MODELLING SUPPLY CHAIN MANAGEMENT IN THE SUGAR INDUSTRY

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Abstract

Greater competitiveness and deregulation in agribusiness and the food industry require new forms of co-ordination between farmers and their clients to increase the efficiency and profitability of the supply chain. Various co-ordination processes are used by processing firms to control the quantity and quality of their raw material. In the sugar industry, millers plan their cane supply to ensure that the mill operates at optimum capacity throughout the entire season. They may also take into account variations in cane quality within the supply area and at different times during the season to maximise sugar production. These decisions will impact on the choices growers make with regard to their harvest capacities and management and, depending on the cane payment system in place, on their incomes as well. Other stakeholders in the supply chain, such as contractors and hauliers, also directly affect its management and results. Any modification to the structure of the supply chain or the management rules should take into account stakeholder strategies and ways of operating. A modelling approach based on two complementary models has been developed to simulate on a weekly basis the planning and operation of mill supply throughout the season. The first model compares weekly and total sugar production for a season. The second model focuses on the simulation of logistic chains, and enables the impacts of technological and structural changes on daily harvest and transport capacities to be assessed. Both models can be used to support discussion and negotiation between growers and millers regarding evolutions in the supply chain management.

Keywords: sugarcane, mill supply, supply chain, management, modelling

Introduction

Escalating market instability calls on firms to be increasingly reactive and flexible, and implies the development of new forms of industrial organisation in agro-food chains. In this context, the control of products from supply areas to processing plants, and from plants to markets, is a critical factor of efficiency. Because numerous elements interact within the supply chain, such as industrial capacities, production risks and diversity of farm structures, finding organisational solutions that satisfy the objectives and constraints of all stakeholders is not a simple process.

The sugar industry faces such co-ordination problems, especially when a large number of cane suppliers are involved. Millers organise their cane supply to ensure regular mill operation throughout the entire season in accordance with milling capacity, and may also take into account variability in cane quality, to maximise sugar production. Decisions made by the millers impact on the choices growers make regarding their harvest capacities and management. Depending on the cane payment system in place, these decisions could affect grower incomes as well.

Other stakeholders, such as contractors and hauliers, also directly affect supply chain management and results.

This paper investigates modelling approaches and support tools that could be valuable in negotiations between firms seeking organisational solutions to problems. The first part of the paper briefly reviews theoretical frameworks used in chain analysis, and suggests a modelling approach to flow of material between firms. The approach provides negotiation support to stakeholders involved in the supply chain by highlighting the impact of individual strategies on the efficiency of the chain as a whole. The second part describes how this approach has been implemented in the sugar industry. Practical applications in La Réunion and South Africa are presented at this Congress in two complementary papers (Lejars *et al*., 2003; Guilleman *et al.*, 2003).

Theoretical Background

Some research work has shown that joint decision making between several firms yields higher profits for the whole chain in the case of a distribution channel (Eliashberg and Steinberg, 1987). However, such problems are difficult to solve in practise. Different theoretical frameworks have been proposed to deal with this type of problem, either in the field of economic analysis of vertical relationships, or in the field of Management Science and Operational Research.

Co-ordination within the supply chain

Co-ordination between firms within the supply chain involves four processes:

- definition of contracts and limitations
- choice of supply organisation
- management of supply process
- information management (Schary and Skøjtt-Larsen, 1995).

Contract and limitation issues have been studied mainly in the field of economic theory. For example, incentive theory aims at designing optimal contracts to induce co-operation in a world of asymmetric information plagued by the opportunism of the agents (Holmstrom and Milgrom, 1994). Applications of this theory look for pricing rules and incentives. Limitation analysis focuses on the impact of vertical restraints on chain efficiency, and their compatibility with antitrust policy.

A large number of studies have been based on these two theoretical frameworks. Some describe modes of co-ordination between firms, such as strategic alliances between agro-business firms (Sporleder, 1990). Others highlight the role of information technology and information asymmetry in encouraging vertical integration within the supply chain (Streeter *et al*., 1991; Hennessy, 1996).

Some of this work has led to a modelling approach aimed at characterising the level of inter-firm integration within a chain. For instance, Franck and Henderson (1992) focus on how transaction costs impact on food industry vertical linkage. They show that these costs are critical factors for firms that are vertically co-ordinated by non-market arrangements. Focusing on vertical relationships in the Champagne wine chain, Giraud-Héraud *et al*. (1999) analysed the market between grape producers and wine merchants. Their model simulates the impact that the economical behaviour of producers and merchants has on the efficiency of the chain.

