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# Web-services-based supply-chain-control logic: an automotive case study

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This paper discusses the design and implementation of a decision-support software system based on web services, capable of modelling the supply chain and querying the supply-chain partners to provide information, regarding the availability of parts, required for the production of a highly customisable product. Furthermore, it describes the details of a software system for the evaluation of time and financial feasibility of acquiring the necessary parts in order for the customised product to be built. The feasibility of implementing this approach is demonstrated in a typical automotive case study. The system is capable of simulating the customer's orders impact on the supply-chain operation, while it utilises the Web services technology for facilitating the supply-chain control logic.

**Keywords:** supply-chain control; web services; workflow model

## 1. Introduction

Individual companies will no longer compete with each other, but rather, they will be members of competing supply chains or networks (Carrie 2000). The production network refers to cross-company cooperations. The main idea behind production networks is the mutual use of resources and the joint planning of the value added process. In a production network, both the company and the suppliers exchange detailed data concerning the actual and future loads of machines, the availability of resources among the net partners, order volumes of future and planned demands, and the order progress along the value added chain in the network. This leads to an intensive flow of information among all the participants in a production network (Wiendahl and Lutz 2002). In the automotive industry, the pressure for innovation as well as the incorporation of a wide range of technologies, urges the manufacturers to collaborate quite closely with a variety of suppliers, in order to achieve innovation by minimising the cost and the heavy investment in new competences (Lung and Volpato 2002). Additionally, coordinating production and inventory levels is essential so that the work can be completed 'just in time', with minimal inventory (Chryssolouris 1996, Chryssolouris *et al*. 2004). Furthermore, as the automotive industry converges increasingly into a multi-tier organisation, involving manufacturers, suppliers, integrators, dealers, etc., the problem of information sharing and knowledge diffusion grows (Makris *et al*. 2011).

The problems created for the supply chain owing to highly customised products are summarised as follows. From the point of view of production scheduling, forecasting customers' requirements prior to receiving their orders, is difficult and becomes even harder when considering that each customer requests a unique variation of the product. Additionally, it is hard to evaluate the impact of production schedule changes on the supply network (Makris *et al*. 2011). From the supply chain's perspective, inventory visibility is both limited to the in-transit parts and the Original Equipment Manufacturer's (OEM) inventory. An available supplier's inventory is not visible. There is no confirmation from the supplier that the production schedule is feasible. Supply-chain management and production scheduling do not look at information, such as a supplier's inventory, its capability and supply confirmation, because of the difficulties encountered in obtaining it (Makris *et al*. 2011). Moreover, a late change in a production schedule creates increased transportation costs, especially when parts are produced in distant locations. Logistics planning, in a flexible environment, requires an integrated and dynamic planning tool to control the supply network. These are the challenges addressed in the work presented in this paper.

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### 1.1 *State of the art – collaborative production networks*

There is a great potential for synergies between Collaborative Networks and Sustainability. The challenges of sustainability call for a wide collaboration among multiple stakeholders, as the required changes exceed the capacity and capability of individual actors. A number of such synergies have been introduced in Camarinha-Matos *et al.* (2010). The method discussed in this paper addresses the requirement for such synergies among the production network stakeholders.

Computer-aided design (CAD) agents have been used to aid collaborative design with heterogeneous systems in a multi-user environment. This methodology has been applied to an example, taken from literature showing interesting results (Mishra *et al.* 2011). Modelling and analysis of complex and coordinated supply chains is a crucial task owing to its inherent complexity and uncertainty. Petri nets have been used for the modelling of the dynamic behaviour of the supply chain. This modelling methodology embeds two enticing features, i.e. cost and batch sizes, in deterministic and stochastic Petri nets for the modelling and performance evaluation of supply-chain networks (Khilwani *et al.* 2011). Therefore, a near real-time decision-support tool is required in order to facilitate the decision-making process across the production network. This is where this paper advances the current state of the art.

On the issue of optimisation of logistics, a reverse logistics problem, motivated by many real-life applications has been examined. A set of heuristics, based on an extended branch and bound heuristic, genetic algorithm, and simulated annealing for solving SDPC, has been discussed. The heuristics were tested on standard, derived and randomly generated datasets of TSP, TSDP, and SDPC, and satisfying results, with high convergence in reasonable time, were obtained (Anbuudayasankar *et al.* 2010). A contribution of this paper is that it considers not only logistics, but also capacity issues and production resource availability at the supply-chain level, which has not been considered by previous research.

Practically, every major company with a retail operation has its own Web site and online sales' facilities. Web usage/data-mining techniques for the identification of customer Internet browsing patterns have been developed to underpin a personalised product recommendation system for online sales. Within the architecture, a Kohonen neural network or self-organising map (SOM) has been trained for both offline use, to discover user group profiles, and real-time use to examine active user click stream data, make a match to a specific user group, and recommend a unique set of product browsing options appropriate to an individual user (Zhang *et al.* 2007). However, product customisation falls far beyond the offering of a variety of cutstomised and available products. Vehicle supply has traditionally been based on forecast-driven production, and a large number of cars have been sold from stock – a practice that incurs a considerable cost in terms of stock holding and sales' incentives. The benefits of responsive supply systems, capable of providing customised vehicles, in short lead times, have been pointed out as they have derived from the success of other industries. While the theoretical discussion of such 'build-to-order' (BTO) strategies is well advanced, the feasibility of implementing these concepts is not yet sufficiently adopted. Using a simulation of a multi-tier supply chain-system, the impact of altering key aspects of the scheduling activities with the objective of determining the scope for potential improvements, in responsiveness of the supply chain, was investigated. The simulation results showed that the current vehicle supply systems were not capable of supporting BTO, owing to insufficient feedback between supply and demand, as well as due to the strong reliance on forecasting in the scheduling process (Holweg *et al.* 2005).

Regarding the time required for new car buyers to take delivery of their cars from the time they placed their orders; 59% of all respondents said that it should take up to two weeks, and 81% maintained that it should be delivered up to 3 weeks after the order had been placed (Elias 2002). There is also a discussion on the so called Virtual Build to Order (VBTO) concept: the producer has the ability to search across the entire pipeline of finished stock, products in production, and those in the production plan, in order to find the best product for a customer (Brabazon and MacCarthy 2004, Brabazon and MacCarthy 2006). The impact on the information technology implementation and on the firm's market performance in the supply chain of collaborative activities and joint decision-making has been considerd. The results of the study have indicated that successful collaboration among supply-chain echelons does positively affect a firm's market performance provided that effective communication in the process of decision-making is fostered (Li *et al.* 2006). This provides a sound basis for the development of the system that this paper is discussing.

