



HAL
open science

Integrated tactical production planning with multi transportation modes and multi supply sources: the case of a phosphate company

Bassma Azzamouri, Vincent Hovelaque, Vincent Giard

► To cite this version:

Bassma Azzamouri, Vincent Hovelaque, Vincent Giard. Integrated tactical production planning with multi transportation modes and multi supply sources: the case of a phosphate company. ELSEVIER, 2022, IFAC PapersOnLine 55-10 (2022) 872-877, <10.1016/j.ifacol.2022.09.523>. <hal-03833112>

HAL Id: hal-03833112

<https://hal.science/hal-03833112v1>

Submitted on 5 Dec 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

Integrated tactical production planning with multi transportation modes and multi supply sources: the case of a phosphate company

Bassma AZZAMOURI^{*,**} Vincent HOVELAQUE^{*,**} Vincent GIARD^{*,***}

^{*} *Emines- School of Industrial. Management, Mohammed VI Polytechnique University, Benguerir, Morocco (e-mail: Bassma.azzamouri@emines.um6p.ma)*

^{**} *UNIV RENNES 1, CNRS, CREM - UMR 6211, Rennes, France (e-mail: Vincent.Hovelaque@univ-rennes1.fr)*

^{***} *Paris-Dauphine, PSL Research University, LAMSADE; France (e-mail: Vincent.giard@dauphine.fr)*

Abstract: This paper deals with production activities planning on a tactical horizon for the phosphate industry. The studied supply chain is organized depending on the transportation modes used. There exist trains and pipeline that transport phosphate rock and pulp (respectively) to export and local customers. Due to the predetermined allocation of raw materials used currently in producing the final product, planning production activities in this supply chain should be then reorganized in such a way as to consider all the production configurations related to the use of each of the two transportation modes using such a flexible allocation instead. Moreover, customer requirements in terms of product quality represented by quality charters may be changed by the customer over time and from one order book to another for the same final product, which makes satisfying those requirements difficult. Thus, an integer linear programming model is developed and allows a global optimization of allocating raw materials and routings dynamically to satisfy the two types of customers at a lower cost. This work concerns a real industrial context and the numerical results provided prove the efficiency and flexibility ensured by our approach in comparison to the practices adopted currently.

Copyright © 2022 The Authors. This is an open access article under the CC BY-NC-ND license (<https://creativecommons.org/licenses/by-nc-nd/4.0/>)

Keywords: tactical planning, multi transportation modes, blending, routings

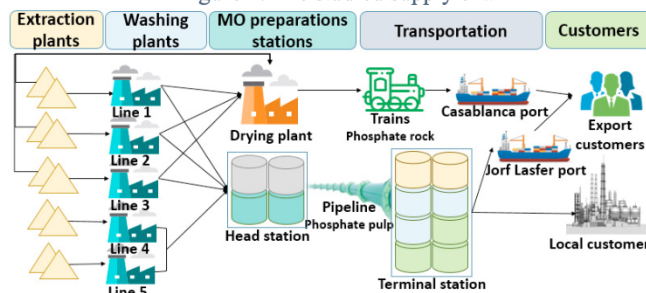
1. INTRODUCTION

This paper deals with the tactical planning of the treatment of phosphate rock in a part of the phosphoric supply chain (SC) of the OCP Group, a Moroccan worldwide company specialized in producing rock phosphate and its derivatives. It proposes a more efficient and effective planning process than the current one.

The concerned supply chain, Figure 1, produces merchantable ores (MO) either delivered to the port by train (phosphate rock) for external customers or transported to a terminal station by pipeline (phosphate pulp of a product called K09) for internal customers (chemical site of fertilizers and phosphoric acid) or export ones. Each MO is characterized by its chemical composition constrained by a quality chart (QC) where the percentage of each retained component must belong to a given range. Raw ores, called source ores (SO), are supplied from five mines and stored dynamically in different areas upstream production plants. Each SO is also characterized by its chemical structure in a set of components. Washing plants (lines 1 to 5) may enrich SO to provide intermediate products called Washed Source Ores (WSO) through one of three existing routings: washing, washing and flotation, washing and flotation, and grinding. The enrichment is obtained by eliminating impurities, which reduces the SO's weight and modifies its chemical composition. The production configuration depends on the used transportation mode: MOs

sent by pipeline are obtained by a blend of WSO processed in washing (P configuration), while MOs sent by train are obtained by blending SOs and/or WSOs followed by an obligatory drying process (T configuration). This supply chain is strongly constrained by the prohibition on disrupting the supply of pulp to chemical plants (local customer) via the pipeline (loss of prime events).

