Integrated Supply Chain Modelling and Application in SugarCane

Launching Workshop Report

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1. **Introduction**

The Protea project named ***Integrated Supply Chain Modelling and Application in Sugar Cane*** is co-funded for two years (2006 – 2007) by the French Ministry of research and the South African National Research Foundation. This project is co-ordinated by Carel Bezuidenhout from the University of KwaZulu-Natal and Pierre-Yves Le Gal from CIRAD. It is based on previous research work conducted by both partners (see the integral project description in Appendix). It aims at (i) extending and integrating the approaches developed and implemented by both teams into a general conceptual framework; (ii) developing consistent links between the available modelling tools; and (iii) identifying the knowledge and modelling gaps that would need further research.

The project description specifies that three kinds of interaction should be included into the general conceptual framework, the interaction between i) operational, tactical and strategic decisions within the chain, assuming that these decisions are not independent; (ii) the successive tasks along the chain, i.e. cane production at field and farm levels, cane supply, cane processing and sugar marketing; (iii) the supply chain and value chain, by assessing the economic and financial impacts of changes in the supply chain management. On the modelling side the project aims at providing comparisons between the main techniques usually used and finally at developing some links between the existing tools.

The Protea project was approved at the beginning of 2006, however the funds were only made available in May, making it difficult to conduct field studies in 2006. It was therefore decided to start the project by organizing a workshop in Montpellier from 4 to 6 July 2006 in order to (i) review the various models developed and used by both teams; (ii) list the kind of issues addressed by the models' combination; (iii) examine the available methodology for integrating models; (iv) to carry out a real case study; and (v) decide on the way forward, especially the work plan for the whole project duration.

The workshop was attended by:

South Africa
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Louis Lagrange (University of KwaZulu-Natal) Lagrangel@ukzn.ac.za
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France
Sandrine Auzoux (CIRAD) sandrine.auzoux@cirad.fr
Computer specialist, co-developer of the Magi® application
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Computer specialist, information system developer
Pierre-Yves Le Gal (CIRAD) pierre-yves.le_gal@cirad.fr
Co-ordinator of the project, conducting research on supply chain management in agro-food process industries (sugarcane, dairy)
Michel Passouant (CIRAD) michel.passouant@cirad.fr
Modeler specialist (information system, UML)

Morocco
Rachida Jorio (IAV Hassan II) rjorio@hotmail.com
Operation Research specialist, conducting research on logistics modelling at a Moroccan sugar mill

2. **Reviewing existing models**

The following models were reviewed during the first session of the workshop:

Speakers	Models
Carel B.	CAPCONN (Capacity Constricted Conveyance)
Pierre-Yves L.G.	MAGI® (Modelling sugarcane mill supply)
Rachida J.	Logistic simulation in a Moroccan sugar mill area
Jean-Baptiste L.	RAINETTE & TSIG@NE
Peter L.	Trashing model
Carel B.	Crop models (CANESIM; CANEGRO)
Pierre-Yves L.G.	Cane payment system simulation

2.1. ***Supply planning models***

Both CAPCONN and MAGI® simulate supply planning at the mill area level on a weekly time-step. CAPCONN investigates mainly how capacities match along the chain, from field harvest to sugarcane process within the mill. Simulations indicate where bottlenecks arise in the chain, due to lack of capacity. Compared to MAGI®, CAPCONN provides a more detailed outlook of the mill process, plus a cost assessment of each scenario. But it does not take into account the delivery allocation rules which constitute the co-ordination basis between growers and millers. MAGI® includes this component, as well as the cane quality pattern linked to production units. So its outputs are mainly based on assessing sugar produced by each supply scenario.

The two tools differ as well regarding their development level. CAPCONN is still a research tool developed with Excel®, while MAGI® is based on both a database developed with Access® and calculations programmed with Visual Basic®. It should be available in September on the Cirad website. Finally the features of the two tools could be tested on a real mill supply area (see Table below) after detailing the way the supply chain is described in each case.