Agent based systems have been applied, in a variety of cases, to geographical information systems, operating systems management, electronic commerce trading, etc. (Tang *et al.* 2001, Feng *et al.* 2003). The use of multi-agent-based models for bilateral multi-objective negotiation in electronic commerce trading has been suggested (Li and Wang 2007). The agents interact with each other to create the most appropriate solution for both of the negotiating parties (Hou *et al.* 2007, Luo *et al.* 2007). This paper proposes a distributed control architecture, based on web services that lie beyond the previously performed research, since its focus is on the supply-chain issues for enabling the manufacturing operations rather than enabling electronic commerce and logistics.

A number of models and algorithms discussed in the literature are tested on artificial/synthetic data sets. This indicates another important avenue for further research that is to apply these existing methodologies on real-life data sets to examine their applicability in practice. To this end, industrial collaboration with BTO practitioners is essential to provide the research community with real data sets upon which efficient multi-objective optimisation tools can be developed (Mansouri *et al.* 2012). A further contribution of this paper is that the concept is demonstrated in a real life test case.

Other models have been proposed that are focusing on the internal supply chain of supplier firms (Venkatadri *et al.* 2006). The current paper considers not only the internal supply chain, but also suppliers' capacity, suppliers' material availability, as well as material in transit.

Nowadays, many organisations use web services to provide customers with access to their information. Web services are self-contained and encapsulate some kind of functionality. The interaction pattern among services is a known as Service-Oriented Architecture (SOA), in which a service is a well-defined and self-contained function that does not depend on the context or state of other services. Web-service technology uses a loosely coupled integration model that enables a flexible integration of heterogeneous systems in a variety of domains. Web-service orchestration is a viable technology when it comes to automating supply chains and can be used to create alliances among partners and connect organisations to the loosely coupled business processes of network partners (Janssen 2010). This work discusses the design and implementation of a web-based system, utilising web-services technology and is capable of modelling the supply chain and dynamically querying the supply-chain partners to provide real-time or near real-time information, regarding the availability of parts, required for the production of a highly customizable product. Furthermore, it describes the details of the software system for evaluating the time and financial feasibility of acquiring the necessary parts in order for the customised product to be built. The feasibility of the implementation of this approach is demonstrated in a typical automotive case study.

The currently available organisational structure and information systems, at least in the automotive industry, are not capable of supporting efficiently the needs of building customised products (Holweg *et al.* 2005, Makris *et al.* 2011). These systems are implemented based on the mass production concept. The requirement for producing highly customised products imposes the need to reconsider the organisational structures and support them with advanced information technology. Such a decision support system is not in place today but it is an efficient solution to the problems previously described. This paper discusses a software system that has been designed and implemented by the authors and offers the following decision-making functionality:

- simulates how customer orders influence the supply-chain operation;
- calculates the lead time and cost associated with the production change;
- considers a supplier's inventory, production capability and capacity constraints and confirmation of the supplier's ability to support the plan;
- enhances a web-based flow of information in both directions from OEM to supplier and vice versa;
- utilises the Web services technology for facilitating the supply-chain control logic.

## 2. Automotive supply chain

A company's supply chain comprises geographically dispersed facilities, where raw materials, intermediate products, or finished products are acquired, transformed, stored, or sold, and transportation links connect the facilities along which the products flow (Shapiro 2000).

The industrial case study, considered in this paper, is based on data from an automotive manufacturer's supply chain. The supply-chain network is for the rear seat sub-assembly of a manufacturer's model. The components produced by the second-tier suppliers are metals, foam, trim, plastics, and carpet backs, while the first-tier supplier is performing the seat assembly. Finally, the seats are transported to the OEM's assembly plant in order to be fit for use in the vehicle.

The information flow starts when the 1st tier supplier receives a material release from the manufacturer. There is a separate release for each seat derivative required. The release shows the ship date from the sequence facility only, as this is the nominated ship point. The supplier's facility receives an electronic copy of the release. In order for this to be facilitated and protected against any assembly or transportation delays, an adequate level of inventory of

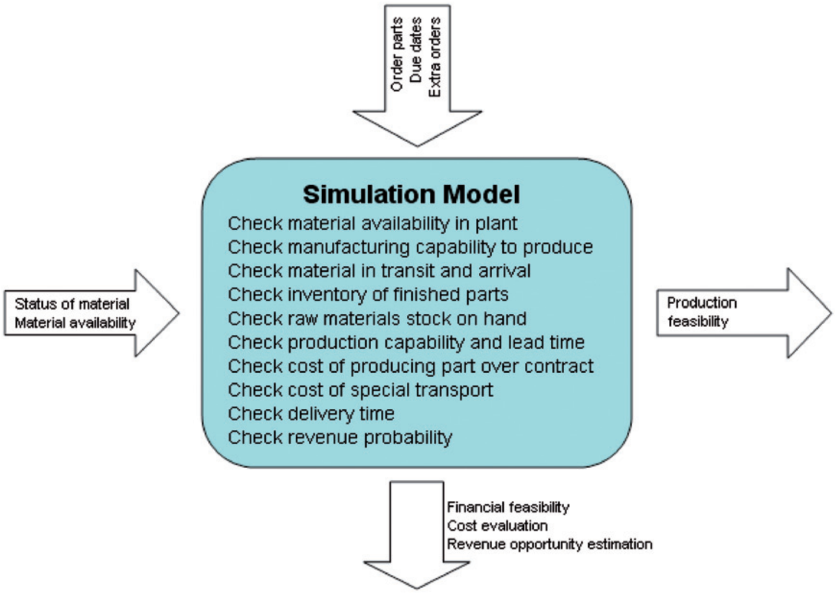


Figure 1. Concept of the simulation model.

assembled seats is held by the supplier. The supplier converts the manufacturer's material release data into their own internal scheduling system to schedule delivery, manufacture and supply of the sub-components from the second tier's suppliers.

## 3. Flexible supply-chain workflow modelling

In order to enable the flexible operation of the supply chain, an Internet based software system is discussed in this paper. The basic logic of the software system is shown in Figure 1. The model simulates the production feasibility, in terms of material availability in-plant/in-transit and the financial feasibility, in terms of cost of special transport and cost of producing parts, over a contract price and the installed capacity e.g. overtime. The output of the simulation model is the production and financial feasibility in terms of time and cost.

