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LOT SIZING AND SCHEDULING OF A PERISHABLE PRODUCT IN A DAIRY INDUSTRY

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ABSTRACT

This paper considers a dairy industry problem on integrated planning and scheduling a Mixed Integer Linear Programming (MILP) formulation is introduced to integrate tactical and operational decisions with uncertain demand and a heuristic approach is proposed to decompose time buckets of the decisions. The decomposition heuristic improves computational efficiency by solving big bucket planning and small bucket scheduling problems. the proposed decomposition heuristic has consistent results minimizing the total cost.

Key words: MILP, heuristic, inventory, distribution centers.

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1. INTRODUCTION

The milk production is a semi-continuous process and subject to individual characteristics. Yoghurt and dahi is a notably perishable product within the category of dairy industry. The perishability highly restricts its storage duration and delivery conditions. It has a wide variety of retail cup sizes or labels, contents and special ingredients with numerous flavoured and coloured types. When it comes to producing large numbers of products from a few initial product recipes, product dependent cleaning, sterilizing, re-tuning issues of pipes and mixing units arise to avoid contamination Especially, long sequence-dependent setup times and high costs are considerable at the filling and packaging stages of the yogurt production and, they cause a noticeable reduction of available production times and increase the costs. Hence, planning and scheduling of the yoghurt production require specific models to support decision making.

Mixed integer linear programming (MILP) models provide mathematical frameworks for the operational research problems and to get optimal solutions. Kopanos *et al.* 2011a, 2012a, Bilgen and Çelebi (2013) applied MILP as an extensively accepted tool in the manufacturing industry for well-defined problems. Sel and Bilgen (2014a) state that integrated multi-echelon, multi-period planning and scheduling models accounting for multi-stage semi-continuous production particularities are found to be of practical use. production and distribution problem for a two-stage semi-continuous yoghurt production which is also comparable to other dairy production processes (*e.g.,* cheese, butter, curd and ice cream) is considered in this paper. The production side fundamentally corresponds to packaging and fermentation/incubation operations. The distribution side considers the storage of products and the delivery to distribution centres (DCs). Grossmann(2004) present the integration planning and scheduling at the supply chain level as a future challenge to be tackled.

The scope of the considered problem is illustrated in Fig.1(b).

Figure 1 (a): Yoguhrt production cycle

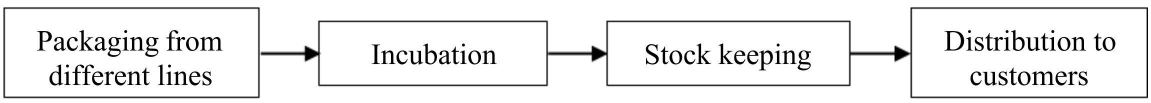

Figure 1 (b) The part of the cycle considered for problem

A multi-echelon, multi-period integrated MILP model with shelf life consideration is the better model for this problem. The scheduling constraints are formulated similar to parallel machine scheduling with sequence dependent setup times. A decomposition heuristic which divides the model into different planning and scheduling time buckets can reduce the complexity caused by the scheduling decisions due to MILP formulation.

Constraint programming (CP) has been developed as a useful modelling and solution paradigm overcoming the computational limitations for many scheduling cases such as staff, train, assembly line, batch plant and flexible manufacturing system scheduling (Novas and Henning, 2014). The CP models provide more convenient analyses for real cases by requiring less computational efforts. Harjunkoski and Grossmann, 2002, Jain and Grossmann (2001) used hybrid mixed integer linear programming/constraint programming (MILP/CP) decomposition strategies to minimise the computational limitations of scheduling problems..

In this paper it is proposed a decomposition heuristic which divides the integrated planning and scheduling model into big bucket planning, and small bucket scheduling sub-models. In each iteration of the algorithm ,the heuristic limits tactical production planning and distribution decisions (*e.g.,* stock keeping, demand satisfaction) with an actual production capacity determined by a simulated annealing (SA) based optimization heuristic. Further, MILP and CP methodologies are combined with the proposed algorithm to show their complement. The rest of the paper is organized as follows. In Section 2 narrated. A detailed description of the production system. Relevant literature is mentioned in Section 3. The mathematical formulation in Section 4 and the proposed solution approach is explained in

Section 4 and Section 5 respectively. An illustrative case study is discussed with the results in Section 6. Finally, the main conclusions are given in Section 7.

2. PRODUCTION SYSTEM

The yoghurt/dahi production process starts with collection of milk and continues withpasteurization,standardization,homogenization,cultureaddition, fermentation/incubation, packaging and storage, distribution operations.

