource' itself, while 'Attributes' and 'Service Level Options' are optional. This is advantageous for SMEs who did not wish to provide data such as the quantity of their resource, e.g., because it was difficult to calculate, or commercially sensitive. However, detailed resource descriptions support the mathematical model driving the matching process, and, as a business adviser stated, are more likely to ensure conversations about matches are "hits" rather than "misses". The decision to instead use optional fields reflects the researchers' difficulties in eliciting this information during the initial design interviews and surveys. Many workshop participants realised that the level of detail about their resources would affect the quality of their matches, with some who had initially skipped the optional fields subsequently adding them as they did not want to "miss" matches by not being "descriptive enough".

Interestingly, some users consciously leveraged the level of detail in the interface to their advantage through strategic behaviours. For example, some participants selected as few filters as possible to avoid "shutting doors" and feel that there are "no generic responses" to matches without seeking further information. In contrast, others set a minimum volume in their service level options to deliberately exclude some parties from contacting them, such as hobbyists requesting small wood quantities which may pose OHS risks. This demonstrates that some users are aware of trade-offs, and are taking an active role in managing them.

6 Conclusions

This study has demonstrated a variety of conceptual models IS platform users hold about industrial resources, and explored two major design trade-offs resulting from those differences. Feedback captured through the interviews and workshops indicates that decisions regarding these trade-offs are being well managed. Users from both the business adviser and SME groups acknowledged that while the system does not perfectly meet everyone's needs, users "understand this" and are successfully establishing resource exchange relationships. The high number of resource registrations and low number of queries and complaints further indicates that "we are getting the balance right". Since the platform has only been live since October, future work will involve more extensive feedback gathering over a greater time period, and involving a wider sample of participants to analyse the ongoing effectiveness of the resource model.

7 Acknowledgements

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CONTACT US

t 1300 363 400
+61 3 9545 2176
e csiroenquiries@csiro.au
w www.csiro.au

FOR FURTHER INFORMATION

Data61
Melanie Ayre
t +61 3 9545 8473
e melanie.ayre@csiro.au
w www.csiro.au

Manufacturing
Sarah King
t +61 3 5246 4747
e sarah.king@csiro.au
w www.csiro.au