The overall supply-chain coordination model involves the calculation of production and financial feasibility of customising a vehicle. The aim of the simulation model is to evaluate all the above cost factors and any additional costs in order to bring a revenue opportunity and profit to the OEM. This should be achieved through a two-stage approach where, first, the physical availability of the parts is confirmed, and provided this is positive, the financial feasibility is then confirmed as can be seen in Figure 2.

The OEM data would include information about the inventory (in-plant and in-transit with the anticipated arrival date) that is currently available in the OEM's systems (Figure 3). Suppliers would be required to confirm their ability to supply the parts either from their finished or WIP inventory or to confirm their ability to meet all the requirements. To maximise the effectiveness of the simulation tool, the maximum level of data should be pulled from the existing data sources, and any manual interpretation and input by either the OEM or the supplier should be minimised.

The financial feasibility simulation in terms of the special transport and supplier costs of producing a part over the contract price is also calculated by the system. Special transport cost factors are driven by the supplier's response on a date availability, the required in plant date, the availability of 'normal' transport data, and the size of 'special shipment' data. The supplier's cost of producing a part over a contract price is driven by the factors of overtime and of obtaining parts from second-tier suppliers (e.g. special freight). The cost factors, described in Figure 3, have been considered in the financial simulation model. The cost of producing parts over contract (e.g. overtime) from the supplier and the cost of special transportation and revenue opportunity of the OEM are calculated. The normal freight cost has been considered as this incurred in any event, but any extra non-standard costs (i.e. cost for special transport, cost of producing part over contract price) need to be considered further. An additional freight cost will

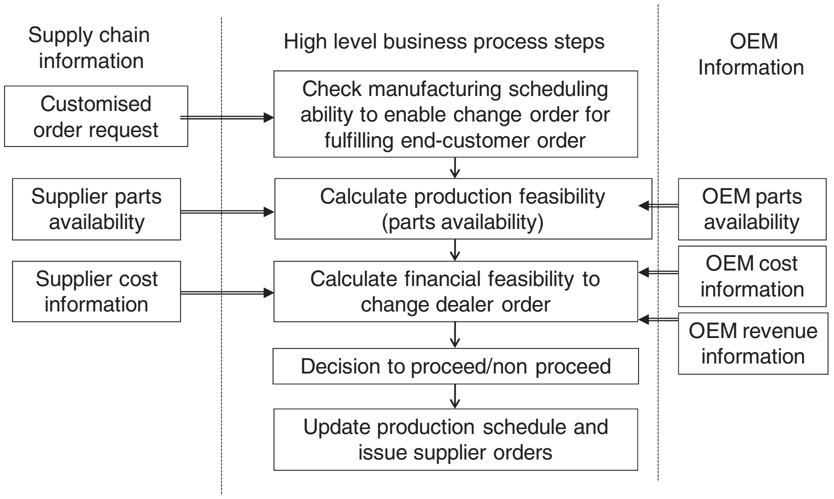


Figure 2. High-level calculation of physical and financial feasibility for supply-chain adaptation.

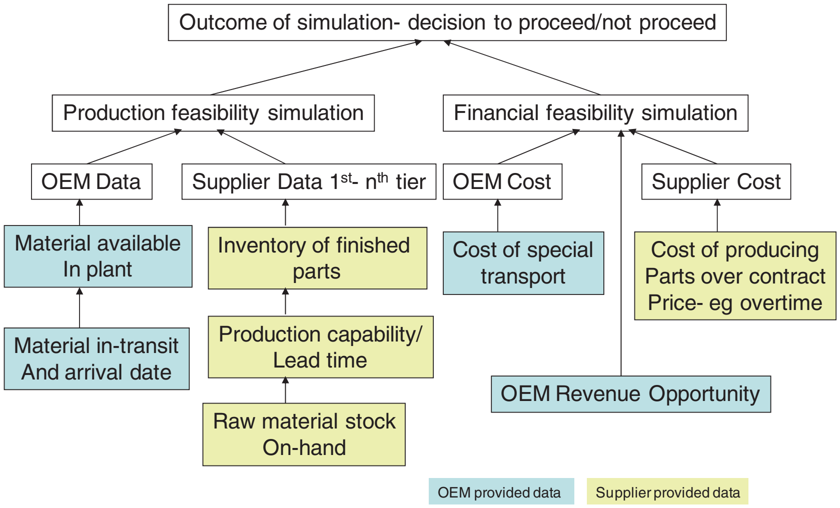


Figure 3. High-level data requirements for enabling supply-chain adaptation.

be added, in case of the reduced transit time available, the transportation delay or transportation of extra orders/products. In addition, an extra supplier's cost for the production of parts over the installed capacity or working overtime will be considered. The simulation model evaluates all the above cost factors and additional costs in order to provide the OEM with revenue opportunities and profits. The revenue opportunity is calculated by a customer's assessment module that considers the customer's likely response to accept or reject a vehicle that is offered in a certain time frame. This model has been discussed in another research (Makris and Chryssolouris 2010, Makris *et al*. 2011).

## 4. Software architecture and implementation

### 4.1 *Workflow for supply-chain simulation*

The overall process model was analysed, with the help of a functional partitioning list. This list is used to describe in detail the functions performed by each partner/actor. Each actor's list of actions is outlined as follows:

- End customer at dealership, Submit order request
- OEM, Check for a close match
- OEM, Check BOM
- OEM, Check material available in plant

- OEM, Check material available in transit
- OEM, Check supplier's material availability
- Supplier, Check material's availability in inventory of finished parts
- Supplier, Check earliest availability
- Supplier, Check earliest build date
- Supplier, Determine when material can be available
- OEM, Check earliest build date
- OEM, Check need of special transport
- Supplier, Define extra cost of producing parts over contract
- OEM, Check extra costs
- OEM, Evaluate final profit
- End customer at dealership, Buy confirmation
- OEM, Allow/Deny proceed order

The above functions describe the overall process model. Each function is performed by a specific partner (actor in UML) in the network. This representation could be extended to include more function levels, depending on the desired level of detail. In the above figures, there is a description of the functions occurring in the process model which is correlated with the actors responsible for them. Figure 4 describes the sequence of the aforementioned functions, occurring in the overall sequence process model.

