

A WEB SERVICE FRAMEWORK FOR ENVIRONMENTAL AND CARBON FOOTPRINT MONITORING IN CONSTRUCTION SUPPLY CHAINS

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ABSTRACT

With the growing environmental concerns, green supply chain management (GSCM) is gaining significant attention in the construction industry. Tracking and monitoring the environmental effects brought forth by the participating members along a supply chain is important to GSCM. The GreenSCOR model developed by the Supply Chain Council provides a generic framework for measuring the total carbon footprint and environmental footprint in a supply chain. The model is based on the Supply Chain Operations Reference (SCOR) model, which represents a supply chain network in a hierarchically structured manner. This paper describes the GreenSCOR framework and its potential application to the construction industry. This paper also presents a web services approach to incorporate the GreenSCOR model to the implementation of collaborative information systems. Each process element in the SCOR model is represented and delivered as individual web service units, which can be reused and integrated using standard web service technologies. The service units are combined and managed in a web service collaborative framework, called SC Collaborator, that is designed and developed for supporting construction supply chain management. An illustrative example is presented to demonstrate the implementation of the GreenSCOR-based SC Collaborator framework.

KEYWORDS

Green supply chain management (GSCM), Supply Chain Operations Reference (SCOR) model, performance monitoring, service oriented, web services.

INTRODUCTION

The environmental impacts of construction activities have received considerable attention. The industry has been described as a major exploiter of natural resources, and a significant contributor to environmental pollution (Spence and Mulligan 1995). In construction processes, environmental impacts accumulate along supply chains from raw material extraction, manufacturing, distribution, installation, maintenance, to demolition and disposal. Minimizing the environmental impacts of one product stage may increase the impacts at other stages. Therefore, green supply chain management (GSCM) which provides a holistic cradle-to-grave view of supply chain processes is needed to reduce the environmental impacts of construction project delivery.

The application of GSCM in the construction industry has been studied in recent years (Trigos 2007; Xiao 2006). There is a trend in the construction industry to incorporate environmental considerations in supply chain operations. Green purchasing which includes environmental requirements in material procurement becomes increasingly common. Green delivery which consolidates shipments and transportation schedules, routes, and carriers to minimize fuel and energy consumption is suggested. Recycling and reuse of materials are recommended when deciding construction methods and processes as well.

Tracking and monitoring the green performance of supply chain members are important to successful GSCM. They help identify any severely polluting component in a supply chain and offer the basis for supply chain process evaluation, re-engineering and improvement. Moreover, companies have been increasingly demanded to disclose their potential risks and liabilities due to environmental issues and effects on climate change. For example, Restriction of Hazardous Substances (RoHS) (Commission of the European Communities 2003a) already regulates the use of hazardous substances in electrical and electronic equipment, while the accompanying regulation, Waste Electrical and Electronic Equipment (WEEE) (Commission of the European Communities 2003b) restricts the disposal of these products. However, building a supply chain performance

monitoring system is a non-trivial task because it involves understanding and integration across organizational boundaries. Integration and collaboration are particularly challenging in the construction industry because information is often scattered among highly fragmented project participants. Furthermore, the relationship between members in construction supply chains is often project-based and temporary. That is, construction supply chains keep changing from project to project. Current solutions for cross-organizational integration and collaboration are not flexible enough to adapt such frequent changes.

This paper presents a web service framework for environmental and carbon footprint monitoring in construction supply chains. What to monitor and how to monitor in the framework will be addressed in the following sections. The framework adopts a process-based approach for measurement and monitoring. The Green Supply Chain Operations Reference (GreenSCOR) model proposed by the Supply Chain Council (2008) is leveraged to identify the members and the corresponding process elements in a construction supply chain. Each process element represents a discrete unit for footprint monitoring. The performance metrics suggested in the GreenSCOR model serve as the basis for measuring the environmental footprints. The GreenSCOR model is implemented leveraging web services technology to provide system flexibility. The deployed web service units are integrated and managed in the SC Collaborator system, that is designed and developed to support construction supply chain management.

SUPPLY CHAIN PERFORMANCE MONITORING

In the construction industry, various researchers have developed conceptual frameworks and systems for performance monitoring and measurement. Kagioglou, Cooper, and Aouad (Kagioglou et al. 2001) presented a conceptual framework for project performance measurement based on the balanced scorecard (BSC), which was introduced by Kaplan and Norton (Kaplan and Norton 1992); the framework measures performance from four perspectives: financial, customer, internal business processes, and learning and growth. The performance measurement framework developed by (Yu et al. 2007) is also based on BSC perspectives; however, the measurements are conducted at the company level instead of at the project level. Leveraging Internet and database technologies, a web-based construction project performance monitoring system (PPMS) has been developed and introduced by (Cheung et al. 2004). Most of these research efforts on the performance management in construction focus on performance at the project level. Study on the performance management of construction supply chains is relatively lacking.

The lack of performance measurement systems that spans the entire supply chain is one of the major obstacles to effective supply chain management (Chan 2003; Ross 1998; Wong and Wong 2007). Various performance metrics for supply chain management have been suggested, investigated, and analyzed in the literature (Hausman 2004; Kleijnen and Smits 2003; Lambert and Pohlen 2001). Gunasekaran et al. (2001) emphasize performance metrics related to suppliers, delivery performance, customer-service, and inventory and logistics costs in a supply chain. Kleijnen and Smits (2003) analyze performance metrics in the fill rate, confirmed fill rate, response delay, stock level, delivery delay, and sales/inventory ratio. Gunasekaran and Kobu (2007) review recently published literature on performance measurement in supply chains and summarizes 27 key performance indicators for supply chain management. These works provide references to performance monitoring and measurement for supply chain management.