CAPCONN	**MAGI®**
Mill process capacities Cost analysis	LOMS Cane quality curves Delivery allocation rules Sugar production
Mill supply area structure? Harvest and transport capacities	

2.2. ***Logistics models***

R. Jorio presented the work she conducted for her PhD thesis regarding the modelling and simulation of harvesting, transporting, reception and crushing system of sugarcane in the

Gharb region. While the supply planning models are based on an aggregate perspective of the supply chain in term of production units, tasks and variables, the logistics models aim at providing a view as close as possible of the real supply chain. They are based on an exhaustive and accurate description of the tasks carried out from the fields to the mill and they operate at a daily time-step.

Rachida used a software package called Simul8 to develop her model. She investigated the way to improve the use of resources involved in the supply chain in order to reduce both delays along the chain and the impact of rain and breakdown stoppages on the chain operation. The model is quite comprehensive as it takes into account the whole supply area split according to the local agricultural districts for the whole harvest season. Simulations include scenarios without constraints as well as assessing the system sensitivity to events such as mill breakdowns. The model also uses statistical queuing data for each step in the supply chain, considering the supply chain as a series of queues impacting on each other. Cost analysis is not included.

Her work is quite similar to some studies conducted in the past at SASRI with different modelling platforms (Barnes et al., 1998)). For example ASICAM was used by Giles et al. (2005) to simulate transport at the Sezela mill for a specific week assuming a central controller. But the approach developed by Rachida consisting of modelling the whole supply area seems well adapted to the project objectives, while Simul8 seems very flexible. Thus the work conducted in Morocco could be useful for Louis Lagrange's PhD study as well as for the Protea project.

2.3. ***Other models***

Several other models were presented during the session for their links with the supply chain issue. Carel introduced crop models such as CANESIM and CANEGRO which can simulate the cane dry matter production in relation with climate and soil conditions. CANEGRO is mainly a research tool, while CANESIM aims at providing decision support to growers. Options include the ability to include the harvest-to-harvest cycle into this process. But using these models depends on the field data availability, and they do not really take into account the way growers manage their cane production.

SASRI and CaneGrowers developed some tools to compare trashing *vs* burning cane on both technical and economic levels. These tools operate at the farm level, but they do not take into account the way growers practically manage their work during harvest periods (something carried out by a simulation tool such as OTELO developed in the 90's by INRA teams). The impact of trashing cane on the supply chain is not addressed, and the labour resources required for that task are much higher than for burning and cutters.This is aggravated because cutters are becoming a scarce resource in the SA sugar industry.

Some CIRAD researchers, including J.B. Laurent, are busy developing a tool coupling a GIS weather database called REINETTE with crop and supply management models in a framework called TSIG@NE. This tool aims at supporting both millers and growers in managing cane production and supply to the mill. It could improve crop estimation while planning supply for the whole harvest season, as well as monitoring crop cutting during the season.

Finally P.Y. Le Gal presented the simulation tool developed in Sezela in 2004 for studying the links between supply planning and the cane payment system. This tool is based on Excel and will not be developed further on in the near future. These simulations highlight the mutual impact of cane payment systems on supply scenarios. Economics may thus be investigated using two main methods: the cost-benefit analysis and the contract theory which includes cane payment systems. The first one is included in CAPCONN, while the second one is currently being carried out by C. Lejars as part of her PhD study. Her results should be available at the end of this year.

2.4. ***Which links between modelling tools?***

Following these presentations a discussion was conducted regarding the potential integration of these models in the course of the project. The four following points were discussed.

A scale issue

The available models take into account different management scales. The crop models are mostly non-dimensional as they are based on a plant perspective. Models such as trashing *vs* burning are based on a farm level approach but they do not take into account the crop/work management issues that may arise at the field or farm levels. Logistics as well as supply planning models operate at the supply area level.

Integrating these models would mean tackling the scale change issues, for example by aggregating results from level *n-1* to level *n*. This process is often difficult to conduct because of a lack of knowledge regarding the farm diversity or the growers' agricultural practices and decision-making processes. Information systems such as REINETTE may partially solve some problems, but specific surveys are often necessary to understand how farmers manage their crop and their farms.