### 4.2 *Architecture integration for information flow and data exchange*

The concept of information flow, between the suppliers and the OEMs' manufacturing facility, is described in Figure 5. The information flow starts when the OEMs accept the order for the customer's requested vehicle. The OEM accepts the customer's order, analyses the content and calculates the required materials based on the vehicle BOM. Following the process that has been described in Section 4.1, the OEM manipulates and plans the material's orders, which will be sent to the suppliers. The supplier, respectively, processes the OEM's requests, evaluates the material's availability in the inventory, and responds to the OEM about the material's cost and its availability.

#### 4.2.1 *Web-service architecture*

The system's architecture for enabling the interaction of partners within the supply chain is shown in Figure 6.

Two major modules constitute this diagram, those of the OEM's, and the supplier's.

#### 4.2.2 *OEM module*

The OEM's module consists of several components. The *front panel* represents the user interface of the entire integration. It consists of the administrative panels as well as those with a supplier's details (i.e. production capacity, lead time, stock on-hand, etc.). This component also includes panels for the design of a simulation model, the interaction with it (by changing the model parameters) and the visualisation of the model's simulation. The user interface is a web application, which executes four basic things in a specific order:

- interprets client requests, which are user interactions with the web browser;
- dispatches those requests to business logic;
- selects the next view for display;
- generates and delivers the next view.

The Web application receives each incoming HTTP request and invokes the requested business logic operation in the application model. Based on the operation's results and the model's state, the controller then selects the next view to display and finally generates the selected view and transmits it to the client for presentation.

The Model-View-Controller (MVC) pattern has been used for the implementation of the web application. The MVC integrates, in an elegant and efficient way, elements such as a *Servlet* that receives the requests, a *Java Bean* that connects to data sources for data retrieval, and *JSPs*, which are special codes that generate the HTML pages response with the use of data from the Java Bean. The MVC pattern is implemented in a special framework,

Figure 4. Overall process sequence interactions.

which is known as the Jakarta Struts Framework (Brown 2001). The operation's overall scheme of the struts framework is shown in Figure 7 and represents the MVC principle.

*Web Services* are the core element of the proposed architecture. The Web services provide a standard means of interoperating between different software applications, running on a variety of platforms. The purpose of the Web services is to provide a communication interface for enabling the execution of a workflow. The web service wraps the concrete piece of software that implements the functionality by sending and receiving messages, while the service is the resource, characterised by the abstract set of functionality that it provides. Web services are used as a wrapper component for the simulation tool. Its input is the simulation model together with the simulation parameters, while the output is a model simulation with cost calculation.

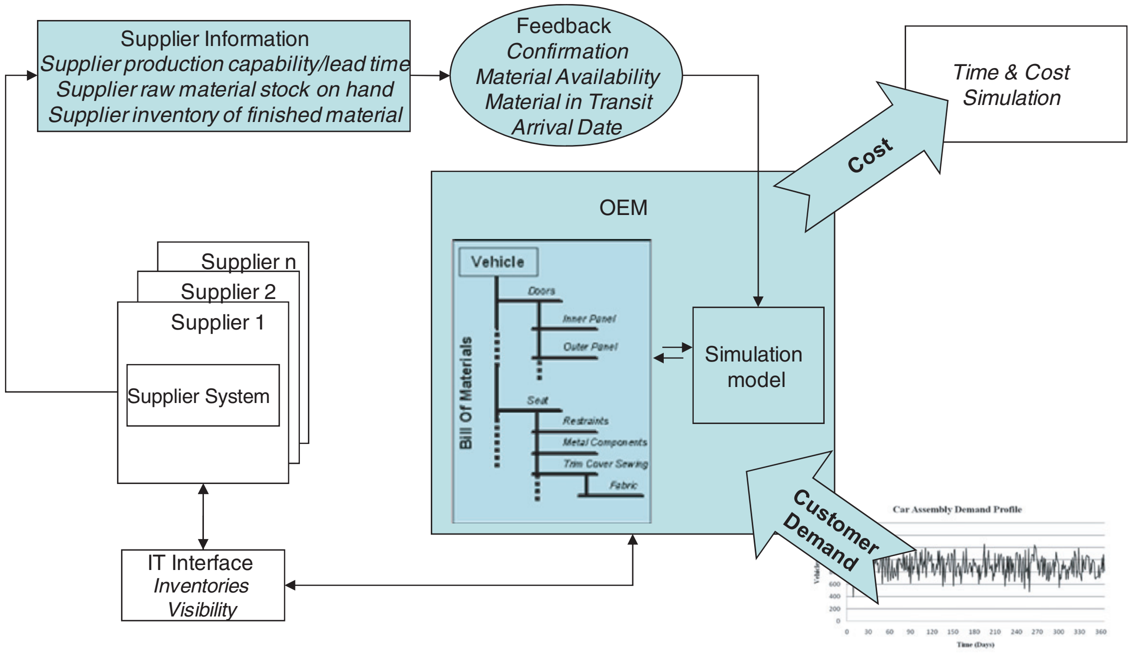


Figure 5. Network visibility and information flow.