APPLICATION OF THE GREENSCOR MODEL

The Green Supply Chain Operations Reference (GreenSCOR) model (Supply Chain Council 2008) proposed by the Supply Chain Council (SCC) is used as a conceptual framework in this research to model construction supply chains and to define the performance metrics. The GreenSCOR model is based on the Supply Chain Operations Reference (SCOR) model (Supply Chain Council 2008), which is widely used to model supply chain network structures and operations for strategic planning purposes (Huan et al. 2004). The GreenSCOR model provides a generic conceptual framework to measure the total carbon footprint and total environmental footprint in a supply chain. This section will first briefly review the SCOR model. The modeling of construction supply chains and the definition of green performance metrics using the GreenSCOR model will then be discussed.

Supply Chain Modeling using the SCOR Model

There are very few standard methods or models for representing and modeling supply chain structures. Typically, tables are used to enlist members of a supply chain. Alternatively, network diagrams can be used to represent supply chain structures that show the supply chain members as well as the relationships and roles between them. Lambert and Cooper (2000) proposed a mapping of supply chain structures using three primary

attributes: members of the supply chain, structural dimensions, and types of business processes between the members. However, these methods do not provide a direct migration from the modeling of supply chain structures to the modeling of the business operations.

The Supply Chain Operations Reference (SCOR) model established by the Supply Chain Council provides a framework to systematically map the relationships among the organizational units and the partnering companies, and to specify the operations involved in a supply chain. The SCOR model is based on five basic management processes – Plan, Source, Make, Deliver, and Return (Figure 1). Plan includes processes that balance resources to establish plans that best meet the requirements of a supply chain and the sourcing, production, delivery, and return activities. Source includes processes that manage the procurement, delivery, receipt, and transfer of raw material items, subassemblies, products, and services. Make includes processes that transform products to a finished state. Deliver includes processes that provide finished goods and services, including order management, transportation management, and distribution management. Return includes post-delivery customer support and processes that are associated with returning or receiving returned products (Supply Chain Council 2008). As illustrated in Figure 2, within a company, the Source processes are linked to the Make processes, which in turn are linked to the Deliver processes. Return processes are related to the internal Source processes and Deliver processes, whereas Plan processes are related to the internal Source processes, Make processes, Deliver processes, and Return processes. The Source processes of one company are linked to the Deliver processes of the downstream supply chain partners, while the Deliver processes of one company are linked to the Source processes of the upstream supply chain partners.

With the SCOR framework, the supply chain structures and relationships can be defined progressively level by level. There are four levels of model development defined in the SCOR framework (Figure 2). Level 1 modeling defines the overall scope and content, in terms of the Plan, Source, Make, Deliver, and Return processes (Figure 1). The five basic management processes are divided into process categories in the Level 2 model, which allows companies to describe the configuration of their supply chains and to conceptually specify the relationship and interactions among supply chain members. The conceptual specification can then be extended to describe the process workflow through Level 3 modeling. In the Level 3 modeling, companies can define the information for detailed planning and goal setting as well as the performance metrics. In Level 4 modeling, the implementation details of each Level 3 process are specified to meet their own needs. Through the four levels of development, the SCOR models can be extended to capture and represent complex interactions among supply chain partners. The SCOR model provides a systematic framework for modeling construction supply chains, which usually involve many organizations in a project and are complex in nature.

Modeling of Construction Supply Chains

The structures of construction supply chains can differ from project to project, organization to organization, and product to product. For example, the supply chains of one product in different construction projects may involve different number of suppliers and different operations for procurement and delivery. Figure 3 shows the SCOR model of a typical construction supply chain for mechanical, electrical and plumbing (MEP) products that have low turnover rate and/or high inventory cost, such as light fixtures and switchgears. Suppliers of this type of MEP products usually do not keep stocks of their products. Instead, they manufacture, assemble and configure the MEP products only after the receipt and validation of a firm customer order from the distributors,



Figure 1 SCOR Level 1 modeling (Supply Chain Council 2008)