Optimisation approach

In the field of Operational Research and Management Science, there have been many investigations into the value of co-ordinating two functions within a firm (to build a production and distribution plan, for example) or several firms within a chain.

The main purpose of these studies is to find efficient production schedules, product delivery and inventory pricing in the face of unstable demand. Usually, modelling is used to find the plan that provides the best co-ordination between marketing and manufacturing.

For instance, Chandra and Fisher (1994) study the co-ordination problem by comparing two approaches: (i) where production scheduling and vehicle routing problems are solved separately, and (ii) where they are co-ordinated in a single model. They combine the number of products and retail outlets, the cost of set-ups, inventory holdings and vehicle travel. de Groote (1994) addresses the problem of flexibility of manufacturing processes in relation to marketing. He analyses both product variety and process flexibility, concentrating on changeover costs and inventory costs. This leads to insights into manufacturing systems and 'just-in-time' production.

Some studies related to this field of research have been carried out in the Australian sugar industry. An optimisation model was developed at the mill area level to maximise the sugar yield and net revenue of the chain by defining suitable harvest dates and crop cycle lengths for a range of production units (Higgins, 1999; Higgins *et al*., 1998). This model includes cultivation, harvest, transport and transformation costs, and provides an optimum solution for harvest scheduling, given the structure and capacity of the supply chain. The model appears well suited to the Australian situation, since the mill and its suppliers are closely integrated. Indeed, the growers still harvest their own cane - but it is the mill that schedules the arrival of the containers used for cane transport. As harvest is almost totally mechanised, and cane deterioration thus all the more rapid, the growers have the incentive to follow the schedules imposed by the mill.

Inter-firm modelling as a support for decision making
Theoretical economic frameworks are useful for analysing and understanding the strategic interactions between stakeholders (information asymmetry, market powers), but they miss the technical aspects of the observed phenomena (inventory costs, delay costs, production systems). These approaches focus more on the way the total chain value is shared between stakeholders than on ways of increasing that value (Soler and Tanguy, 1998).

The reverse situation occurs in the field of Operational Research and Management Science, where technical issues are highlighted, and interaction between stakeholders receives least attention. Management tools are often based on an implicit organisation, which is far from being realistic; i.e. there is no communication problem and no conflict of interests, and uncertainty is taken into account in a 'probabilistic' way.

The alternative approach described in this paper aims to go beyond these limitations by combining the potential of both theoretical fields.

This approach, which has been applied to the wine industry as well as the sugar industry (Gaucher *et al*., 1998), is based on the following principles:

- It will be more useful for stakeholders to consider ways of increasing the total value of the chain, rather than engage in altercation over the distribution of the existing value. The first issue is thus to investigate the possibility of developing co-operative strategies. Value sharing will be the second stage in the process.
- This position leads to designing a collective plan for the whole chain, and requires stakeholder commitment and a description of individual expectations. The link between whole-chain strategy and the way in which flow of goods is managed between stakeholders is therefore of particular significant.

- Mechanisms regulating quantities and prices will be designed when each stakeholder has accepted both the whole-chain strategy and its impact on flow management.
  These agreements pave the way for controlling the common strategy. Critical factors governing the strategy's success are negotiated between firms, either within an inter-professional body such as the South African Sugar Association, or through a classic market relationship between firms.

This approach confers a major role to the development of planning simulation models, rather than sophisticated forecasting tools, optimal scheduling systems or incentive devices. The models are designed to assist stakeholders in reorganising the planning and operation processes, and feature a number of key characteristics consistent with their use in planning when it is considered as an interactive process between stakeholders (Ponssard and Tanguy, 1993). This approach assumes that a certain degree of uncertainty is *a priori* collectively admitted. It also assumes limited communicative capacity and a certain amount of inflexibility in the transfer of resources from one stakeholder to another.

The support process does not aim at formulating new policies by using a model which the stakeholders regard as a 'black-box', but aims instead at designing new benchmarks, first by considering any and all conflicting points of view about future plans and then by investigating mutual readjustment of individual proposed positions.

