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Technology selection in the absence of standardised materials and processes: a survey in the UK composite materials supply chain

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Abstract

Composite materials is an industry where technology selection has major consequences as there is not a standard manufacturing process, nor are there standardised materials with defined or proscribed properties for companies to select as multiple solutions are technically viable. This research aims to identify key factors for manufacturing technology selection in the UK composite materials supply chain. Literature review and managers' opinions were used to identify 18 factors affecting manufacturing technology selection. This was followed by a survey comprising the multi-tier supply chain of the composite materials industry. The results of the survey show 'on time deliveries/service level to customers', 'improve quality' and 'reduce cycle time' received the highest average ratings. In this study a correlation analysis was performed to identify the underlying dependencies between the factors investigated. The identification and use of underlying dependencies rather than highest average provided a more comprehensive picture of the factors that affect technology selection in the composite materials industry. For this study, experts in composite materials were asked to comment on the findings of the survey and their value to the industry. The results presented may assist companies in the composite materials industry with technology selection decision-making processes.

Keywords: Technology selection, Manufacturing supply chains, Supply chain management, Composite materials, UK

1. Introduction

The development of new products and applications based on new materials and technological innovations offers great business opportunities but also numerous challenges. One of the key challenges facing young, dynamic industries is the selection of manufacturing technologies. Technology selection and justification involve decision-making tasks that are critical to the profitability and growth of a company in the increasing competitive global scenario (Chan et al., 2000). The decision-making process of technology selection represents a major challenge facing managers as this most likely impact their company's business operations (Farooq and O'Brien, 2015).

The process of technology selection in young, dynamic industries may be even harder than in traditional, well-established sectors. In young, dynamic industries there may not be standard manufacturing processes, nor are there standardised materials with defined or proscribed properties for companies to select. Inherently, the selection of manufacturing technology has ramifications that can impact the supply chain. The traditional definition of supply chain management relates to the creation of value by reaching beyond the traditional borders of a firm including suppliers, customers and other stakeholders (Groen and Linton, 2010).

The available academic literature addressing the challenge of technology selection is characterised for the use of different approaches. In their research comprising the different mechanisms used to integrate new technology into existing products, Karlsson et al. (2010) considered the level of product advancement as a key factor based on whether a new technology renders an existing product to have enhanced functionality beyond its original scope. Other examples include: the use of competitive strategy analysis based on performance indicators such as cost, quality, flexibility and dependability (Kleindorfer and Patovi, 1990), theory of fuzzy sets applied to hierarchical structural analysis and economic evaluations (Chan et al., 2000), tangible and intangible factors used in integrated fuzzy logic in decision-making processes (Wu and Barnes, 2014) and evaluation models that take into account technical capability (Sarkar and Mohapatra, 2006), technological innovations (Choy et al., 2003) and elaborated methods for formulating criteria to use in partner selection decision-making in agile supply chains (Wu and Barnes, 2010). Other methodologies available include analytical hierarchy process (AHP) using technical level and supply capacity (Xia and Wu, 2007) and the use of Quality Function Deployment (QFD) for technology selection in industrial environments such as metallurgy (Lowe et al., 2000).

The number of studies that address technology selection from a supply chain perspective is still limited. For example Farooq and O'Brien (2012) highlight the lack of studies that incorporate the importance of the supply chain in the technology selection decision-making process. The researchers emphasize that this aspect is particularly acute in manufacturing organisations who are dependent on advanced manufacturing technologies for their competitive advantage and rely on extended supply chains. In a more recent article, Farooq and O'Brien (2015) make clear that technology selection has a fundamental role in the configuration of the supply chain, as opportunities and threats are normally associated with a technology alternative in the supply chain context.

It is well-accepted technology is a major area within manufacturing strategy (Farooq and O'Brien, 2012). However, the process of technology selection and how it relates to the supply chain is not completely understood and it may be challenged by the nature of young, dynamic industries like composite materials/carbon fibre. Young, dynamic industries may enable the identification of new trends and particularities about technology selection. Polymer matrix composites (PMCs), also known as fibre reinforced polymers (FRPs), consist of a matrix material, which is a polymer based resin, surrounding and supporting a reinforcement of some kind (typically fibres, particles or flakes). The resultant PMC has properties that are advantageous compared to those of either the matrix or the reinforcement when used on their own (Shakspeare and Smith, 2013). The composite materials industry is characterised for having flexible and innovative approaches to forming shapes, adapting processes and modifying materials. In the metallurgy industry tolerances for example are well defined, but in composites that is not the case. In composite materials there are no standard manufacturing processes, nor are there standardised materials with defined or prescribed properties to select. As result for any particular challenge there are frequently multiple solutions proposed that are technically viable. Organisations in this industry need to make informed decisions about which specific solution they have to adopt in order to strengthen their own position within the supply chain specific to the part or family of parts they are aiming to make.

Recent numbers show the global composite materials market value is estimated at USD $23.9 billion in 2013 and expecting to reach USD $35.2 billion by 2019 (O'Dea, 2014). In such context, inevitably many companies in the composite materials sector face the challenge of making decisions about the selection of technologies to support the demand for resins and fibres, semi-finished materials, components and structures used in some of the most advanced and innovative solutions for the aerospace, automotive, construction, medical equipment, marine, oil and gas, rail and renewables sectors including wind energy. In the foreseeable future, in the automotive industry the use of composite materials and in particular carbon fibre technology will become crucial for reducing vehicle weight and meet future Corporate Average Fuel Economy (CAFE) standards in various countries.

The composite materials is an industry that has been experiencing substantial growth because of new products and technological applications developed in recent years. Around the world the composite materials industry is growing steadily in many locations, as the expected global demand for carbon fibre will grow from 46,000 tons in 2011 to 140,000 tons by 2020 with production capacity being increased from 102,000 tons in 2011 to 129,000 tons in 2015, with the potential for further growth to 185,000 tons by 2020 (Roberts, 2011). The composite materials/carbon fibre is a promising high-tech industry facing several challenges as manufacturing methods are complicated and expensive to adopt in high volume applications. Hence it is possible to see companies being actively investigating high-volume use of carbon fibre in automotive applications. Ford Motor Company and DowAksa signed a deal to explore high-volume uses of carbon fibre composites as its use has been impeded by the absence of high-volume manufacturing methods and affordable material formats (Automotive News, 2015). The use of PMCs can be found in several state-of-the-art products. For example, in the new 2016 BMW 7 series sedan, carbon fibre reinforced plastic (CFRP) is found in the B- and C-pillars, in the roof bows, along the centre tunnel, on the package tray, in the sills, and in a 9-foot arc that runs from the base of the A-pillar to the rear of the car along the roofline (Autoweek, April 21, 2015). The body structure of the new car is 90 pounds lighter compared with the previous generation model.

Technology innovative industries like composite materials require a clear understanding of the various echelons/stages that comprise the supply chain. Figure 1 depicts the simple structure of the composites supply chain made of four tiers. The work by Shakspeare and Smith (2013) provides a detailed a description of the tiers that comprise the composites supply chain.

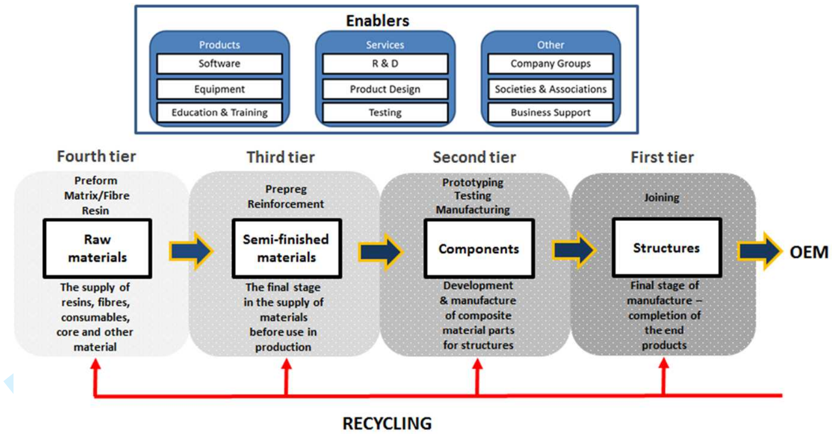

Figure 1. Diagrammatic representation of the composite materials supply chain.

In figure 1, the fourth tier, raw materials, covers the supply of resins, fibres and core materials. Among the most important raw materials we can find polyesters, epoxy resins, vinyl ester resins, phenolic resins, polyurethane and high value thermoplastics. Fibres cover glass fibre, carbon fibre, aramid fibre and natural fibre. Semi-finished materials cover the materials that go through processes such as ‘prepreg’ (pre-impregnated composite fibres which often take the form of a weave with a matrix material, usually epoxy). In prepregs the matrix is used to bond the fibres with other materials during production. The matrix is only partially cured requiring cold storage. Some of the most representative semi-finished materials cover thermoset prepreg, thermoplastic prepreg and consolidated sheet/panels. Components refer to the development and manufacture of composite material parts. An example of components can be represented by the transmission tunnel of a motor vehicle made of carbon fibre. Structures refer to the manufacture of composite systems by joining several components such as the wing or fuselage of an aircraft. Enablers would be those companies that provide engineering services, tooling, training and business support. At the end of the chain there are OEMs who manufacture end products that can include from planes, to cars, to furniture used in railway stations, sports gear, medical equipment and many more.

The aim of this paper is to select, rank and identify underlying dependencies of factors affecting manufacturing technology selection in a young and dynamic sector such as the composite materials industry. This is done by means of a survey addressing the entire supply chain, from raw materials, to semi-finished, components, structures, OEMs and enablers. Indeed, this study has the particularity of addressing the technology selection problem by considering the entire composites supply chain rather than focusing on a single company/echelon.

The next sections of this paper cover the literature review on factors related to manufacturing technology selection, followed by the generation of research questions. The methodology section comprises the utilisation of a survey of UK-based companies in the composite materials industry to rate the importance of technology selection factors identified in the literature. The responses to the survey were analysed to identify trends and underlying dependencies of factors directly affecting the technology selection process in the UK composite materials industry. Furthermore this research adopted the use of triangulation, where experts in composite materials commented on the findings of the survey and their value to the industry.

2. Literature review

One important aspect of technology selection is that it can have multiple ramifications and can be assessed in various ways. In fact, technology is mostly assessed in terms of financial benefits, however, these models have been subject to criticism over time (Farooq and O'Brien, 2012). In the work by Farooq and O'Brien (2012) it is possible to find technology selection models that address shortcomings that include aspects such as: a) technology selection processes fail to incorporate risk calculations in strategic technology selection; b) the threats associated with a technology alternative are not considered in the technology selection process and their importance in technology evaluation is usually neglected; and c) lack of support for the inclusion of inter-organisational factors in the technology selection decision-making environment.