Figure 1. The studied supply chain



Currently, MO orders and SOs are assigned to one of the two configurations (P or T), and predetermined routings are used to produce the MOs. This makes it challenging to meet the QC, which leads the managers to privilege the BPL (the element representing the richness of products in P_2O_5) to the detriment of other components. Less and less, customers accept this degradation. In addition, the lack of needed SOs or the unavailability of some resources may delay preparing the final product. We shed light via our paper on planning at a tactical

level (mid-term). This level generally defines quantities of supplied products, resources requirements, inventory, quantities of produced products, and distribution canals (Rohde and Wagner, 2005; Rudberg and Cederborg, 2011).

The model developed in this paper finds effective and efficient tactical planning of production activities, keeping the MOs assignments to P and T configurations but relaxing constraints of SOs pre-affectation and routings to use. In section 2, we review the literature on planning production activities in process industries. In section 3, we present the different hypotheses adopted on this studied supply chain and the mathematical model developed. Numerical studies and analysis are proposed in section 4, before concluding with some perspectives.

2. LITERATURE REVIEW

Planning production activities in process industries were treated several decades ago by researchers (Kaz'min, 1965; C.Hax, 1973; Schuermann and Kannan, 1978; L. Smith-Daniels and E. Smith-Daniels, 1986). Planning decisions concern generally resource acquisition or utilization and have extensively been considered by many process industries: Dairy (Schuermann and Kannan, 1978); petroleum and petrochemical (Kaz'min, 1965; Al Sharrah, 2001); chemical (Arbiza et al., 2008; Shah and Ierapetritou, 2012; Hahn and Brandenburg, 2018; Dutta et al., 2018; Demirhan et al., 2020), Steel (Berr, 1979; Rudberg and Cederborg, 2011; Dutta and Fourer, 2004), tomato (Rocco and Morabito, 2016), pharmaceutical industry (Feng et al., 2011), mining (Azzamouri et al., 2021; Hilali et al., 2022), etc.

The two types of decisions mentioned previously differ in scope and depend mainly on three aspects: the nature of supporting information, level of management involvement, and length of their planning horizons (Hax, 1973). For the horizons, planning production activities were treated at a strategic/long term by Dutta et al. (2018), tactic or mid-term by Rudberg and Cederborg (2011), or operational (short-term), which refers to scheduling and deals with assigning tasks in time (Arbiza et al., 2008) or through considering several levels (Hax, 1973; Hahn and Brandenburg, 2018). The different industries improving their planning techniques produce either for the final customer, which is a direct consumer of products (individuals) as was the case for Schuermann and Kannan (1978) for the production of a high-volume standardized product (the 1-gallon package of milk), or produce intermediate products or developed raw materials for further treatments in other companies as for Al-Sharrah et al. (2001) in producing for plastic and synthesis resins manufacturing. Generally, researchers have dealt with planning in the literature via the development of OR models and using optimization techniques (Schuermann and Kannan, 1978; Berr, 1979; Al-Sharrah et al., 2001, etc.); development of algorithms (Florian et al., 1980), or via Advanced Planning Systems and metaheuristics (Rudberg and Cederborg, 2011; Arbiza et al., 2008), etc. Concerning the objectives, some researchers have chosen to focalize on only one objective, which is an economical one with minimizing production costs (Florian et al., 1980) or maximizing profit (Dutta et al., 2018). Other papers have chosen a combination of objectives among customer satisfaction, environmental impact, economic

considerations, makespan, and lead time (Arbiza et al., 2008; Hahn and Brandenburg, 2018; Shah and Ierapetritou, 2012; Feng et al., 2011).

To the best of our knowledge, no work has considered the problem of loss of performance due to resources partition depending on different types of clients, transportation modes, and the related production configurations at a tactical level. Our work considers as well a combination of aspects that haven't been yet addressed in the literature: (i) choosing between different supply sources (mines), (ii) choosing among different alternative routings, (iii) integrating a predefined sequencing program depending on the storage and non-disruption with loss of prime, and resources capacity of the TS tanks (iv) prioritizing the satisfaction of some customers among others, (v) producing products which are primary ones for other customers (companies) and (vi) managing through the objective function products quality and production costs.