Through this approach, modelling provides support tools that aim at facilitating negotiations between stakeholders (Tanguy, 1989; Nakhla and Soler, 1996):

- Describe and discuss the implicit rules governing technical stakeholder interfaces. Lack of clarity in these rules, and a consequent misinterpretation of their content, can lead to breakdowns in co-ordination and have serious consequences.
- Stimulate collective investigation to find more efficient rules, and to share the overall economic stakes associated with the governance derived from these rules.
- Establish monitoring and control of the new arrangements determined by the rules.

The next section of this paper shows how this theoretical background has been put into practice within the sugar industry. The conceptual model described here is based on a research project conducted since 1996 in La Réunion Island. Its design has been confirmed by a similar study carried out in South Africa since 2002.

Application of the model to the sugar industry

A modelling framework based on two components

In the cane or beet sugar industry, co-ordination between growers and millers focuses on the organisation and process of the mill supply. Decisions made by millers regarding mill capacity, the location of mill and transloading centres, and delivery allocations, will impact on the choices made by growers regarding mechanisation and harvest management. In turn, decisions made by growers regarding variety selection, harvest capacity and work organisation, will impact on milling efficiency. Poor cane quality will reduce crushing capacity, while irregular deliveries will disrupt the continuity of mill supply. Intermediate operators involved in cane flow management, such as harvest contractors and hauliers, will also affect the supply process. Total sugar production at mill area level thus depends on the efficient functioning of these technical interfaces, as well as on each stakeholder's management processes.

To increase the total value of the chain its various components, from the cane fields to the mill, must be taken into account.

Issues that should be considered are:

- How to match capacities (industrial and agricultural) with an unstable tonnage of cane at the industry or mill area level: number of mills, individual capacities, location of mills in existing or potential supply areas?
- How to organise the mill supply area in order to transport cane flows from the fields to the plant: location and capacity of transloading centres, role of hauliers and contractors?
- Which planning and operation rules would be efficient and in line with the objectives and constraints of each stakeholder: season length and dates, delivery allocation and flow monitoring?

A modelling framework consisting of two components was developed to address these issues, with interaction between the miller and the growers that supply the cane. The model is based on the above theoretical background and on an analysis of real mill supply organisation in La Réunion and South Africa.

These two cases are similar, in that

(i) a large number of growers supply each mill, and

(ii) similar tasks are carried out as the cane moves from the growers to the mill. The difference between the two cases is in the way these tasks are managed by the different stakeholders (Figure 1).

In La Réunion, growers have to haul their cane to transloading centres managed by the mill, while in South Africa, hauliers load the cane at loading zones on the farms and transport it to the mill (see Lejars *et al.*, 2003 and Guilleman *et al.*, 2003 for more details).

The modelling framework provides a comprehensive picture of mill supply chain management, with particular focus on interaction between stakeholders along the chain, and simulates and compares supply scenarios by assessing the impact they have on each stakeholder and on the chain as a whole.

The first modelling component looks at supply management over the entire mill area, and is called the *strategic model* as it addresses mid-term strategic issues such as the relocation of mills and transloading centres, investments in industrial and agricultural capacities and new rules governing delivery allocation. It models the planning and operation of a crushing season on a weekly basis, based on a simplified representation of both cane flows and the stakeholders involved in the process.

The grower level is fairly simple, as it is not possible to take into account the harvest and transport constraints of each individual supplier. Harvest, loading and transport capacities are thus combined into an aggregated variable, which gives an estimate of potential capacity that can be used by a group of growers or a cane production area to convey a given amount of cane during a week.