The literature provides relevant examples of academic work that has identified factors and attributes for the purpose of selecting manufacturing technologies and supply chain partners. In Farooq and O'Brien (2010) there is a discussion about a framework that combines supply chain and manufacturing together. Among the elements included in the framework are the evaluation of current supply chain, identification of critical supply chain factors, planning range, identification of manufacturing technologies, detailed assessment of identified technologies and risk assessment of technology alternatives.

The rating of technology-related factors is important as new technologies and new technological developments continue to affect the performance of manufacturing and the supply chain. For example, in the case of new technological developments such as cloud computing, the work by Cegielski et al. (2012) highlights that cloud computing, as an emerging technology, is changing the form and function of information technology infrastructures and spreading within the supply chain. Using an analogy we can argue composite materials represent a new technology that is changing manufacturing operations and opening the doors for the creation of new products and spreading across multiple tiers in the supply chain.

Factors affecting manufacturing technology and supply chain configuration can impact decision-support making processes. Moreover, the development of decision-making support tools in supply chain management has received significant attention in recent years. The development of decision-support tools that can assist organisations in the design and configuration of their supply chain is particularly important in young industries experiencing high levels of uncertainty. It has long been acknowledged that change and uncertainty in business environments are primary causes of great loss in manufacturing industries (Sharifi and Zhang, 1999; Huang and Li, 2010).

2.1 Factors related to selecting manufacturing technologies with respect to the supply chain

Technology selection plays a fundamental role in the operations of today's supply chains as there can be multiple benefits that can be achieved. Technologies and strategies affecting manufacturing operations result in better competitiveness and improvement programmes (Rosenzweig et al., 2003). Technology selection has a fundamental role in the configuration of the supply chain, as opportunities and threats are normally associated with a technology alternative in the supply chain context (Farooq and O'Brien, 2012). Technology represents a key variable for identifying competitive policies, production strategy, innovations, creativity and commercialisation activities among others (Joshi et al., 2013).

On the selection of green technologies and the role of suppliers, Xia et al. (2015) highlight that the strategies of key suppliers are among several factors including the availability of supporting facilities and infrastructure that affect the application of technologies. The same authors mention suppliers as part of a group who can shape the market structure and affect operational orientation in green technology selection.

Suppliers may play an important role when it comes to technology selection. Judge and Elenkov (2005) acknowledge that suppliers can provide firms valuable feedback once a certain technology has been adopted. Furthermore, it is expected close links between technology selection and supplier selection because of its strategic implications for design/planning in the supply chain. Wu and Barnes (2011) reviewed the literature on supply partner selection published between 2001 and 2011 using a classification framework developed by Luo et al. (2009) and based on De Boer et al. (2001). Wu and Barnes (2011) recognise that the use of De Boer's et al. (2001) formulation of criteria, qualification, final selection and application feedback allows for an effective means of solving highly complex problems. Hwang et al. (2014) provided a selection criteria for Third-party logistics (3PLs) in high-tech manufacturing. Their proposed criteria comprising performance, service, cost, quality assurance, IT and intangibles was developed to assist manufacturers of integrated circuits plan logistics outsourcing actions. In their work on supplier selection Wu and Barnes (2010) developed a three-sage model for partner selection criteria formulation based on the identification of 116 generic supplier evaluation attributes applicable to any industry. The authors created a general hierarchy criteria comprising eight major groups including one for production and logistics and another one for technology and knowledge. Using a sample of Taiwanese IT manufacturers, Lin and Chen (2008) proposed a model for examining factors affecting the selection of distributors based on firm infrastructure, marketing capabilities, relationship intensity and logistics capabilities.

The review of the literature shows the role suppliers play when it comes to technology selection in manufacturing supply chains. Hence, we identified 18 factors related to the technology selection process in manufacturing supply chains: 'reduce cycle time' (Parthiban et al., 2013); 'improve quality' (Wu and Barnes, 2010); 'reduce scrap and rework' (Young et al., 2014); 'hire/train staff with new skills' (Yigin et al., 2007); 'increase capacity' (Yigin et al., 2007); 'automation' (Elgh, 2012); 'low cost manufacturing' (Wu and Barnes, 2010); and also operational in scope at the supply chain level such as ‘supply chain performance’ (Lin and Chen, 2004); ‘reduce supply chain cycle time’ (Lyons et al., 2005) and ‘capacity sizing and high volumes manufacturing’ (Mendoza and Ventura, 2012); others include ‘increase market share’ (Wang and Chen, 2012); ‘reduce labour costs’ (Parthiban et al., 2013); ‘reduce inventory levels’ (Protopappa-Sieke and Seifert, 2010); ‘rapid manufacturing/prototyping’ (Wang et al., 2013); ‘on-time deliveries/service level to customer’ (Choy et al., 2002; Coronado Mondragon and Lyons, 2008); ‘technology used by our suppliers’ (Choy et al., 2003); ‘technology used by our customers’ (Choy et al., 2003) and ‘return on investment’ (Protopappa-Sieke and Seifert, 2010).

Following the literature review of the factors affecting technology selection, a questionnaire was designed and presented to an audience comprising managers and experts in the UK composite materials industry who provided comments and validated the criteria selected. As a matter of fact, few countries in the world have an industrial base with the required expertise and know-how in composite materials like the one currently present in the UK. The UK possesses a strong composite industrial base developing state-of-the-art applications for wind turbines, aircraft, motorsports, automotive, marine and rail among others.

2.2 The composites supply chain and the relationship with factors involved in the technology selection process.

Companies in the manufacturing industry are collaborating with suppliers and customers to achieve seamless integration of manufacturing and supply chains (Farooq and O’Brien, 2012). Businesses in all sectors will agree that supply chain management integrates ‘‘key business processes from end user through original suppliers that provides products, services, and information that add value for customers and other stakeholders’’ (Lambert and Cooper, 2000).

The study of the supply chain of composite materials is a growing field as sectors such aerospace representing a global market of $4,471 billion USD continue to expand the adoption of structures and components made of composite materials. Other sectors such as automotive has seen an increase in the use of composite materials as there is need to lightweight vehicle structures in order to meet new legislation regarding emission reduction. Benefits of composite materials to automotive applications include reduced number of parts, reduction in tooling costs, good corrosion resistance and excellent crashworthiness properties among others (Shakspeare and Smith, 2013).

In this research the purpose of using a survey in the composite materials industry was twofold. First, it was used to rate the factors identified in the literature review and second, to identify correlations between each of them. Figure 2 depicts the major components associated to this research including, the technology selection factors identified in the literature, the multi-tier supply chain structure of the composite materials industry, markets served and the challenges faced by the industry. The use of a survey allows us to rank and identify dependencies between factors as seen as by companies operating in the UK.

Figure 2 also includes the listed challenges facing the composite materials industry when it comes to technology selection: a) The time to recruit and train additional staff maybe higher than the lead time for introducing a new technology; b) There are no standard manufacturing processes companies can use as reference; c) Skills and competencies may not exist within the company and within the general labour pool; d) Multiple solutions may be technically viable and e) Complex interaction traversing numerous industry sectors.

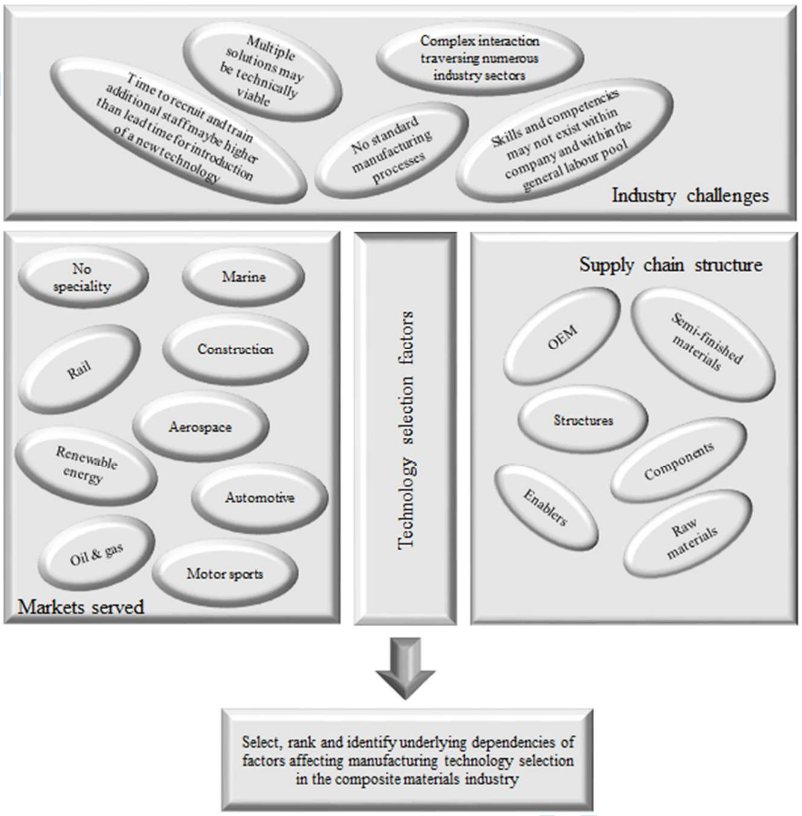

Figure 2. Conceptual model on selection, ranking and identification of underlying dependencies of factors affecting manufacturing technology based on supply chain structure, markets served and industry challenges.

Questions may arise in terms of what are the most relevant factors for the composite materials industry and their association to a particular stage in the supply chain. Also the analysis of industry ratings to the above factors may reveal underlying dependencies which may result in the creation of links related to technology selection. Hence three research questions were formulated as follows:

- Question 1: Which are the most relevant factors for manufacturing technology selection in the composite materials industry?
- Question 2: Are there major differences to the ratings companies in each tier of the supply chain give to the factors related to technology selection?
- Question 3: Using correlation analysis, what are the underlying dependencies between the factors investigated?

An important research gap identified is the lack of studies on technology selection that address the entire multi-tier supply chain. This means going beyond the supplier-firm, one-to-one, link and include upstream suppliers of the manufacturing supply chain. The composite materials is a truly multi-tier manufacturing supply chain.

The characteristics of the composites materials supply chain are explained in the following section. It is of particular interest to identify correlations among some of these factors identified in the literature and considering the supply chain position and market served by the companies surveyed.

In the composites industry, several manufacturing technologies are available to support production processes. This can be appreciated in table 1 which shows four major groupings: open mould, closed mould, continuous processing and pre/post processes comprising at least 34 different manufacturing technologies commonly used in the manufacturing of composite materials.