3. CONCEPTION AND MATHEMATICAL MODEL

3.1 Hypothesis and conception

Planning the production activities of the studied supply chain implies considering the site's infrastructure and the physical and organizational constraints resulting from the integration of the pipeline and trains.

On the one hand, the local customer cannot suffer shortage (loss of prime constraint) and consumes a continuous rate of a specific MO fed from tanks of the terminal station with a limited capacity to store phosphate pulp temporarily. On the other hand, there is more flexibility in preparing orders for export customers (whatever configuration T or P) due to the delivery time, which takes the form of a time interval. Therefore, production should be organized in washing plants while considering storage constraints and order books for export customers. We propose to consider a predefined sequencing program and adopt the logic of "repeating production cycles". Since the supply need of the local customer is continuous and remains stable, while integrating smoothed orders to satisfy export customers, repeating production cycles leads to a steady-state. We propose to introduce two sequences A and B. In sequence A, the production concerns only the local customer using all the available production lines until the saturation of storage tanks downstream the pipeline in K09. In sequence B, the production is shared between production lines of washing plants to produce sequentially for local customers and export ones. In parallel, this second sequence ensures emptying storage tanks of K09 saturated during sequence A. Sequence A followed by sequence B composes a "production cycle". The duration of each sequence depends on the output flow rate of lines mobilized, the capacity of storage tanks, and the internal consumption rate of the local customer. The maximum total volume of final product produced in sequence A is divided into several batches for quality insurance (each batch may have its blending formula depending on available ores). For sequence B, we choose to start production for export-pipeline customers. The residual volume allowed to produce during a production cycle for the export customers will be then dedicated to export-train customers and divided into several batches non-affected to orders, and the model attributes (or not) one batch or more

to this category of customers. Figure 2 illustrates one production cycle with the duration of each configuration, the stock evolution for each one during each sequence, and the corresponding evolution of stocks. Consider that the upstream rate (resp. downstream rate) of TS stock is r_1 (resp. r_2), expressed in m^3/h , and the storage capacity is L . Then, sequence A lasts $L/(r_1-r_2)$ hours with a production of $r_1.L/(r_1-r_2) m^3$; the stock fills up with $24(r_1-r_2) m^3$ per day. For confidentiality reasons, only some values are explicitly represented in the figure.

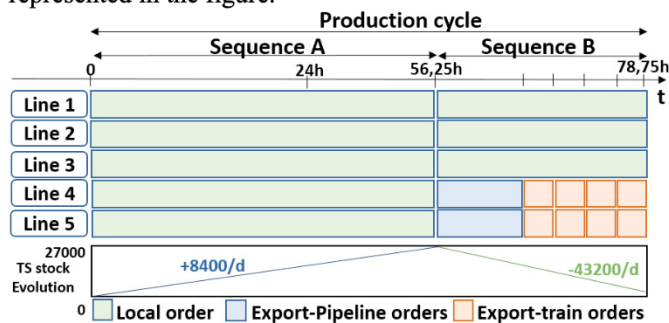


Figure 2. Illustration of the proposed sequencing program

3.2 Mathematical model

The developed integer linear model takes into account the proposed sequencing program and a set of data related to the current infrastructure. It doesn't consider any maintenance constraints or set-up times. Volumes are expressed in m^3 and the output rate of washing plants in m^3/h . However, conversions from m^3 to the ton or the inverse occur with a standard rate determined by OCP Group. The model considers some restrictions (predicates defined with the operator ' $|$ ' in the mathematical model) to reduce the number of variables and constraints and, consequently, the execution time.

Index	Description
t	Index of time.
i	Index of inputs.
j	Index of outputs.
p	Index of export-train orders.
r	Index of export-pipeline orders.
k	Index of elementary orders to produce in washing plants.
m	Index of mines.
h	Index of routings
c	Index of chemical components.
l	Index of washing lines.

Parameter Description

General parameters

D_k	Volume of elementary orders k (in m^3).
D'_p	Volume of orders p (in m^3).
λ_k	Output index of local elementary orders.
ρ_r	Output index of export-pipeline orders.
π_p	Output index of export-train orders.