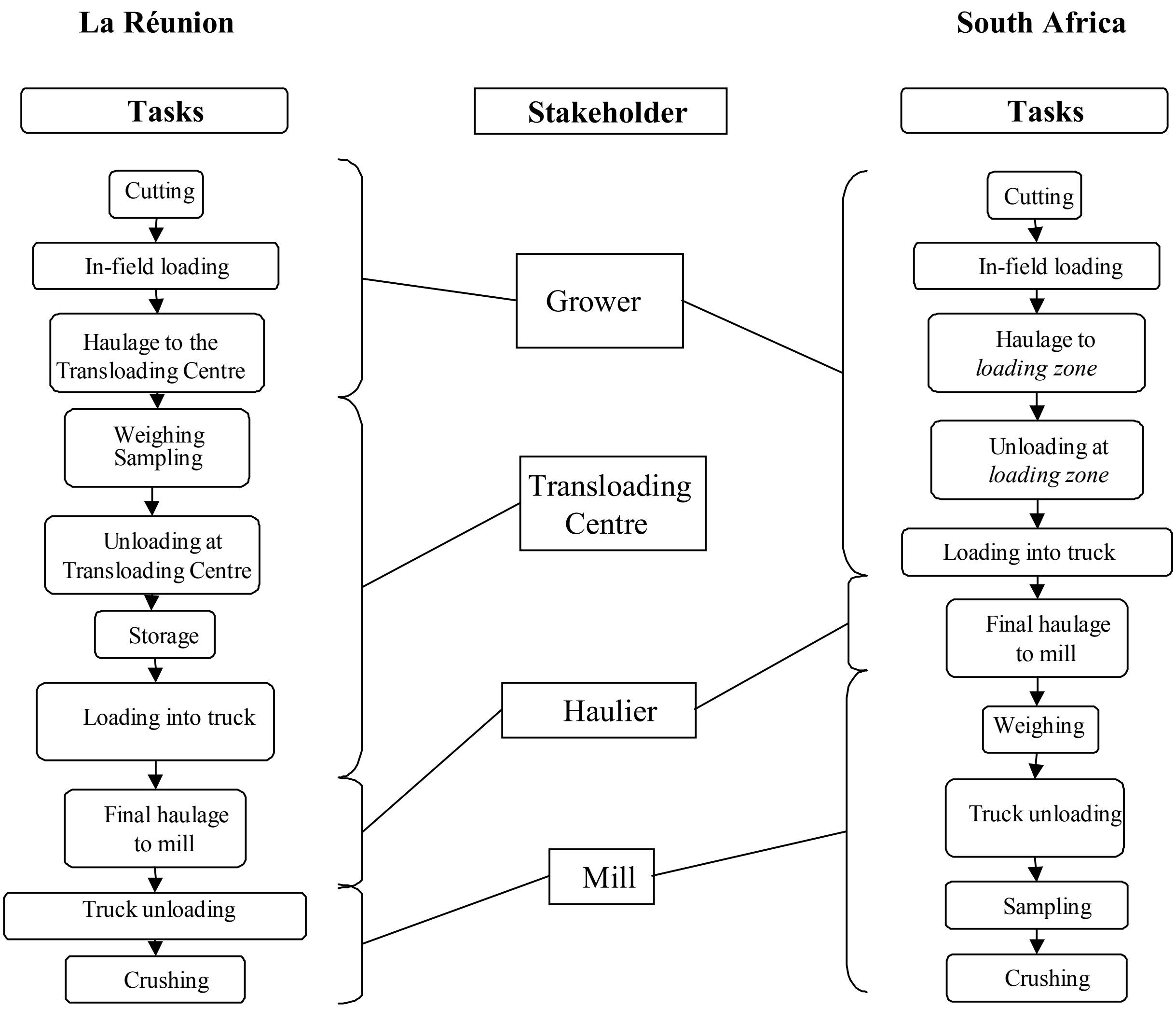

Figure 1. Structure of cane flows between grower fields and the mill in La Réunion and South Africa.

The second modelling component, the *logistic model*, details the way cane is conveyed from the fields to the mill on a daily basis. It aims at assessing the impact that logistic constraints such as harvest, loading and transport capacities, have on mill supply management. As seen in Figure 2, the two components are linked conceptually. The feasibility of aggregated capacities used in the strategic model can be addressed in the logistic model, while the capacities of new logistic chains can be simulated in the logistic component before being implemented in the strategic model.

Strategic model

The strategic model is made up of two sub-modules, the first for supply planning and operation, and the second for cane processing (Figure 3). It is based on a three-level representation of the supply area, including mill, intermediate operators such as hauliers and transloading centres, and production units (PUs), and simulates a crushing season on a weekly step basis, according to the cane flow paths between these three levels, their given characteristics and certain planning and operating rules.