Fresh milk can be collected from farms to the production plant with churn collection or bulk collection. The pasteurization of milk is carried out to get rid of pathogenic organisms in milk. After pasteurization, standardization and homogenization takes place in order to enhance the quality of the yoghurt product. It involves adjustment of the fat or dry solids contents of milk and disruption of fat globules into much smaller ones. Then, cultures are added to incubate the mix. later fermented. Filling and packaging operations are performed in parallel packaging machines. The packed yoghurt is placed in cooling storage containers and usually delivered to Distribution centers (dc).The product subdivided into different groups based on chemical composition, vitamin addition, fat content, cup sizes. The fermentation /incubation is operated with heating and chilling units in which the set type yoghurt is put with specific temperature conditions and predefined duration.

3. LITERATURE REVIEW

In this section, the most relevant and recent literature considering planning and scheduling problems in production units including dairy industry are furnished. quantitative models for supply chain management within the dairy industry are reviewed by Sel and Bilgen (2014a).

The planning and scheduling decisions take place at operational and tactical level during production. The difference between the two levels lies in their decision time horizon. LütkeEntrup *et al.*, 2005; Marinelli *et al.*, 2007; Doganis and Sarimveis, 2007 dealt scheduling decisions at operational level. The tactical level concerns further planning decisions. Integration of operational and tactical level decisions leads to better solutions (Kopanos *et al.*, 2012b; Amorim *et al.*, 2012,; Bilgen and Çelebi, 2013).

LütkeEntrup *et al.* (2005) focus only on the production. Production and storage are mostly integrated components (*e.g.,*Marinelli *et al.*, 2007; Doganis and Sarimveis, 2007; Kopanos *et al.*, 2010). Amorim *et al.* (2012), Kopanos *et al.* (2012b) and Bilgen and Çelebi (2013, 2014) prefer optimizing production, storage and distribution processes simultaneously stirred yoghurt is commonly considered in the literature (LütkeEntrup *et al.*). Authors (Marinelli *et al.*, 2007; Doganis and Sarimveis, 2007; Amorim *et al.*, 2011b)research does not define the type of yoghurt, sequencing of the additional incubation operation explicitly in their papers. The production comprises of fermentation, filling/packaging and incubation operations. The packaging process scan consist of a single unit or multiple parallel units. Doganis and Sarimveis (2007, 2008, 2009) conducted research presenting a methodology for optimal scheduling of a single packaging line and parallel units .Other researches dealt with independently packaging process with hybrid solution approaches (*e.g.,* Marinelli *et al.*, 2007; Amorim *et al.*, 2011b; Bilgen and Çelebi, 2013). The fermentation process is considered with time and capacity constraints by authors LütkeEntrup *et al.*, 2005 and Kopanos *et al.*,2010).

Importance of perishability is considered in supply chain by authors (Amorim *et al.*, 2011a, Karaesmen *et al.*, 2011, LütkeEntrup, 2005). The dairy production is relatively complex due to its highly perishability nature and some degree of shelf life. The shelf life can be considered as a loss or benefit function accounting for the economic value of cleanness products in objective functions (Amorim *et al.,* 2011b, 2012). In addition, Doganis and Sarimveis (2009), LütkeEntrup *et al.* (2005).The production activities are performed daily in a maximum allowed time inclusive of overtime. LütkeEntrup *et al.* (2005) and, Bilgen and Çelebi (2013) considered regular time and overtime issues.

The changeover operations can be taken into account as sequence independent and sequence dependent. Some of the research handles changeover operations as sequence independent by assuming negligible differences or that the different products have almost similar setup durations (*e.g.,* Marinelli *et al.*, 2007;). Others treated with explicit setup treatment (Allahverdi *et al.*, 1999, 2008). Sequence dependent changeovers are common in dairy supply chains (*e.g.,* Van Elzakker *et al.*, 2014*,* LütkeEntrup *et al.*, 2005; Doganis and Sarimveis, 2007; Kopanos *et al.*, 2010).

The integration of the planning and scheduling decisions provides coordination between production, storage and distribution processes. Hence, the integration constitutes a research direction at supply chain level.