Technical parameters

α_{ci}	Proportion of component c in the weight of input i .
η_{ih}	Reduction of weight coefficient of input i by routing h . If the routing h is not used to process SO i , then $\eta_{ih} = 0$.
γ_{cih}	Distorsion coefficient of component c belonging to input i using routing h .
$[\beta_{cj}^{\text{Min}} - \beta_{cj}^{\text{Max}}]$	Lower and upper bounds of the proportion (%) of component c in the weight of output j , with $-j = \lambda_k$: of order k of the local customer. $-j = \rho_r$: of order r of the export-pipeline customer. $-j = \pi_p$: of order p of export-train customers.
τ_{cj}	Target bound of the proportion (%) of component c in the weight of local output $j = \lambda_k$ of the order k .
B_{kl}	Boolean worth 1 if the elementary order k involves washing plant l , 0 otherwise.
A_k	It is equal to 1 if k corresponds to the local customer, equal to 2 for the export-pipeline customers, and 3 for the export-train customers.
μ_i	Mine from which the input i is extracted.
Π_{ml}	Boolean worth 1 if the mine m feeds the washing plant l , and 0 otherwise.
Ψ_m	Boolean worth 1 if the mine m feeds the drying plant, and 0 otherwise.
C_k	Index of the export-pipeline order r to which the elementary order k belongs.
<u>Time parameter</u>	
θ_k	Production time of the elementary order k .
ω_k	End period of elementary order k production.
F_k	Starting production periods of elementary order k .
E_p	Earliest delivery period of order p .
L_p	Latest delivery period of an order p .
<u>Inventory parameters</u>	
S_i^{init}	Initial stock of input i at $t=0$.
Q_{it}	Provisional production program of mines, defined by input and period t .
d_l	Hourly production rate of washing plant line l (in m^3/h).
<u>Cost parameter</u>	
σ_c	Gap penalty for each component c .
ϕ_h	Cost of treatment using routing h .
$\psi_{\mu_i}^1$	Cost per unit of conveying SO i to drying plant.
$\psi_{\mu_i}^2$	Cost per unit of conveying SO i that needs enrichment to washing plant and then to drying one.

$\psi_{\mu_i}^3$ Cost per unit of conveying SO i to washing plant for enrichment.
 σ' Cost per unit of extracting SO.

Constants

M Big number.
 ε Minimal quantity to use for each order.

Variables Description

Decision variables

x_{ihlk} Binary worth 1 if SO i is processed by routing h on washing plant l to produce elementary order k forwarded via pipeline.
 y_{ihlkp} Binary worth 1 if SO i is processed by routing h on washing plant l to produce elementary order to prepare order p and to forward via trains to export customers.
 z_{itp} Quantity of SO (in ton) used to produce order p delivered at time t and forwarded via train.
 δ_{pt} Binary worth 1 if the production of order p ends at time t .

Auxiliary variables

μ_{clk} Weight of component c in the volume produced by washing plant l for the constitution of elementary order k .
 μ'_{cp} Weight of component c in the volume D'_p .
 Δ_{ck} Gap between the optimal solution proposed by the model and a target value from the customer charter of each component c .
 S_{it} State of stock of input i at the end of period t (in ton).

Objective function and constraints

$$\text{Min}(P_1 + P_2 + P_3 + P_4) \tag{1}$$

with:

$$P_1 = \sum_{c,k} \sigma_c \cdot \Delta_{ck}$$

$$P_2 = \left(\sum_{i,h,k|A_k < 3 \wedge B_{kl} = 1 \wedge \Pi_{\mu_i l} = 1 \wedge \eta_{ih} > 0} \frac{d_l \cdot \theta_k \cdot x_{ihlk}}{\eta_{ih}} \cdot \Phi_h + \sum_{i,h,k,p|A_k = 3 \wedge B_{kl} = 1 \wedge \Pi_{\mu_i l} = 1 \wedge \eta_{ih} > 0 \wedge E_p \leq \omega_k \leq L_p} \frac{d_l \cdot \theta_k \cdot y_{ihlkp}}{\eta_{ih}} \cdot \Phi_h \right)$$

