Chapter 1

Introduction

The main goal of this dissertation is to provide computationally efficient market-based auction mechanisms for automating the process of optimal supply chain partner selection. This is achieved by means of two progressive, non-trivial extensions of combinatorial auctions (CA). On the one hand, we extend CAs to determine optimal outsourcing strategies. Thus, we aim at providing a useful tool to optimise make-or-buy decisions across the supply chain. On the other hand, we propose a novel CA that automates the process of collaborative supply chain network design, planning[1], and formation. The outcome of such a new auction is the coordinated plan of a totally integrated supply chain (the selection of a set of supply chain partners along with the ordered set of operations that each partner must perform). Analogously, in the latter case we aim at providing a useful tool to optimise make-or-buy-or-collaborate decisions, and therefore to tightly link sourcing, outsourcing, and collaboration strategies. In this context, *make*, *buy*, and *collaborate* mean that a stakeholder of the supply chain decides whether to perform a set of services or operations by himself (make), to outsource them (buy), or to perform them in collaboration with other stakeholders (collaborate).

This chapter is organised as follows. In section 1.1 we explain why some think that our economy is undergoing profound changes in the next years. In section 1.2, we go back to reality and explain what is currently changing in our economy and what is required to adapt to such changes. In section 1.3 we recall some concepts and terminology related to supply chain management. In section 1.4, we specify and thoroughly exemplify the problems we cope with in this PhD thesis. In section 1.5 we highlight the contributions of this dissertation with respect to the state-of-the-art. Finally, in section 1.6, we elaborate on the structure of this dissertation.

1.1 A hypothesis for the future: Wikinomics

In his recent article, Burkeman (Burkeman, 2005) summarises and discusses the eye-opening new book of Don Tapscott called *WIKINOMICS: How Mass Collaboration Changes Everything* (Tapscott and Williams, 2006). According to Don Tapscott, a guru

[1] We remark that *supply chain planning* consists in assessing who will do what and when in a supply chain.

of the Web, “we have barely begun to imagine how the Internet will change the way we live and work”. We are living a revolution that is undermining the very basis of traditional economy. In his article, Burkeman recalls three examples of this transformation from the *Wikinomics* book:

- *Self-Organisers*: China’s flourishing motorbike industry is not composed of big organised firms hiring thousand of employees and outsourcing tasks to small subcontractors. Instead, a myriad of smaller companies collaborate and self-organise in order to share risks and profits. Their representatives meet in tea-shops or in on-line places and jointly plan a product, to which they contribute with the service they are best at. Even the final assembly is a service. A “self-organised system of design and production” has emerged.

- *Prosumers*: when amateurs began to hack the computerised parts at the heart of the Lego Mindstorm range (Shaeffer, 2007), the company initially threatened to sue them. Then, perceiving the wind of change, Lego started to encourage them to be *prosumers*, consumers that have an active role in the design of a product. This lead to an increased satisfaction of customers without harming the enterprise profit.

- *The new gold rush*: the Gold mine at the Red Lake in Ontario, owned by Goldcorp, was in a terrible crisis in 1999. When the chief executive Rob McEwen heard a talk about Linus Torvald, the inventor of Linux, he came up with a revolutionary idea. If developers collaboratively code on the Web, why not share the mining activity on the web? Then, he put Goldcorp secret geological data on the web and set a 575,000 $ prize to reward the discovery of new gold veins in Red Lakes’s mine. Around 80 valid targets were identified and the company value turned from $100m to $9bn.