A time-step issue

Various time-steps are used according to the model, from daily to the whole season. Again aggregation may provide a good way to switch from one model to another, keeping in mind that (i) the issues addressed by each model are different, and (ii) aggregation leads to simplification. For example the weekly harvest capacity considered in MAGI aggregates various tasks that may be separated in a logistics model operating at a daily time-step.

A supply chain component issue

Finally these models address different issues linked to different components of the supply chain, as mentioned in Figure 1 below. Modelling the whole supply chain consists of logistics and supply planning models, which address various issues. As mentioned in Gaucher et al. (2004)[1] the *supply planning model* addresses mid-term strategic issues such as the location 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

[1]Source : Gaucher S., Le Gal P.-Y., Soler L.-G., 2004. Modelling supply chain management in the sugar industry. *Sugar Cane International*, 22(2) : 8-16.

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.

The *logistic model*, details the way cane is conveyed from the fields to the mill on a daily basis (Figure 2 for an example in La Réunion). It aims at assessing the impact that logistic constraints such as harvest, loading and transport capacities, have on mill supply management.

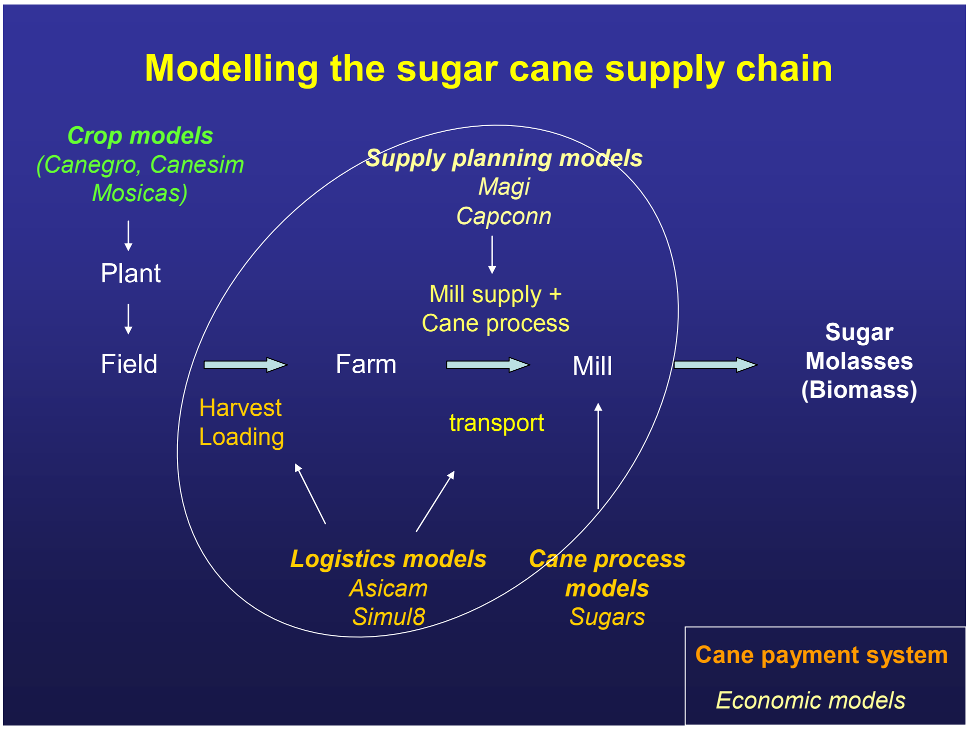

Figure 1. General perspective of the sugarcane supply chain modelling

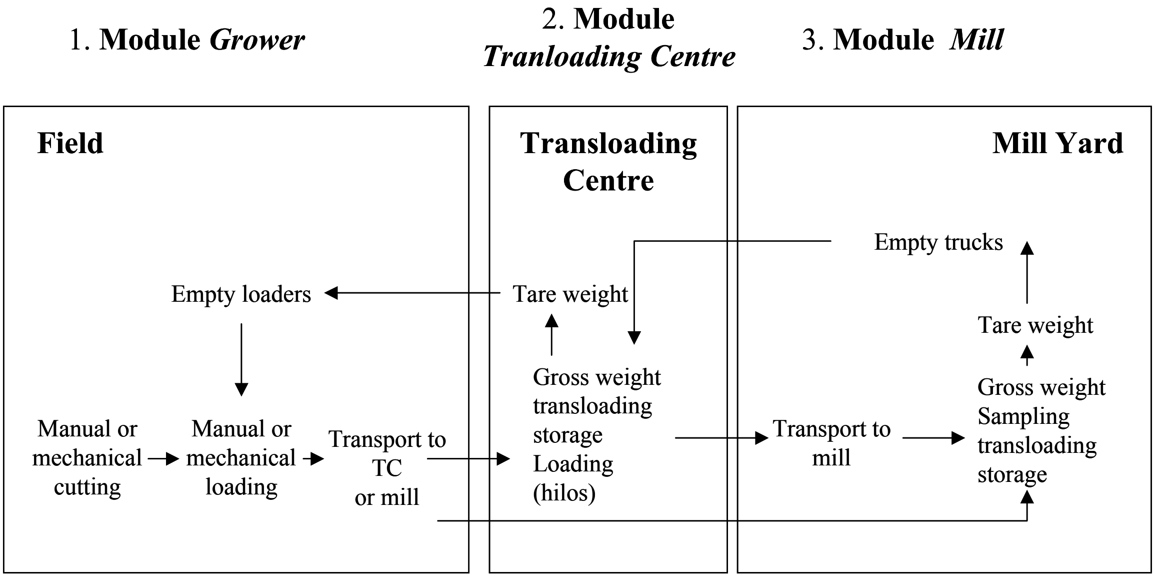

Figure 2. Logistic modelling of cane flow.

As seen in Figure 3, 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.

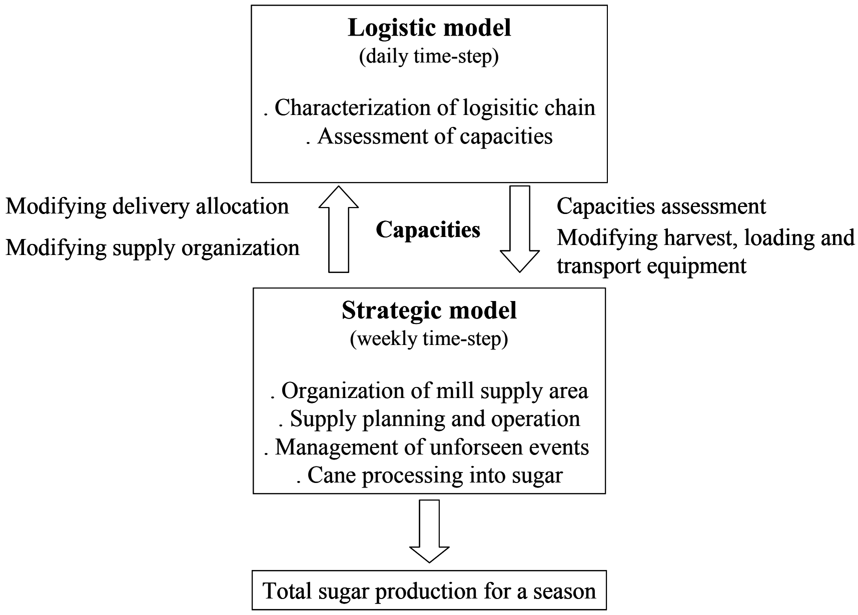

Figure 3. Conceptual links between logistics and supply planning models

Do we need modelling techniques to link models?

The project does not aim at developing new tools. Nevertheless links between tools may require some conceptual framework. M. Passouant presented a modelling methodology called UML (for Unified Modelling Language), that could be useful for formalizing the links between database and models, and between models themselves. P.Y. Le Gal will attend a training session in October on this modelling technique.

3. **The Noodsberg case**

The South African team identified the Noodsberg area and sugar mill in South Africa as a possible case study to consider for this project. Data on available mill area characteristics and sugar mill characteristics were presented including daily and weekly delivery patterns as well as sucrose curves over the milling season. Supply chain trends like spiller to bundle ratio changes, yard optimisation, mechanised harvesting and vehicle delays were provided. A few perceived supply chain bottlenecks presently transport and mill related properties, were identified and debated.