$$P_3 = \left(\sum_{i,t,p|\Psi_{\mu_i} = 1 \wedge E_p \leq t \leq L_p} z_{itp} \cdot \psi_{\mu_i}^1 \right) + \left(\sum_{i,h,k|A_k < 3 \wedge B_{kl} = 1 \wedge \Pi_{\mu_i l} = 1 \wedge \eta_{ih} > 0} \frac{d_l \cdot \theta_k \cdot x_{ihlk}}{\eta_{ih}} \cdot \psi_{\mu_i}^2 \right) + \left(\sum_{i,h,k,p|A_k = 3 \wedge B_{kl} = 1 \wedge \Pi_{\mu_i l} = 1 \wedge \eta_{ih} > 0 \wedge E_p \leq \omega_k \leq L_p} \frac{d_l \cdot \theta_k \cdot y_{ihlkp}}{\eta_{ih}} \cdot \psi_{\mu_i}^3 \right)$$

$$P_4 = \left(\sum_{i,t,p|\Psi_{\mu_i} = 1 \wedge E_p \leq t \leq L_p} z_{itp} + \sum_{i,h,k|A_k < 3 \wedge B_{kl} = 1 \wedge \Pi_{\mu_i l} = 1 \wedge \eta_{ih} > 0} \frac{d_l \cdot \theta_k \cdot x_{ihlk}}{\eta_{ih}} + \sum_{i,h,k,p \in \mathcal{P}|A_k = 3 \wedge B_{kl} = 1 \wedge \Pi_{\mu_i l} = 1 \wedge \eta_{ih} > 0 \wedge E_p \leq \omega_k \leq L_p} \frac{d_l \cdot \theta_k \cdot y_{ihlkp}}{\eta_{ih}} \right) \sigma'$$

Subject to:

$$\sum_{i,h|\Pi_{\mu_i l} = 1 \wedge \eta_{ih} > 0} x_{ihlk} = 1, \forall k, l | A_k < 3 \wedge B_{kl} = 1 \tag{2}$$

$$\sum_{h,l|\Pi_{\mu_i l} = 1 \wedge \eta_{ih} > 0 \wedge B_{kl} = 1} x_{ihlk} \leq 1, \forall i, k | A_k < 3 \tag{3}$$

$$\mu_{clk} = d_l \cdot \theta_k \cdot \sum_{i,h|\Pi_{\mu_i l} = 1 \wedge \eta_{ih} > 0} x_{ihlk} \cdot \alpha_{ci} \cdot \gamma_{cih}, \forall c, l, k | A_k < 3 \wedge B_{kl} = 1 \tag{4}$$

$$\beta_{c\lambda_k}^{\text{Min}} \cdot D_k \leq \sum_{l|B_{kl} = 1} \mu_{clk} \leq \beta_{c\lambda_k}^{\text{Max}} \cdot D_k, \forall c, k | A_k = 1 \tag{5}$$

$$\beta_{cp_r}^{\text{Min}} \cdot \sum_{k|A_k = 2 \wedge C_k = r} D_k \leq \sum_{k|A_k = 2 \wedge C_k = r \wedge B_{kl} = 1} \mu_{clk} \leq \beta_{cp_r}^{\text{Max}} \cdot \sum_{k|A_k = 2 \wedge C_k = r} D_k, \forall c, \forall r \tag{6}$$

$$\sum_{i,h,p|\Pi_{\mu_i l} = 1 \wedge \eta_{ih} > 0 \wedge E_p \leq \omega_k \leq L_p} y_{ihlkp} = 1, \forall k, l | A_k = 3 \wedge B_{kl} = 1 \tag{7}$$

$$\sum_{t|E_p \leq t \leq L_p} \delta_{pt} = 1, \forall p \tag{8}$$

$$z_{itp} \leq M \cdot \delta_{pt}, \forall i, p, t | \Psi_{\mu_i} = 1 \wedge E_p \leq t \leq L_p \tag{9}$$

$$D'_p = \sum_{i,t|\Psi_{\mu_i} = 1 \wedge E_p \leq t \leq L_p} z_{itp} + \sum_{i,h,k,l|A_k = 3 \wedge B_{kl} = 1 \wedge \Pi_{\mu_i l} = 1 \wedge \eta_{ih} > 0 \wedge E_p \leq \omega_k \leq L_p} d_l \cdot \theta_k \cdot y_{ihlkp}, \forall p \tag{10}$$

$$\mu'_{cp} = \sum_{i,t|\Psi_{\mu_i} = 1 \wedge E_p \leq t \leq L_p} \alpha_{ic} \cdot z_{ipt} + \sum_{i,h,k \in \mathcal{S}_c, l|B_{kl} = 1 \wedge \Pi_{\mu_i l} = 1 \wedge \eta_{ih} > 0 \wedge E_p \leq \omega_k \leq L_p} d_l \cdot \theta_k \cdot \alpha_{ic} \cdot \gamma_{hci} \cdot y_{ihlkp}, \forall c, \forall p \tag{11}$$