MILP is commonly used to define planning and scheduling problems of dairy industry in a mathematical framework (*e.g.,* LütkeEntrup *et al.*, 2005; Marinelli *et al.*, 2007; Doganis and Sarimveis, 2007). Stochastic programming and Simulation are used to account for stochastic properties of the yoghurt production problem (*e.g.,*; Bilgen and Çelebi, 2013). Constraint programming is accepted as an effective approach in solving scheduling problems (Maravelias and Grossmann, 2004b; Harjunkoski and Grossmann, 2002). Marinelli *et al.* (2007) develop a two stage optimisation heuristic using a local search strategy. The heuristic is based on the decomposition of the integrated problem in lot sizing and scheduling sub-problems. Amorim *et al*. (2011b) introduce a bi-objective model on maximization of the life and minimization of production related costs. Bilgen and Çelebi (2013) propose an iterative hybrid optimization-simulation procedure for the scheduling problem in dairy industry. The CP applications (*e.g.,* Castro *et al.*, 2006; and the hybrid MILP/CP approaches (*e.g.,* Harjunkoski *et al.*, 2000; Jain and Grossmann, 2001; Maravelias and Grossmann, 2004a) have been formulated for batch plant scheduling problems. For the planning and scheduling problems, MILP and CP can be used for decomposition heuristics to solve the problem more efficiently (Kilic, 2011).

Perishability issues, sequence dependency and working time planning are other components which can help for the decision-making process are the key features in dairy industry, most of the authors dealt when demand can be forecasted accurately.

Due to the contract signed between the company and a customer the demand could be changed by certain percentage points from the mentioned value. the demand uncertainty interval is [0.9 of demand, 1.1 of demand]. No additional information is available, such as probabilities or distribution function, .The manufacturer aims to satisfy each possible realization of the demand from the uncertainty set, while minimizing the production costs. The question is: how many units should the manufacturer produce?, the problem becomes more complex

From the literature review a gap has been identified to include uncertain demand including consideration of fixed cost in yogurt production .an attempt is made in this plant.

4. MATHEMATICAL FORMULATION

The problem statement and the integrated planning and scheduling MILP model are given as follows. The corresponding parameters and decision variables are listed in the nomenclature.

4.1. Problem Statement

The problem consists of tactical planning and operational scheduling decisions. The production, storage and distribution operations ,inventory age ,work time ,fixed cost are considered in the tactical planning decisions. The product type is set type yoghurt, the packaging and incubation operations are considered in the scheduling decisions.

Assumptions

- Single production plant and multiple distribution centers are considered.
- The demand is considered and backlogging not allowed .inventory balances are updated on a daily basis .production capacities are considered. storage costs considered. An overtime production is allowed in every working day under environment of heavy demand, uncertain demand is also considered.
- A product cannot be processed on more than one line simultaneously and a line cannot process more than one job at a time. The production precedence, preemption, cancellation, batch splitting and mixing are not allowed. The production is limited with minimum and maximum lot-sizes.
- The variable production costs are considered for each product.
- Sequence dependent setups are required because of hygiene and contamination rules. The changeover time and cost are involved for possible transitions between products. Finished products are checked in the final control process.
- The minimum shelf life required by the customers is defined as a critical rate which is a fraction of maximum shelf life. The decrease of shelf life is considered by a loss function.

Indices & Sets

$i \in I^S$	days
$d \in D^S$	demand days
$j,k,t \in P^{S1}$	products $P^{S0} = \{0..P\}$, $\underline{P}^{S1} = \{1..P\}$,
$l \in L^S$	lines
$a \in A^S$	distribution centres

Parameters

$Loss_j$	Cost of the decrease on the shelf life of product *j*, rs/litre per day
$VarCost_j$	Variable production cost of product *j*, rs/litre
$StrgCost_j$	Inventory cost of product *j*, rs/litre
$SetupCost_{jk}$	Changeover cost from product *j*tc
$LineCost_l$	Operating cost of line *l*, rs per day
$PwCost_j$	Wastage cost of product *j* during pa
$IncCost$	Operating cost of incubation room
$OverTCost$	overtime cost, rs/minute
$TransCost_a$	Transportation cost from plant to
$UnmDCost_j$	Unmet demand cost of product *j*,
$CrRate_j$	Minimum shelf life requirement of customer for product *j*, % of shelf life
$IncTime_j$	Incubation time ofproduct *j*, minute

$Demand_{jda}$ Demand of DC *a*for product *j* on demand day *d,* litre
QContTime Quality control time, day
MchSpeedj Machine speed for product j, litre per minute
StCapacity Storage capacity f the plant, minute
IncCapacity Incubation capacity of the plant, minute
$MinLot_j$ Minimum production lots of project *j*, litre
$MaxLot_j$. Maximum production lots of project *j*, litre
$SetupTime_{j\in P^{so}k}$ Changeover time for oroduct j to k
$Maxtime_i$ Maximum available time per day
$RTime_i$ Regular time per day
$Capacity_i$ Production capacity per day
γ_j Factor for converting product quantity to storage unit
M very big number say 10000
$IncDuration_j$ Incubation duration job *j*, minute
T_j The type associated with each interval in the sequence, a non-negative integer
Setup Setup time defined as triple hour *setup* = {<*j,k,st*> | *j,k,in*
ST^S Set of setup times
Fc = fixed cost
β_{maxa} = *factor* greater than 1 for distributor a
β_{mina} = *factor* less than 1 for distributor a

