Distributed Information and Automation Lab

Professor Duncan McFarlane
Institute for Manufacturing
University of Cambridge
Department of Engineering
2015
Distributed Information & Automation Lab

**MISSION**

- smarter, distributed ways of automating systems
- Getting better value from industrial information and quantifying it
- Managing systems subject to disruption and change

Resilient Manufacturing Automation & Control

Automated System Repair

Asset & Infrastructure Information Management

Intelligent Logistics

Efficient Airport Operations

Distributed Information And Automation Lab

UNIVERSITY OF CAMBRIDGE

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Which route to next paint station?

Is this the right truck?

Can we schedule maintenance to optimise availability?

Adjust train speed - weak bridge

DIAL in PICTURES 1995-2015
Some Key & Current Projects

KEY PROJECTS
1997-1999 Responsiveness of Manufacturing Production [EPSRC]
1997-99 MASCADA [EU, Mercedes]
2000-2003 Auto ID Centre [103 industrial sponsors]
2004-2008 BRIDGE, PROMISE, SMART [EU, SAP, Nestle, …]
2005-2007 Aero ID Programme [16 industrial sponsors]
2007-2010 Self Serving Assets [SAHNE -Boeing]

CURRENT PROJECTS
2004 - Auto ID Labs [GS1]
2011- Infra Asset Management & Futureproofing [EPSRC]
2011- Intelligent Data in Procurement [Boeing]
2012 - Resilient Manufacturing [DisTAL - Boeing]
2014 - Intelligent Logistics [ITALI - Y H Global, China]
2015 – Virtual Procurement Data Prediction [VIPR – Boeing]
2015 - Advanced Manufacturing Supply Chain [LOR, IUK, BCC]
2015 - 3D Printing in Distributed Production Networks [EPSRC]
Industrial Product Intelligence

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Example 1: That Microwave Oven!

A favourite Auto-ID example is the heating of ready meals in microwave ovens. Figure 1 illustrates how the recipe for a jar of fresh soup itself is independent of any particular type of heating appliances. Either through an interpretive panel on the oven or by human interpretation this recipe is converted into a set of steps for the microwave to follow so that it cooks the soup in a way that does not breach any of the constraints described in the recipe. The same recipe could also be used to generate an alternative set of machine instructions for cooking in a conventional oven.

1.3. Outline of the Report

The uses of recipe information in the supply chain – and in fact the entire product life cycle – are numerous, ranging from supporting out-sourced production, to distribution instructions for perishable products, to directing maintenance procedures. In the context of an Auto-ID system, rules and recipes form part of the information set that a tagged product may be connected to, in addition to basic parameters and history data. Clearly such information will be closely linked to the Physical Mark-up Language developments currently underway.

The role of rules and recipes in the product life cycle

Associating rules and recipes directly with a product can lead to an alternative way in which supply chain information is managed, with a product or an order “carrying” with it the basic requirements for its creation and useful life.

In this section we overview classes of recipe information associated with each stage of the product life cycle illustrated in Figure 2.

Figure 1

Figure 2

[Auto ID Center 2000]
Intelligent Supply Chain Vision 2002

benefits of product driven supply chain

Consumer Driven Supply Chain
Overview

• Introduction: “Product Intelligence” in use
• Industrial Rationale
• Product Intelligence?
• Research Issues
• Examples of Developments
• Deployment Challenges
Linked Concepts

Product intelligence

Customer orientation

“Pull” systems

Order Driven systems
Kanban production control system

<table>
<thead>
<tr>
<th>Part Description</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smoke-shifter, left handed.</td>
<td>14613</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Qty</th>
<th>Lead Time</th>
<th>Order Date</th>
<th>Due Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>1 week</td>
<td>9/3</td>
<td>9/10</td>
</tr>
</tbody>
</table>