$$\beta_{c\lambda_p}^{\text{Min}} \cdot D'_p \leq \mu'_{cp} \leq \beta_{c\lambda_p}^{\text{Max}} \cdot D'_p, \forall c \in \mathcal{C}, p \in \mathcal{P} \tag{12}$$

$$S_{it} \geq 0, \forall i, t \tag{13}$$

$$S_{i0} = S_i^{\text{init}}, \forall i \tag{14}$$

$$\forall i, \forall t, S_{it} = S_{i,t-1} + Q_{it} - \sum_{p|\Psi_{\mu_i} = 1 \wedge E_p \leq t \leq L_p} z_{ipt} - \sum_{h,k,l|A_k = 1 \wedge \Pi_{\mu_i l} = 1 \wedge \eta_{ih} = 1 \wedge B_{kl} = 1 \wedge F_k = t \wedge \eta_{ih} > 0} d_l \cdot \theta_k \cdot x_{ihlk} / \eta_{ih} - \sum_{h,k,l|A_k = 2 \wedge \Pi_{\mu_i l} = 1 \wedge \eta_{ih} = 1 \wedge B_{kl} = 1 \wedge F_k = t \wedge \eta_{ih} > 0} d_l \cdot \theta_k \cdot x_{ihlk} / \eta_{ih} - \sum_{h,p,k,l|A_k = 3 \wedge \Pi_{\mu_i l} = 1 \wedge \eta_{ih} = 1 \wedge B_{kl} = 1 \wedge F_k = t \wedge \eta_{ih} > 0} d_l \cdot \theta_k \cdot y_{ihlkp} / \eta_{ih} \tag{15}$$

$$\Delta_{ck} \geq \sum_{l|B_{kl} = 1} \mu_{clk} - \tau_{c\lambda_k} \cdot D_k, \forall c, k \tag{16}$$

$$\Delta_{ck} \geq \tau_{c\lambda_k} \cdot D_k - \sum_{l|B_{kl} = 1} \mu_{clk}$$

$$\Delta_{ck} \geq \sum_{l|B_{kl} = 1} \mu_{clk} - \tau_{c\lambda_k} \cdot D_k, \forall c, k$$

$$\Delta_{ck} \geq \tau_{c\lambda_k} \cdot D_k - \sum_{l|B_{kl} = 1} \mu_{clk}$$

3.3 Comments

- Relation (1): We are interested in a cost objective function, which aims to minimize the total costs related to P1: penalty attributed to the deviance between a target value of the quality charter for each component c and the proposed solution by the model. P2: Production cost related to the use of routings h . P3: Production cost related to conveying ingredients between the entities. P4: Production cost related to extracting SO.
- Relation (2) reflects the fact that every treatment line affected to an elementary order k should produce a unique WSO and describe that each input is used at most once to produce the elementary order k . This constraint is realized while using a set of predicates described above.
- Relation (3): WSO flows forwarded via pipeline can not mobilize a SO more than once.
- Relation (4) represents the weight of component c in the WSO used to produce the elementary order k .

- Relation (5) is the constraint that allows respecting the quality charter related to the local customer, which is realized in the HS, once the WSO are blended
- Relation (6) is for respecting the quality charter related to the products export-pipe. Once all the batches that compose the final product arrive at the terminal station, the quality of the blended products respects the quality charter requested by the customer.
- Relation (7) signifies that every treatment line is affected to produce a unique WSO for the elementary order *k* to produce the export train order *p*. The reserved batches for this type of customer are programmed, and the model determines the batches that should belong to the orders *p*.
- Relation (8) reflects the necessity of determining the end date of treatment of order *p*. This should integrate a binary decision variable δ_{pt} that takes the value 1 if the preparation of order *p* ends at period *t*.
- Relation (9) determines the minimum quantities of raw ingredients to use for each order *p*.
- Relation (10) represents a conservation constraint for respecting the volume of export-train orders.
- Relation (11) illustrates the weight of component *c* in the SO and WSO used to produce the order *p*.
- Relation (12) is the constraints of respecting quality charter for export train products.
- Relation (13), (14) & (15) represent the equation of stocks conservation. It considers the volume of products consumed for each order during the period *t* and the provisional production program of mines.
- Relation (16) is a formulation of the gap between a target value of the quality charter and the solution proposed by the model for local product.