Decision Variable of

x_{ijld} Quantity of product *j* produced on line *l* on day *i* for demand day *d* , litre
y_{jda} Quantity of product *j* produced for DC *a* for demand day *d* , litre
$UnmD_{jda}$ Unmet demand of product *j* for DC *a* on demand day *d* , litre
inv_{ij} Inventory of product *j* at the end of day *i* , litre
$overtime_i$ Overtime on day *i*, minute
PT_{ij} Production time of product *j* on day *i,* minute
$FT_{ij\in P^{S0}l}$ Finishing time of product *j* on line *l* on day *i* , minute
$CmaxLine_{il}$ Maximum completion time of line *l on day i*
$CmaxProduct_{ij\in P^{S0}}$ Maximum completion time of product on day i
$IncNb_{ij\in P^{S0}}$ Number of incubations for product *j on day i*
$binsetup_{ij\in P^{S0}k\in P^{S0}l}$ Changeover from product *j* to *k on line l day i*
$IncSequence_{ij\in P^{S0}k\in P^{S0}}$ Incubation sequence of product *j on day i*
bin_{ijl} Production of product *j* on line *l* on day *i*
x_{jld} Quantity of product *j* produced on line *l* for demand day *d* , litre
PT_j Production time of product *j* , minute
$FT_{j\in P^{S0}l}$ Finishing time of product *j* on line *l* , minute
$CmaxLine_l$ Maximum completion time of line *l* , minute

$CmaxProduct_{j\in P^{S0}}$ Maximum completion time of product *j*

$IncNb_{j\in P^{S0}}$ Number of incubations for product *j*

$binsetup_{j\in P^{S0}k\in P^{S0}l}$ Changeover from product *j* to *k* on line *l* , binary

$Incsequence_{j\in P^{S0}k\in P^{S0}}$ Incubation sequence of product *j* preceding product *k* , binary

$Task_j$ Activities corresponding with each of job *j* , interval variable

$OptTask_{jl}$ Operational activities which has optional size of duration Optional activities correspond with each of job *j* operated on line *l*

$Duration_j$ Size of the $OptTask_{jl}$

Inc_j Incubation activities which has size of *j*

IncTime, Interval variable, Incubation activities correspond with each of job *j*

$Schedule_l$ Variable represents a total order over a set of $OptTask_{jl}$, sequence variable *j T* integer type is used

The key decisions for each planning and scheduling period are; (i) the produced quantity of each product on each line (ii) distribution quantity of each product transported to each DC and corresponding unmet demand, (iii) inventory level of each product, (iv) finishing time of each product on each line, production time of each product and overtime (v) maximum completion times of each product and each line, (vi) number of incubation operation required for each product and incubate.

$$\min Z = \sum_{ijld} x_{ijld} .Lost_j .\left[\frac{(d-i)}{(1-CrRate_j).ShelfLife_j}\right] + \sum_{ijld} x_{ijld} .Var\ \mathrm{Cost}_j$$
$$+\sum_{ij} inv_{ij}.StrgCost_j + \sum_{ijkl} binsetup_{ijkl}.SetupCost_{jk} + \sum_i overtime_i.OverTCost$$
$$+\sum_{il} CmaxLine_{il}.LineCost_l + \sum_{ij} CmaxProduct_{ij}.PwCost_j + \sum_i Inc.Nb_{ij}.IncCost$$
$$+Fc + \sum_{jda} y_{jda} .TransCost_a + \sum_{jda} UnmD_{jda} .UnmDCost_j \quad (1)$$

In Eq.(1), the linear objective function aims at minimizing total cost. The total cost corresponds to cost of the loss of product value caused by deterioration and, production, inventory, changeover, wastage cost, overtime, fixed cost packaging and incubation operations, transportation and unmet demand costs. The loss of product value caused by deterioration is calculated using a shelf life dependent loss function which is adopted from LütkeEntrup *et al.* (2005). The shelf life dependent loss increases linearly for the customer with every additional day of shelf life. For instance, suppose that product *j* has a total shelf life of 15days (*i.e.,* 15_j*ShelfLife*•), the customers require 66% of shelf life as a minimum residual shelf life (*i.e.,*0.66_j*CrRate*•).