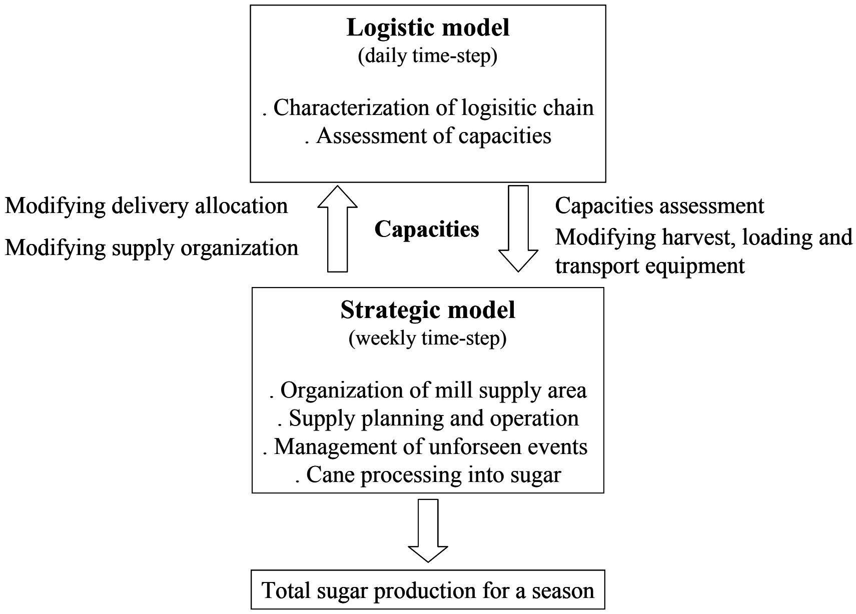

Figure 2. The two-component modelling framework.

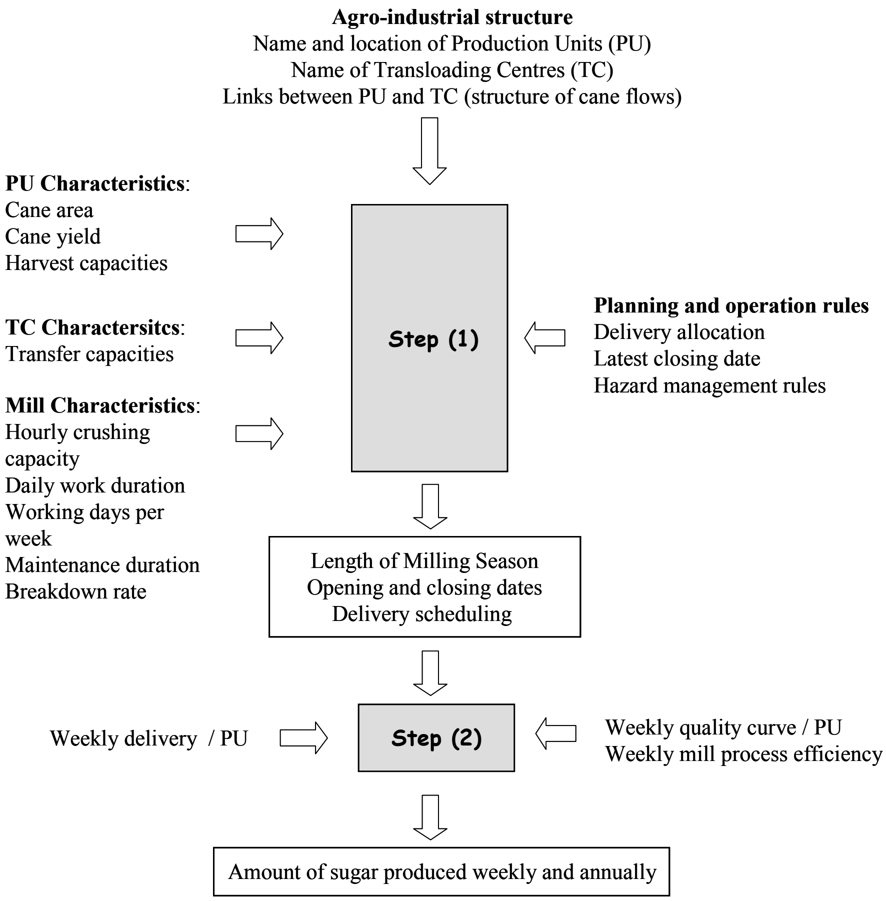

Figure 3. Conceptual framework of mill supply modelling (adapted from Gaucher, 2002).

Production units are defined as individual elements considered as homogeneous from a capacity and cane quality point of view, as well as the planning and operating rules that the mill applies to them.

Production units are thus described in terms of (i) cane quantity (cane area and yield), (ii) a quality curve and (iii) an optimum flow rate that includes limitations for harvest and transport to a given transloading zone or to the mill.

PUs are a group of growers located in a given zone within the mill supply area. Location governs the distances between the production areas and the mill, which impact on transport capacity, and climatic variables such as rainfall and temperature, which impact on cane yield and sucrose curves. Harvest, loading and transport capacities are assessed either by conducting farm surveys or by processing data collected for each consignment at the miller's weighbridge. These values are then aggregated to evaluate the potential capacity that will be used in the simulation.

