Building an operational controlling system for continuous or hybrid supply chains

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Abstract. This paper proposes a method to measure hybrid supply chain performance by coupling Discrete Event Simulation models with process evaluation using the Activity-Based-Costing method. Our aim is to develop a Decision Support System for hybrid supply chains. In this context, a number of approaches are discussed in literature from a generic standpoint and for discrete supply chains exclusively. Our paper describes an approach that is suitable for Decision Support System construction for hybrid supply chains, as well as its implementation for "Office Cherifien des Phosphates" (OCP)' supply chains. This approach enables the coupling of Activity Based Costing and Discrete Event Simulation to develop a controlling model based on Business Units.

Keywords: Hybrid Supply chains, discrete event simulation, Activity Based Costing, Interactive Decision making support System, scorecard

1 Introduction

"Office Cherifien des Phosphates" (OCP SA, OCP) is the Morocco's largest company. It is widely considered as owning some 60% of phosphate world reserves and is engaged in a process of Supply Chain control. Initially specialized in phosphate ore extraction, OCP SA has expanded, few years ago, its activities to include production of phosphate fertilizers and acids using chemical processing. Under our research project, we focus on economic management of OCP's Hybrid Supply chain (HSC) [1]. A HSC comprises multiple interrelated discrete and/or continuous processes together forming an integrated process from the supplier down to the end customer. In such a system, the production rationale includes both batch and flow models. Each discrete or continuous process seeks to capture part of the value created by the organizational collaboration performed either in internal supply chains made up of business unit or in external ones made up of legally independent entities.
After a description of the performance evaluation methods for the HSC financial and physical flows (section 2) we go on to describing the approach used to develop Decision Support System (DSS) in the context of the HSC (section 3). We then turn to its implementation as part of OCP's HSC (section 4) before drawing some conclusions (section 5).

2 Evaluation of Hybrid Supply Chain physical and financial flow performance

In order to develop a DSS, we first need to assess HSC physical and financial flow performance. Two types of model have been widely applied in production management and are suitable for supply chain management. They are of the prescriptive and descriptive kind: the prescriptive models are used for decision-making purposes while descriptive ones are used to measure the performance of a particular system. Under our research, we developed a process-based model of OCP's HSC capable of designing simultaneously HSC physical flow simulation models and ABC value creation models for the entities comprising the HSC. The Modelling / Simulation techniques used to draw up a supply chain model are that of Discrete Event Simulation (DES). According to [2], this describes a system as a network of queues and activities where status changes result from discrete events. In the context of order fulfilment, this implies developing a specific controlling system and defining a dynamic referential derived from the simulation model. This referential is useful for management control DSS as a tool to enhance decision-making. Accordingly, one is to measure economic impact, assess alternative decisions and analyse deviations. Where deviations between actual and forecasted results are observed, we propose remedial action. To this end, one refers to management accounting based on another type of modelling / simulation to produce a cost model. This particular simulation uses a finer description of the process through a shorter reporting period than that for monthly financial reporting. This provides a finer account of cost drivers. Such cost modelling is used to back decisions, especially for competitive edge pricing and for low cost production.

Academics have proposed and tested a number of cost modelling techniques to inform design and production decisions at an early stage of the development process.

We have analysed articles dealing with DES and ABC method coupling, particularly articles describing coupling aimed at integrating cost analysis into simulation models. To this end, we classified the literature according to the relevant criteria for the scope of our analysis. Our classification is based on the approaches adopted in several articles dealing with specific supply chains issues involving simulation and cost calculation. The main key words used to scan databases included "*Supply Chain Costing / Discrete event Simulation / ABC*". We did not attempt to review periods prior to the 1980's and the emergence of the DES.

The idea of coupling DESs and ABCs is hardly new [3] and was explored by a number of authors over the last two decades. According to [4], the "ABC – model simulation" combination model yields a detailed breakdown of costs for each activity, such that these costs can be used for decision-making purposes. The benefit of matching an ABC with a DES is to improve the quality of decision-making through improved data quality. According to [5], a DES software is extremely useful to design an ABC method. To simulate discrete events, the model refers to an event corresponding to the start or end of an activity: this serves to establish the connection between a cost and its driver. Then, in order to include an ABC in a simulation model, the cost calculation for each activity must be included in the simulation model. [6] has attempted to couple a DES with an ABC method to improve cost assessment, planning and forecasting tools. In the simulation model, the physical items go through a series of production operations while in the ABC model, the costs are driven through the model by activity drivers defined in relation to the physical model. [7] thinks that simulation models pay scant attention to assessing the economic impact of a productive configuration. For them, this involves integration of the ABC method in the simulation model. At the end of the simulation, a detailed list is produced to describe all the costs associated to the production and supply chain operations. According to [8], the application of the ABC model simulation technique offers users a way of evaluating profitability factors for all activities. In addition, by using simulation results in an ABC analytical model, the costs of allocated resources is more precise, so avoiding the risk of arbitrary allocation (versus the use of cost allocations directly in the DES software). Other, more recent approaches also looked into the coupling of ABC and Simulation methods [9], [10] [11].