Those three cases above aim at showing that the collaborative structure, recently emerged in social and collaborative networks as Wikipedia (Lih, 2003) and Sourceforge (SourceForge, S.F., 2007), could be far more radical and change the way we think about manufacturing. In his book, Tapscott introduces his revolutionary idea of “wikinomics”, an idea that originates in a work that dates back to 1937 (Coase, 1937). At that time, Ronald Coase, a Nobel prize economist, noticed something odd in capitalism. Capitalism predicates the free market and exchange. If capitalist theory was correct American or British people should do business among them as individuals in an open market, and not organise themselves in firms, as it happens. The motivation (Coase, 1937) is that making things requires collaboration, and that finding and linking up all the people who need to collaborate costs money. Companies emerge when it is cheaper gathering people, materials, and tools under the same roof, rather than going out looking for the best deal every time a few hours’ work is required. However, the Internet is radically lowering the cost of collaborating. Consequently, big companies are doomed to reduce their size in order to leave space to more agile and flexible collaborative structures. A symptom of this new collaborative reorganisation is that, for instance, large companies, from media outlets to clothes shops, are trying to make profit by incorporating final customers in the creation of their products. However, *Wikinomics* forecasts a further radical revolution: it is not given that the company will stay in the driving seat at all. Quoting Tapscott: “We are talking about a new means of production. Collaboration can occur at an astronomical scale, so if you can create an encyclopedia with a bunch of people, could you create a mutual fund, a motorcycle?”.

Tapscott is not the only one prohetising a wiki future. For instance, Laubaucher and Malone (Laubacher and Malone, 2003) claim that “The most radical new organisational form, the virtual corporation, involves small firms and free-lancers, or even e-lancers — electronically connected free-lancers, who post their qualifications and find assignments on the Internet — joining forces on a temporary basis, working together on a project, then disbanding when the work is completed. Virtual corporations of this sort have long characterised film production and construction and are increasingly prevalent in the most dynamic and fastest-growing sectors of the economy — computers and telecommunications, entertainment, biotechnology.”

Other terms employed to indicate analogous concepts are *virtual corporation*, *virtual organisation* (Mowshowitz, 2002), and *extended enterprise* (Dyer, 2000).

1.2 With the feet in the air & the head on the ground

The provocative title quotes The Pixies’ song *Where is my mind*. It aims at highlighting the fact that wikinomics is a far goal. However, any revolution takes its time to entirely develop, and probably several intermediate steps are required to approach the new economy envisaged by Tapscott and Couse. Then, in this section we stay with *the head on the ground* and we analyse what is going on in the business world now. We will summarise what is changing and why. At the same time we will comment on the requirements that originate from such changes.

We are witnessing an important transformation of the firm organisational structure. Today’s business world is experiencing a progressive disintegration of the traditional vertical integrity[2] of the enterprises’ organisational structure. This is witnessed by a heavy increment in the use of outsourcing. Quoting Greaver (Greaver, 1999), “Outsourcing is the act of transferring some of an organisation’s recurring internal activities and decision rights to the outside providers, as set forth in a contract”. Outsourcing is one of the success keys of western economies and is widely employed. Indeed, a recent on-line news (DMReview.com online news, 2005) about outsourcing claims that, “According to a newly released IDC study, the worldwide BPO (Business Process Outsourcing) market is vibrant and brimming with opportunity. The comprehensive BPO report finds that worldwide BPO spending will experience a five-year compound annual growth rate (CAGR) of 10.9 percent, growing from $382.5 billion in 2004 to $641.2 billion in 2009. This forecast covers eight BPO markets: human resources, procurement, finance & accounting, customer service, logistics, sales & marketing, product engineering, and training”. Another on-line news (DMReview.com online news, 2006) says that “According to a newly released IDC study, the business outsourcing market progressed positively in 2005, experiencing a 33 percent increase in the volume of deals signed. [...]. Small and mid-size deals are fuelling growth. Underlying this trend is

[2]In microeconomics and management the term *vertical integration* describes the degree to which a firm owns its upstream suppliers and its downstream buyers.

an increase in the share of new deals versus extensions and renewals, which indicates that a growing number of new organisations are buying into the business outsourcing model. [...]. Manufacturing, financial services, and government verticals registered the strongest adoption of business outsourcing overall".

The trend is quite clear. We are moving from vertically integrated structures to collaborative structures whose components tend to reduce their sizes (Lucking-Reiley and Spulber, 2001; Hammer, 2001). This means that we are slowly moving towards the paradigm of virtual enterprises. This is a symptom endorsing the *Wikinomics* theory. Such transformation is due to many factors.