The team concluded that Noodsberg would make a good case study as it has a difficult owner operated transport system. If solutions to these problems could be modelled/found it would be easier to apply the model to other sugar mills.

4. **Some practical considerations**

Following this workshop P.Y. Le Gal will go to South Africa in September 2006 (21 to 28) in order to (i) meet stakeholders in Noodsberg, (ii) work with Carel on the complementary features between MAGI and CAPCONN and (iii) prepare a proposal for a French student who will do his/her internship with the project in 2007.

In addition to this internship two trips to South Africa are planned in 2007. One of them will take place for the ISSCT Conference in July 2007. A paper will be submitted at this occasion. It was decided to focus the paper on the available models and to discuss their possible integration, as no concrete result will be available at that stage from the Protea project (especially as the summary needs to be submitted before mid-September).

Some opportunities associated with the project were also discussed. The first one concerns Carel's sabbatical period in Europe from January to June 2007. Carel could spend two months in Montpellier working on the project, two months at Cransfield University in UK and two months at Wageningen University within a group dedicated to supply chain management in agro-food industries. This 6-month period could finish with a workshop to be attended by the various researchers he will meet during his European stay.

The second opportunity concerns links to be developed between Louis Lagrange and Rachida Jorio about logistics modelling. It is envisaged that the simulation model developed could be applied to the SouthAfrican case study at Noodsberg. Rachida expressed willingness to adapt the model to suit the case study if needed. The South African team should explore methods of transporting Rachida for an on site visit and collaboration with the sugar mill on adapting the model. A few runs of the model with comparisons to actual data would be beneficial to all.

Conclusion

This first workshop was useful for participants meeting and sharing both their view and results on existing modelling supply chain in the sugarcane industry. Time was too short for analyzing precisely each model's structure and operation and investigating their potential links. This task will be conducted in the course of the project, first during P.Y. Le Gal's trip in September in Pietermaritzburg, and then with the study planned in Noodsberg in 2007.

This link with a real case is essential for the project, as a way to test the models' utility in supporting stakeholders' decision process. But it means that the concrete issues to be addressed will be mainly selected according to the problems this case is facing. Transport optimisation should be central in Noodsberg. In that case the project will focus preferentially on the links between logistics models, such as the application developed by R. Jorio, and supply planning models such as MAGI and CAPCONN.

The potential links between these two kinds of models were already conceptualized in Gaucher et al., 2004 (Figure 3). But the practical study and implementation of these links were never conducted on a real case. The current project provides the opportunity to assess the value of integrating both the logistics perspective at a daily-time step and the supply planning perspective at a weekly time-step in tackling issues such as changes in harvest techniques or reduction of transport fleet. Moreover these links will be studied by coupling a flow modelling approach with a cost-benefit analysis.

Appendix 1

Integrated Supply Chain Modelling and Application in Sugar Cane

Project description

1. **Detailed description of the subject**

Agro-industries provide income opportunities for large-scale as well as small-scale farmers who will supply their process units. In that respect they contribute to rural poverty alleviation, especially where small-scale farmers' access to agricultural marketing channels is limited. For example the South-African sugar industry contracts about 30000 small-scale growers, who account for 15% of its whole sugarcane production.

Nevertheless these industries usually operate in a competitive environment, both on national and international markets. They are permanently seeking gains of efficiency in order to remain profitable and able to keep a large diversity of farmers in the business. So their contribution to the socio-economic development of their country depends on their capacity to adjust to their environment pressure and changes.

Classically efficiency gains have been sought at the individual firm level. For example how to improve yields and decrease production costs of agricultural raw material at the farm level? How to better coordinate purchasing, process and distribution within an industrial firm? These concerns are still relevant but they need to be investigated in a broader picture, the supply chain, defined as *"a set of relationships between suppliers, manufacturers, distributors, and retailers that facilitates the transformation of raw materials into final products"* (Beamon, 1998). Efficiency gains in a supply chain are sought not only within companies but also within the relationships between companies, as joint decision making yields higher profits for the whole chain (Eliashberg and Steinberg, 1987). These relationships concern the planning and control of materials and information flows as well as logistics activities along the chain (Chen and Paulraj, 2004). Then the supply chain becomes the central unit of competitive analysis and of efficiency improvement (Croom et al., 2000).