4. NUMERICAL RESULTS

4.1 Data used

The model is executed using fictive data, but close to the ones used from Khouribga’s site. The inputs integrated consider customer's requirements in terms of volume, quality defined by the customer charters, and delivery time for export-train customers. We consider as well the data related to the studied infrastructure: output flow rates of washing plants lines, mobilization of lines for each type of order, the provisional production program of mines per SO and period and the corresponding quality, the initial stock per SO, indicators of quality management in washing plants (reduction weight rate and distortion rate), the existing conveyors and links between mines and washing plant on the one hand, and on the other hand between mines and drying unit. The model takes into account the proposed sequencing program for washing plants lines, the necessary production duration of each elementary order *k*, the volume of each *k*, starting and ending periods of production for each order *k*, the correspondence of elementary orders *k* to a local order, export-pipeline or export-train orders. The model is fed by cost indicators related to the extraction, conveying, and enrichment of ingredients. For illustration purposes, the model is executed using the example of one production cycle but composed of several orders to satisfy. The model can consider an order book much bigger, covering

several months of production, depending on the available information about the availability of ingredients, their chemical characteristics, and the customer's orders.

4.2 Model execution

The model is executed using FICO’s Xpress-IVE AML. One of the main/strong characteristics of the proposed formulation of the model is the intensive use of predicates to represent the physical complexity of the studied supply chain with fewer constraints. It reduces drastically the computational time with an average of 20 s. The model defines as well the periods of using raw products, the mine source, the quantities of each ingredient composing each order, the washing plants lines to mobilize, the chemical composition of the orders, and the state of stock at the end of each period. The tables below (Table 1, Table 2) present the optimal solution for each type of customer, depending on the possible production configuration allowed for use in each order and while considering the three chemical components BPL, MgO, and Cd.

Table 1. The proposed solution for export-train orders

Trains orders	SO			Trains orders	WSO					
	Inputs	Periods	Quantities of SO to use		Inputs	Lines	Routing	Elementary order	Quantities of WSO to use	Quantities of SO to use
1	13	11	349,22	1	5	1	1	10	3465	4029,07
	15	11	1964,1		5	1	1	12	3465	4029,07
	17	11	10757		5	1	1	8	3465	4029,07
2	15	17	3537,1	2	5	2	1	10	1925	2238,37
	20	17	29148		5	2	1	12	1925	2238,37
	15	11	2721,3		5	1	1	9	3465	4029,07
3	17	11	9573,8	3	5	1	1	11	3465	4029,07
					5	2	1	8	1925	2238,37
					5	2	1	9	1925	2238,37
					5	2	1	11	1925	2238,37
					5	2	1	11	1925	2238,37

Table 2. Proposed blendings for the order book

Sequences	Elementary Orders	Type of customers	Inputs	Routing	Line	Quantities of WSO to use	Quantities of SO to use	Total order quantity (m3)
Sequence A	1,2,3,4,5	Local	1	1	1	10125	14627,28	40500
			10	1	2	5625	7147,40	
			15	1	4	7875	10739,12	
			17	1	3	9000	12100,03	
			18	1	5	7875	10158,67	
Sequence B	6	Local	15	1	3	18000	24546,57	46500
			16	1	5	15750	22108,37	
			23	1	4	15750	21175,05	
	7	Export-pipeline	2	1	1	2925	3985,01	4550
			10	1	2	1625	2064,80	

The model proposes a solution that fully satisfies the constraints integrated and most importantly customer requirements. It provides a general program including all entities of the site from mines to the last stages before shipping MO and organizes production activities.

Our approach leads to improve the studied supply chain performance by proposing efficient allocations of SO/routing to the different types of orders depending on the transportation modes used. It replaces the current approach where predefined recipes and routings are used while prioritising the satisfaction of some orders among others because of their high volume or

special chemical characteristics. Currently, any lack in the ingredients of the predefined recipes leads to several problems related to satisfying customers' needs. Instead, and with the proposed approach, more flexibility is ensured and all orders should be satisfied depending on their specificities and the ingredient's availability.