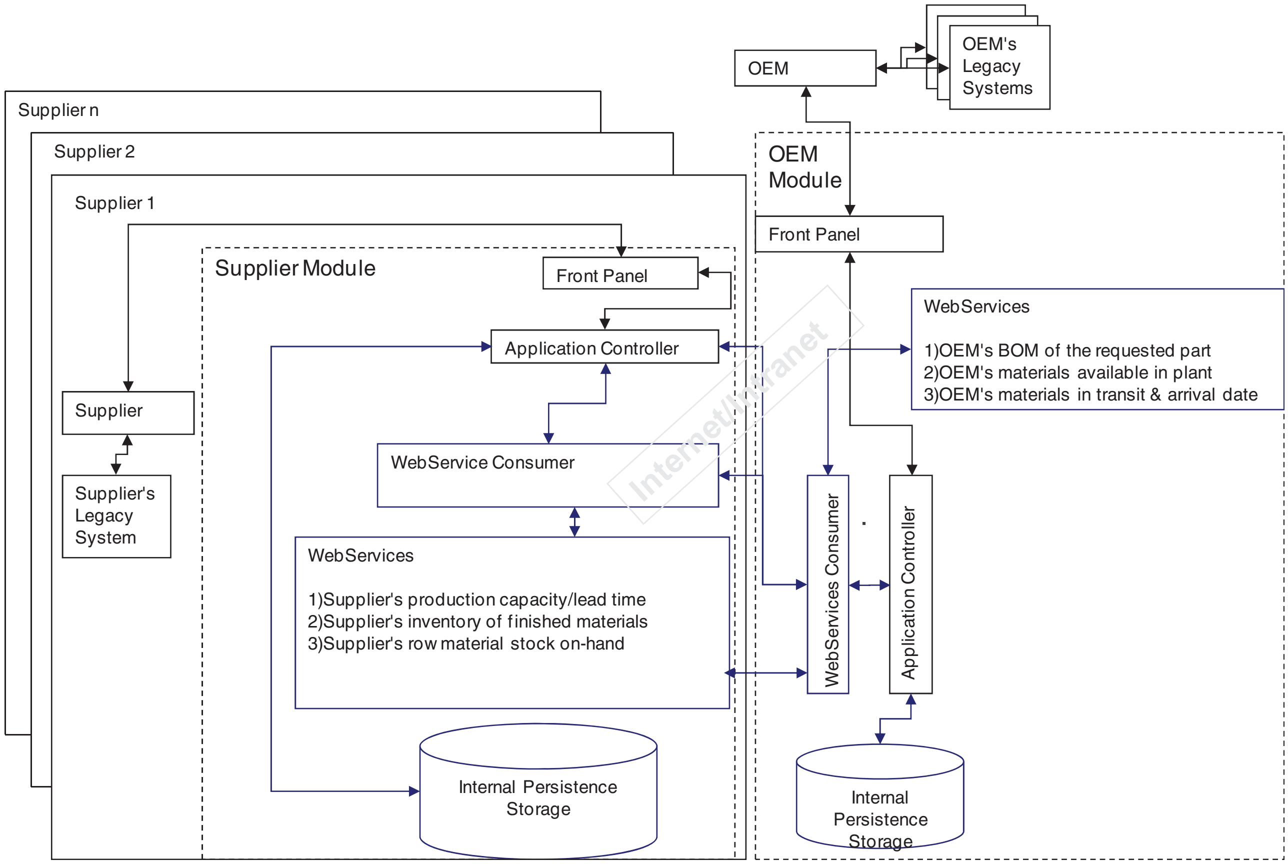


Figure 6. Information flow and data exchange.

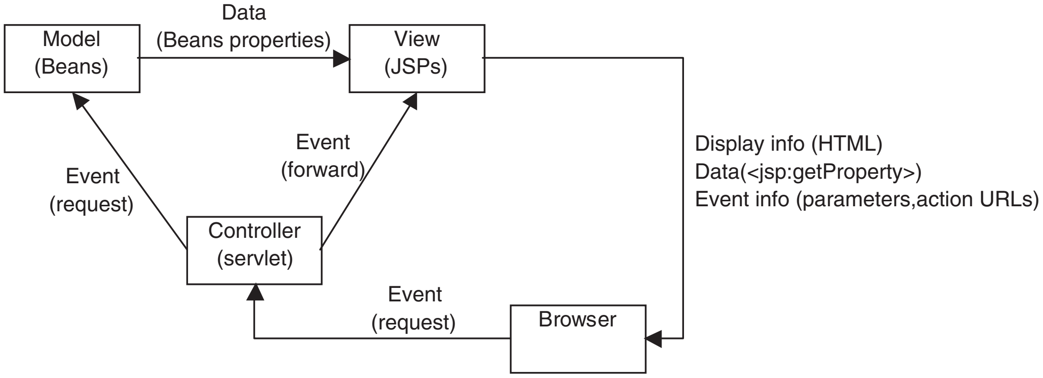


Figure 7. Jakarta struts framework.

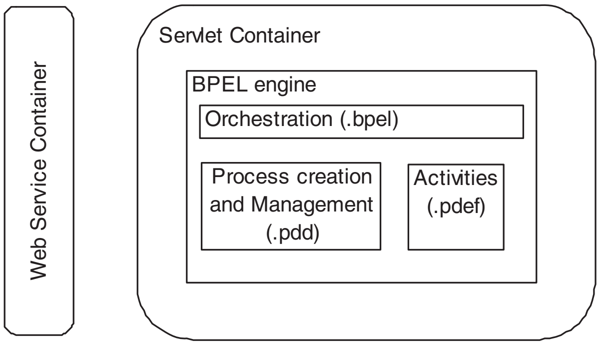


Figure 8. BPEL engine implementation architecture.

The *Web Service Consumer* is the major component that interacts with the supplier's web services as well as the Legacy System's Web Services and the Simulation tool Web Services. The information flow is administrated by the application's controller component.

The *Application Controller* is responsible for the overall orchestration. It supports the transactions, security, users/roles and implements all business logic besides serving as a mediator between other components and the database

The simulation-software tool is implemented with the use of the Business Process Execution Language (BPEL). The BPEL is a business process modelling language that is executable and requires that a BPELengine container be used. (Makris *et al.* 2011). An active BPEL is an engine that can be deployed inside a servlet container (i.e. Apache Tomcat). A BPEL process orchestrates a set of web services by providing a .bpel file that contains the invocation flow as well as the exchanged messages between web services, which are called partners inside the .bpel file. In this file, the external web services that participate in the process are defined by referencing the respective Web Service Definition Language (.wsdl) files. A Process Deployment Descriptor (.pdd) file is required to advise the BPEL engine about the BPEL process as shown in Figure 8. Finally, a Partner Definition (.pdef) file will be created containing pieces of information on authentication and between the partners of the process. The overall process is implemented as a standalone web service and is triggered by the use of the Graphical User Interface of the OEM.

Inside the .bpel file, the process sequence includes a 'Human Task' (asynchronous) that requires the interaction of a human for its completion as well as a task that is either synchronous or asynchronous and can be completed without human interference.

The overall process is monitored, and a status will be displayed upon a user's request inside the GUI.