Each PU is assigned to an intermediate operator, who collects cane from different units and transfers it to another operator, or takes it directly to the mill. These operators are described in terms of maximum weekly transfer capacity that includes cane handling capacity, storage capacity and limitation for final transport to the mill.

The mill is described in terms of its weekly crushing capacity and its sugar extraction efficiency. Weekly crushing capacity is calculated from elements that take into account mill operation and work organisation, such as hourly crushing capacity, weekly working hours, maintenance time and frequency of breakdowns. Both hourly crushing capacity and sugar extraction efficiency depend on the quality of the cane during a given week. For example, South African millers calculate a quality-dependent crush rate by taking into account brix, fibre or non-sucrose handling capacity, sugar lost during processing and cane quality figures forecast from historical data.

Based on the definition of the supply organisation, the planning and operation module aims at (i) determining a planned delivery schedule and (ii) simulating this schedule, with unforeseen events being introduced into the scenario.

The weekly delivery schedule is defined according to the following procedure:

- Cane tonnage to be delivered by PUs is estimated from the cane area and the yield.
- The length of the milling season is calculated by dividing total cane production by mill crushing capacity.
- The closing date of the season is defined and the starting date is calculated according to the season duration.
- Weekly delivery rights are allocated to PUs, according to particular rules, e.g. rateable deliveries over the entire season or variable deliveries during specific harvest windows.

Unplanned events such as mill breakdowns or delivery shortfalls, and joint rules of adjustment, may be introduced into a scenario. For example, the non-delivered tonnage allocated to a given PU can be transferred to other PUs linked to the same intermediate operator, as long as this does not exceed the operator's handling capacity for the week. If it does, the extra tonnage will be transferred to another intermediate operator, who will re-allocate it to his PUs, or it will be carried over to the next season. Such events and adjustments will impact on final sugar production, as sucrose curves vary from one PU to another.

Simulations run by this module provide a weekly delivery schedule for the entire mill supply area, as well as for each PU. The cane deliveries are then transformed into sugar production through the processing module, taking into account PU sucrose curves and milling efficiency. The amount of sugar produced weekly and annually is calculated and used as an indicator when evaluating and comparing scenarios.

Other indicators can be used, such as (i) the difference between potential and actual capacity along the chain, which highlight under- or over-capacities, (ii) the amount of cane carried over to the next season and (iii) mill supply irregularities, which show adjustments that should be made to cater for unforeseen events.

This model provides a way to:

- characterise the links between the mill supply organisation and the planning and operating rules governing supply at the mill area level
- evaluate how these links impact on supply chain efficiency
- support stakeholder discussion about changes in supply management by comparing simulated scenarios.

The model has been used in La Réunion and in South Africa to address alternative mill supply management, which takes into account the variability in cane quality within the mill supply area (see Lejars *et al.*, 2003; Guilleman *et al.*, 2003). A specific computer program, MAGI, developed from this conceptual framework, facilitates simulations and transfer of the approach to various potential users (Le Gal *et al.*, 2003).

Logistic model

Modelling of logistic chains has already been carried out in the sugar industry, to investigate the reduction of harvest-to-crush delays (Barnes *et al*., 1998, 2000; Semenzato, 1995) and matching harvest capacity to mill crushing capacity (Arjona *et al*., 2001). These models describe precisely the paths followed by cane consignments and the machinery used from fields to mill, with the aim of pinpointing potential bottlenecks and their impact on the supply chain.

A similar methodology was used in La Réunion to evaluate the impact of various changes in the supply chain (alternative means of transport, closure of transloading centres.) on cane harvest and transfer capacities. While the strategic model takes into account the entire supply area, the logistic model simulates a given logistic chain on a daily basis, leaving the rest of the supply organisation the same. These principles allow a detailed description of the tasks involved in conveying the cane from the fields to the mill via a transloading centre. For example, PUs are characterised by their cutting, loading and transport equipment (size, number of machines, hourly capacities), their work organisation (number of workers, working schedule), the distance to their allocated transloading centre and their transport speed, depending on the type of road they use. At the transloading centre and mill levels, cane flows delivered both by the logistic chain being studied and by the remaining suppliers are simulated in order to calculate queuing delays.