The limits of the DES approach concern the level of the information it provides on costs. In order to assess operation-related costs and the influence of the diversity of management scenarios, the direct variable costs should be able to be measured. In many simulators (Witness, Simul8…) each processor integrates the possibility of calculating direct variable cost (in proportion to the number of items moving through the processor) and using a launching cost parameter (change of reference, manufacturing order…). The question that then arises is the relevance of the model, in other words, are the processors selected all able to represent the drivers? Two ways of dealing with this problem are proposed in literature:

- either designing modelling rules capable of directly developing a valuation model associating direct variables costs by batch and by driver [10];
- or coupling a simulation model and an analytical ABC model [9], [12] to then obtain other valuation combinations (management by margin, analysis of created value…) and potentially enable the construction of hypercube images in scorecards.

A cross-reference of the typologies (simulation technique and cost model) was made through a mapping (table 1).

Table 1: Coupling Simulation and ABC for the supply chain.

Authors	Year	Type of problem	Nature of the integration	Level of granularity	Decisional Horizon	Simulation Technique
Krishnamurthi *et al.* [3]	1990	Building a simulation model for a workshop integrating the valuation of activities	ABC direct use	Workshop	Operational	Discrete Event Simulation
Williams, R. *et al.*[4]	1997	Assess the supply chain organizations configurations.	ABC direct use	Workshop	Operational. / Tactical	Discrete Event Simulation
Baines et al. [13]	1998	Presentation of modelling techniques suitable for the assessment of discrete production strategies.	ABC direct use	Supply Chain	Operational. / Strategic.	Discrete Event Simulation
Spedding, T.A. *et al.* .[5]	1999	Combined use of the DES and ABC to assess discrete production systems	Coupling	Workshop	Operational	Discrete Event Simulation
Beck and Nowak.[2000]	2000	Evaluation of transfer process within a factory and between factories	Coupling	Factory	Tactical	Discrete Event Simulation
Lee and Kao.[8]	2001	Margin management in a supply chain system	Coupling	Supply Chain	Tactical	Discrete Event Simulation
Savory, P. *et al.*.[7]	2001	Integrating an ABC in a DES for discrete systems as part of production operations	ABC direct use	Workshop	Tact.	Discrete Event Simulation
Chan *et al.* [14]	2003	Methodology to solve the problem of yield, process control, discrete production system cost management.	ABC direct use	Supply Chain	Operational. / Strategic	Discrete Event Simulation
Ozbayrak *et al.*[8]	2004	Workshop management based on tactical horizon costs	Coupling	Workshop	Tactical	Discrete Event Simulation
Comelli, et al. [9]	2008	Approach to assess physical and financial flows when planning tactical production for a discrete supply chain	Coupling	Supply Chain	Tactical	Discrete Event Simulation
Fenies P. *et al.* .[12]	2010	Approach for assessing the nature of a point of sale with reference to supply chain activity	Coupling	Supply Chain	Strategic	Discrete Event Simulation
Lange, J. *et al.*[10].	2012	Presentation of a method for the planning and evaluation of costs for discrete process chains	Coupling	Workshop	Tactical	Discrete Event Simulation
Mahal, I. *et al.*[11].	2015	Presentation of the ABC method and its combination with DES within a DSC.	Coupling	Supply Chain	Tactical	Discrete Event Simulation

Table 1 show for each research paper:

- the type of problem addressed and the nature of the supply chain;
- the cost model used (ABC versus another approach);
- the level of granularity (entire supply chain versus an entity of the supply chain);
- the type of decision (strategic / operational / tactical);
- the simulation technique employed (DES, dynamic simulation, hybrid simulation, multi-agents simulation);
- The nature of the integration between ABCs: either direct ABC use in the simulation software performed through input of attributes, or the authors propose to couple a DES and an analytical ABC model yielding a larger range of information. This last solution is deemed more suitable for management by margin and linking the indirect items with the expenses recorded in the accounting balance than through use of estimated costs with somewhat arbitrary aggregation…).