The web application is controlled by the user in order to process the requests or orders, given by the customers. The user can manually control all the steps of a request or the processing of an order. However, the whole procedure can also be carried out automatically. All that the user has to do is to enter the required parameters, i.e. request

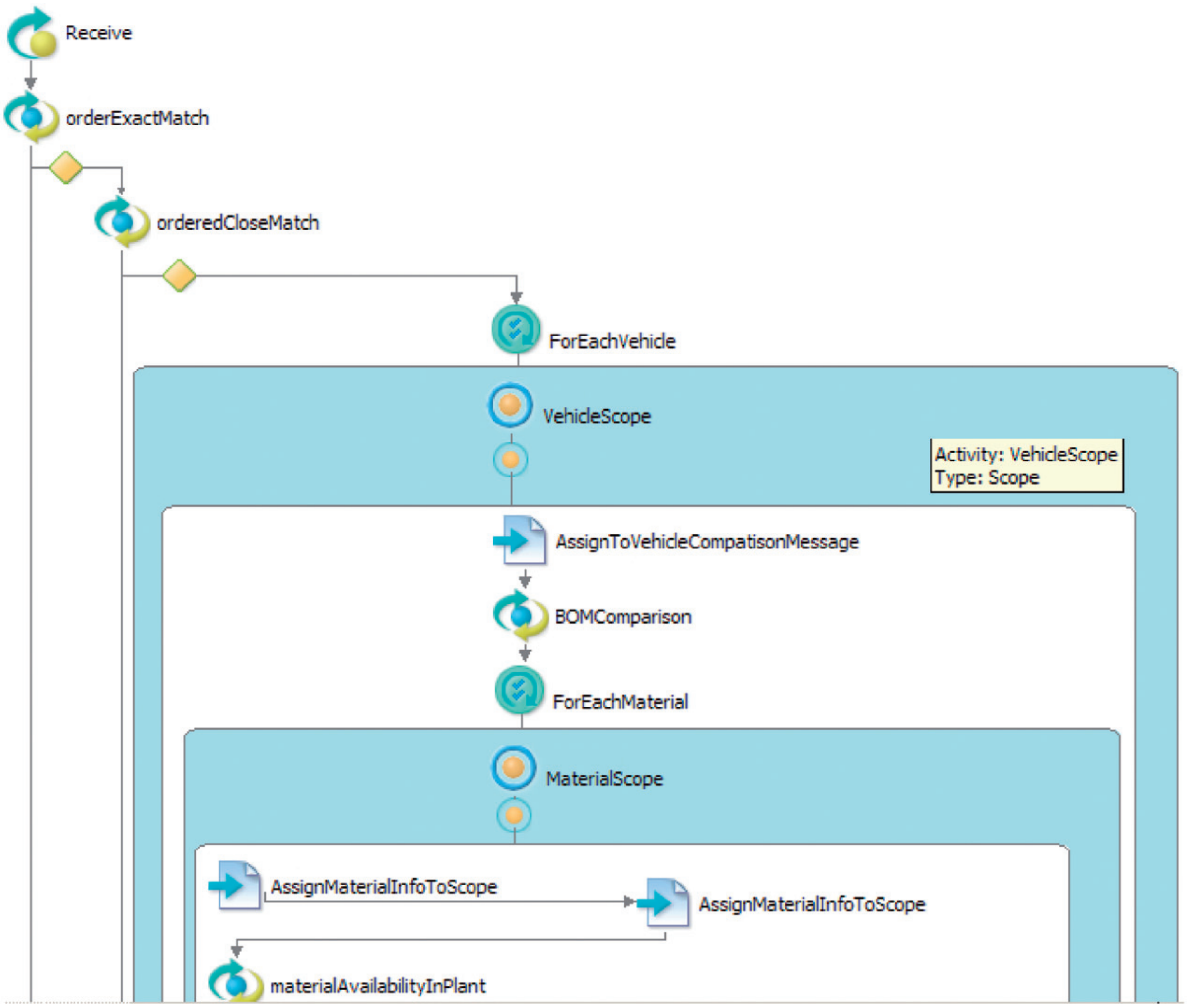


Figure 9. Portion of the business process execution model.

specifications, desired delivery date etc. This is implemented with the use of the web services and the BPEL. The structure of the BPEL diagram is shown in Figure 9.

The BPEL diagrams' implementation has been based on the supply-chain control logic discussed in Section 3.

Most of the circulated information is data generated dynamically by the Web Services. However, persistence storage is required for the simulation model tool since multiple vehicle models with different customisation options, delivery times and other parameters need to be stored and simulated. Furthermore, cached data should be stored in case of a communication break down in order to enhance the communication speed. The data repository has been developed as a database schema, containing all the required data such as product availability, production schedules, etc.

### 4.2.3 *Supplier module*

Each supplier, participating in the network should have a module onsite just like the OEMs have. The supplier's module does not differ significantly from that of the OEM's. It consists of the same components but it will be exporting different operations which are specific and need to be exposed to communicate with the OEM's web services.

### 4.2.4 *Information exchange/flow within the enterprises of the supply chain*

When a Web Service of the software application is executed, it imports data in order to proceed with the application. After completion of the processing, the Web Service generates the data results. The input data are either loaded from the database, or they are results of a previously executed Web Service. Equivalently, the data generated by a Web Service can be either stored into the database or used as input data for the next running of the Web Service. The following web services have been implemented in the system:

- ORDERTOOEMPRODUCTIONEXACTMATCHSERVICE: This Web Service is used to searching for any untagged orders that match exactly with the dealer's request.
- ORDERTOOEMPRODUCTIONCLOSEMATCHSERVICE: This Web Service is used to searching for any untagged orders that match closely with the dealer's request
- BILLOFMATERIALCOMPARISONSERVICE: This Web Service compares the requested vehicle with the selected exact or close match vehicle. Then, it returns the extra materials required for the implementation of the request.
- OEMINVENTORYSERVICE: This Web Service is used to checking the materials available in the OEM's inventory.
- TRANSPORTATIONINVENTORYSERVICE: This Web Service is used to checking the materials that are currently available in transit.
- SUPPLIERINVENTORYSERVICE: This Web Service is used to checking the materials available in the supplier's inventory.
- SUPPLIERPRODUCTIONSERVICE: This Web Service is used to determining whether or not the supplier is able to produce, in time, the extra material required.
- OEMCOSTAPPROVALSERVICE: This Web Service is used to examining whether a request is finally approved or not. The approval depends on possible extra costs that aggravate the car's total cost. If the total cost is over a certain limit, then the specific close match order is rejected and a new one should be selected.