MANUFACTURING TECHNOLOGIES
Open mould
Automated Fibre Placement
Automated Tape Laying
Wet Hand Lay Up
Wet Spray Up
Filament Winding (Multi-axis)
Prepreg Hand Lay-Up
Closed Mould
Vacuum Infusion
Resin Film Infusion
Resin Transfer Infusion
Resin Transfer Moulding
Vacuum Assisted Resin Transfer Moulding
High Pressure Resin Transfer Moulding
Structural Reaction Injection Moulding
Injection Moulding
Centrifugal Moulding
Rotational Moulding
Cold/Warm Press Moulding
Hot Press Moulding
Stamping
Diaphragm Forming
Continuous Processing
Pultrusion
Pulwinding
Extrusion
Continuous Pipe Winding
Continuous Sheet Manufacture
Filament Winding (2-axis)
Pre/post process
Gel Coating
Post-Cure
Surface Finishing
Adhesive Bonding
Mechanical Fastening
Welding

Oven/Autoclave Curing	
Preforming	

Table 1. Manufacturing technologies available in the production of composites materials

Hence, this study makes a contribution in understanding the criteria and priorities for the composite materials supply chain when it comes to manufacturing technology selection.

3. Methodology

A survey was designed to obtain data regarding companies rating the factors related to the process of selecting manufacturing technologies. Before the questionnaire was distributed, a pilot survey was conducted where one company in each stage of the composite materials supply chain (raw materials, semi-finished materials, components, structures, enablers) answered the questions. During quarterly meetings, a group of managers in composite materials provided observations about the factors and questions and then explanations regarding the patterns observed during the development of the survey. This gave the opportunity to refine the structure of the questionnaire and re-write some questions. Once changes were made, the questionnaire was submitted to the same companies for validation and then the survey was distributed to 271 enterprises found in the directory of Composites UK[1] and conducted from September 2014 to March 2016. Managing/manufacturing directors were asked to rate the factors presented in the questionnaire. The structure of the questionnaire covers the following details:

- Company details, UK sites, length of operation, turnover, number of employees, etc.
- The structure and size of the company's supply chain including:
  - Company position in the supply chain.
  - Number and types of links up and down the supply chain.
- Manufacturing processes currently used, use of recycled materials.
- Market areas the company currently supply to and/or plan to supply to.

Nonetheless, correlation tests performed on the responses received were used to confirm association between factors. The companies that participated were asked to rate each of the factors using a 5-point Likert scale. The factors they were asked to rate include:

- The importance of 18 factors in selecting manufacturing technology in a 1 to 5 scale comprising 'cycle time', 'quality', 'labour cost', 'scrap and rework', 'capacity', 'market share' and 'inventory', 'the technology used by your suppliers', 'the technology used by your customers', 'automation', 'rapid manufacturing', 'capacity sizing and high volume production', 'supply chain cycle time', 'low cost manufacturing', 'return on investment', 'supply chain performance', 'on time deliveries/service level' and 'hiring/training staff with new skills'.

We can highlight from the structure mentioned above that the first section of the questionnaire aims to capture general information about participating companies such as age of business in the composites sector, turnover, etc. The second section is related with the

[1] https://compositesuk.co.uk/join-us/current-members

supply chain structure and the position in the UK composite materials supply chain as indicated in figure 1. Finally, in the third section participating companies were asked to rate the factors for selecting manufacturing technology. Respondents to the questionnaire used a five-point Likert scale (5 for very important to 1 for unimportant) to rate each of the factors identified. The companies contacted to participate in this survey are members of the Composites UK Trade Association. The questionnaire was distributed via email to each of the members of Composites UK Trade Association. Appendix A shows a sample of the questionnaire sent to participating companies.

This research considered the use of a triangulation approach where experts from the composite materials industry were asked to provide their views regarding the findings of the survey and the value these represent to the industry. Creswell (2008) comments that using a single research method to conduct research may cause bias. Gill and Johnson (2010) mention that the combination of research methods provide opportunities for methodological triangulation. For example, Zhang's et al. (2016) work on how engineering companies develop and integrate solution-based capabilities in small batch production relies on the use of triangulation. In their work, the primary data collected by the researchers were complemented by documents for purposes of triangulation and validity in a study involving a multiple case study based on the use of semi-structured interviews. In our research we decided to approach two UK-based experts in the composite materials industry. Their comments are used to support the validity and reliability of the findings of the survey and identify the value to the industry.

4. Analysis of results

The total number of responses received from the surveyed companies represent about 30% of the members of the Composites UK Trade Association. The response rate registered for this survey is higher to what other people have achieved conducting research involving supply chains in the manufacturing sector. For example, Wagner et al. (2012) achieved a response rate of 18.3% when collecting data from managers of manufacturing firms in the USA, UK, Germany, Austria, Switzerland, and France. In our research a total of 81 usable answers were returned. General descriptive statistics about the responding companies show details regarding age of business with 28.2% of the sampled companies operating in composite materials for less than 10 years, 28.2% between 10 and 20 years, 26.9% between 21 and 30 years and 16.7% more than 30 years (there were three missing answers). These results show that newcomers to the industry represent a minority. The results of the survey show that companies have turnovers typical of small-medium enterprises (73.5% of the sampled companies have a turnover lower than £10,000,000, however 32 of the respondents did not want to disclose their turnovers).

Composite materials have been labelled as a young, growing sector with characteristics of a high-tech industry. According to the definition provided by the OECD (2005) high-tech industries devote on average more than 10% of their expenditures to R&D. The results of the survey shows that about 24.2% of the companies that participated in the survey have a R&D

expenditure of 10% or more. Many companies were reluctant to disclose the amount allocated to R&D, hence 48 companies did not answer this question.

Figure 3 shows a pie chart with the results of the respondents' primary position in the supply chain. In figure 3, 27.2% of surveyed companies identified themselves as components manufacturers, followed by structures (16%), raw materials (13.6%) and semi-finished materials (9.9%). The remaining companies identified themselves as enablers (23.5%) but only few of them as OEMs (8.6%) with 1.2% companies did not identify themselves.

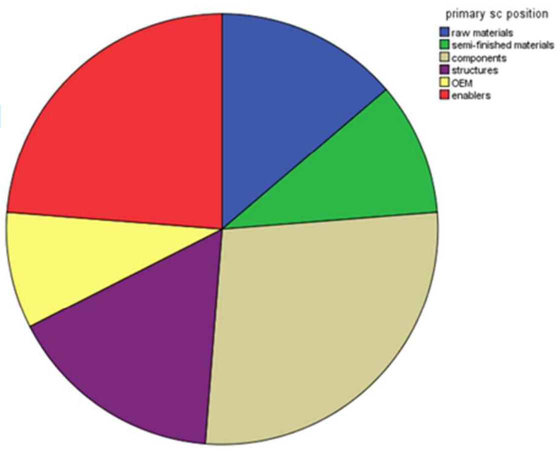

Figure 3. Primary position in the composites supply chain by the respondent companies.

The answers surveyed companies gave to the question about the primary market served are depicted in Figure 4. The results of figure 4 show that about 29.6% of surveyed companies answered they do not have a speciality market (4.9% of missing answers), that means they serve multiple markets. Companies who serve the aerospace sector represented 22.2% of the total, automotive with 12.3%, construction and marine with 8.6% each, motorsport with 3.7%, rail and defence with 2.5% each, and oil and gas, leisure and renewable energy – tidal and wind with 1.2% each.

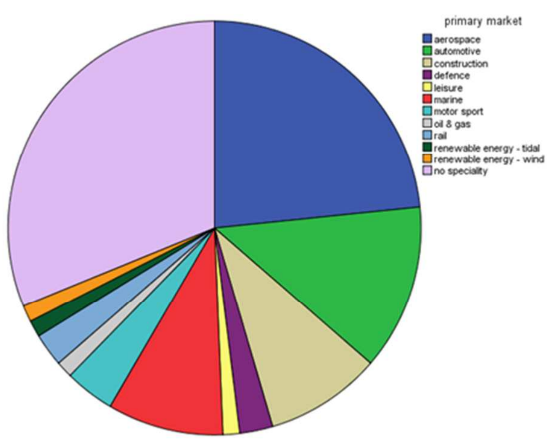

Figure 4. Primary markets served by the respondent companies.

The average ratings to the factors investigated based on the position of the companies in the composite materials supply chain are presented in table 2. Based on the answers received 'reduce inventory levels', 'supply chain cycle time' and 'low cost manufacturing' are factors rated as not important by companies identified as semi-finished materials suppliers. The results show that some factors received average rates lower than 3 depending on the position of the surveyed companies in the supply chain. For example, raw materials rated 'rapid manufacturing'; semi-finished materials rated 'inventory levels', 'supply chain cycle time' and 'low cost manufacturing'. Components and enablers rated 'inventory levels'.

As a matter of fact, 'technology used by your suppliers' received a high-rating only by OEMs while 'technology used by your customers' received a high-rating only by raw materials companies and enablers. Moreover, 'rapid manufacturing' received a high-rating only by enablers and finally 'reduce supply chain cycle time' together with 'low cost manufacturing' received a high-rating only by structures companies.

	Raw materials	Semi-finished	Components	Structures	OEMs	Enablers
Reduce cycle time	4.67	3.67	4.37	4.63	4.00	4.17
Improve quality	4.83	4.17	4.26	4.38	4.40	4.00
Reduce labour cost	4.50	3.67	4.11	4.38	4.60	3.58
Reduce scrap and rework	4.83	3.67	4.05	4.00	4.00	3.58
Increase capacity	3.83	3.83	4.16	4.50	3.80	3.67
Increase market share	4.83	4.17	3.74	4.13	4.40	3.50
Reduce inventory levels	3.83	2.50	2.79	3.13	3.40	2.67
The technology used by your suppliers	3.67	3.33	3.16	3.75	4.00	3.50
The technology used by your customers	4.00	3.83	3.26	2.88	3.60	4.00
Automation	3.33	3.67	3.21	3.38	3.40	3.92
Rapid manufacturing or prototyping	2.67	3.17	3.84	3.00	3.20	4.00
Capacity sizing and high volume production	3.83	3.17	3.26	3.75	3.20	3.25
Reduce supply chain cycle time	3.33	2.50	3.37	4.00	3.40	3.75
Low cost manufacturing	3.00	2.83	3.79	4.00	3.60	3.42
Return on investment	3.83	4.00	4.00	4.00	4.40	4.00
Supply chain performance	4.67	3.33	4.05	3.75	4.20	3.92
On time deliveries/services level to customers	4.83	4.17	4.68	4.37	4.86	4.08
Hiring/training staff with new skills	4.50	3.50	3.95	4.38	4.20	3.67

Table 2. Average ratings of factors by position in the composites materials supply chain.

The results of the average ratings to the factors based on markets served are presented in table 3. From the results it is clear that respondents prioritised their answers based on the markets they serve. For example, for companies serving the automotive 'rapid manufacturing', 'capacity sizing' and 'supply chain cycle time' received an average rate between 4 and 5. The results also show average rates lower than 3 for some specific factors and sectors, including construction with 'rapid manufacturing' and marine with 'inventory levels' and 'supply chain cycle time'. No speciality companies gave 'inventory levels' a rate below 3.