Firstly, today's business environment is getting tougher and tougher. Indeed, nowadays customers are increasingly demanding better and innovative goods, as well as progressively more customised products. This new situation entails some implicit production requirements and constraints like timeliness, convenience, responsiveness, quality, and reliability. Moreover, ever lower prices are imposed by a fierce market competition.

Secondly, the rapid pace of innovation has entailed a shorter product and technology life cycle (for instance, the PC or phone industries where new models are introduced each 3 to 9 months), and an increased uncertainty in supply and demand. Notice that the presence of technology, in particular the Internet, has also made the work of modern organisations placeless. This has forced an increased specialisation of the operational activities across an organisation.

Thirdly, we are experiencing a worldwide increment in competition (hypercompetition). We are fastly moving from a best-in-class to a best-in-world paradigm, barriers are dropping quickly, competition is just one click away from any customer. Companies that recently were in separate fields now compete in the same narrow market (for instance, Apple with the iPod efficiently entered into the MP3 player market).

Finally, we are witnessing a rapid commoditisation of goods[3], due to the rapid price decline and to the increased pressure for improved performances.

Thus, the ability to quickly and efficiently design, develop, produce and sell a new product has become a key competitive advantage. That is why the structural integrity of organisations is breaking down; the traditional vertically integrated organisations, controlling as many of the production factors as possible, is being quickly replaced by better focused and more specialised organisations. An increased number of capable service providers, the pressure deriving from the hypercompetitivity, and the pervasive presence of technology impose a new strategic vision. As a result, new supply chain management (Simchi-Levi et al., 2000) strategies are emerging, like strategic outsourcing (Quinn and Hillmer, 1995; Greaver, 1999; Corbett, 2004) and collaborative supply chain network design (Viswanadham, 2002).

Notice that the intersection between portions of supply chains of different firms is often non empty. For instance, *original equipment manufacturers* (OEM) are typical in rapidly chaining markets. The term *original equipment manufacturer* (OEM) refers to a company that sells a manufacturing component to another company, that in turn resells it as its own, usually as a part of a larger product.

[3]In essence, commoditisation occurs as a good or service becomes undifferentiated across its supply base by the diffusion of the intellectual capital necessary to acquire or produce it efficiently. As such, many products which formerly carried premium margins for market participants have become commodities, such as generic pharmaceuticals and silicon chips (Schrage, 2007).

In this environment, the selection of the right business partners is critical, which are quickly moving from the role of suppliers, manufacturers, customers, to the role of *collaborators*. Hence, many enterprises now face critical *make-or-buy-or-collaborate* strategic decisions across their supply chain: different types of actors, as component suppliers, contract manufacturers, service purchasers, logistic providers, and final customers have to be efficiently integrated into the supply chain. In particular, one of the main objectives of current supply chain management (Simchi-Levi et al., 2000) is to integrate as much as possible the *back-end* of the supply chain (its production and manufacturing portion) to the *front-end* (the final customer).

Another fundamental requirement stemming from the business environmental changes explained above is a need for an increased automation across the supply chain. Indeed, static and vertically integrated supply chains are quickly giving way to more flexible value chains composed of partners that can be assembled in real time to meet unique requirements. This phenomenon is being accelerated by the Internet, that lowered the communication barriers transforming a game that was firm against firm into a game that is supply chain network against supply chain network (Viswanadham, 2002).

A spectrum of possible solutions is possibly needed by enterprises. On the one extreme, companies must make decisions about whether to outsource part of their production processes (buy/make decisions) in business environments characterised by myriads of possible partners (lower barriers caused an increment in competition). On the other extreme of the spectrum, virtual enterprises may need agile *decision support systems* (DSSs) that allow them to automatically form self-organising supply chains.

Indeed, we do believe that nowadays firms, or group of firms, require DSSs that allow them to nimbly and automatically select strategic business partners. With this goal, those DSSs should allow firms to:

- automate the process of partner selection, optimising critical *make-or-buy* decisions across the supply chain (i.e. trading off decisions of internal vs external production) with myriads of potential partners. Clearly this entails a tight integration of the procurement and outsourcing strategies.