An example of a Web Service of the software application along with its data inputs and outputs is as follows:

- BPEL Web Service ‘OrderToOEMProductionExactMatchService’

Input data:

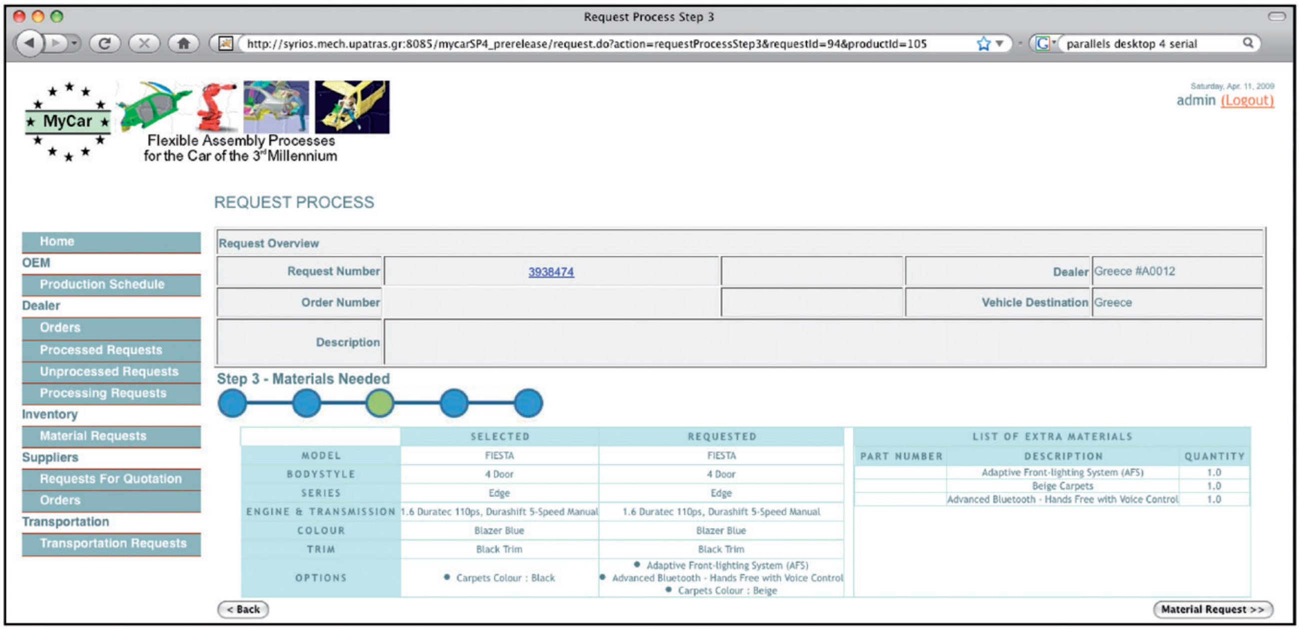
- *Dealer's information:* This information consists of the unique identification, the dealer's name and location. It also contains information about the vehicle's transit time from the plant to the dealer. The transit time is expressed in days.
- *Car model information:* This information contains the unique identification, the requested delivery date, the name of the model and the selected features. The features are related to the configuration of the car, and they consist of the name and the value of every feature available.

Output data:

- *Exact match vehicles:* The returned information, regarding each vehicle, is the Vehicle Identification Number (abbreviated as ‘vin’) and the date that the vehicle is scheduled for production.

The xml schema of the service is as follows.

```
<element name=‘orderToOEMProductionExactMatch’>
<xs:complexType>
<xs:sequence>
<xs:element name=‘exactMatches’minOccurs=‘1’maxOccurs=‘1’>
<xs:complexType>
<xs:sequence>
<xs:element name=‘vehicle’minOccurs=‘0’maxOccurs=‘unbounded’>
<xs:complexType>
<xs:sequence>
<xs:element name=‘vin’type=‘xs:string’minOccurs=‘1’maxOccurs=‘1’/>
<xs:element name=‘productionDate’type=‘xs:date’minOccurs=‘1’maxOccurs=‘1’/>
```



REQUEST PROCESS

Request Overview

| | | | | |
|---|---|---|---|---|
| Request Number | 3938474 | | Dealer | Greece #A0012 |
| Order Number | | | Vehicle Destination | Greece |
| Description | | | | |

Step 3 - Materials Needed

| | SELECTED | REQUESTED |
|---|---|---|
| MODEL | FIESTA | FIESTA |
| BODYSTYLE | 4 Door | 4 Door |
| SERIES | Edge | Edge |
| ENGINE & TRANSMISSION | 1.6 Duratec 110ps, Durashift 5-Speed Manual | 1.6 Duratec 110ps, Durashift 5-Speed Manual |
| COLOUR | Blazer Blue | Blazer Blue |
| TRIM | Black Trim | Black Trim |
| OPTIONS | • Carpets Colour : Black | • Adaptive Front-lighting System (AFS)<br>• Advanced Bluetooth - Hands Free with Voice Control<br>• Carpets Colour : Beige |

LIST OF EXTRA MATERIALS

| PART NUMBER | DESCRIPTION | QUANTITY |
|---|---|---|
| | Adaptive Front-lighting System (AFS) | 1.0 |
| | Beige Carpets | 1.0 |
| | Advanced Bluetooth - Hands Free with Voice Control | 1.0 |

Figure 10. System screenshot. A list contains all the needed materials.

```
</xs:sequence>
</xs:complexType>
</xs:element>
</xs:sequence>
</xs:complexType>
</xs:element>
</xs:sequence>
</xs:complexType>
</element>
```