Supplier: Acme Smoke-Shifter, LLC
Planner: John R.
Location: Rack 183

2-bin Kanban
# Web Based Shopping

**Total: £12.15**

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Product</th>
<th>Price</th>
<th>Delete</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sainsbury’s British Fresh Milk, Semi Skimmed 1.13. (2 pint)</td>
<td>£0.75/ltr</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Silver Spoon Natural Vanilla Extract 38ml</td>
<td>£1.04</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Silver Spoon Chocolate Flavoured Strands 65g</td>
<td>£0.75</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Sainsbury’s Pink Glitter Sugar 75g</td>
<td>£1.09</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Silver Spoon Sprinkle Decorations 80g</td>
<td>£0.79</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Silver Spoon Icing Sugar 500g</td>
<td>£1.13</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Sainsbury’s Dark Chocolate, Basics 100g</td>
<td>£0.70</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Sainsbury’s Milk Chocolate, Basics 100g</td>
<td>£1.40</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Sainsbury’s Modica Cake, Basics</td>
<td>£3.36</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Sainsbury’s Unsalted Butter, Basics 250g</td>
<td>£1.19</td>
<td></td>
</tr>
</tbody>
</table>

| Savings | £0.00 |

*If you have e-vouchers, we’ll deduct these when you checkout.*

> Save trolley
> Full trolley view

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Batch Control: S88 / ISA-95

**GENERAL RECIPE**
- Process
  - Process
  - Stage
  - Operation
  - Action

**EQUIPMENT**
- Process Cell
  - Unit
  - Equipment Module
  - Control Module

mapping

customer

Provider(s)
Autonomous [Pizza] Logistics!
Common Threads?

- Customer directly shapes order
- Customer directly shapes execution of order  
  \textit{STATIC}
- Customer can influence who executes the order
- Customer can change aspects of the order execution  
  \textit{DYNAMIC}
- Customer can change aspects of the order during execution
- Customers influence is automated  
  \textit{AUTONOMOUS}
Overview

• Introduction: Examples of “Product Intelligence”

• Industrial Rationale

• Product Intelligence?

• Research Issues

• Examples of Developments

• Deployment Challenges
Provider vs Customer Oriented

Customer Orders -> Operation [resources] -> Customer

Provider

Active

Passive
Provider vs Customer Oriented

Provider

Operation [resources]

Customer Orders

Customer
Customer
Customer
Customer
## When Customer Orientation can help?

<table>
<thead>
<tr>
<th>Static Scenarios</th>
<th>Dynamic Scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Multi Organisation:</strong> When a product or order moves between organizations in its delivery</td>
<td><strong>Changing Environment:</strong> When options arise frequently and unpredictably for alternative routings to be considered.</td>
</tr>
<tr>
<td><strong>Multi Ordering:</strong> When a specific item can be part of multiple orders/consignments for certain stages of its production/delivery.</td>
<td><strong>Frequent Disruption:</strong> When disruptions are frequent and performance guarantees are difficult to achieve.</td>
</tr>
<tr>
<td><strong>Customer Specific:</strong> When a customer’s specific requirements for his order is at odds with the aggregate intentions of the logistics organisation.</td>
<td><strong>Dynamic Decisions:</strong> When decision making about order management requires human resources that are not available.</td>
</tr>
<tr>
<td><strong>Distributed Orders:</strong> When an order exists in multiple segments scattered across multiple organizations.</td>
<td><strong>Customer Preference Changes:</strong> When customer’s preferences change between ordering and delivering.</td>
</tr>
<tr>
<td><strong>Unique Order:</strong> When an order is irreplaceable</td>
<td></td>
</tr>
</tbody>
</table>

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Overview

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Intelligent Product [Descriptive]

“A physical order or product that is linked to information and rules governing the way it is intended to be made, stored or transported that enables the product to support or influence these operations”

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomatoes [supplied]</td>
<td>150.0g</td>
</tr>
<tr>
<td>Tomato puree type A [supplied]</td>
<td>10.0g</td>
</tr>
<tr>
<td>Onions [supplied]</td>
<td>10.0g</td>
</tr>
<tr>
<td>Garlic [supplied]</td>
<td>0.9g</td>
</tr>
<tr>
<td>Basil [supplied]</td>
<td>0.5g</td>
</tr>
<tr>
<td>Sugar [supplied]</td>
<td>10.0g</td>
</tr>
<tr>
<td>Preservatives [supplied]</td>
<td>0.5g</td>
</tr>
</tbody>
</table>