- decide whether to collaborate with other firms to complete some tasks across its supply chain. In this case companies need to automate *make-or-buy-or-collaborate* critical decisions across the supply chain with myriads of potential partners.

- automate the process of collaborative supply chain network design and planning with a large number of potential partners. In particular, the decision support should allow them to self-organise by allowing to:

  - integrate and coordinate all the supply chain stakeholders;
  - include component suppliers, contract manufacturers, logistic providers and final customers into the supply chain design process;
  - optimise the overall performance of the supply chain (i.e. not a local optimisation);

– easily support mass customisation[4]; and
– integrate potential suppliers and final customers into new product developments.

Obviously, decisions like the ones considered above can emerge as long as the supply chain stakeholders collaborate and share information like capacity, schedule, and cost structures. However, full transparency and collaboration is rather unlikely. Then, all the previous requirements should come with the possibility to share only part of a stakeholder's internal information, without being forced to reveal every piece of critical production information.

With the above-mentioned requirements fulfilled, competitive companies could easily cope with a wide range of difficult business decisions: from the selection of optimal, tightly connected procurement, outsourcing, and collaboration strategies, to the formation of virtual enterprises.

In the next section, we briefly introduce the definition of supply chain and we provide some terminology that will be useful in the remaining of the chapter.

1.3 Supply Chain and Supply Chain Management

According to (Simchi-Levi et al., 2000), "In a typical supply chain, raw materials are procured and items are produced at one or more factories, shipped to warehouses, for intermediate storage, and then shipped to retailers and customers. [...] The supply chain, consists of suppliers, manufacturing centers, warehouses, distribution centers, and retail outlets.".

Supply chain management (SCM) "is a set of approaches utilised to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimise system-wide costs while satisfying service level requirements" (Simchi-Levi et al., 2000). One of the core objectives of the supply chain is to perform a global optimisation across the supply chain. But many features of the way businesses are run today prevent this from happening: the uncertainty underlying the supply, the demand, the transportation time, the vehicles and the tools breakdowns. Furthermore the various stakeholders across the supply chain locally maximise their utility disregarding the performances of the other elements within the supply chain. In fact, the different components often have even conflicting objectives. Traditional SCM deals with all these problems acting on different aspects of control: distribution network configuration, supply contracts, distribution strategies, supply chain integration and strategic partnering, inventory control, outsourcing and procurement strategies, information technology and DSSs, etc.

In particular, aspects relevant to our work are:

(1) outsourcing and procurement strategies considered in the first part of this dissertation; and

[4]According to (Simchi-Levi et al., 2000) "mass customisation involves the delivery of a wide variety of customised goods or services quickly and efficiently at low cost".

(2) supply chain integration and strategic partnering, considered in the second part of the PhD thesis.

Since our work mainly focuses on outsourcing issues, in what follows we provide some basic related terminology. Different operational aspects of the supply chain can be outsourced. More specifically, we classify the types of possible supply chain partners into four categories:

- *component suppliers*, also called providers, that supply raw or intermediate goods across the supply chain;
- *contract manufacturers*, that provide services or manufacturing operations across the supply chain;
- *service purchasers*, that require services or manufacturing operations across the supply chain;
- *logistic providers*, in charge of the transportation, distribution, and storage of raw, intermediate or manufactured goods; and
- *final customers*, at the end of the supply chain, be them either retailers, or, in the new Internet era, final clients.

In this dissertation we narrow the focus of the investigation to the collaboration of component suppliers, contract manufacturers, service purchasers, and final customers. We deem necessary the incorporation of the logistic portion into the problem. However, in this dissertation the collaboration with logistic providers is left out, and will be thoroughly discussed as a path of future work in chapter 9. Therefore, in this dissertation we assume that logistics are negotiated independently.