This new approach raise a range of complex issues for both practitioners and researchers: how to efficiently co-ordinate the various tasks and stakeholders along the chain? How to improve the value chain and to share gains between stakeholders (Dekker, 2003)? Supply chain management is a complex process which combines autonomous operators, activities and resources. It is assumed that modelling provides relevant tools to both analyze an existing context and support problem-solving processes (Georgiadis et al., 2005).

Various modelling techniques are used to address the three main kind of issues faced by supply chain: (i) operation issues on a daily/weekly basis, such as scheduling transport of raw material in a plant supply area; (ii) tactical issues on a mid-term basis, such as planning supply of agricultural raw material throughout the harvest/process season; and (iii) strategic issues on a long-term basis, such as selecting investments along the chain (production, process and distribution stages).

Modelling techniques include optimisation based on mathematical programming (Melo et al., 2005; Neiro and Pinto, 2004), simulation (Minegishi and Thiel, 2000; van der Vorst et al., 2000) and hybrid models (Min and Zhou, 2002; Petrovic, 2001). Mathematical programming provide optimal solutions that are useful to guide decision-makers facing well-structured problems, but they might be difficult to develop and understand when supply chain complexity increase. Simulation is more flexible and suitable to explore poor-structured issues and complex systems. It may assist stakeholders in reorganizing jointly the planning and operation processes by comparing various "what-if" scenarios featuring key characteristics of their relationship (Ponssard and Tanguy, 1993).

Nevertheless limited research is dedicated to supply chain management as a system, taking into account the various links between stakeholders, tasks and resources (Chan and Chan, 2005). Moreover published research shows various limitations regarding:

- the adaptability of a modelling methodology to a large range of context and issues;
- the kind of industry modelling is applied to. For example process industries in agriculture deal with specific problems such as raw material deterioration, supply regularity throughout harvest seasons, uncertainty of supplied batches, and strong links between batches quality and process efficiency;
- the effective use of modelling as a decision support tool in real cases.

This project aims at exploring the potentiality of integrating various modelling techniques and modelling tools applied to the South African sugar cane supply chain, in order to (i) better define the main constraints to improving the chain efficiency from cane production to sugar and co-products marketing and (ii) to explore potential solutions committing the various stakeholders along the chain.

The South African sugar industry exports over a half of its total production at a price that fluctuates according to the global market. It is currently facing new challenges to remain internationally competitive in an environment characterized by low sugar prices, a strong local currency against the US dollar and several dry seasons. It is characterized by a large number of suppliers, split into three main categories (3000 large-scale growers, 40000 small-scale growers and mill farms belonging to one of five milling companies) supplying 14 sugar mills in the industry on an exclusive basis (each grower delivers its cane to only one factory).

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 (Gaucher et al., 2004). Decisions made by the millers impact on the choices growers make regarding their harvest capacities and management, while cane quality delivered by growers impacts on the sugar process efficiency. Depending on the cane payment system in place, these decisions affect the total value chain and both growers and millers incomes. Other stakeholders, such as contractors and hauliers, also directly affect supply chain management and performances. Providing an integrated decision support system to the supply chain should improve the stakeholders' capability to design both innovative and efficient solutions.

2. **Scientific and technological background**

Sugar industries throughout the world are looking to increase production and efficiency due to decreasing trends in profitability and market security. New avenues of improvement in all components of the supply chain are being investigated. Modelling has been recognised as a means of understanding and improving supply chains and will play an increasingly important role in future planning and management (Higgins et al., 2004). In the sugar supply chain, various models are used by stakeholders to assist in planning and decision making. They represent the physical system, and some also include an economic component (Salassi et al., 2002; Le Gal et al., 2005). Model planning horizons range from daily to long term. Algebraic equations, spreadsheets and linear programming are used for operational planning, which typically involves a low level of integration and considers a high level of practical detail (Jiao et al., 2005). Dynamic programming, mixed integer programming and simulation modelling are usually used for long planning horizons which involve high integration levels and tend to simplify physical systems to practical modelling levels (Gigler et al., 2002; Ronnqvist, 2003; Higgins and Muchow, 2003). The use of equations, spreadsheets or linear programming for modelling integrated systems involves a high level of system simplification, which limits model validity and applicability (Loubser, 2002).