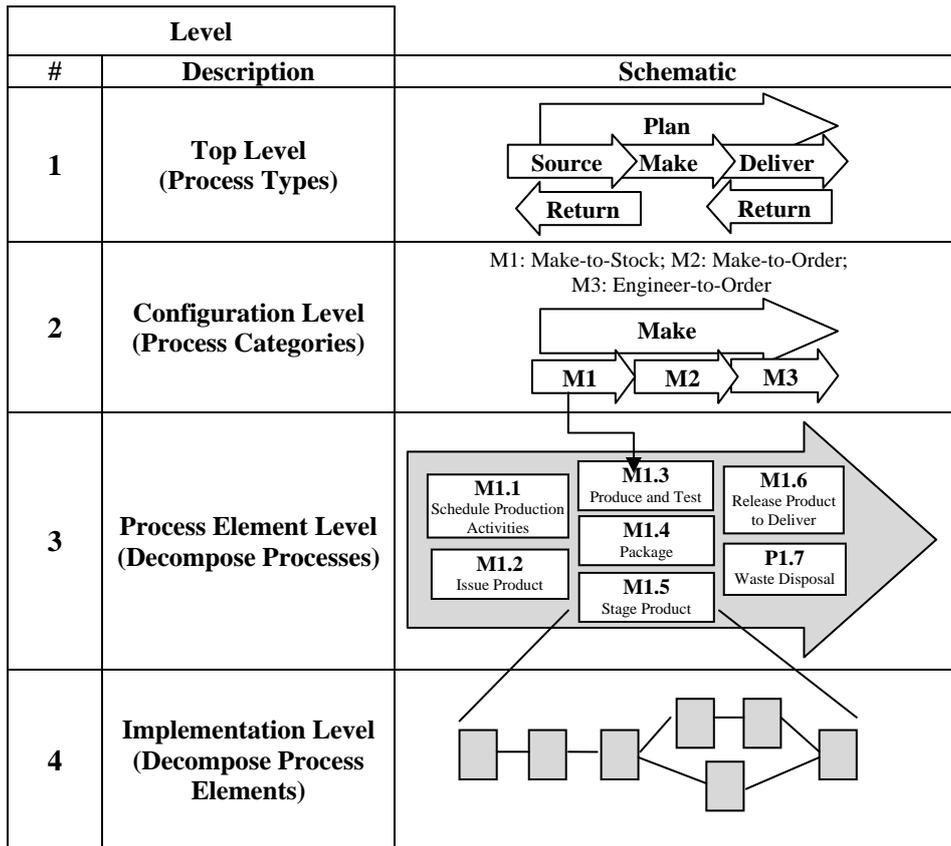


Figure 2 Four levels of SCOR business processes (Supply Chain Council 2008)

(P1: Plan supply chain; P2: Plan source; P3: Plan make; P4: Plan deliver; S1: Source stocked product; S2: Source make-to-order product; M1: Make-to-stock; M2: Make-to-order; D1: Deliver stocked product; D2: Deliver make-to-order product)

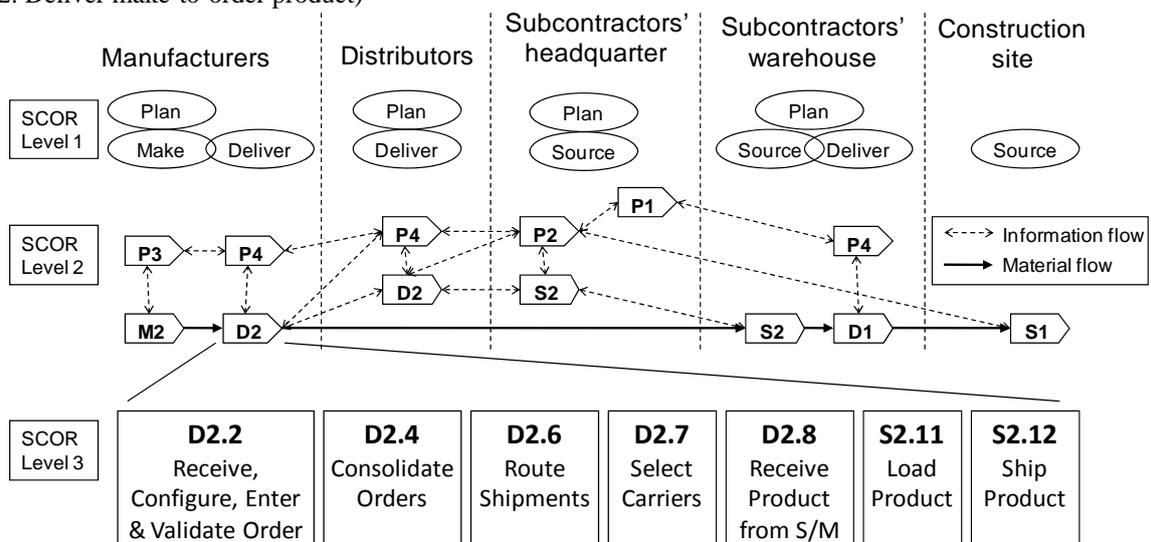


Figure 3 The SCOR model of a typical construction supply chain for mechanical, electrical and plumbing (MEP) products with low turnover rate and/or high inventory cost