1.4 The Problem

Once outlined in section 1.2 the requirements originating from the vertiginous changes in today's business world, we focus on the requirements that we tackle in this dissertation. In particular, we present two motivating examples concerning the main issues we intend to face in this thesis: the problem of efficiently solving *make-or-buy* and *make-or-buy-or-collaborate* decisions across the supply chain. Both examples consider an imaginary company devoted to produce and sell apple pies called *Grandma & co*. The examples, along with the emerging implicit requirements, are thoroughly presented in sections 1.4.1 and 1.4.2.

1.4.1 Optimising make-or-buy decisions

The first example aims at making explicit the requirements regarding the automation of *make-or-buy* decisions.

Example 1.1. Consider a company, named *Grandma & co*, devoted to produce and sell apple pies. The internal production structure of the company, i.e. the way apple pies are prepared, is presented in figure 1.1. Each circle represents a raw, intermediate or manufactured good. Squares connecting goods represent manufacturing operations. An arc connecting a good to an operation indicates that the good is an *input* to the operation, whereas an arc connecting an operation to a good indicates that the good is an *output* of the operation. Then, *butter*, *sugar*, and *flour* are *input goods* to the *Make Dough* operation, whereas *dough* is an *output good* of the *Make Dough* operation. The labels on the arcs connecting *input goods* to operations, and the labels on the arcs connecting *output goods* to operations indicate the units required of each *input good* to perform an operation and the units generated per *output good* respectively. In our example, the preparation of two units of *dough* requires one unit of *butter*, three units of *sugar*, and two units of *flour*.

Each operation has an associated cost every time it is carried out. We label each operation with a cost. In our example, the *Make Dough* operation costs 5 €.

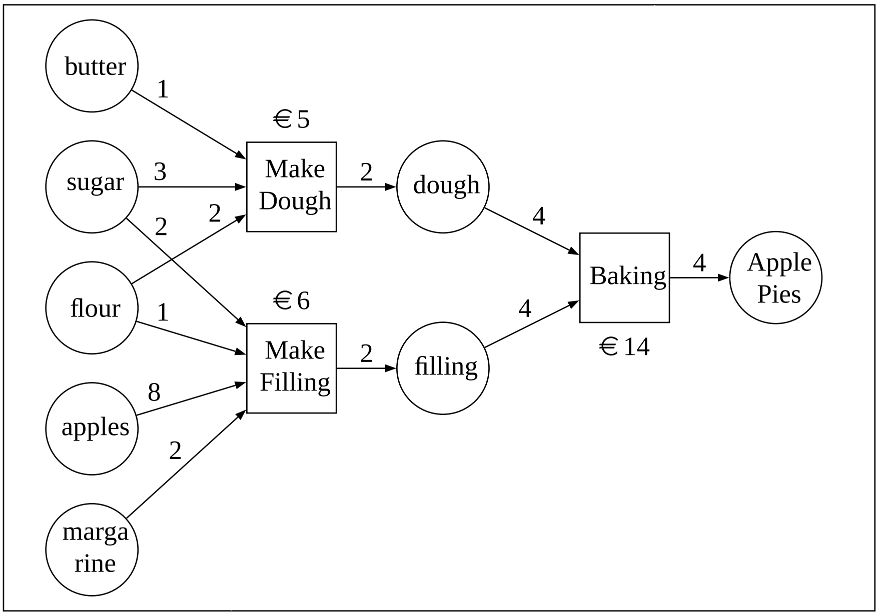

Figure 1.1: Apple pie production flow.

Consider that the marketing department at *Grandma & co* forecasts that two hundred apple pies will be sold within a month. Therefore, the company starts an automated sourcing (Minahan et al., 2002) process to acquire the basic ingredients needed for producing pies, namely *butter*, *sugar*, *flour*, *apples*, and *margarine*.

However, the production management staff decides to test a new sourcing process. Instead of limiting the procurement to basic ingredients, they decide to incorporate in the sourcing process intermediate and final goods as well, namely *dough*, *filling*, and *apple pies* in figure 1.1. More precisely, the production management wonders whether to *outsource* part of its production process. In fact, the executive staff noticed that more and more specialised enterprises are entering the organic food market. Since *Grandma & co* is a well-known brand for pies, it decides that in order to reduce costs, it could be suitable to negotiate and collaborate with those new brands.