Note that all the approaches reviewed (table 1) deal exclusively with discrete supply chains and that we may conclude that there does not appear to exist:

- any ABC approach that is centered on an evaluation of continuous or hybrid supply chains;
- any method or modelling rules enabling the setting up of an ABC with simulation-oriented DSS for HSCs;
- any explicit coupling between ABC simulation methods for hybrid / continuous supply chains.

As discrete event simulation lends itself to the identification of cost drivers and therefore to the use of ABCs, our aim is to propose a coupling between DES and ABC in order to develop an DSS for HSCs. In this context, several approaches exist in literature, generically and exclusively for discrete supply chain. These are:

- TOVE (Toronto Virtual Entreprise) which, according to [15], is a modelling methodology for integrated businesses. Its extension, proposed in the thesis drawn up by [16] in the form of a cost ontology for integrated businesses can be used to design modelling environments that take performance into account in the form of ABC models. The evaluation of performance takes the form of analytical models.

- INPIM (INtgrated Multidimensional Process Improvement Methodology) according to [14] is a methodology based on performance evaluation relying on discrete event simulation aiming to introduce in manufacturing activities a combination of approaches derived from controlling and Quality Management.
- PREVA (PRocess EVAluation) which, according to [17], is an approach that measures the financial flows of the supply chain process with the help of an analytical model chained to an action model for the evaluation or optimization of physical flows.

Both the TOVE and INPIM approaches present a single model for physical and financial processes, while the PREVA adopts a different modelling approach for financial and industrial processes in order to deal with data aggregation operations [18]. This approach, used at different occasions to set up supply chain controlling systems (exclusively in discrete industries), appears to us suitable to be tailored for HSC purposes. The robustness of this approach was shown at different levels:

- At strategic level in the context of chaining of production networks with distribution networks [12,19],
- At tactical level in the supply chain of a tire manufacturer [8].

However, the approach was not used at operational level or on hybrid production systems. We therefore wish to test it and implement it on hybrid production systems at operational level.

3 An Approach for the Evaluation of Physical and Financial flows for a Hybrid Supply Chain

To implement an economic evaluation of a supply chain based on the combined use of an ABC with a DES, we suppose that it is possible to break up internal supply chains into activities considered as *Business Units* (BUs), all of which deemed to be autonomous entities belonging either to the entity of the supply chain or to a supplier/ distributor who is integrated into the latter. We therefore assume the existence of an HSC made up of 1 to *n* BUs, this generic term doing away with the functional break up of an HSC. In order to use the ABC models in the evaluation of the processes, we propose to allocate, for each BU (a subsidiary, a plant, a transport activity …) made up of at least one elementary supply chain process, the different items that are required to translate physical flow activities into financial flow items.The design and evaluation of activities by PREVA for HSCs involves 3 steps, the second and third of which will be discussed in detail in our paper as they deal with building a Supply Chain Costing model that is HSC-orientated:

(i) The *first step* deals with the evaluation of physical flow performance with the help of a DES that reproduces the HSC's functional operations. This first step produces, from a decisional point of view, the level of performance expected for the activity in the physical flow of the HSC process; this step involves building a full mapping of the supply chain processes at different levels of granularity; the model is then translated into a simulation model reproducing the HSC flows. Accordingly, strict rules are to be designed to enable the modelling / simulation of physical flows of continuous / hybrid / discrete processes for the HSC [21], [22].

(ii) The *second step* deals with the evaluation of the financial flows. The items delivered by the simulation of the physical flow, in the form of a planning or of simulation tracks, constitute the initial input variable of the ABC analytical model to develop an economic evaluation of supply chain (hybrid, discrete or continuous) processes. The model serves to assess the efficacy and efficiency of the financial flows through several indicators; for it to work, this model needs to be fed with information from the information system of BUs comprising the supply chain. This approach serves to determine indirect cost consumption thanks to the evaluation of process costs for each BU as well as for the overall chain. In this context, the ABC cost of the supply chain is the sum of each BU's process costs plus the sum of the direct costs of the manufactured items. The value of inventory may also be calculated at any level of the chain. The value creation potential similarly is measured by combining the difference between demand and the quantity sold by a BU (or by the overall chain) with the margin on direct costs. To be developed for an HSC, the ABC valuation system requires:

- To start from the process mapping developed in the previous phase. The de-synchronization points identified (switch from one processing process to the next hybrid / discretization points of the flow) constitute, at a given level of granularity, the potential "boundaries" for the building of BU-orientated processes. These points of de-synchronization of the flow also indicate (figure 1) possible cost drivers in the HSC. These decoupling points are also related to product batch processing flow mechanisms for the M / S to be able to rely on a DES. These mechanisms play a role in the definition of drivers. By comparison, in discrete production, there is no ambiguity as to the physical features of the manufactured product and therefore only few conventions are required. This, therefore, is a clear argument in favor of adopting a different approach from a Supply Chain Costing' point of view for a discrete system and a continuous system when implementing an ABC method.

- To formalize concretely the rules of translation in order to be able, based on existing industrial controlling systems associated to cost centres and functional entities, to switch to BU-orientated industrial processes. This implies being able to derive new filters from the accounting balance to allocate the income and expense items accurately.
- The completion of the two above steps thus serves to develop an ABC analytical model with several levels of granularity (HSC / entity or BU / product…) taking into account different types of existing production / processing processes (figure 2).

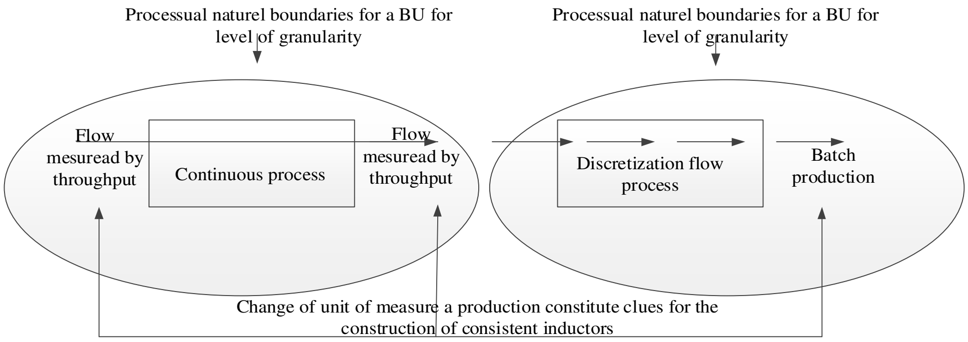

Figure 1. Switch from continuous to discrete

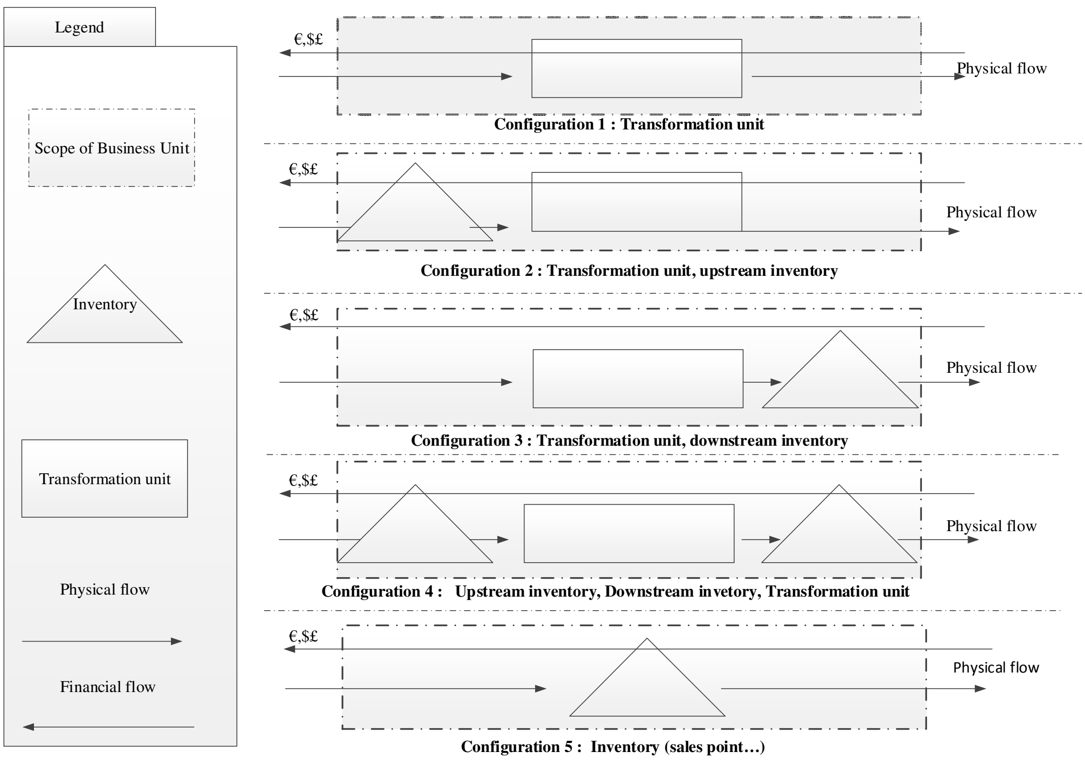

Figure 2. The different assumptions on the financial scope of a Business Unit.

(iii) In the *third step*, the results are structured into prospective scorecards; in this step, the performance indicators for the physical flows and the financial flows are plotted on scorecards corresponding to management scenarios and reflecting the operational and tactical decisional issues. Thus, for example, the structuring proposed at step 2 serves to back and analyze the decisional information in relation to the product families and the processing BUs. The processes are then "consolidated" by BU and by product family (goods or services). Table 2 illustrates the rationale used to consolidate the financial decisional information. We thus assume that the HSC produces a set of goods and services that may be grouped into product families where each family consumes P process activities. Many different BU are able to product the same family and are therefore identified as using the same nature of processes. Supply Chain manager needs information by families, processes, and business unit.