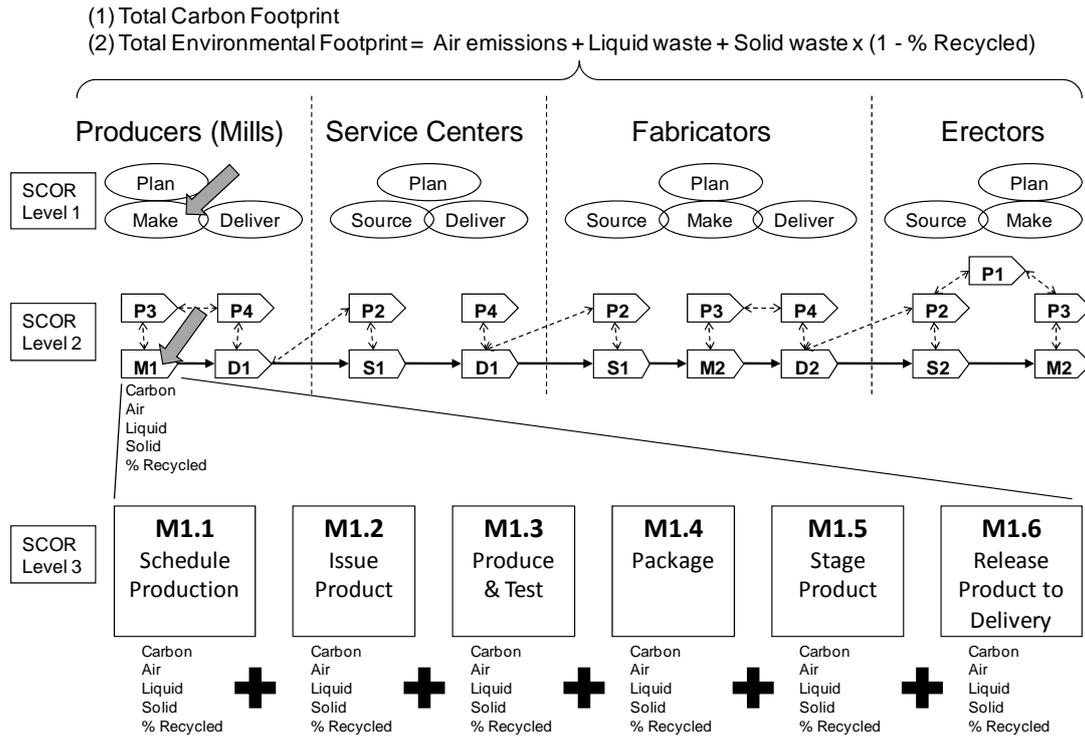


Figure 4 Application of the GreenSCOR model to the conceptual framework for carbon and environmental performance monitoring along a structural steel supply chain

who serve as a sales middleman. The products are often delivered to the subcontractors' warehouse for temporary storage before they are needed. On the other hand, as illustrated in Figure 4, a typical construction supply chain for structural steel is better structured. The mills extract steel material and send it to service centers for inventory storage. Upon receipt of a purchase order from erectors, structural steel fabricators source the steel material from inventory and begin the fabrication of structural steel components according to the design. In general, construction supply chains often do not have a standard and well structured configuration. The SCOR model provides a generic framework for modelling and describing construction supply chains of various types, scales, and complexity.

Definition of Green Performance Metrics

The SCOR model suggests 524 distinct performance metrics that are divided into five categories: supply chain reliability, responsiveness, agility, costs, and asset management. In the GreenSCOR model, the Supply Chain Council proposed five additional performance metrics to include the environmental concerns in supply chains (Supply Chain Council 2008). The five proposed environmental metrics are (1) carbon emissions in tons of carbon dioxide equivalent, (2) air pollutant emissions, (3) liquid waste generated, (4) solid waste generated, and (5) percentage of solid waste that is recycled. The metric of carbon emissions measures the climate impact from carbon dioxide and other global warming air emissions. The metric of air pollutant emissions considers carbon oxides, nitrogen oxides, sulphur oxides, volatile organic compounds (VOC), and particulate. The metric of liquid waste includes the liquid waste that is either disposed of or released to open water or sewer systems.

The total environmental footprint of a supply chain member is the sum of the air pollutant emissions, liquid water generated, and solid waste that is generated and not recycled. In other words, using the performance metrics in the GreenSCOR model, the total environmental footprint of a supply chain member is given as:

$$\text{Environmental Footprint} = \text{Air emissions} + \text{Liquid waste} + \text{Solid waste} \times (1 - \% \text{ recycled}) \quad (1)$$

The carbon footprint can be obtained directly from the measurement of actual carbon emissions, or indirectly from calculation based on energy consumption, fuel type and consumption, and process throughput. In the monitoring framework presented in this paper, the carbon footprint is calculated indirectly from the energy consumption using the carbon footprint model developed by Defra (2009), and from the gas emissions to air

using the Global Warming Potential (GWP) factors (The Intergovernmental Panel on Climate Change (IPCC) 1990). Using Defra's model, the carbon footprint from the energy consumption can be calculated as:

$$\text{Carbon Footprint} = \text{Energy consumption} \times \text{Conversion factor} \quad (2)$$

where the conversion factor is given in the Defra's guidelines (Defra 2009). For example, the conversion factor for coal is 0.32937 kg CO₂eq per kWh. Therefore, the carbon footprint due to the consumption of 100 kWh of energy generated by coal is calculated as 329.37 kg CO₂ equivalent. Global Warming Potential (GWP) is a measure of the relative radioactive effect of a greenhouse gas compared to carbon dioxide, integrated over a chosen time horizon. McCarthy (2001) provides procedures for calculating the GWP factors, which are based on an assessment report released by Intergovernmental Panel on Climate Change (IPCC).

As illustrated in Figure 4, monitoring and measurement of the green performance of a structural steel supply chain can be performed by aggregating the performances of the planning, sourcing, production, and delivery activities of each supply chain member. The footprint measurements of the planning activities include the energy consumption by the planning tools and the facilities that carry out the planning activities. The measurements of the sourcing activities consider supplier management such as procurement planning and supplier selection, and material acquisition management such as incoming material inspection and material storage. The measurements of the production (make) activities take into account (1) the direct emissions in the production processes, (2) the footprint due to the energy required for production, and (3) the footprint due to the energy consumed by the labour, the tools and the facilities. The measurements of the delivery activities include the distribution, transportation and installation of products, as well as the supporting operations for customer management.