	Aerospace	Automotive	Construction	Marine	Motor sport	No speciality
Reduce cycle time	4.25	4.90	3.80	4.67	4.50	4.07
Improve quality	4.25	4.33	4.60	4.17	4.50	4.36
Reduce labour cost	3.92	4.50	4.80	4.67	4.50	3.57
Reduce scrap and rework	4.08	4.17	4.40	3.83	4.00	3.93
Increase capacity	4.08	4.00	3.80	4.17	4.00	3.86

Increase market share	3.83	4.00	4.20	4.33	3.00	3.86
Reduce inventory levels	3.17	3.17	3.00	2.83	3.50	2.79
The technology used by your suppliers	3.67	3.00	3.20	3.50	2.50	3.64
The technology used by your customers	3.67	3.67	3.40	3.00	3.50	3.71
Automation	3.67	3.83	2.60	3.67	1.50	3.64
Rapid manufacturing or prototyping	3.50	4.00	3.40	3.17	3.50	3.43
Capacity sizing and high volume production	3.00	4.33	3.20	3.00	2.00	3.50
Reduce supply chain cycle time	3.75	4.00	3.20	2.50	2.50	3.29
Low cost manufacturing	3.50	4.00	4.00	3.67	3.50	3.21
Return on investment	3.67	4.33	4.60	4.50	4.00	3.57
Supply chain performance	4.33	4.17	4.20	3.83	3.50	3.64
On time deliveries/services level to customers	4.75	4.67	4.80	4.33	4.50	4.14
Hiring/training staff with new skills	3.92	3.83	4.40	4.33	4.00	3.86

Table 3. Average ratings of factors by markets served.

In the survey managers of participating companies were asked to rate the importance of eighteen factors in selecting manufacturing technology in a 1 to 5 scale (5 for very important to 1 for unimportant). Figure 5 shows the results of the rates given to the factors associated to technology selection.

Figure 5 answers the first research question. The respondents gave 'on time deliveries/service level to customers' the highest average rate, followed by 'improved quality', 'reduced cycle time', 'return on investment', 'reduce labour cost', 'increase capacity', 'reduce scrap and rework' and 'supply chain performance'. These are the eight most important factors as rated by the companies that participated in the survey. On the other hand 'reduction of inventory levels', 'capacity sizing and high volume production', 'automation', 'reduce supply chain cycle times', 'technology used by your suppliers' and 'rapid manufacturing or prototyping' are factors that received the six lowest ratings by the respondents.

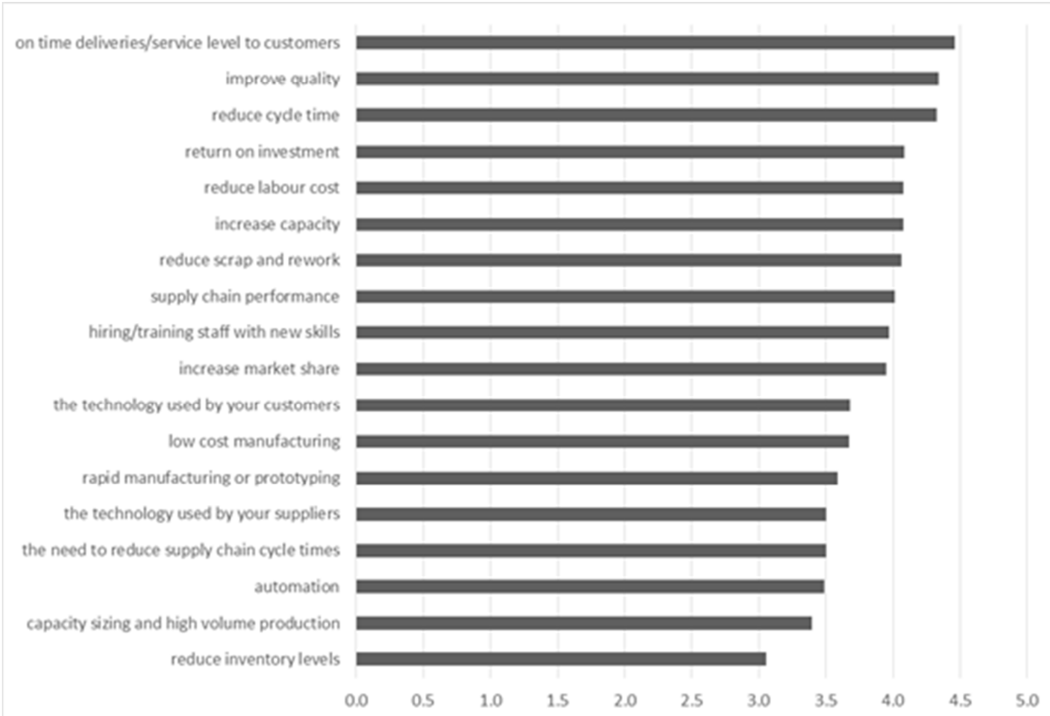

Figure 5. Responses to factors related to technology selection by participating companies.

The responses received to the above factors reveal that companies in the UK composites industry still possess the characteristics of organisations operating in niche markets. This is represented by the high rates given to 'on time deliveries/service level to customers', 'improve quality' and 'reduce cycle time'. As the industry continues to develop and increases its volume output, in the future it would be possible to see higher rates to factors like 'rapid manufacturing/prototyping' and perhaps 'automation'.

Furthermore, regarding the answer to the second research question, the results show that at the supply chain level only a handful of factors showed differences among the tiers investigated. No major differences to the ratings of the majority of the factors were observed. The few exceptions observed include 'reduce inventory levels', 'reduce supply chain cycle time' and 'low cost manufacturing' which received a low-rating by semi-finished materials companies. Others include 'rapid manufacturing' which received a low rating by raw materials companies. On the other hand, some factors received a high-rating only for some stages.

4.1 Correlations between factors tested

The analysis performed at the 0.01 level of confidence (2-tailed) revealed correlation between several factors. The results of the correlation analysis are presented in table 4.

'Supply chain performance' showed the highest number of correlations, nine, followed by 'reduce scrap and rework' with seven and 'hiring/training staff', 'return on investment' and 'reduce inventory levels' each with six. The majority of the factors considered showed a modest number of correlations between them, from five to three. Those with five include: 'increase capacity', 'reduce supply chain cycle times' and 'low cost manufacturing'.

Factors that reported four correlations include: 'reduce cycle time', 'improve quality', 'reduce labour cost', 'increase market share', 'capacity sizing' and 'high volume production'. 'Technology used by suppliers', 'technology used by customers' and 'on time deliveries/service level' reported only three each. Finally, 'automation' (with 'capacity sizing' and 'rapid manufacturing and prototyping' (with reduce supply chain cycle times') showed only one correlation each.

The existing correlations can be represented as a network diagram illustrating the underlying dependencies between the factors investigated as shown in figure 6. Correlation between factors are represented in light grey links. Moreover, the results of the correlation analysis show core factors that reported the highest number of correlations for the surveyed companies. 'Supply chain performance', 'reduce scrap and rework', 'reduce inventory levels', 'return on investment' and 'hiring/training staff' are core factors that reported the highest number of correlations for this research. These five factors are coloured in dark grey and white letters compared to the lighter shades of grey for factors that reported fewer correlations. Also factors with more correlations are bigger in size than those with less correlations. The stronger the correlation between factors the thicker and darker the connecting link.

The overall analysis shows that factors that reported the highest number of correlations ('supply chain performance', 'reduce scrap and rework', 'reduce inventory levels', 'hiring/training staff' and 'return on investment') were not among the top five factors that received the highest average ratings by the surveyed companies ('on time deliveries/service levels', 'improve quality', 'reduce cycle time', 'reduce labour cost' and 'increase market share'). Nonetheless, the factors that showed the highest number of correlations, each has correlation with at least two of the factors with the top five highest average ratings. Focusing on underlying dependencies based on the correlation analysis is more inclusive and wider in scope than just focusing on the highest average ratings.

Based on the findings of the correlation analysis we can suggest that the five factors with the highest number of correlations reflect underlying dependencies based on the views and conditions of surveyed companies regarding the factors affecting technology selection. In addition, the results reveal strong correlation between the primary market served and the factor 'on time deliveries/service level to customers'.

	reduce cycle time	improve quality	reduce labour cost	reduce scrap and rework	increase capacity	increase market share	reduce inventory levels	the technology used by your suppliers	the technology used by your customers	automation	rapid manufacturing or prototyping	capacity sizing and high volume production	the need to reduce supply chain cycle times	low cost manufacturing	return on investment	supply chain performance	on time deliveries/service level to customers	hiring/training staff with new skills
reduce cycle time	1	.356**	.390**	.305**	.315**	.124	.255*	-.031	-.042	.018	.210	.288*	.316*	.263*	.085	.137	.047	.194
improve quality	.356**	1	.231*	.637**	.271*	.228	.349**	.146	.155	-.116	.003	.151	.179	.196	.034	.295*	.156	.376**
reduce labour cost	.390**	.231*	1	.368**	.364**	.111	.221	-.222	-.281*	-.017	-.018	.140	-.008	.355**	.083	-.071	-.087	.076
reduce scrap and rework	.305**	.637**	.368**	1	.255*	.396**	.345**	.266*	.133	-.047	-.017	.284*	.241	.198	.195	.488**	.136	.516**
increase capacity	.315**	.271*	.364**	.255*	1	.147	.408**	-.146	-.107	.066	-.016	.182	.355**	.483**	.124	.053	.284*	.164
increase market share	.124	.228	.111	.396**	.147	1	.242*	.281*	.193	.017	-.133	.265*	.173	-.116	.425**	.441**	.207	.598**
reduce inventory levels	.255*	.349**	.221	.345**	.408**	.242*	1	.167	.325**	-.126	-.134	.156	.257*	.160	.142	.356**	.387**	.268*
the technology used by your suppliers	-.031	.146	-.222	.266*	-.146	.281*	.167	1	.408**	.202	.033	.152	.205	-.010	.215	.434**	.230	.313**
the technology used by your customers	-.042	.155	-.281*	.133	-.107	.193	.325**	.408**	1	.100	.234	.092	.115	-.284*	.108	.387**	.204	.284*
automation	.018	-.116	-.017	-.047	.066	.017	-.126	.202	.100	1	.297*	.434**	.208	.117	.144	.018	-.072	.191
rapid manufacturing and prototyping	.210	.003	-.018	-.017	-.016	-.133	-.134	.033	.234	.297*	1	.290*	.376**	.290*	.217	.136	.057	.051
capacity sizing and high volume production	.288*	.151	.140	.284*	.182	.265*	.156	.152	.092	.434**	.290*	1	.491**	.314**	.405**	.163	.172	.301*
the need to reduce supply chain cycle times	.316*	.179	-.008	.241	.355**	.173	.257*	.205	.115	.208	.376**	.491**	1	.474**	.296*	.394**	.313*	.310*
low cost manufacturing	.263*	.196	.355**	.198	.483**	-.116	.160	-.010	-.284*	.117	.290*	.314**	.474**	1	.335**	.099	.073	.054
return on investment	.085	.034	.083	.195	.124	.425**	.142	.215	.108	.144	.217	.405**	.296*	.335**	1	.395**	.344**	.370**
supply chain performance	.137	.295*	-.071	.488**	.053	.441**	.356**	.434**	.387**	.018	.136	.163	.394**	.099	.395**	1	.540**	.404**
on time deliveries/service levels to customers	.047	.156	-.087	.136	.284*	.207	.387**	.230	.204	-.072	.057	.172	.313*	.073	.344**	.540**	1	.276*
hiring/training staff with new skills	.194	.376**	.076	.516**	.164	.598**	.268*	.313**	.284*	.191	.051	.301*	.310*	.054	.370**	.404**	.276*	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 4. Correlation table for surveyed factors.