Separate raw materials:
- Wash tomatoes
- Chop tomatoes
- Wash to deseed
- Peel onions
- Chop onions
- Peel garlic to separate cloves
- Peel cloves
- Crush cloves
- Wash basil
- Separate leaves from main stalk
- Chop leaves

Prepared raw materials:
- Weigh QUANTITY A of tomatoes
- Weigh QUANTITY B of tomato puree
- Weigh QUANTITY C of onions
- Weigh QUANTITY D of garlic
- Weigh QUANTITY E of basil
- Weigh QUANTITY F of sugar
- Measure QUANTITY G of Preservatives
Characteristics of Intelligent Product

- Possesses a unique identity
- Is capable of communicating effectively with its environment
- Can retain or store data about itself
- Deploys a language to display its features, production requirements etc.
- Is capable of participating in or making decisions relevant to its own destiny

(Wong et al., 2002, McFarlane et al, 2003)
Characteristics of Intelligent Product

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(Wong et al., 2002, McFarlane et al, 2003)
Levels of Product Intelligence

- **Level 1 Product Intelligence**: which allows a product to communicate its status (form, composition, location, key features), i.e. it is *information-oriented*.

- **Level 2 Product Intelligence**: which allows a product to assess and influence its function in addition to communicating its status, i.e. it is *decision-oriented*.

  (Wong et al., 2002)
Levels of Product Intelligence

**Level 1**

- Represent the (customer) needs linked to the order: e.g. goods required, quality, timing, cost agreed
- Communicate with the local organisation (as well as with the customer for the order)
- Monitor/track the progress of the order through the industrial supply chain

**Level 2**

- [Using the preferences of the customer] influence the choice between different options affecting the order when such a choice needs to be made
- Adapt order management depending on conditions.
Who is doing Research in [Industrial] Product Intelligence?

- Aalto University (Finland)
- Research Center for Automatic Control - CRAN
- University of Cambridge
- Katholieke Universiteit Leuven
- University de Valenciennes / Lille Nord du France
- University of Groningen (Netherlands)
- Universit of Bremen
- Universite Politehnica of Bucharest
- Universit of Porto
- Czech Technical University
- Oxford University
- + others e.g. Physical Internet movement in USA/Canada,
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Product Intelligence Benefits Modelling

4. Industrial logistics provider example

In this section, we will illustrate the usage of the model presented in the previous section using an industrial example. We also discuss some lessons learned from this particular application as well as a set of guidelines for the adoption of this model from a potential user.

4.1. Scenario

A logistics provider is offering transportation services of small and big packages around the globe. It is currently offering two options for transportation. The first option offers a short delivery time but it is expensive and the second one offers longer delivery times and is cheaper than the first option. Over the years, the company has developed a specialisation in the transportation of spare parts for aircraft and thus it currently has a number of big customers who operate in the airline industry. From its everyday interaction with customers, the logistics provider has realised that there are many cases when customers need to change the delivery date of a particular package/freight item while the package is en-route, for example due to changes in the maintenance schedule of the aircraft or due to faster than expected degradation of aircraft parts. There are frequent cases when customers call the logistics provider, asking for a change in the delivery date and/or delivery location, in which cases the company spends a considerable amount of time and effort in order to find a solution for his customer's needs. For this reason, the owner of the company is considering developing a new business model when his customers will be permitted to modify the delivery date of their shipments whilst in transit. The company has decided to start by focusing on its largest customer who generally requests transportation services between two particular locations. The company knows that the implementation of such a model for this customer, between these locations, is feasible. Before launching the new service, the owner of the company wants to know under which conditions such a business model could be profitable and under which (pricing) circumstances this extra service is likely to be used by his customers (or not). Figure 3 depicts the different options available at the moment as well as the opportunity for expedition of delivery in the new business model.
Product-Oriented Process Modelling