DEVELOPMENT OF THE WEB SERVICE MONITORING FRAMEWORK

The GreenSCOR model provides a generic guideline for planning and defining the carbon and environmental footprint monitoring framework. In this study, the conceptual model is implemented using web services technology, which enhances system flexibility and customizability of the monitoring framework. Information sources and software functionalities are delivered as individual web service units, which are distributed over a network through a standard protocol. The service units can be reused and combined by other services residing on a network. This "plug-and-play" capability allows agile development and quick reconfiguration of the system, which are essential for fast changing and unstable construction supply chains. The implementation of the web service monitoring framework is discussed in the following subsections.

Development of Web Service Units from the GreenSCOR model

As discussed above, construction supply chains are decomposed into process elements using the SCOR model through four levels of modeling. The process elements are then represented and delivered as web service units to be integrated. The supply chain network and its members are identified and modelled through the SCOR Level 1 and Level 2 modeling. After that, process maps of internal and external supply chain operations are produced through SCOR Level 3 and Level 4 modeling. In our implementation, the resulting Level 3 and Level 4 models are represented in the Business Process Modeling Notation (BPMN) standard (Object Management Group (OMG) 2008), which is a graph-oriented modeling language offering a visual modeling notation to specify business processes in a diagram. BPMN serves as a high level process specification for business users since BPMN diagrams are easy to read and understand. BPMN can also be used as a low level process description for implementers, who can add further details to a BPMN diagram in order to facilitate software implementation. Figure 5 illustrates the BPMN representation of the SCOR Level 3 process element "M1.3 Produce & Test".

BPMN models are stored and transferred using XML Metadata Interchange (XMI) format. XMI is a standard developed by Object Management Group for exchanging metadata information via Extensible Markup Language (XML). To convert BPMN models into BPEL files, the XMI output of the BPMN models are exported, and then parsed to extract the process definitions and sequences. In the XMI output, as shown in Figure 5, every BPMN event and activity is represented as an individual <vertices> element, while every connecting arrow is represented as a <sequenceEdges> element. We have built a Java conversion program to parse XMI files and to create a Business Process Execution Language (BPEL) process file for every BPMN model. After parsing all the <vertices> elements in an XMI file, a linked list of process elements can be produced internally in the conversion program. The linked list is converted into a tree hierarchy and exported into an XML file with the corresponding BPEL element tags.

In this paper, Business Process Execution Language (BPEL) (Organization for the Advancement of Structured Information Standards (OASIS) 2007) is used for execution and orchestration of web service units. BPEL is an executable XML-based language for specifying a business process in which most of the tasks represent the interactions between the process and the external web services. The language is interpreted and executed by an orchestration engine which realizes the process flow and invokes the connected web services. The BPEL standard supports basic activities like service invocation and message waiting, as well as structured activities that describe programming logic for a BPEL process such as conditional and while loop. Since BPEL is widely supported by commercial and open source orchestration engines, it has become the implementation-level standard for web services composition.

Implementation in the SC Collaborator system

The BPEL web service units of the SCOR Level 3 models and Level 4 models are deployed in SC Collaborator, a web service collaborative framework that we have designed and developed for construction supply chain management (Cheng et al. 2010). The SC Collaborator system leverages web portal technology to provide a secure and customizable user interface. The system consists of an access control engine, a database support, a communication layer, a portal interface layer, a business application layer, and an extensible computing layer. Open source technologies including Apache ODE (Apache Software Foundation 2008), Hibernate framework (Red Hat 2008), and MySQL (Sun Microsystems 2007) are used for system implementation.

As shown in Figure 6, information sources, application functionalities, and monitoring operations for the GreenSCOR performance metrics are wrapped and deployed into individual web service units in the GreenSCOR-based SC Collaborator system. The web service units can be located and invoked via the standardized Simple Object Access Protocol (SOAP) (World Wide Web Consortium (W3C) 2003). These reusable web service units are integrated and orchestrated into different workflows for various business processes described in the BPEL models. Each web service unit is associated with a Web Service Description Language (WSDL) (World Wide Web Consortium (W3C) 2007) file, which describes the schema, functions and location of the web service. The WSDL file of a web service provides the BPEL models with the information on how to invoke a specific function of the connected web service. Each BPEL model describes the relationships of service units and the logic involved during the connections among the service units. The SCOR