An industrial simulation tool has been used to model and simulate cane flows associated with a given logistic chain. The modelling structure is based on three modules: (i) growers' cane fields, (ii) transloading centre and (iii) millyard (Figure 4). The modules are linked by cane transport from one level to another. For example, a cane trailer is loaded in the field, taken to the transloading centre to be unloaded and is then sent back empty to the field. Rules of work organisation such as cutting time or opening-closing time of transloading centres, are also taken into account.

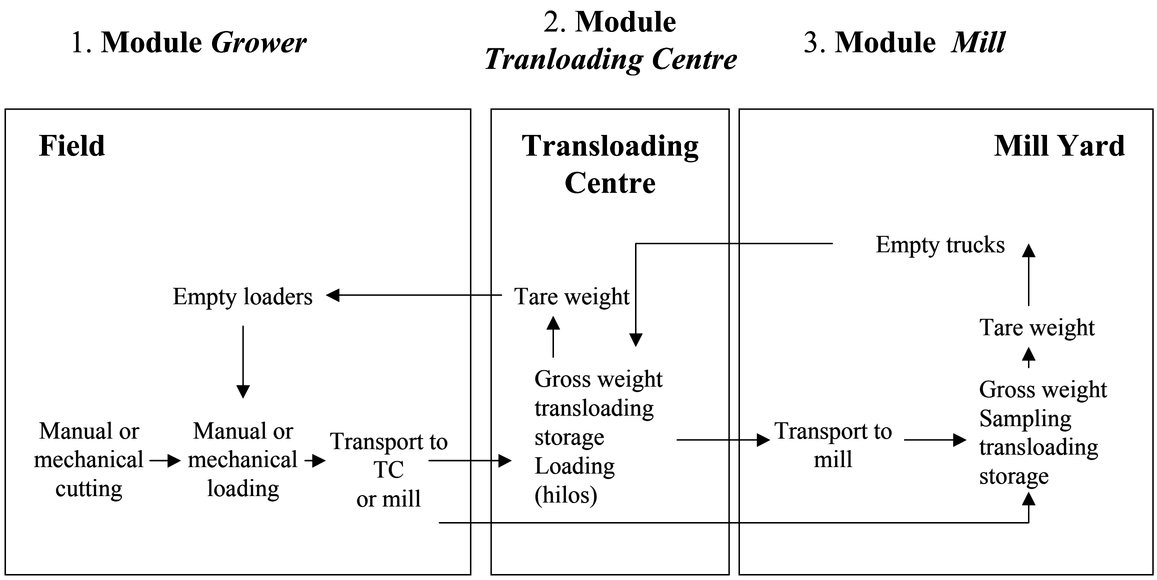

Figure 4. Logistic modelling of cane flow.

Using the logistic model in conjunction with the strategic model, issues can be addressed in detail. The logistic model is used mainly to assess the impact of (i) restructuring the supply organisation, e.g. by closing or opening transloading centres to modify distance from fields, (ii) introducing new equipment at PUs, transloading centres and at the mill, or (iii) changing delivery allocations to match the harvest capacities of growers.

This model was tested in La Réunion to assess the value of grouping growers around bigger loaders and trailers, to reduce queues at a smaller number of transloading centres. The results obtained by simulation show that loader utilisation decreases when the distance between fields and transloading centres increases (Figure 5). This negative impact can be partially corrected by increasing the number or capacity of trailers, keeping the tonnage delivered the same. Closing some transloading centres means grouping the more distant growers around fewer, bigger trailers. Simulation allows general results to be quantified and discussed in more detail.

Conclusion

The modelling framework described in this paper aims at providing stakeholders with information that will enhance discussion and negotiations with regard to the design of an efficient supply organisation. The interaction between stakeholders along the mill supply chain is represented in two stages: the entire mill supply area and the logistic chains. Two models, based on simulation rather than optimisation, have been designed for this purpose. The strategic model, based on a simplified picture of the entire supply chain area, assesses the impact of stakeholders' technical interfaces on total sugar production. The logistic model allows assessment of the feasibility of strategic scenarios in terms of task capacities and daily management of cane flows.

This modelling approach also provides a valuable basis for informed discussion between stakeholders. For example, new delivery allocation arrangements may lead to an alternative cane payment system to maintain equity between growers. Grouping growers around common equipment or encouraging contracting arrangements may lead to co-ordination problems between growers and contractors, which will impact on cane flow regularity and cane quality (Le Gal and Requis, 2002).