<table>
<thead>
<tr>
<th>Sensor Type</th>
<th>$E_{po-o}$</th>
<th>$E_{po-wo}$</th>
<th>$E_{pt-o}$</th>
<th>$E_{pt-wo}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximity Sensors</td>
<td>${e_1, e_3}$</td>
<td>${\varepsilon}$</td>
<td>${\varepsilon}$</td>
<td>${e_2, e_4}$</td>
</tr>
<tr>
<td>Identity Sensing</td>
<td>${e_1, e_3}$</td>
<td>${\varepsilon}$</td>
<td>${e_2, e_4}$</td>
<td>${\varepsilon}$</td>
</tr>
</tbody>
</table>
Product Languages

Diagram showing the relationship between a Recipe, Resource Instructions, Resource Capabilities, and Resource Capability.
Architecture Selection

Selection Criteria

- Computational intensity
- Communications burden
- Decision making complexity
Operational Performance

Figure 4. Solution optimality. (a) Optimal decisions versus the number of component agents, and (b) optimal decisions versus the number of provider agents.
## System Performance

<table>
<thead>
<tr>
<th></th>
<th>IP Driven Control</th>
<th>Conventional Control</th>
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</thead>
<tbody>
<tr>
<td>Configurability (design)</td>
<td>103</td>
<td>220</td>
</tr>
<tr>
<td>Configurability (implementation)</td>
<td>2407 (1585)</td>
<td>497</td>
</tr>
<tr>
<td>Reconfigurability Extension</td>
<td>Strategy: 1.24</td>
<td>Strategy: 1.54</td>
</tr>
<tr>
<td></td>
<td>Development: 1.15</td>
<td>Development: 1.62</td>
</tr>
<tr>
<td>Reconfigurability Reuse</td>
<td>0.95</td>
<td>0.4</td>
</tr>
</tbody>
</table>
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PI Developments in Manufacturing

(Chirn et al., 2002)  (Sallez et al., 2009)  (Thomas et al., 2012)

(Morales-Kluge et al., 2011)
Eg: Intelligent Orders and Parts Production
PI Developments in Logistics

(Giannikas, McF 2012)

<table>
<thead>
<tr>
<th>Product ID</th>
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<tbody>
<tr>
<td>Type</td>
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<tr>
<td>=  &quot;Customised Violin&quot;</td>
</tr>
<tr>
<td>seller.address = &quot;Shanghai, China&quot;</td>
</tr>
<tr>
<td>receiver.address = &quot;Cambridge, UK&quot;</td>
</tr>
<tr>
<td>deliverBefore = 24.12.2012, 12:00 GMT</td>
</tr>
<tr>
<td>route = &quot;Shanghai;; Istanbul;; Frankfurt;; Birmingham;; Cambridge&quot;</td>
</tr>
<tr>
<td>deliveryDate = 22.12.2012, 13:30 GMT</td>
</tr>
<tr>
<td>newDeliveryDate</td>
</tr>
</tbody>
</table>

Customised violin

"Put this box in the next flight to London"

Figure 7: Product selection based on utility gain

(Meyer et al, 2009)

(Schuldt, 2011)

(Karkkainen et al, 2003)
Eg: Intelligent Warehouse Order Picking

Order Request

Warehouse Manager (Mediator)

Order-pickers

Storage Locations

Order requests to be picked

Inform associated picker(s)

Ask for potential storage locations

Report the potential storage location

Feedback the decision: acceptance or rejection of picking the new order

Order assignment decision

Inform the associated picker that responsible for the picking

Confirm the picking of order and the associated storage location

Confirm the picking from selected storage location
PI Developments in Services

(LeMortellec et al, 2012)

(Parlikad et al, 2008)

(Brintrup et al, 2010)
Eg: Self Organising Spare Parts Management

- **Problem**: System to manage ever increasing complexity in spare parts ordering across multiple supplier

- **Approach**: Treating aircraft components as intelligent products which trigger own repair and replacement. Multiple software agent architectures trialled
PI Developments in Construction
Eg: IoT Smart Highway Project
Overview

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Deployment Challenges: Barriers

- **technical feasibility:** scalability, stability, compatibility
- **economic viability:** quantitative benefits specific to IP approach
- **operational practicality:** Ability to deploy IP concept! deployability with existing IT environments?
- **cultural acceptability:** acceptance as opportunity by providers, high level of transparency
Some Recent References