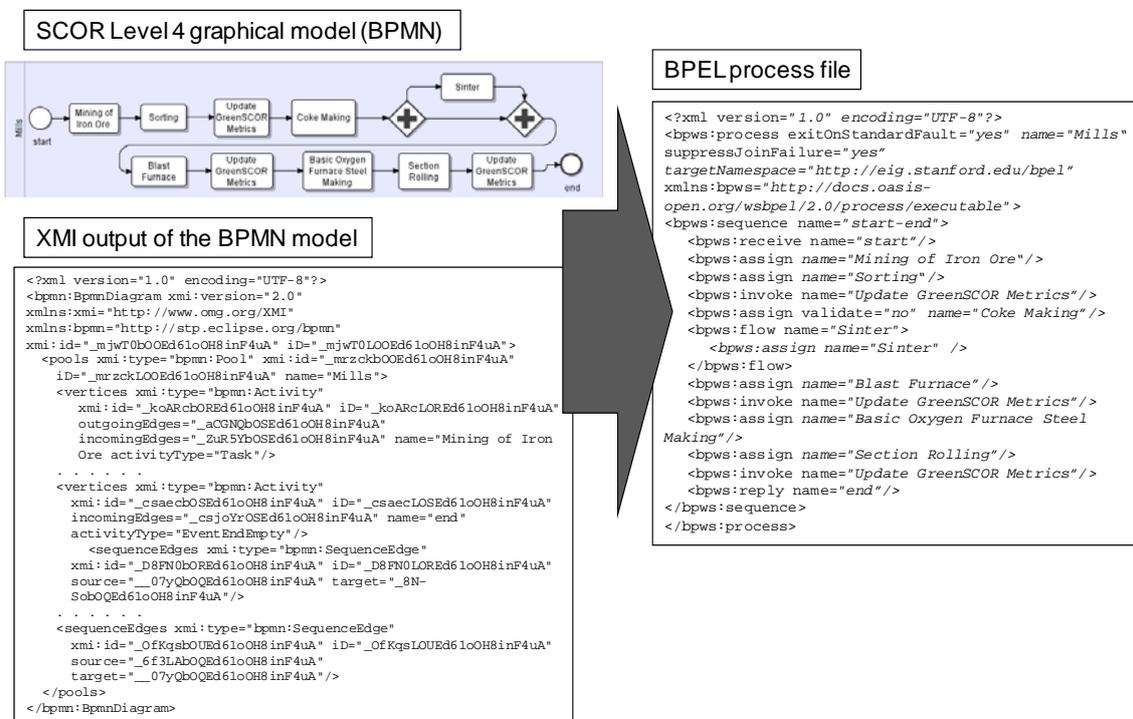


Figure 5 Conversion of the SCOR Level 4 model for the process element "M1.3 Produce & Test" from BPMN representation into BPEL process file

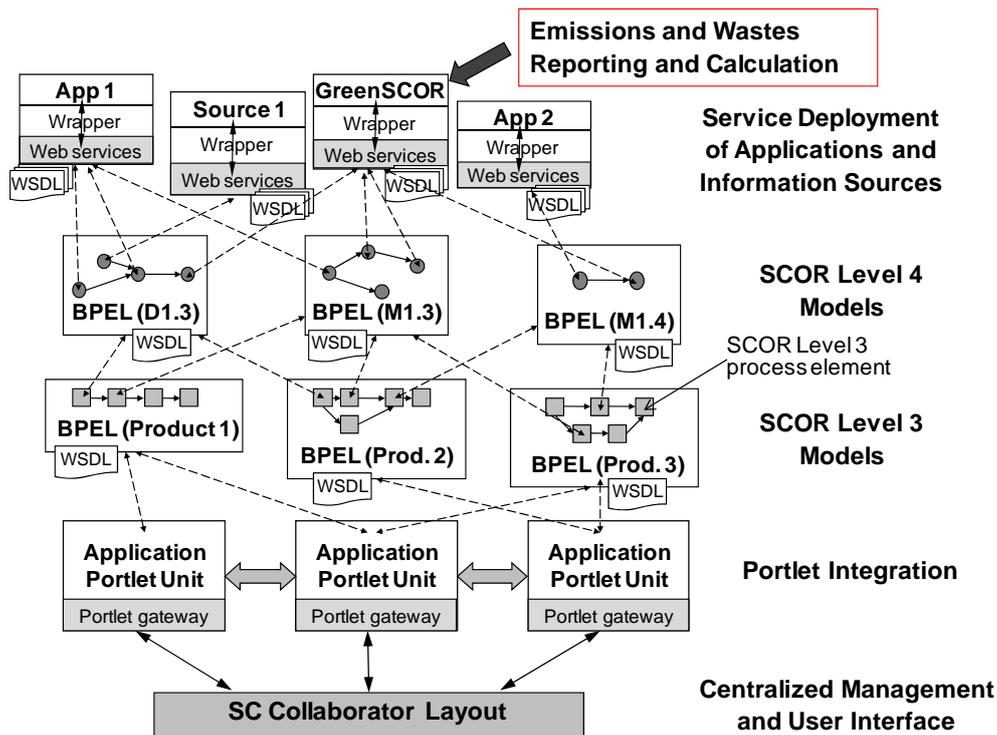


Figure 6 Incorporate GreenSCOR process models and monitoring web service units in SC Collaborator

Level 3 and Level 4 models described earlier are deployed in the BPEL-enabled SC Collaborator system. The BPEL process files of SCOR Level 4 models integrate other web service units in the system to perform individual SCOR Level 3 process elements. The BPEL process files of SCOR Level 3 models link different Level 4 models together to allow automation of supply chain operations for different products. These Level 3 BPEL models are invoked and encapsulated by separate application portlet units with user customized interface.

DEMONSTRATIVE EXAMPLE OF THE MONITORING FRAMEWORK

The application portlet unit in SC Collaborator for reporting of the GreenSCOR performance metrics is illustrated in Figure 7. The portlet unit is supported by the GreenSCOR web service unit residing in the system, which calculates and records the environmental and carbon footprint information from the input measurements. Using Eq. (1), the environmental footprint is calculated from the data of solid waste generated, liquid waste emitted to water systems and gas emissions to air, which are inputted by the users on the right hand side of the portlet unit. Using Defra's carbon footprint model and GWP factors, the carbon footprint in a particular SCOR process element is calculated from the data of energy consumption and gas emissions to air given by the users.

