# TOWARD DEADLINE AWARE LOW CARBON SUPPLY CHAIN

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Abstract: Reduction of $CO_2$ emissions and moving toward a low carbon economy is the great challenge of our time. Aside from the ecological impact, low carbon solutions offer a huge business opportunity. At the same time, organizations must remain competitive and compliant to business rules. One of the important quality criteria in supply chain is temporal compliance. Tasks must be executed within agreed upon deadlines. In this paper we propose a technique that enables organizations to minimize $CO_2$ emissions and at the same time remain temporally compliant.

## 1 INTRODUCTION

Moving toward a low carbon economy is of outmost importance for the society. The accumulation of greenhouse gases in the atmosphere is growing in an alarming rate. It is estimated that global emissions will be approximately 53 billion tones carbon dioxide equivalent (GtCO2e) in 2020 (McKinsey, 2007). The grand technological challenge of our time is tackling climate change with its ecological, economical, social and political consequences. Tackling climate change affects all of us. Energy Efficiency and low carbon solutions have the potential of reducing global greenhouse gases by 15%. In addition to the ecological impact, they also offer a huge business potential up to 600 billion Euros in terms of energy savings and carbon price (Webb, 2008). At the same time it must be ensured that companies and organizations remain competitive and adhere to the business rules. A major contributor to carbon emissions as well as the sector with huge energy saving potentials are supply chains and logistics. One of the major quality criteria in supply chain is temporal compliance and satisfaction of temporal constraints. Processes may have deadlines. Such deadlines and constraints may be a part of the service level agreement between partners or enforced by law, organizational policies or business rules.

We assume that a supply chain is a contract between partners, where all participating organizations are aware of their rights and duties. This protocol captures the core of a business process and serves as an abstract process. It defines the interaction between partners but is not intended for execution. The execution of the tasks of each organization is implemented in detail in its private workflow. In other words, the protocol contains complex activities that hide the implementation details. It shows the interaction on a higher level of abstraction. An organization in a supply chain may have several alternatives to implement its task in the protocol. $CO_2$ emissions of the whole supply chain can be minimized if all involved organizations implement their corresponding parts using activities with the minimum amount of $CO_2$ emissions.

In this paper, based on our previous works on temporal management of workflows and business processes (Tahamtan, 2009; Eder and Tahamtan, 2008a), we propose a technique that enables organizations to move toward a low carbon supply chain and at the same time remain temporally compliant.

## 2 MODEL DESCRIPTION

As the basic modeling language we use timed workflow graphs as described in (Tahamtan, 2009).

They are familiar workflow graphs enriched with temporal information. This model allows for the definition of an interval for activity durations, e.g. $a_d = [a.d_{min}, a.d_{max}]$. $a.d$ refers to the duration of an activity $a$, $a.d_{min}$ its minimum duration and $a.d_{max}$ its maximum duration respectively. For modeling minimum and maximum duration of activities we use the concepts of lower bound and upper bound constraints (Eder and Panagos, 2001). Let $a$ be the source event and $b$ the destination event:

**Lower-bound constraint** identifies the minimum temporal distance between two events. $lbc(a,b,\delta)$ denotes that between the event $a$ and the event $b$ at least $\delta$ time points must pass.

**Upper-bound constraint** identifies the maximum temporal distance between two events. $ubc(a,b,\delta)$ denotes that between the event $a$ and the event $b$ at most $\delta$ time points can pass.

$a.d_{min}$ and $a.d_{max}$ can be modeled by defining the minimum and maximum allowed time points between start event and end event of an activity respectively. This scenario as depicted in fig. 1, where $a.d = [2,7]$. $a_s$ and $a_e$ refer to the start event and end event of the activity $a$. Obviously an activity can also be assigned a fixed value, if $a.d_{min} = a.d_{max}$. Note that in the rest of this paper, for the sake of brevity, we do not illustrate *lbc* and *ubc* as well as start and end events in the graphs. *lbc* and *ubc* are not only used for modeling $d_{min}$ and $d_{max}$ of activities. They can also be used for modeling temporal constraints between different activities, such as approval or rejection of an application may take at most one week after its receipt and sending a notification to the applicant takes at least three days.

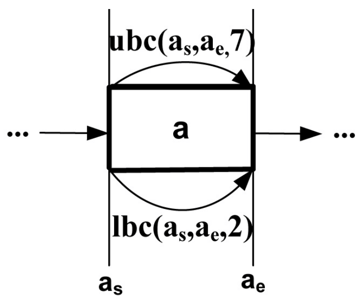

Figure 1: Modeling $d_{min}$ and $d_{max}$ by lbc and ubc.