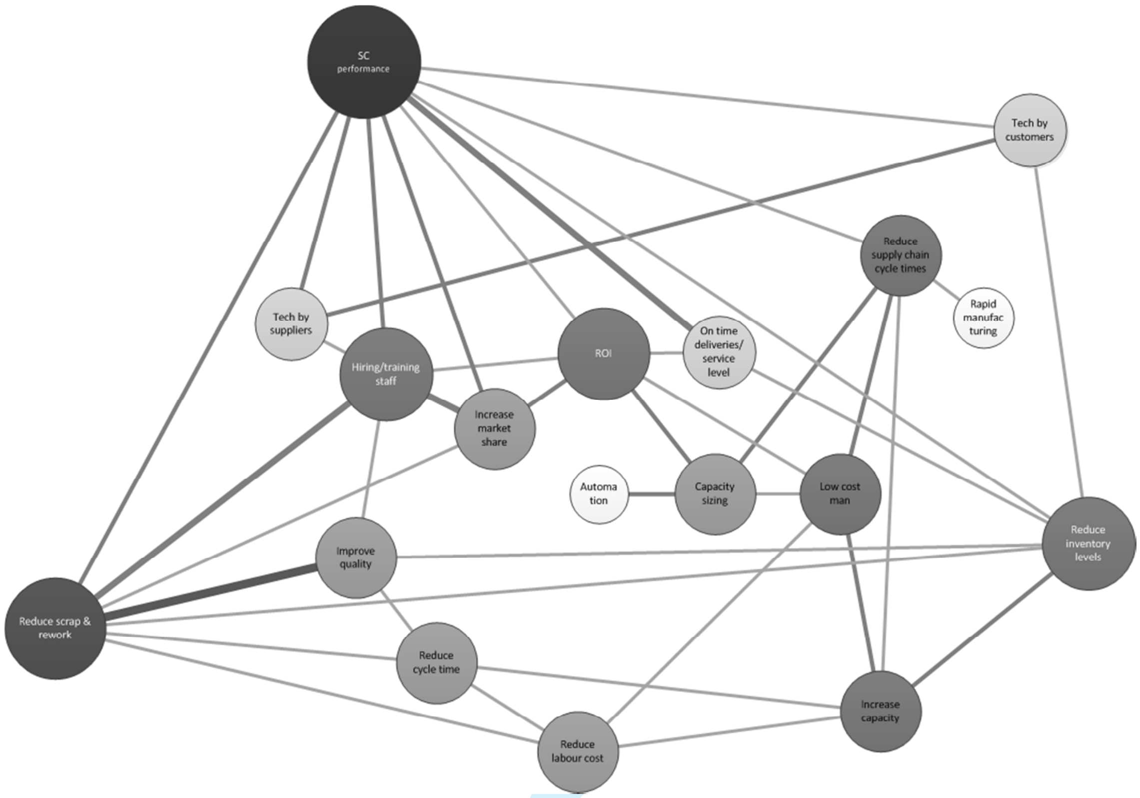

Figure 6. Network representation of correlations between factors investigated.

4.2 Triangulation approach using expert opinions to validate survey results and identify managerial implications

Once the analysis of the survey was completed and based on the proposed methodology, two anonymous experts on composites materials were asked to provide their views on the results of the survey and the value these may have to the composites industry. The first expert approached by the authors, Expert 1, is a manager with decades of experience working in the composites industry and based at one of the top composites research centres in the UK. After reviewing the results of the survey, Expert 1 highlighted that depending on the markets served, different rates are given to certain factors:

"By example we expect to see volume and cost as factors for automotive whereas these do not show up for aerospace which already has a relatively well-performing supply chain. So in some cases responses relate to established supply chains, in others they describe desirable attributes."

It is expected staff skills will play an important role in the future of the composites materials industry as new technologies are introduced. On training staff with new skills expert 1 expressed the following statement based on the results of the survey:

"There is a similar comment about the skills factor where anticipated correlations are seen for probably current technologies but skills for automation, rapid prototyping, low cost manufacturing etc. do not show up."

The introduction of new technologies may result in correlations between training staff with new skills and technology-related factors indicated by Expert 1 such as automation, rapid prototyping and low cost manufacturing.

More important Expert 1 highlighted the factors investigated play a role in what would be labelled as 'supply chain readiness', the expert added: *"a predictor of future competitiveness as much of it depends upon non-technological, commercial factors"* like those included in the survey.

The second expert, Expert 2, has about twenty years work experience in the process development of manufacturing composite materials for sectors using composites like aerospace, marine, construction and oil and gas. One of the aspects addressed in the survey was for companies to identify their location in the composite materials supply chain. Automotive is regarded as a sector that offers numerous opportunities to reshape the configuration of its composites supply chain. Expert 2 added the following observations:
"Current thinking is that to exploit the opportunity for mass production automotive composites, large metallic Tier 1's who already supply into OEMs with metallic components will have to switch to composites rather than getting composite SMEs to scale up to meet the demand of OEMs. There are both technical and non-technical matters to consider. The simplest way of achieving this (if it was technically feasible) would be for existing metal press tools to press form thermoplastic composites."

Expert 2 statements relate directly to the fact that in the automotive sector metal stamping and press tools are highly automated and support high-volume production. In the survey capacity sizing and high-volume production shows correlation with automation. Furthermore, on the differences between sectors Expert 2 expressed that:
"Other sectors such as Rail could benefit greatly from the advances made in Automotive and Aerospace."

Based on the results from the survey and the inputs from the composites experts, there are a number of implications that can be highlighted from this research. Getting the composites supply chain ready depends on technical and non-technical, commercial factors. A lot of work and resources have been spent in the technical aspects of manufacturing composites materials and still more work needs to be done (i.e. high-volume manufacturing of composites parts for automotive applications is still under development). However, the readiness of the composite materials supply chain can be directly affected by factors like hiring/training staff with new skills.

Another point to highlight is the proliferation of technologies which is a major issue in the composite materials industry, hence the survey of factors associated to technology selection may help organisations with the development of technologies that takes into account the real needs of industry rather than throwing solutions that might end marginally accepted.

This paper makes a contribution by exploring how companies comprising a multi-tier supply chain in a young, high-tech, developing industry like composite materials rate some critical factors related to the selection of manufacturing technology. The results may be used to highlight the characteristics of the composite materials supply chain in the UK and how it differs from other young, high-tech industries. The identification and use of underlying dependencies rather than highest average provide a more comprehensive picture of the factors that affect technology selection in a high-tech industry like composite materials. The results presented may assist companies in the composite materials industry with technology selection decision-making processes.

5. Conclusions

The composite materials industry and in particular carbon fibre is a key supplier to many industries such as aerospace, automotive, construction, marine, oil and gas, rail, sports gear, medical equipment and renewable energy among others. Given the growing importance of composite materials to large industries, it has become imperative to identify factors related to the selection of manufacturing technologies. Technology selection exerts great influence on the configuration of supply chains and the composite materials industry is no exception. The situation of the composite materials industry is more complex given the challenges faced by the industry such as the lack of staff with the right skills, the absence of standardised manufacturing processes, the possibility of having multiple solutions technically viable, etc.

Getting the composites supply chain ready is an idea highlighted by one of the experts that participated in this research. The concept opens the door for future research opportunities as non-technological, commercial factors start playing more roles in the composites industry which may affect the future of important manufacturing sectors like automotive, aerospace, rail, etc.

The results of the correlation analysis revealed important relationships between the factors tested in the survey. These factors with the highest number of correlations not only represent underlying dependencies but also reflect the views, trends and conditions of the composite materials industry regarding the factors related to manufacturing technology selection. Based on the results we suggest companies to prioritise those factors that show highest number of correlations rather than those with the highest average ratings.

An industry survey comprising a large pool of companies in various countries in the composite materials industry, perhaps at the European level, will help to confirm and extend the findings regarding the factors affecting technology selection presented in this paper and how that affects the supply chain. In particular a statistical analysis will be required in order to identify possible correlations between the factors and characteristics of the companies in different stages in the composite materials supply chain. Finally, the results of this research may be used to develop conceptual frameworks that can assist companies in the composite materials industry with the decision-making process of having to select a manufacturing technology and the eventual impact on the configuration of the supply chain.

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Appendix A – Questionnaire used

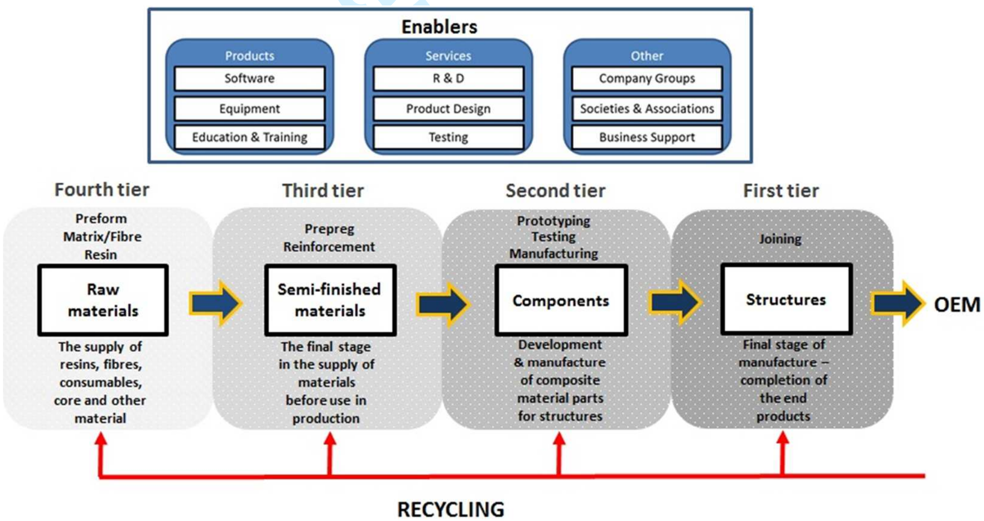
Technology selection in the composite materials supply chain

Thank you for participating in this survey. The information you provide will be used to conduct a research on the composite materials supply chain with particular focus on technology selection. All data you provide will be treated as confidential.