Figure 7 shows an example of monitoring and reporting the green performance of the SCOR Level 3 process element "M1.3 Produce & Test" of a mill called "Mill A" in a structural steel supply chain. For a steel mill, the process "Produce & Test" refers to the production process of steel materials. The steps to data reporting are enumerated as shown in Figure 7. First, the system recognizes the organization and customizes the display when a user logs in the system. Second, the user needs to select a particular SCOR process element before reporting is enabled. Third, the user enters the GreenSCOR performance metrics data whichever are available. Fourth, the user clicks the "Report" button to submit the data for the back-end operations and storage. These values are stored in a centralized database and can be retrieved conveniently. A user can log into the system and reviews or updates these performance values. Eventually, the aggregate footprint values for a particular supply chain member or for the entire supply chain can be monitored and evaluated on a product basis. This information helps the identification of supply chain components with high footprint, planning and re-engineering of supply chain operations, and selection of supply chain members.

CONCLUSIONS AND FUTURE WORK

This paper has presented a framework for environmental and carbon footprint monitoring in construction supply chains. The framework consists of conceptual modeling of supply chain participants and operations,

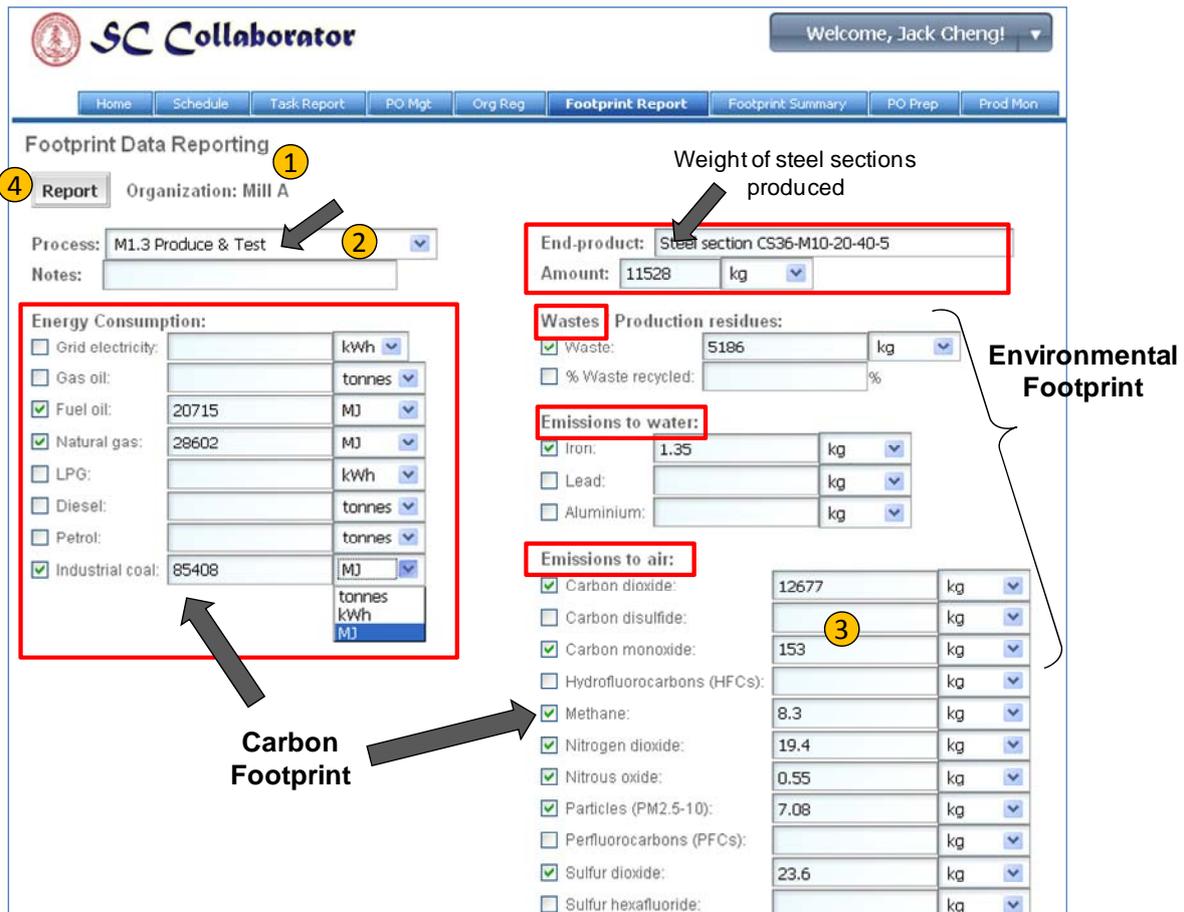


Figure 7 GreenSCOR-based reporting in SC Collaborator, which internally calculates and records the environmental and carbon footprint in a construction supply chain

identification of green performance metrics, and system implementation using web services technology. The GreenSCOR model proposed by Supply Chain Council, Defra's carbon footprint model, Global Warming Potential (GWP) factors, and the SC Collaborator system are leveraged in the proposed framework. The framework has been tested and demonstrated using an illustrative example of structural steel construction supply chain.