CIRAD in collaboration with SASRI has developed a simulation tool called MAGI©, based on a modelling of physical cane flows between production units (i.e. agro-climatic zones or types of farms) and a mill on a weekly time-step throughout a harvest season (Lejars et al., 2002; Le Gal et al., 2003).

MAGI© allows comparing mill supply scenarios according to their sugar production. Various tactical and strategic issues may be investigated: changing capacities along the chain, merging mills, changing production techniques (e.g. varieties distribution), changing rules of delivery allocations, etc. The software has been tested with mills in La Réunion and South Africa (Le Gal et al, 2003 & 2004a,b; Lejars et al., 2003) in order to assess the impact of cane supply rearrangements on the mill area profitability. MAGI© will be freely available on the Cirad website before the end of 2005.

At SASRI a number of crop growth models have been developed. A mechanistic model, named CANEGRO, simulates physiological sugarcane processes and provides sophisticated estimates of cane and sucrose yields (Singels and Bezuidenhout, 2002). The CANESIM model was initially developed as a weather-based irrigation scheduling model and is a simpler model than CANEGRO.

Cane payment systems have been studied since 2004 as part of this collaborative project between CIRAD and SASRI. The objective is to analyze and model the links between the cane supply chain and the value chain (Le Gal et al., 2005). A spreadsheet simulation tool was developed to assess the impact of various cane payment systems on the growers' revenues. It takes into account their diversity in size and location. This work is currently going on as part of a PhD study conducted both in La Réunion and South Africa by C. Lejars, a CIRAD researcher based in La Réunion.

Two studies at the University of KwaZulu-Natal assessed the cane supply and logistics components of the sugarcane supply chain. With a special emphasis on cane deterioration, Barnes (1998) conducted an in-depth simulation study of supply chain components in an attempt to address harvest to crush delays at Sezela. In this study the supply chain was conceptually represented in Arena® and several "*what if*" scenarios were simulated to identify potential bottlenecks. Giles (2005) simulated and theoretically optimised transport logistics at one mill in South Africa. This study also included investigations on changes to some supply chain components, such as changing vehicle configurations, harvesting plans and loading / off loading systems.

3. **Specific objectives and expected significance of the research**

Until now modelling sugar cane supply chain has followed various objectives, techniques and technical results. The general perception is that many tools exist but no integrated framework has been produced so far. In that respect the project has three main objectives:

- extending and integrating the approaches designed and implemented by both teams into a general conceptual framework. This framework will detail the links between the chain components and their modelling transcription;
- developing consistent links between the available modelling tools;
- specifying the knowledge and modelling gaps that would need further research.

As its content and results are focused on decision support approach it should be useful for the sugar industry stakeholders, especially as new strategic issues are raised such as the value of diversifying cane outputs (energy, ethanol, bio-molecules) or the impact of new environmental standards on the industry. Moreover these results should be relevant for many others agro-food chains in South Africa and internationally, as the developed concepts are generic. Lastly the project will provide a strong basis to design and conduct Master level training modules on supply chain management in agriculture and food processing chains.

The project will focus on three kinds of interaction to be included into the general conceptual framework:

- between operational, tactical and strategic decisions within the chain, assuming that these decisions are not independent. For example capacity selection will have an impact on daily logistic;

- between the successive tasks along the chain, i.e. cane production at field and farm levels, cane supply, cane processing and sugar marketing. Models usually take into account only one part of these successions;
- between supply chain and value chain, by generalizing what has been started about cane payment system. The objective is to assess the economic and financial impacts of changes in the supply chain management.

On the modelling techniques side the objective is to provide a guide of comparison between the main techniques usually used and to develop some links between the existing tools (e.g. between MAGI©, the cane payment system tool and the logistic tools). Specifications for new tools or links to be developed for further research will be designed during this 2-year project.