As an additional constraint, the production management knows that strong complementarities among the negotiated goods exist on the supplier side. For instance, suppliers often sell margarine and butter as indivisible bundles. Thus, it is required that those complementarities are taken into account. □

Grandma & co realises that it faces a decision problem: shall it buy the required ingredients and internally produce apple pies, or buy already-made apple pies (outsource all its production), or opt for a *mixed purchase* and buy some ingredients for internal production and some already-made apple pies? This concern is reasonable since the cost of ingredients plus preparation costs may eventually be higher than the cost of already-made apple pies. *Grandma & co* must take a decision among many possible mutually exclusive options:

- buy all the basic ingredients to internally produce all the pies;
- buy from suppliers all the pies and resell them under its name;
- buy already-made dough and filling from suppliers , and bake itself the cake;
- prepare part of the dough and part of the filling, and buy the rest from suppliers;
- buy part of the pies from suppliers and produce the rest itself;
- and so on.

Grandma & co is interested in quantitatively assessing what to buy and from whom, as well as what to produce in house. Such assessment depends on many factors:

(1) the market cost of the basic ingredients (butter, sugar, flour, apples, and margarine);

(2) the market cost of dough, filling, and pies;

(3) the stock goods at *Grandma & co*;

(4) the finally required goods (the sales forecast);

(5) the cost for performing at *Grandma & co* the operations *Make Dough*, *Make Filling*, and *Baking* (the internal cost structure);

(6) the number of units of each good either produced or required for each operation (the internal production structure); and

(7) the complementarity relationships among goods holding on the suppliers' side.

Hence, *Grandma & co* requires a complex decision support system along with a negotiation mechanism that helps it in detecting which is the revenue maximising buying configuration and the internal operations to perform in order to obtain the finally required goods. It is easy to understand from the example that the procurement and outsourcing decisions are tightly linked. Notice that there is a mutual dependency among the outsourcing opportunity, the ingredients' market prices (as Dough, Apples,etc.) and other factors. This kind of dependencies must be absolutely captured by any proposed solution.

The literature on procurement has introduced combinatorial reverse auctions to deal with the problem of complementarities among goods on the bidders' side. In the following section we briefly recall some knowledge about electronic sourcing and combinatorial auctions.

The procurement phase

In the everyday business world, the sourcing process of goods and services usually involves complex negotiations. With the advent of the Internet, a plethora of commercial products to electronically support this process (e-sourcing tools) have started to be commercialised by a significant number of vendors (e.g. Ariba, Emptoris, Perfect, and iSOCO to name a few[5]). Thus, e-sourcing tools have become an established part of the business landscape (Team, 2001). Reverse[6] auctions are at the heart of most of these tools as the mechanism for buying companies to automate their negotiations with the qualified providers in their supply chains.

Although reverse auctions are certainly valuable to swiftly negotiate with providers, combinatorial (reverse) auctions may lead to more efficient allocations whenever complementarities among the goods at auction hold, as argued in (Sandholm, 2002). A combinatorial (reverse) auction (Cramton et al., 2006) is an auction where bidders can sell (buy) entire bundles of goods in a single transaction. Although computationally very complex, selling (buying) items in bundles has the great advantage of eliminating the risk for a bidder of not being able to obtain (sell) complementary items at a reasonable cost (price) in a follow-up auction (think of a combinatorial auction for a pair of shoes, as opposed to two consecutive single-item auctions for each of the individual shoes).

In particular, connected with the introduction of combinatorial auctions are bidding languages (Nisan, 2006) and the winner determination problem (WPD) (Lehmann et al., 2006). Winner determination is the problem, faced by the auctioneer, of choosing what goods to award to which bidder so as to maximise its revenue. The winner determination for combinatorial auctions is a complex computational problem. In particular, it has been shown that the WDP is NP-complete (Rothkopf et al., 1998). Bidding is the process of transmitting one's valuation function over the set of goods at offer to the auctioneer (or rather *some* valuation function — the bidders are of course not required to reveal their true valuation —).