## 2.1 Calculation of Temporal Values

The basic concepts used for calculation of temporal plans come originally from the field of project management and operations research such as critical path method (CPM) (Shaffer et al., 1965) and program evaluation and review technique (PERT) (Cottrell, 1999). For calculation of temporal values, we extend the algorithms developed in our previous work (Eder and Tahamtan, 2008a). At the first use of a model an estimation of the activity durations, e.g. expert opinion, may be used. Later, workflow logs can be mined for actual activity durations. An interval in which an activity may execute is calculated. This interval is delimited by *earliest possible start* (eps-value) and *latest allowed end* (lae-value). $a.eps$ denotes the *eps*-value of an activity $a$ and is the earliest point in time in which an activity $a$ can start execution. $a.lae$ represents the latest point in time in which an activity $a$ must finish execution in order to hold the assigned deadline. Both *eps* and *lae* values are calculated for *best case* and *worst case*. Best case and worst case identify the execution of the shortest and longest path of a flow respectively. $a.bc.eps$ refers to best case *eps* and $a.wc.eps$ refers to worst case *eps* of an activity $a$. The same applies to *lae*-values. *eps*-values are calculated in a forward pass by adding the *eps*-value of the predecessor to its duration. Minimum duration for best case and maximum duration for worst case are considered. For example $b.bc.eps = a.bc.eps + a.d_{min}$ and $b.wc.eps = a.wc.eps + a.d_{max}$ if activity $a$ is a predecessor of activity $b$. If activity $a$ has multiple predecessors, e.g. if activity $a$ is the immediate successor of an AND-join or the target node of an lbc, the maximum of *eps*-values of predecessors of $a$ and the *lbc* is taken into account. The *eps*-value of the first activity or the set of first activities are set to 0. In contrast to the *eps*-values, *lae*-values are calculated in a backward pass by subtracting the *lae*-value of the successor from its duration, e.g. $a.bc.lae = b.bc.lae - b.d_{min}$ and $a.wc.lae = b.wc.lae - b.d_{max}$ if activity $b$ is a successor of activity $a$. If the activity $a$ has multiple successors, e.g. if activity $a$ is the source of an *lbc*, the minimum of *lae*-values of predecessors of $a$ and the *lbc* is taken into account. For a more detailed discussion please refer to (Tahamtan, 2009; Eder and Tahamtan, 2008a). (Eder and Tahamtan, 2008b) describes another approach for checking the temporal conformance of processes.

Temporal values of a business protocol between a buyer, a seller and a shipper is depicted in fig. 2. Given known activity durations, in addition, we can calculate *earliest possible end* (epe-values) and *latest allowed start* (las-values) for an activity using the following formulas: $a.epe = a.eps + a.d$ and $a.las = a.lae - a.d$. We refer to eps-values and epe-values as e-values and to lae-values and las-values as l-values. Note that a temporal plan is valid if no l-value is smaller that its corresponding e-value.

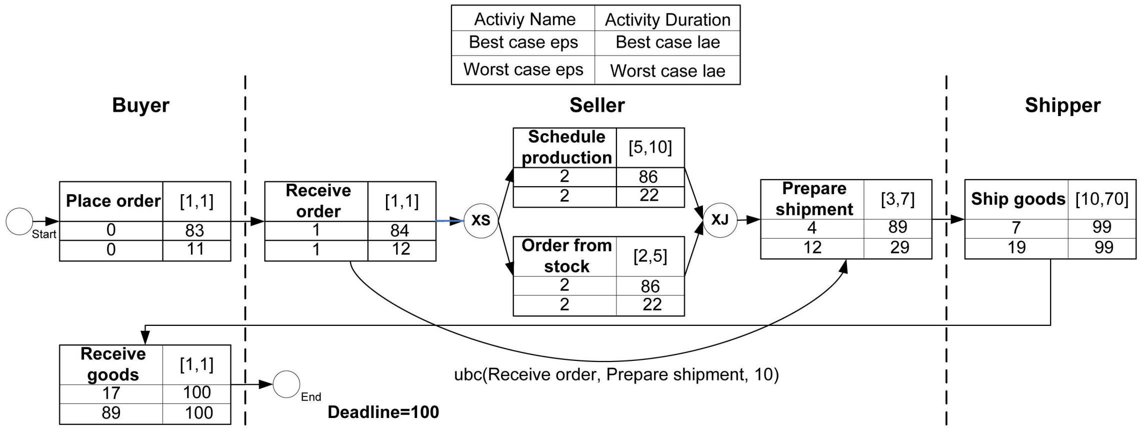


Figure 2: An example of an augmented timed graph with deadline= 100.