I. Company Details. Please fill in the empty spaces.

Name of your organisation: ______________________________________.
Position within your company: _____________________________.
Age of the business: ___ (years).
How long has your organisation been involved in the composites sector: ___ (years).
Number of employees working in the company: __________.
What is the approximate turnover of the company? ___________.
What is the percentage of company expenditure going to R&D? _______%

II. The composites supply chain.



Using the above diagram of the composites supply chain, please answer the following questions (fill in the empty spaces or tick the empty boxes).

1. Where do you locate your organisation within the composites supply chain?

- Raw materials (Fibre/Resins) ☐
- Semi-finished materials ☐
- Components ☐
- Structures ☐
- OEM ☐
- Enablers ☐

2. Market served:

Please select one primary market and all other additional markets that you are involved in. Of those selected, please specify in which you use/produce composite materials now and those which you intend to within the next 3 years.

	Primary Market	Additional Markets	Use or make Composites	Predicted to within 3 years
Aerospace	☐	☐	☐	☐
Agriculture	☐	☐	☐	☐
Automotive	☐	☐	☐	☐
Construction	☐	☐	☐	☐
Defence	☐	☐	☐	☐
Leisure	☐	☐	☐	☐
Marine	☐	☐	☐	☐
Medical	☐	☐	☐	☐
Motor Sport	☐	☐	☐	☐
Oil & Gas	☐	☐	☐	☐
Rail	☐	☐	☐	☐
Renewable Energy - Tidal	☐	☐	☐	☐
Renewable Energy - Wind	☐	☐	☐	☐
Space	☐	☐	☐	☐
Textiles	☐	☐	☐	☐
Sports	☐	☐	☐	☐
No Speciality	☐	☐	☐	☐
Other (Please Specify)	☐	☐	☐	☐

3. Manufacturing technology selection decision process.

What key/new manufacturing technology do you need to adopt in your business to remain competitive?____.

Please, rate the importance of the following factors regarding the selection of manufacturing technology.

Reduce cycle time.

Unimportant	Of little importance	Moderately important	Important	Very important
☐	☐	☐	☐	☐

Improve quality.

Unimportant	Of little importance	Moderately important	Important	Very important
☐	☐	☐	☐	☐

Reduce labour costs.

Unimportant	Of little importance	Moderately important	Important	Very important
☐	☐	☐	☐	☐

Reduce scrap and rework.

Unimportant	Of little importance	Moderately important	Important	Very important
☐	☐	☐	☐	☐

Increase capacity.

Unimportant	Of little importance	Moderately important	Important	Very important
☐	☐	☐	☐	☐

Increase market share.

Unimportant	Of little importance	Moderately important	Important	Very important
☐	☐	☐	☐	☐

Reduce inventory levels.

Unimportant	Of little importance	Moderately important	Important	Very important
☐	☐	☐	☐	☐

Influence of the technology used by your suppliers in the selection of the right manufacturing technology for your business.

Unimportant	Of little importance	Moderately important	Important	Very important
☐	☐	☐	☐	☐

Influence of the technology used by your customers in the selection of the right manufacturing technology for your business.

Unimportant	Of little importance	Moderately important	Important	Very important
☐	☐	☐	☐	☐

Automation.

Unimportant	Of little importance	Moderately important	Important	Very important
☐	☐	☐	☐	☐

Rapid manufacturing/prototyping.

Unimportant	Of little importance	Moderately important	Important	Very important
☐	☐	☐	☐	☐

Capacity sizing and high volumes production.

Unimportant	Of little importance	Moderately important	Important	Very important
☐	☐	☐	☐	☐

The need to reduce supply chain cycle times.

Unimportant	Of little importance	Moderately important	Important	Very important
☐	☐	☐	☐	☐

Low cost manufacturing.

Unimportant	Of little importance	Moderately important	Important	Very important
☐	☐	☐	☐	☐

Return-on-Investment.

Unimportant	Of little importance	Moderately important	Important	Very important
☐	☐	☐	☐	☐

Supply chain performance.

Unimportant	Of little importance	Moderately important	Important	Very important
☐	☐	☐	☐	☐

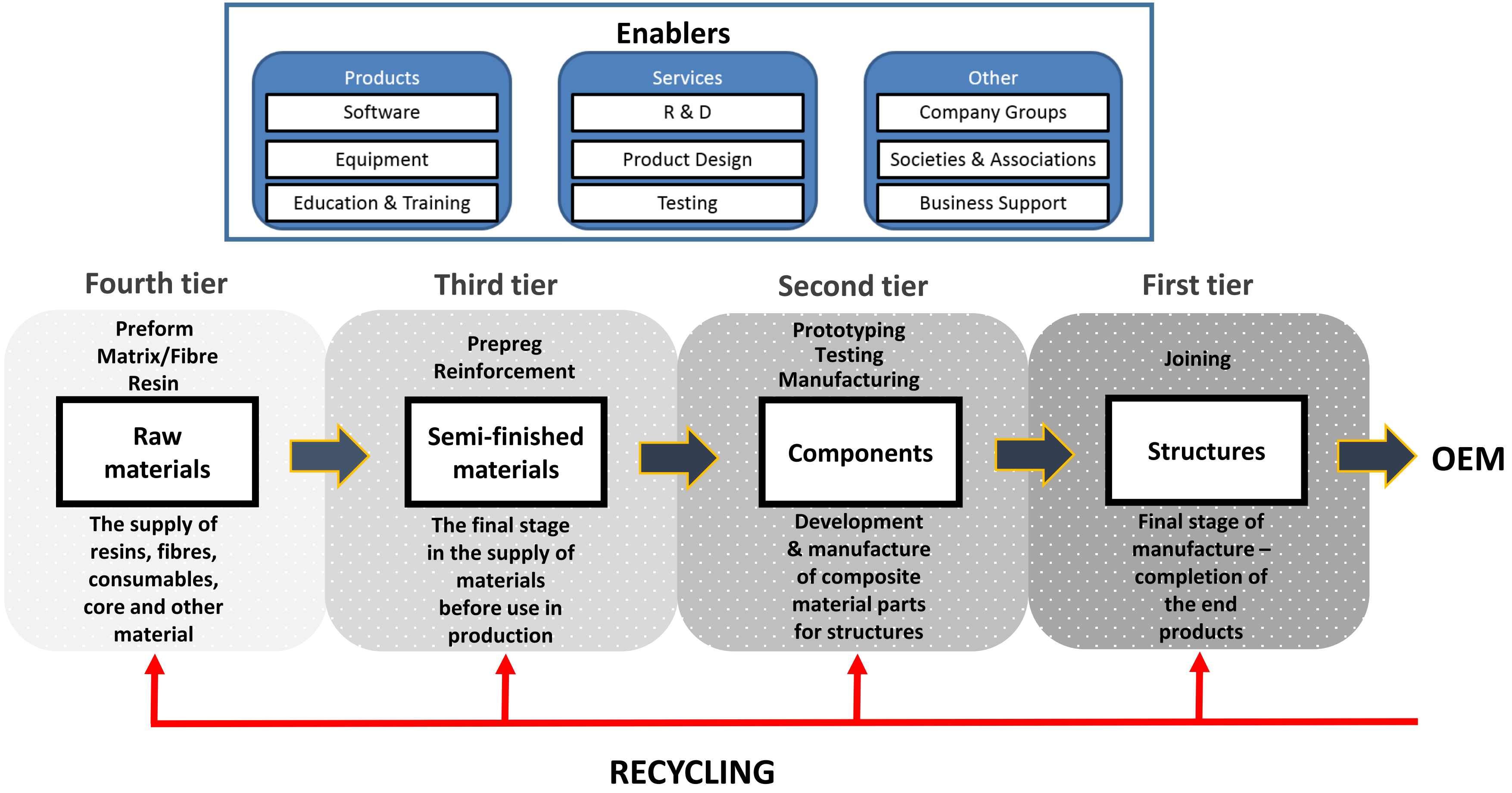
On-time deliveries/service level to our customers.

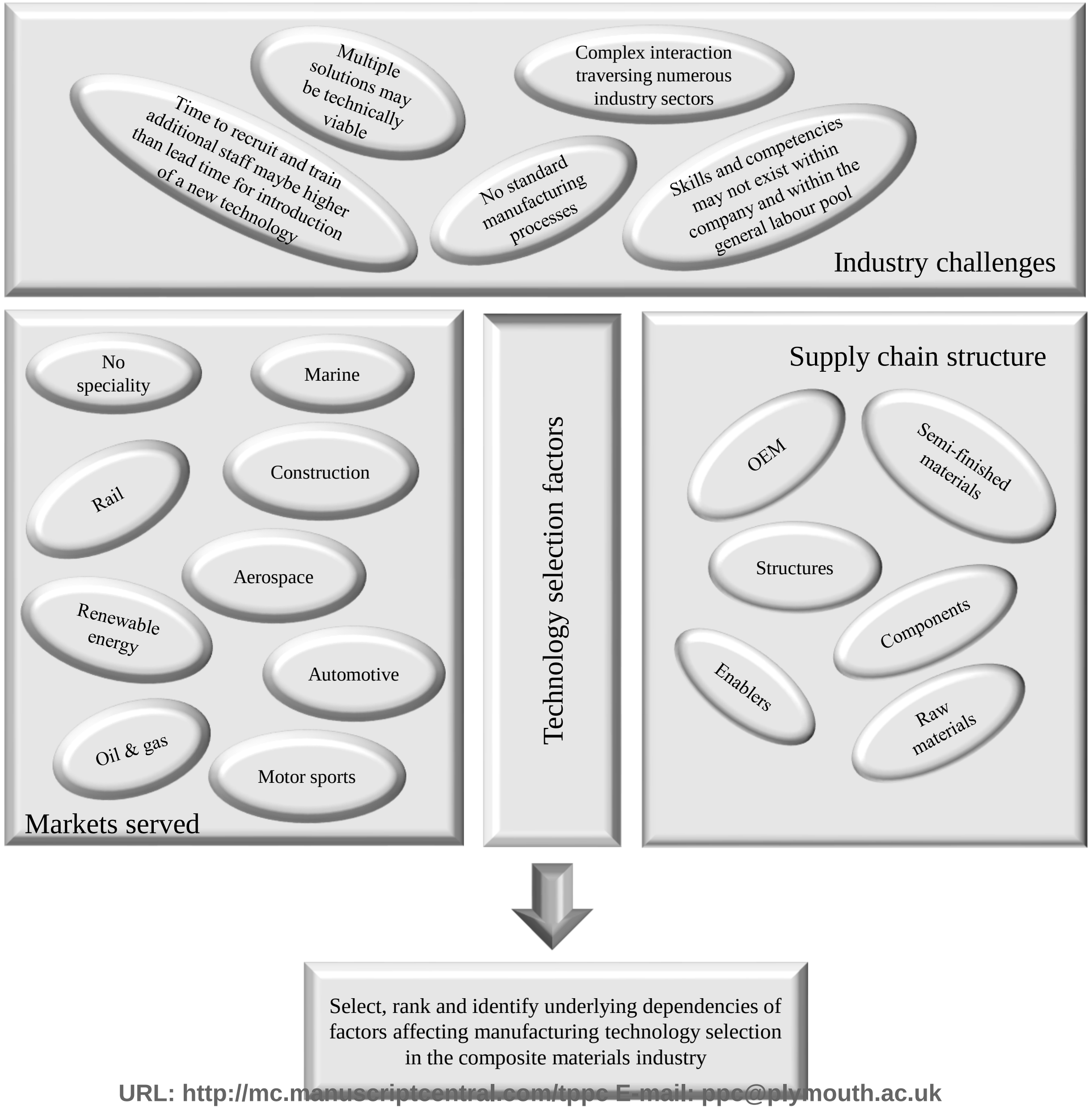
Unimportant	Of little importance	Moderately important	Important	Very important
☐	☐	☐	☐	☐