5. CONCLUSION

This work deals with planning production activities in the tactical horizon of a phosphate industry. Different production configurations exist and depend on the two transportation modes to use while considering the huge infrastructure of the site, ingredients and resources availability, and loss of prime constraint for the chemical complex. This paper proposes a sequencing program of production in washing plants and the development of a MILP model. The outputs of this model are related to defining the optimal combinations of SO/routing to prepare each order while minimizing production costs. This guarantees flexibility and dynamism in preparing orders and better-quality product management. This work stems from a research contract with our industrial partner. In this paper, the conveying constraints between the entities of the site are not considered yet. It is one of the perspectives envisaged. To this is added, the consideration of upstream of the supply chain by the integration of mines and the impact of extraction method used in better satisfying clients.

REFERENCES

- Al-Sharrah, G.K., Alatiqi, I., Elkamel, A., and Alper, E. (2001). Planning an Integrated Petrochemical Industry with an Environmental Objective. *Ind. Eng. Chem. Res.*, 40 (9), 2103–2111.
- Arbiza, M.J., Bonfill, A., Guillén, G., Mele, F.D., Espuña, A., Puigjaner, L. (2008). Metaheuristic multiobjective optimisation approach for the scheduling of multiproduct batch chemical plants. *Journal of Cleaner Production*, 16 (2), 233–244.
- Azzamouri, A., Bamoumen, M., Hilali, H., Hovelaque, V., and Giard, V. (2021). Flexibility of dynamic blending with alternative routings combined with security stocks: a new approach in a mining supply chain. *International Journal of Production Research* 59 (21), 6419–6436.
- Berr, U. (1979). Production program planning in the metal products industry using linear optimization. *Engineering and Process Economics*, 4 (2-3), 99–110.
- Demirhan, C.D., Boukouvala, F., Kim, K., Song, H., Tso, W.W., Floudas, C.A., and Pistikopoulos, E.N. (2020). An integrated data-driven modeling & global optimization approach for multi-period nonlinear production planning problems. *Computers & Chemical Engineering*, 141 (4), 107007.
- Dutta, G. and Fourer, R. (2004). An Optimization-Based Decision Support System for Strategic and Operational Planning in Process Industries. *Optimization and Engineering*, 5 (3), 295–314.
- Dutta, G., Gupta, N., Mandal, J., and Tiwari, M.Kr. (2018). New decision support system for strategic planning in process industries: Computational results. *Computers & Industrial Engineering*, 124, 36–47.
- Feng, P., Zhang, J., Wu, Z., and Yu, D. (2011). An improved production planning method for process industries. *International Journal of Production Research*, 49 (14), 4223–4243.
- Florian, M., Lenstra, J.K., and Rinnooy Kan, A.H.G. (1980). Deterministic Production Planning: Algorithms and Complexity. *Management Science*, 26 (7), 669–679.
- Hahn, G.J. and Brandenburg, M. (2018). A sustainable aggregate production planning model for the chemical process industry. *Computers & Operations Research* 94, 154–168.
- Hax, A.C. (1973). Integration of Strategic and Tactical Planning in the Aluminum Industry. Massachusetts Inst of Tech Cambridge Operations Research Center, Cambridge USA.
- Hilali, H., Hovelaque, V., and Giard, V. (2022). Integrated scheduling of a multi-site mining supply chain with blending, alternative routings and co-production. *International Journal of Production Research* 0, 1–20.
- Kaz'min, G.I. (1965). The problem of planning new heavy-duty petroleum refineries. *Chem Technol Fuels Oils*, 1 (5), 408–411.
- Rocco, C.D. and Morabito, R. (2016). Production and logistics planning in the tomato processing industry: A conceptual scheme and mathematical model. *Computers and Electronics in Agriculture*, 127, 763–774.
- Rudberg, M. and Cederborg, O. (2011). APS for tactical planning in a steel processing company. *Industrial Management & Data Systems*, 111 (4), 608–628.
- Schuermann, A.C. and Kannan, N.P. (1978). A production forecasting and planning system for dairy processing. *Computers & Industrial Engineering*, 2 (3), 153–158.
- Shah, N.K. and Ierapetritou, M.G. (2012). Integrated production planning and scheduling optimization of multisite, multiproduct process industry. *Computers & Chemical Engineering*, 37, 214–226.
- Smith-Daniels, V.L. and Smith-Daniels, D.E. (1986). A Mixed Integer Programming Model for Lot Sizing and Sequencing Packaging Lines in the Process Industries. *IIE Transactions*, 18 (3), 278–285.