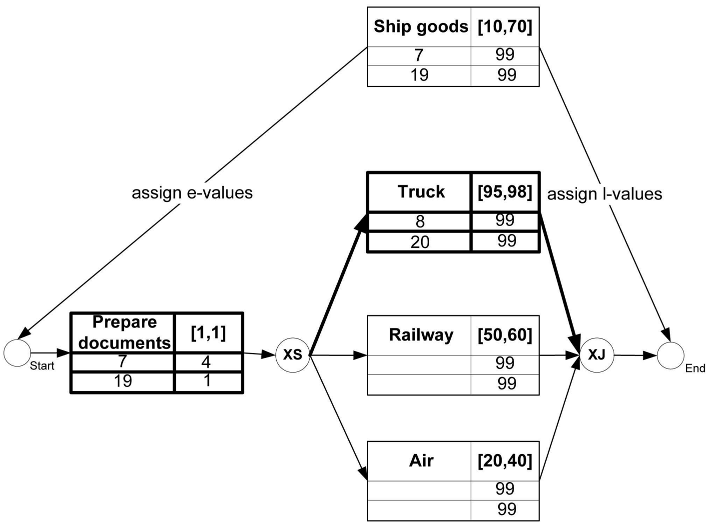


Figure 3: Shipping the goods with truck is temporally not feasible.

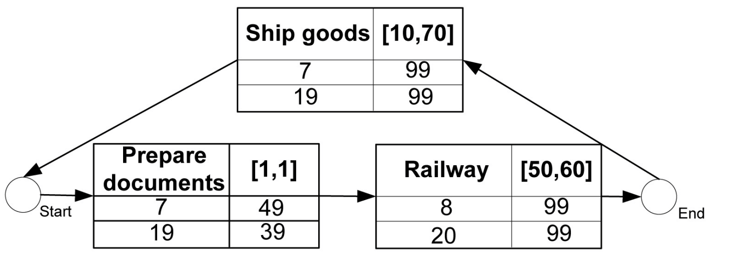


Figure 4: Choosing railway is temporally feasible and produces lowest amount of $CO_2$.

# 3 The proposed Approach

In order to show how our approach can be used for a low carbon supply chain we use a simple procurement example as illustrated in fig. 2. Swimlanes depict corresponding parts of different partners. In this protocol the buyer initiates the process by placing an order. The seller after receipt of the order, either orders the requested item from its stock or if the item is not on stock, schedules its production. After preparing the shipment by the seller, the shipper ships the goods to the buyer. The process ends when the buyer receives his/her order.

The protocol described above captures only the core of a business process. It can be seen as a contract between partners. It describes the minimum amount of tasks that a partner needs to implement in its private workflow. In other words, this protocol describes a skeleton for designing the partner's executable workflows. By calculating the temporal execution plan of the protocol, partners are able to decide what is their valid temporal window for implementation of the tasks. Assume that the shipper implements the task *Ship goods* as depicted in fig. 3. After preparing the documents, the shipper has several possibilities: truck, railway or air. The estimated duration for each transportation is depicted in the figure. In order to calculate the temporal plan of the underlying workflow, the calculated temporal values from the protocol can be used. E-values of the first activity of the shipper are initialized with the e-values of its first complex activity in the protocol and the l-values of the last activity or the set of last activities are initialized with the l-values of its last complex activity. Note that in this simple example the shipper is in charge of execution of only one activity in the protocol. At this stage, it is possible to calculate which activities are temporally feasible. As it can be seen in fig. 3, sending the goods using trucks is not feasible. The execution of this path leads to a conformance condition violation at the activity *Prepare documents*, i.e. the e-values of the activity *Prepare documents* become greater than its l-values. After calculating which tasks are temporally feasible and satisfy the temporal constraints (in our running example shipment by railway or air), the shipper can decide which of the feasible transportation means be actually used for shipment based on their $CO_2$ emissions.

The shipper can minimize the $CO_2$ emissions by choosing appropriate activities. Imagine the transportation with railway produces x tons of $CO_2$ emissions and the transportation by air y tons and $x < y$. The shipper knows that both of the transportation means satisfy the temporal constraints and the buyer receives the order goods within the agreed upon time frame. The shipper can safely choose the activity that produces the lowest amount of $CO_2$ emissions, i.e. railway. The workflow of the shipper for actual implementation is depicted in fig. 4. Other partners of the business process, as well, can use the same approach. By knowing the valid temporal window for each partner, it can be calculated which activities can be used for implementing the tasks described in the business protocol. Among temporally feasible tasks, the partners choose those activities that produce the lowest amount of $CO_2$ in order to minimize the $CO_2$ emissions of the whole supply chain.

# 4 Conclusions

In this paper we proposed a technique for deadline aware low carbon supply chain. We model a supply chain as a two-layer architecture consisting of a business protocol between partners and implementation of the business protocol in partners' workflows. Partners can calculate the execution plan of the business protocol. Based on these values, partners decide which activities are temporally feasible and may be used for implementation of the business protocol. $CO_2$ emissions of the whole process can be minimized by choosing the greenest activities from the set of temporally feasible activities.


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