[5]We refer the reader to (Bartels et al., 2005) for an analysis of e-sourcing tools.

[6]An auction is called *direct* when the auctioneer aims at selling goods, whereas we talk about *reverse* auction when the auctioneer is interested in buying goods.

Since *Grandma & co* aims at dealing with the case in which complementarities among goods hold at the bidder's side, combinatorial auctions is for sure the more suitable sourcing method. Then, in order to cope with *Grandma & co*'s problem, we employ combinatorial auctions. Anyway, combinatorial auctions cannot be directly employed for the problem explained in example 1.1 due to some intrinsic limitations.

To the best of our knowledge, no author directly dealt with the *make-or-buy* decision problem employing reverse combinatorial auctions. On the one hand, combinatorial reverse auctions solve the problem of procurement when complementarities among goods exist on the supplier side. On the other hand, operations research has studied the best *make-or-buy* decisions based on past production information, sell forecast, providers' offers, etc (Aissaoui et al., 2007)[7]. However, nobody embedded the decision problem into the procurement problem when complementarities among goods hold, nobody analysed the procurement decisions in conjunction with the outsourcing decisions in a combinatorial scenario. Then, in what follows, we analyse the requirements associated with the *make-or-buy* decision problem that are not fulfilled by combinatorial auctions, and we discuss the extensions required in order to deal with such decision problem.

Combinatorial Auction limitations

Say that *Grandma & co* opts for running a combinatorial reverse auction (Sandholm et al., 2002) with qualified providers for the procurement of all the required goods. Unfortunately, traditional combinatorial reverse auctions cannot be applied to solve such a problem for three reasons. Firstly, because of expressiveness limitations, namely an auctioneer (*Grandma & co*) cannot express:

- its internal manufacturing operations along with the producer/consumer relationships holding among them (for instance, in figure 1.1, the output of *Make Dough* is an input of *Baking*);

- the relationships between the manufacturing operations and the auctioned goods (for instance, in figure 1.1, the input to the *Make Dough* operation is three units of *sugar*, two units of *flour* and one unit of *butter*, whereas its output is two units of *dough*);

- the relationships between the received bids and the internal manufacturing operations;

- the requirements sent to bidders. This is clarified by observing that even though the final requirements of *Grandma & co* are two hundred apple pies, multiple request configurations fulfil such outcome, for instance:

  - two hundred already-made apple pies
  - the basic ingredients plus in-house production of two hundred apple pies

[7] For a general review on decision support to supply chain management refer to (Erenguc et al., 1999).

How can *Grandma & co* formally describe its requirements? What should be the requirements sent to bidders? In fact, the optimal requirements depends on the received offers, and therefore cannot be stated a priori.

- the cost associated to performing each internal operation or a set of internal operations.

The second problem is that the outcome of a combinatorial auction only provides information about what goods to buy and from whom. However, the information about which internal manufacturing operations to perform and the order in which the auctioneer has to perform them (in the example of figure 1.1, the auctioneer cannot perform the *Baking* operation before *Make Dough* or *Make Filling*) is not provided.

Table 1.1 summarises the requirements stemming from the *make-or-buy* decisions that are not supported by any state-of-the art solution.

TYPE	LIMITATION
Expressiveness	(1) internal manufacturing operations and the producer/consumer relationships among them (2) specification of an auctioneer's final requirements (3) relationships among the manufacturing operations, the auctioned goods, and the received bids (4) specification of an auctioneer's internal cost structure
WDP	(5) information about which in-house operations to perform and in which order

Table 1.1: Summary of unfulfilled requirements.

Although combinatorial auctions help set the market price of each good, they do not incorporate the notion of internal manufacturing operations. This is why all the above-mentioned difficulties arise.

Summarising, *Grandma & co* requires an extended combinatorial reverse auction that provides:

(1) a formal language to quantitatively express, analyse, and communicate its internal production structure and requirements; and

(2) an efficient cost minimising winner determination solver that not only assesses which goods to buy and from whom, but also the sequence of internal manufacturing operations needed to obtain the finally required goods.