This research uses Defra's model, GWP factors, and the performance metrics proposed in the GreenSCOR model to calculate the footprint information. Other carbon footprint and environmental footprint calculation methods will be investigated in the future. Other metrics appropriate to green supply chain management in the construction industry will be explored and incorporated with the monitoring system. Studies on construction supply chains of various types and in different projects may be conducted to generalize the selection and effectiveness of different performance metrics. Future research includes integrating the GreenSCOR-based SC Collaborator with performance sensors so that measurements and data processing can be automated. Such an integrated system can not only minimize data input errors but also enable real-time alert and decision support for green construction supply chain management.

REFERENCES

- Apache Software Foundation. (2008). "Apache Orchestration Director Engine (ODE)."
- Chan, F. T. S. (2003). "Performance Measurement in a Supply Chain." *The International Journal of Advanced Manufacturing Technology*, 21(7), 534-548.
- Cheng, J. C. P., Law, K. H., Bjornsson, H., Jones, A., and Sriram, R. D. (2010). "A service oriented framework for construction supply chain integration." *Automation in Construction*, 19(2), 245-260.
- Cheung, S. O., Suen, H. C. H., and Cheung, K. K. W. (2004). "PPMS: a web-based construction project performance monitoring system." *Automation in Construction*, 13(3), 361-376.

- Commission of the European Communities. (2003a). "Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS)." *Official Journal of the European Union*, 37, 19-23.
- Commission of the European Communities. (2003b). "Directive 2002/96/EC on waste electrical and electronic equipment (WEEE)." *Official Journal of the European Union*, 37, 24-38.
- Defra. (2009). "Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting." UK Department for Environment, Food and Rural Affairs, London.
- Gunasekaran, A., and Kobu, B. (2007). "Performance measures and metrics in logistics and supply chain management: a review of recent literature (1995–2004) for research and applications." *International Journal of Production Research*, 45(12), 2819-2840.
- Gunasekaran, A., Patel, C., and Tirtiroglu, E. (2001). "Performance measures and metrics in a supply chain environment." *International Journal of Operations and Production Management*, 21(1), 71-87.
- Hausman, W. (2004). "Supply Chain Performance Metrics." *The Practice of Supply Chain Management: Where Theory and Application Converge*, T. P. Harrison, H. L. Lee, and J. J. Neale, eds., 61-73.
- Huan, S. H., Sheoran, S. K., and Wang, G. (2004). "A review and analysis of supply chain operations reference (SCOR) model." *Supply Chain Management: An International Journal*, 9(1), 23-29.
- Kagioglou, M., Cooper, R., and Aouad, G. (2001). "Performance management in construction: a conceptual framework." *Construction Management and Economics*, 19(1), 85-95.
- Kaplan, R. S., and Norton, D. P. (1992). "The balanced scorecard: measures that drive performance." *Harvard Business Review*, 70(1), 71-79.
- Kleijnen, J. P. C., and Smits, M. T. (2003). "Performance metrics in supply chain management." *Journal of the Operational Research Society*, 54(5), 507-514.
- Lambert, D. M., and Cooper, M. C. (2000). "Issues in supply chain management." *Industrial Marketing Management*, 29(1), 65-83.
- Lambert, D. M., and Pohlen, T. L. (2001). "Supply chain metrics." *International Journal of Logistics Management*, 12(1), 1-20.
- McCarthy, J. J. (2001). *Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change (IPCC)*, Cambridge University Press.
- Object Management Group (OMG). (2008). *Business Process Modeling Notation (BPMN), Version 1.1*.
- Organization for the Advancement of Structured Information Standards (OASIS). (2007). *Web Services Business Process Execution Language (WS-BPEL), Version 2.0*.
- Red Hat. (2008). "Hibernate framework."
- Ross, D. F. (1998). *Competing through supply chain management: creating market-winning strategies through supply chain partnerships*, Kluwer Academic Publishers.
- Spence, R., and Mulligan, H. (1995). "Sustainable development and the construction industry." *Habitat International*, 19(3), 279-292.
- Sun Microsystems. (2007). "MySQL 5.0."
- Supply Chain Council. (2008). *Supply Chain Operations Reference (SCOR) Model, Version 9.0*.
- The Intergovernmental Panel on Climate Change (IPCC). (1990). *Climate Change: The Intergovernmental Panel on Climate Change Scientific Assessment*, Cambridge University Press, Cambridge, UK.
- Trigos, O. B. (2007). "An investigation of green supply chain management in the construction industry in the UK," Master of Science, University of East Anglia, Norwich.
- Wong, W. P., and Wong, K. Y. (2007). "Supply chain performance measurement system using DEA modeling." *Industrial Management and Data Systems*, 107(3), 361-381.
- World Wide Web Consortium (W3C). (2003). *Simple Object Access Protocol (SOAP), Version 1.2*.
- World Wide Web Consortium (W3C). (2007). *Web Services Description Language (WSDL), Version 2.0*.
- Xiao, X. (2006). "Green supply chain management in the UK and China construction industry," Master of Science, University of East Anglia, Norwich.
- Yu, I., Kim, K., Jung, Y., and Chin, S. (2007). "Comparable performance measurement system for construction companies." *Journal of Management in Engineering*, 23(3), 131-139.