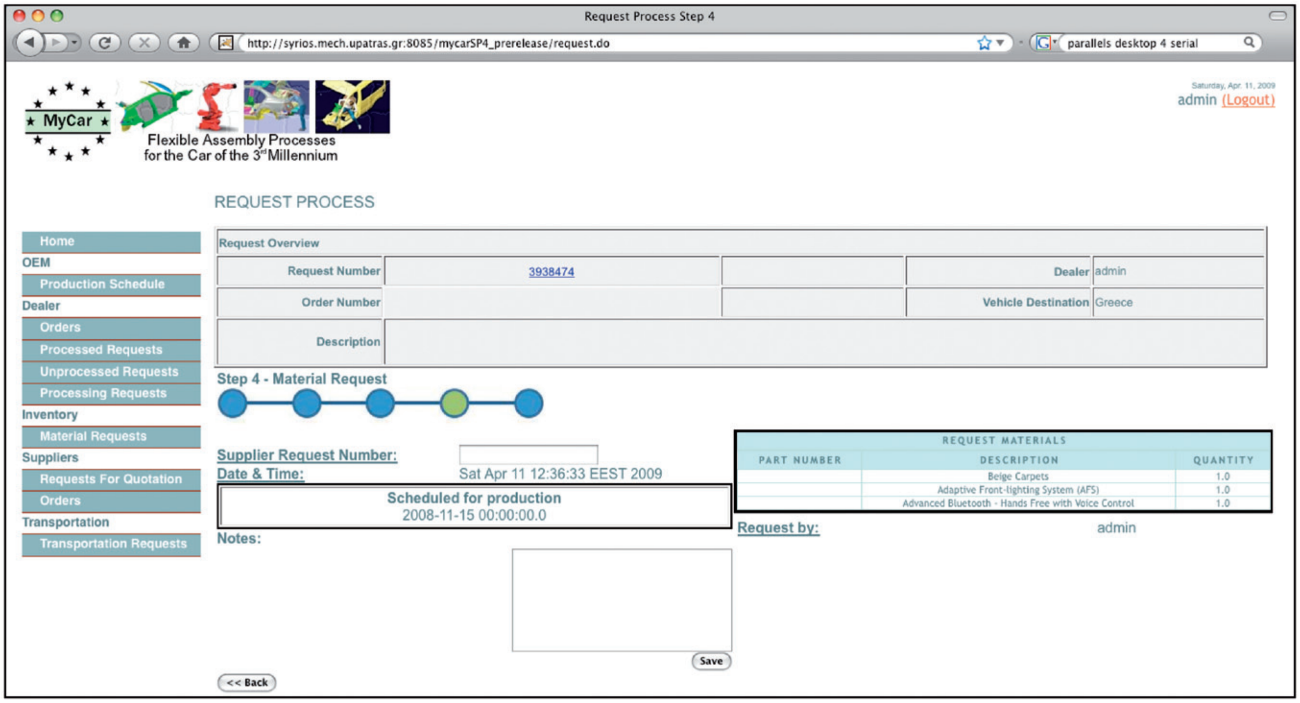
An example of the service usage that returns the number of the exact-match vehicles found is provided by the following message:

```
<ns:orderToOEMProductionExactMatch xmlns:ns="http://mycar/order-configuration-approval/xsd/complex-types/">
  <exactMatches>
  </exactMatches>
</ns:orderToOEMProductionExactMatch>
```

### 4.2.5 *Software implementation*

An example of the system's usage is as follows. When the OEM user decides to evaluate the required materials for customising a vehicle based on a close match, he can follow the process and reach a screen, where the differences are shown in Figure 10. The next step is that the user makes a request for the material(s) required. This can be done by clicking on the Material Request button.

By clicking the Material Request button, the process proceeds with the next step in which the user makes his request for the extra material(s) required. To do so, the user presses the Save button as shown in Figure 11. The material request is then saved and the Send to Inventory button appears that will forward the request to the inventory.



REQUEST PROCESS

Request Overview

| | | | | |
|---|---|---|---|---|
| Request Number | 3938474 | | Dealer | admin |
| Order Number | | | Vehicle Destination | Greece |
| Description | | | | |

Step 4 - Material Request

Supplier Request Number:
Date & Time: Sat Apr 11 12:36:33 EEST 2009

Scheduled for production
2008-11-15 00:00:00.0

Notes:

| REQUEST MATERIALS | | |
|---|---|---|
| PART NUMBER | DESCRIPTION | QUANTITY |
| | Beige Carpets | 1.0 |
| | Adaptive Front-lighting System (AFS) | 1.0 |
| | Advanced Bluetooth - Hands Free with Voice Control | 1.0 |

Request by: admin

Figure 11. Material request screenshot.

## 5. Discussion

The concept and the related software tool have been applied in a real-life scenario from the automotive industry (Mourtzis *et al.* 2008). The logic concept suggested in this paper deviates substantially from the current practice whereby the change of orders is not considered at all, and thus, for customised vehicle orders, the time from Order to Delivery is rather high. The current practice may work well in the mass customisation case, but it is not appropriate for the customisation approach. Given that the trend is to produce on demand a higher amount of customised orders, it is no longer adequate to operate under the mass-production concept. The time from order to delivery has been considered in order to compare how the proposed method advances the current practice. Offering a customised vehicle nowadays cannot be accomplished in less than 21 days owing to business and manufacturing constraints. However, the suggested method has been designed to operate in the period of zero to 14 days from the date of the order. The savings in time are rather high, leading to additional benefits, such as reduction in finished vehicles inventories.

Furthermore, the expected benefits of the proposed method and its impact on inventory levels and on the flexibility of an automotive supply chain have been evaluated. The flexibility is quantified with the use of a flexibility indicator (Chryssolouris 2006). The experiments show that the relation between inventory level and thus material availability and flexibility is proportional. As the material availability in the supply chain increases, so does its flexibility, allowing the supply chain to respond to an increased demand. Therefore, the key factor is to design and operate the supply chain utilising advanced networking and monitoring systems (Mourtzis *et al.* 2010).

## 6. Conclusions

This paper has discussed the implementation of a supply-chain control scheme using web-services technology. Modern information technologies were utilised in order for this approach to be implemented. The control logic handled the customisation orders adequately, thus enabling the supply chain to adapt to market variations, which led to a significant reduction in the order to delivery time. The problem of supply-chain adaptation to enable the manufacture of customised vehicles has not been examined in this context, and thus, there are no comparable results with other decision-support tools. Available methodologies typically focus on the analysis of the problems that are caused by the need for customisation. The uniqueness of the proposed method is that it proposes a decision-support system for enabling improvements in the supply chain such as the reduction in the order to delivery time.

The use of web-services technology proved to be satisfactorily based on achieving the coordination of the web services, with the use of the BPEL and not directly with the web services themselves. The main advantage was the workflow management and monitoring inside the supply chain, since it could be easily altered without any 'web services' related modifications and continuously monitored. The BPEL allowed for error state handling as well as for alternate routing of web-service requests to the back-up servers. Web-services added value is the common communication mechanism; offering neutral messaging in an XML format and an implementation independent way of data exchange, making it one of the most popular ways of application-to-application communication and data sharing.

Further investigation on the logic renders the involvement of supply-chain tiers, even more necessary, after the first one. The verification of the approach to more industries, especially to those whose supply chain is not fixed and is dynamically created, needs to be further investigated.

A comparison of the proposed method with current practice has shown a high potential for improvement in terms of order to delivery time and inventory of finished vehicles reduction. A more systematic analysis of the benefits needs to be carried out in future research and will be presented in follow-up publications.

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