Table 2: Building of decisional scorecards

Families Product				Business Unit
Families f	Families g	Families h		
Processes consumed to produce items of families f	--	--	…	BUs(a) make product belonging to families f and sell families f to external customer and to BUs(b)
--	Processes consumed to produce items of families *g*	--	…	BUs(b) make products belonging to families g buy items to BUs(a), sell families g products to external customer and to BUs(b)
--	--	Processes consumed to produce items of families *h*	…	BUs(c) make product belonging to families h, buy items to BUs(b), sell families h product to external customer and to BUs(d)
…	…	…	…	
Profit & Loss statement for families f	Profit & Loss statement for families g	Profit and Loss statement for families *h*		Profit &Loss statement for the whole supply chain by BU, by product family, by processes…

4 Implementation of the Approach proposed on OCP's Hybrid Supply Chain

OCP hosts two research-intervention projects (David, 2000), the object of theses written under a chair and program financed by the company. OCP is Morocco's largest company

OCP fully controls its supply chain, which is characterized by a continuous production process involving batches to be transported between two links of the chain. This situation lends it the features of both discrete and continuous production systems. In this context, the different sub-systems of the chain are decoupled by multiple inventories of raw materials of different nature and quality. The recent introduction of a 300 km-long *pipe* (Northern axis) between the Khouribga and Jorf Lasfar plants (see figure 3) to carry the modified phosphate ore "mud" complements the supply chain and reduces the production cycle by re-siting a number of operations and by strengthening the coupling between a number of production units. The Khouribga facilities are OCP group's largest phosphate production plant. It is a mining site covering three extraction areas. It has annual production capacity of 19 million tonnes. Extracted production is processed as required to raise phosphate content and regulate silica content. This processing is carried out in washing plants.