Hire/Trains staff with new skills.

Unimportant	Of little importance	Moderately important	Important	Very important
☐	☐	☐	☐	☐

Thank you for your cooperation.


Enablers
Products
Software
Equipment
Education & Training
Services
R & D
Product Design
Testing
Other
Company Groups
Societies & Associations
Business Support
Fourth tier
Preform
Matrix/Fibre
Resin
Raw materials
The supply of resins, fibres, consumables, core and other material
Third tier
Prepreg
Reinforcement
Semi-finished materials
The final stage in the supply of materials before use in production
Second tier
Prototyping
Testing
Manufacturing
Components
Development & manufacture of composite material parts for structures
First tier
Joining
Structures
Final stage of manufacture – completion of the end products
OEM
RECYCLING


Multiple solutions may be technically viable
Complex interaction traversing numerous industry sectors
Time to recruit and train additional staff maybe higher than lead time for introduction of a new technology
No standard manufacturing processes
Skills and competencies may not exist within company and within the general labour pool
Industry challenges
No speciality
Marine
Rail
Construction
Aerospace
Renewable energy
Automotive
Oil & gas
Motor sports
Markets served
Technology selection factors
Supply chain structure
OEM
Semi-finished materials
Structures
Components
Enablers
Raw materials
Select, rank and identify underlying dependencies of factors affecting manufacturing technology selection in the composite materials industry

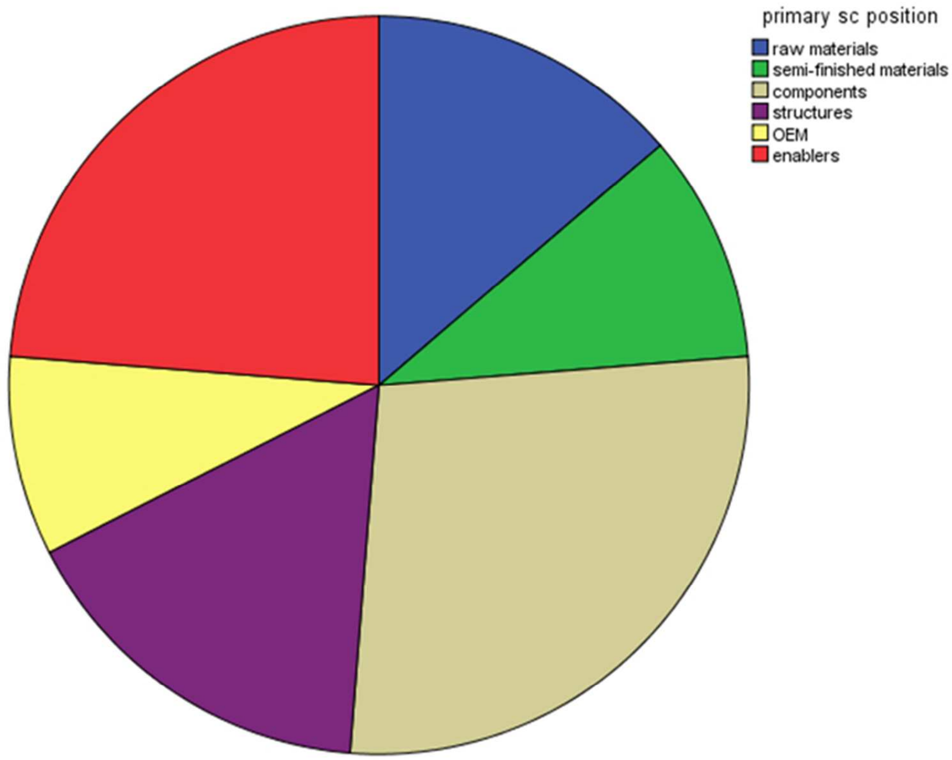


Figure 3. Primary position in the composites supply chain by the respondent companies.

190x152mm (96 x 96 DPI)

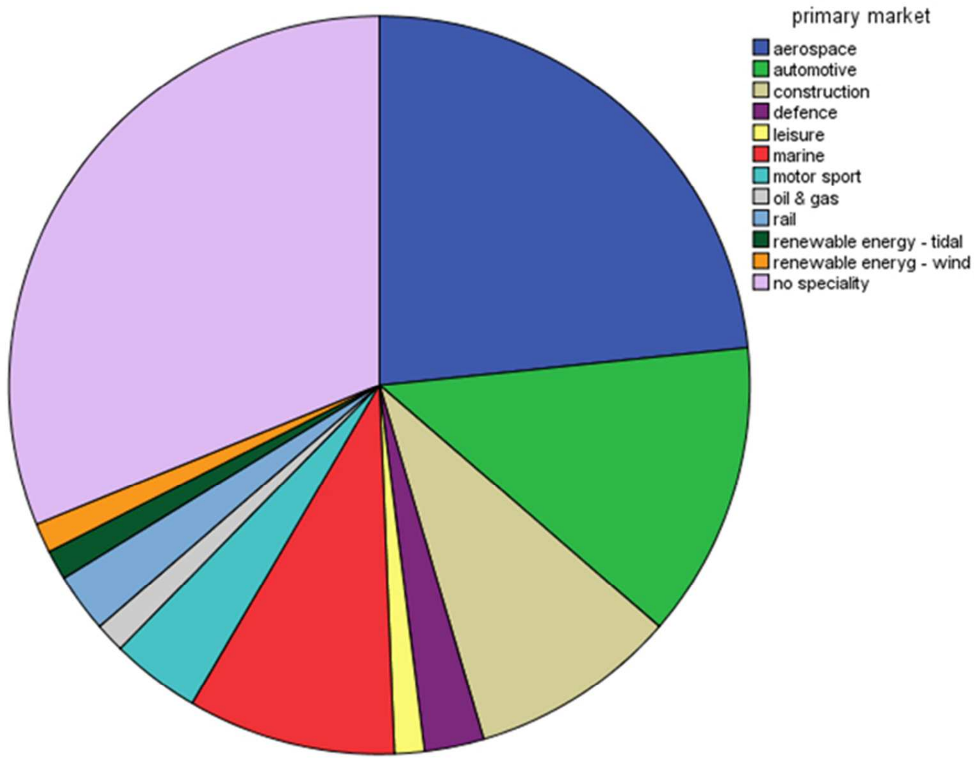


Figure 4. Primary markets served by the respondent companies.

190x152mm (96 x 96 DPI)

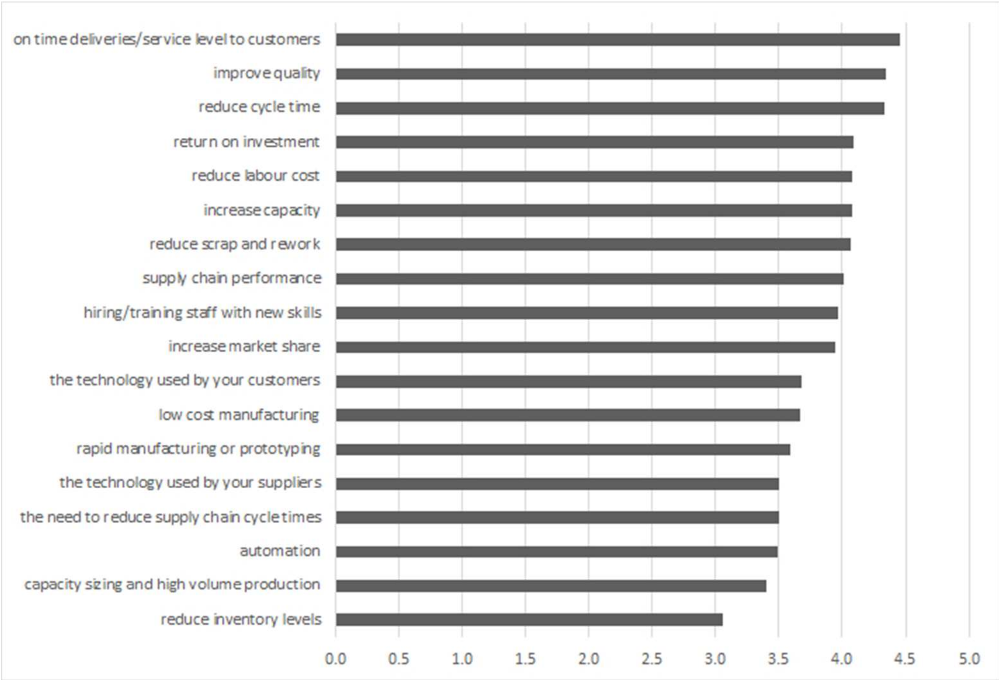


Figure 5. Responses to factors related to technology selection by participating companies.