To remain simple and easy to use, these models do not include any direct economic calculations. It is assumed that the financial consequences of a given scenario could be assessed by a separate cost-benefit analysis (see Salassi and Champagne, 1998 for an example). Economic analysis is particularly relevant when evaluating the trade-off between length of season and sugar extraction, when investments in industrial and agricultural capacities are involved (Cock *et al*., 2000; Moor and Wynne, 2001). Combining supply chain and budget simulations will provide a comprehensive view of the consequences that can be expected from strategic changes. Stakeholders interaction and supply chain efficiency will benefit from such a decision support approach.

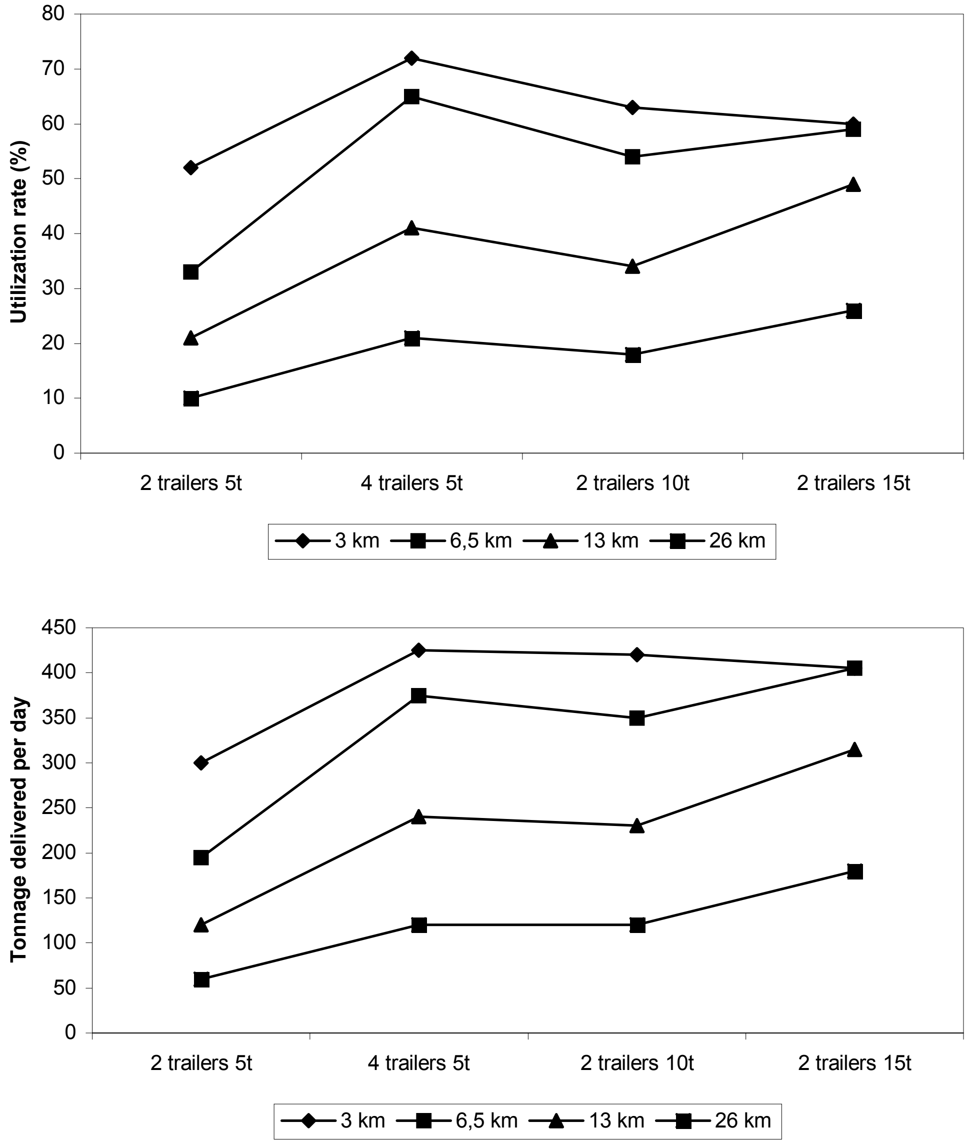

Figure 5. Results of logistic simulation (impact of transport equipment and distance between fields and transloading centres on the use of loaders and the delivered tonnage per day).

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