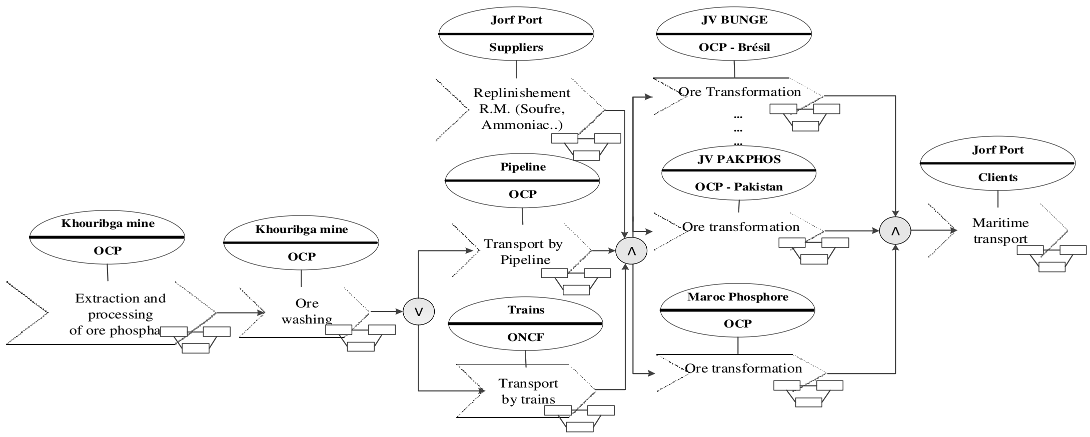

Figure 3. OCP's aggregated supply chain Model– Northern Axis

To process the phosphates from its mining sites, OCP Group built a large industrial facility at Jorf Lasfar which is called Morocco Phosphore III-IV. This plant has an annual production of 1.7 million tonnes of phosphoric acid and 1.8 million tonnes equivalent Di-Ammonium Phosphate, requiring the processing of: (i) 1.7 million tonnes of sulphur; (ii) 0.5 million tonnes of ammonia; and (iii) 6.5 million tonnes of phosphate. This platform comprises the following facilities: sulfuric acid production plant, phosphoric acid production plant, fertilizer production plant, utilities facilities, storage and transportation facilities. Under our research, we designed an aggregated and detailed model of the entire chain – Northern axis (see figure 4) – serving both to designing HSC physical flow simulation models and HSC entity ABC value creation models. Our proposed approach (see section 3) is implemented in OCP's HSC. We only present here the result of approach implementation that serve to structure and understand the consolidation process for the ABC evaluation models of OCP's HSC. Table 3 illustrates a proposed mapping of OCP's "Northern" Supply Chain activities by product family. Moreover, each production step involving a process change and contributing to its discretization represents a trigger event highlighting a cost driver. We have thus treated each process and activity at "Acid" BU level and "Fertilizer" BU level in order to determine the drivers used to allocate functional accounting balance expenses for OCP's northern axis Supply Chain. Our ABC model therefore serves to measure value creation for each of the HSC's BU and is capable of taking into account all the output and inputs of each process entity (energy production, waste recycling, choice of order to be treated as a priority…). The model will at a later stage either be directly fed into the simulation, or coupled to it. This step, currently in its implementation stage, is being tested at two plants considered to be two autonomous BUs (the sulfuric acid plant – with important methodological issues attached since it also produces electricity and intermediary products) and the fertilizer plant.

Table 3: Instanciation of the decisional scorecard building approach

Ore families	"Acid" Families		Fertilizer families	BU
• Ore extraction • Loading and transportation in dumpers by quality type • Ore processing at washing facilities • *pipe line transport for chemical processing (around 200km) in order to product Acid* • *Ore transportation by dumpers by type of quality for third-party customers*	--		--	Profit&Loss statement for Extracting Business Units
--	**Phosphoric Acid Production (PAP) Process** *Part of the processed ore consumed by phosphoric acid production (PAP)* *Part of H_2SO_4 Production consumed by PAP Production Process* + • *pipe line transport for chemical processing (around 200 km)* • grinding, Fileting • Decantation, , Clarification • P_2O_4 storage • *Transportation to end customer* • *Transportation for Joint venture use* • *Transportation for fertilizer production*	**H_2SO_4 (Sulfuric Acid) Production Process** • Unoading of solid sulfur • solid sulfur storage • Transport for joint venture /production process use • H_2SO_4 production • H_2SO_4 storage • Energy production • *Transportation to Joint Venture* • *Transportation to PAP process*	--	Profit&Loss statement for Acid Business Units
--	--		**Part of the processed PAP consumed by fertilizer families** + • Granulation, Drying Sifting • Cooling/grinding/ Coating • Fertilizer storage *Transporationt and sale of fertilizer*	Profit&Loss statement for Fertilizer Business Units
Profit & Loss statement for Ore families	Profit & Loss statement for Acid families		Profit and Loss for fertizer families	P&L for Supply Chain

5. Conclusion

Following a review of literature our paper shows than the ABC modelling approaches are centered on discrete supply chains and that coupling ABC and Simulation models enables implementation of DSSs to evaluate both the physical flows and the financial flows in a hybrid supply chain. We also show that the specific features of hybrid supply chains call for a different approach from that normally used for the coupling of ABC and simulation models because the de-synchronization of continuous / discrete processes in a hybrid supply chain actually serves to define ABC cost drivers and associated levers of action for HSC management purposes.The implementation of our proposed approach for OCP's HSC is currently the subject of a research program designed to validate:

- the design of the coupling of the HSC's DES and ABC;
- the design of the ABC model used to evaluate the HSC's physical flows;
- the design of translation rules from a functional entity controlling system to a process-based entity controlling system.

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