188x128mm (96 x 96 DPI)

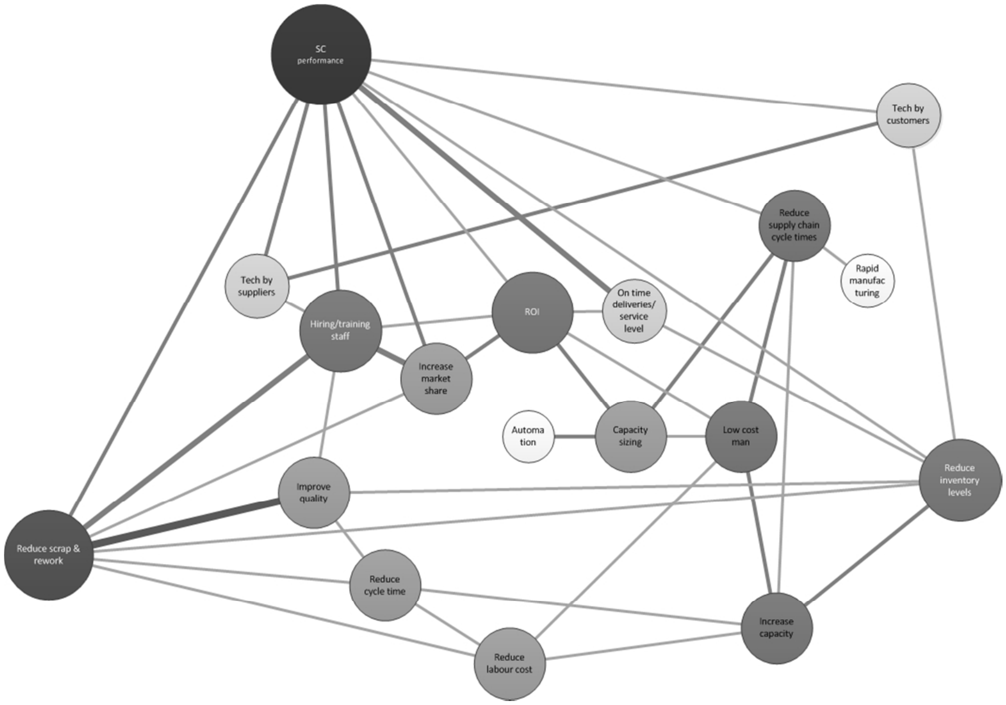


Figure 6. Network representation of correlations between factors investigated.

280x195mm (96 x 96 DPI)

Tables

MANUFACTURING TECHNOLOGIES
Open mould
Automated Fibre Placement
Automated Tape Laying
Wet Hand Lay Up
Wet Spray Up
Filament Winding (Multi-axis)
Prepreg Hand Lay-Up
Closed Mould
Vacuum Infusion
Resin Film Infusion
Resin Transfer Infusion
Resin Transfer Moulding
Vacuum Assisted Resin Transfer Moulding
High Pressure Resin Transfer Moulding
Structural Reaction Injection Moulding
Injection Moulding
Centrifugal Moulding
Rotational Moulding
Cold/Warm Press Moulding
Hot Press Moulding
Stamping
Diaphragm Forming
Continuous Processing
Pultrusion
Pulwinding
Extrusion
Continuous Pipe Winding
Continuous Sheet Manufacture
Filament Winding (2-axis)
Pre/post process
Gel Coating
Post-Cure
Surface Finishing
Adhesive Bonding
Mechanical Fastening
Welding
Oven/Autoclave Curing
Preforming

Table 1. Manufacturing technologies available in the production of composites materials

Tables

	Raw materials	Semi-finished	Components	Structures	OEMs	Enablers
Reduce cycle time	4.67	3.67	4.37	4.63	4.00	4.17
Improve quality	4.83	4.17	4.26	4.38	4.40	4.00
Reduce labour cost	4.50	3.67	4.11	4.38	4.60	3.58
Reduce scrap and rework	4.83	3.67	4.05	4.00	4.00	3.58
Increase capacity	3.83	3.83	4.16	4.50	3.80	3.67
Increase market share	4.83	4.17	3.74	4.13	4.40	3.50
Reduce inventory levels	3.83	2.50	2.79	3.13	3.40	2.67
The technology used by your suppliers	3.67	3.33	3.16	3.75	4.00	3.50
The technology used by your customers	4.00	3.83	3.26	2.88	3.60	4.00
Automation	3.33	3.67	3.21	3.38	3.40	3.92
Rapid manufacturing or prototyping	2.67	3.17	3.84	3.00	3.20	4.00
Capacity sizing and high volume production	3.83	3.17	3.26	3.75	3.20	3.25
Reduce supply chain cycle time	3.33	2.50	3.37	4.00	3.40	3.75
Low cost manufacturing	3.00	2.83	3.79	4.00	3.60	3.42
Return on investment	3.83	4.00	4.00	4.00	4.40	4.00
Supply chain performance	4.67	3.33	4.05	3.75	4.20	3.92
On time deliveries/services level to customers	4.83	4.17	4.68	4.37	4.86	4.08
Hiring/training staff with new skills	4.50	3.50	3.95	4.38	4.20	3.67

Table 2. Average ratings of factors by position in the composites materials supply chain.

Tables

	Aerospace	Automotive	Construction	Marine	Motor sport	No speciality
Reduce cycle time	4.25	4.90	3.80	4.67	4.50	4.07
Improve quality	4.25	4.33	4.60	4.17	4.50	4.36
Reduce labour cost	3.92	4.50	4.80	4.67	4.50	3.57
Reduce scrap and rework	4.08	4.17	4.40	3.83	4.00	3.93
Increase capacity	4.08	4.00	3.80	4.17	4.00	3.86
Increase market share	3.83	4.00	4.20	4.33	3.00	3.86
Reduce inventory levels	3.17	3.17	3.00	2.83	3.50	2.79
The technology used by your suppliers	3.67	3.00	3.20	3.50	2.50	3.64
The technology used by your customers	3.67	3.67	3.40	3.00	3.50	3.71
Automation	3.67	3.83	2.60	3.67	1.50	3.64
Rapid manufacturing or prototyping	3.50	4.00	3.40	3.17	3.50	3.43
Capacity sizing and high volume production	3.00	4.33	3.20	3.00	2.00	3.50
Reduce supply chain cycle time	3.75	4.00	3.20	2.50	2.50	3.29
Low cost manufacturing	3.50	4.00	4.00	3.67	3.50	3.21
Return on investment	3.67	4.33	4.60	4.50	4.00	3.57
Supply chain performance	4.33	4.17	4.20	3.83	3.50	3.64
On time deliveries/services level to customers	4.75	4.67	4.80	4.33	4.50	4.14
Hiring/training staff with new skills	3.92	3.83	4.40	4.33	4.00	3.86

Table 3. Average ratings of factors by markets served.

Tables

	reduce cycle time	improve quality	reduce labour cost	reduce scrap and rework	increase capacity	increase market share	reduce inventory levels	the technology used by your suppliers	the technology used by your customers	automation	rapid manufacturing or prototyping	capacity sizing and high volume production	the need to reduce supply chain cycle times	low cost manufacturing	return on investment	supply chain performance	on time deliveries/service level to customers	hiring/training staff with new skills
reduce cycle time	1	.356**	.390**	.305**	.315**	.124	.255*	-.031	-.042	.018	.210	.288*	.316*	.263*	.085	.137	.047	.194
improve quality	.356**	1	.231*	.637**	.271*	.228	.349**	.146	.155	-.116	.003	.151	.179	.196	.034	.295*	.156	.376**
reduce labour cost	.390**	.231*	1	.368**	.364**	.111	.221	-.222	-.281*	-.017	-.018	.140	-.008	.355**	.083	-.071	-.087	.076
reduce scrap and rework	.305**	.637**	.368**	1	.255*	.396**	.345**	.266*	.133	-.047	-.017	.284*	.241	.198	.195	.488**	.136	.516**
increase capacity	.315**	.271*	.364**	.255*	1	.147	.408**	-.146	-.107	.066	-.016	.182	.355**	.483**	.124	.053	.284*	.164
increase market share	.124	.228	.111	.396**	.147	1	.242*	.281*	.193	.017	-.133	.265*	.173	-.116	.425**	.441**	.207	.598**
reduce inventory levels	.255*	.349**	.221	.345**	.408**	.242*	1	.167	.325**	-.126	-.134	.156	.257*	.160	.142	.356**	.387**	.268*
the technology used by your suppliers	-.031	.146	-.222	.266*	-.146	.281*	.167	1	.408**	.202	.033	.152	.205	-.010	.215	.434**	.230	.313**
the technology used by your customers	-.042	.155	-.281*	.133	-.107	.193	.325**	.408**	1	.100	.234	.092	.115	-.284*	.108	.387**	.204	.284*
automation	.018	-.116	-.017	-.047	.066	.017	-.126	.202	.100	1	.297*	.434**	.208	.117	.144	.018	-.072	.191
rapid manufacturing and prototyping	.210	.003	-.018	-.017	-.016	-.133	-.134	.033	.234	.297*	1	.290*	.376**	.290*	.217	.136	.057	.051
capacity sizing and high volume production	.288*	.151	.140	.284*	.182	.265*	.156	.152	.092	.434**	.290*	1	.491**	.314**	.405**	.163	.172	.301*
the need to reduce supply chain cycle times	.316*	.179	-.008	.241	.355**	.173	.257*	.205	.115	.208	.376**	.491**	1	.474**	.296*	.394**	.313*	.310*
low cost manufacturing	.263*	.196	.355**	.198	.483**	-.116	.160	-.010	-.284*	.117	.290*	.314**	.474**	1	.335**	.099	.073	.054
return on investment	.085	.034	.083	.195	.124	.425**	.142	.215	.108	.144	.217	.405**	.296*	.335**	1	.395**	.344**	.370**
supply chain performance	.137	.295*	-.071	.488**	.053	.441**	.356**	.434**	.387**	.018	.136	.163	.394**	.099	.395**	1	.540**	.404**
on time deliveries/service levels to customers	.047	.156	-.087	.136	.284*	.207	.387**	.230	.204	-.072	.057	.172	.313*	.073	.344**	.540**	1	.276*
hiring/training staff with new skills	.194	.376**	.076	.516**	.164	.598**	.268*	.313**	.284*	.191	.051	.301*	.310*	.054	.370**	.404**	.276*	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 4. Correlation table for surveyed factors

RESPONSE TO REVIEWERS

Reviewer(s') Comments to Author (if any):

Reviewer: 1

Comments to the Author

The revised manuscript has improved in terms of proving its relevance to the industry. The inclusion of triangulation has strengthened the reliability and validity of this study. The inclusion of composite material experts has provided clearer managerial implications of this research.

The authors thank the reviewer for the positive comments made to our work.

Reviewer: 2

Comments to the Author

I have read the new version of the manuscript focusing on the changes made by the authors. I believe that the authors have addressed my major concern that was their motivation from real world practice as well as the importance of the research findings for the sector of composite materials. The idea of asking experts to commend on the problem is excellent. Therefore, I believe that the new version of the manuscript is adequately improved and it could be published in the PPC journal in its present form.

The authors thank the reviewer for the positive comments made to our work.