Constraints

Shelf life;

$x_{ijld} = 0 \forall i,j,l,d : I > d : \mathrm{QContTime} > (d-i) > (1-\mathrm{CrRate}_j)\cdot \mathrm{ShelfLife}_j$ (2)

above equation says that the demand of demand day *d* cannot be produced after the demand day.

Demand satisfaction;

$$\sum_{a} y_{jda} \leq \sum_{il} x_{ijld} \quad (3)$$

$$Demand_{jda} \leq y_{jda} + UnmD_{jda} \quad (4a)$$

$$Demand_{jda} < \beta_{maxa} * Demand_{jda} \quad (4b)$$

$$Demand_{jda} \geq \beta_{mina} * Demand_{jda} \quad (4c)$$

Eq.(3) provides that the total quantity of product *j* transferred to DCs for demand of day *d* is less than or equal to the total quantity of product *j* produced on line *l* on day *i* . Eq.(4a,b,c) computes the quantity of unmet demand. Backorder is not allowed.

Inventory balance:

$$inv_{ij} \leq \sum_{dl} x_{ijld} - \sum_{a} y_{jld} \qquad \forall i,j : i = 1 \quad (5)$$

$$inv_{ij} \leq inv_{(i-1)j} + \sum_{d} x_{ijld} - \sum_{a} y_{jla} \qquad \forall i,j : i > 1 \quad (6)$$

$$\sum_{j} inv_{ij} \cdot \gamma_{j} \leq StCapacity \qquad \forall i \quad (7)$$

Eq.(5) shows the inventory level only for the first day. Eq.(6) refers to the inventory level of product *j* at the end of day *i* . Eq.(7) converts the inventory of product *j* on day *I* into unit storage (*e.g.,* pallets) by multiplying with the corresponding factor *j* and limits the stored inventory level.

Sequencing of parallel packaging machines

$$PT_{ij} \geq \sum_{ld} x_{ijld} \Big/ MchSpeed_{j} \qquad \forall i,j \quad (8)$$

Eq.(8) shows that processing time

$$\sum_{j \in P^{so}, l: j \neq k} binsetup_{ijkl} \leq 1 \ \forall i,,k \quad (9)$$

Eq.(9) ensures that each product is processed maximum once

$$\sum_{j \in P^{so}: j \neq k} binsetup_{ijtl} - \sum_{k \in P^{so}: k \neq t} \qquad \forall i,t,l \quad (10)$$

$$\sum_{k \in P^{so}} binsetup_{i0kl} \leq 1 \qquad \forall i,l \quad (11)$$

Eq.(10) shows relation between product predecessor and a successor. Eq.(11) ensures that each machine starts with one product

$$FT_{ild} \geq FT_{ijl} + SetupTime_{jk} + PT_{ik} + (binsetup_{ijkl} - 1).M \ \forall i,j \in p^{50},k,l \quad (12)$$

$$FT_{ijl} \leq \sum_{k \in P^{so}: j \neq k} binsetup_{ikjl}.M \qquad \forall i,j,l \quad (13)$$

$$FT_{ijl} \leq CmaxLine_{il} \qquad \forall i,j,l \quad (14)$$

Eq.(12) calculates the product completion times. Eq.(13) enforces the finishing time *j* on line *l* on day *i* to zero. Eq.(14)defines the maximum completion time of day *I* corresponding with line *l*.

$$\sum_{j \in P^{so}: j \neq k} IncSequence_{ijk} \leq 1 \quad (15)$$

$$\sum_{j\in P^{so}:j\neq k} IncSequence_{ijt} - \sum_{k\in P^{so}:k\neq t} IncSequence_{itk} = 0 \qquad (16)$$

$$\sum_{t\in P^{so}:j\neq t} IncSequence_{itj} = \sum_{k\in P^{so}:l,\,j\neq k} binsetup_{ijkl} \qquad \forall i,j \qquad (17)$$

$$\sum_{k\in P^{so}:j\neq k} IncSequence_{i0k} \leq 1 \qquad \forall i \qquad (18)$$

$$IncNb_{ij} \geq \sum_{ld} x_{ijld}.\gamma_j \,/\, IncCapacity \qquad \forall i,j \qquad (19)$$

$$CmaxProduct_{ik} \geq CmaxProduct_{ij} + IncTime_k.IncNb_{ik} + (IncSequence_{ikj} - 1).M \qquad \forall i,j\in p^{50},k \qquad (20)$$

$$CmaxProduct_{ij} \geq \sum_{l} FT_{ijl} + IncTime_j.IncNb_{ij} \qquad \forall i,j\in p^{50},k \qquad (21)$$

$$\sum_{l} FT_{ikl} \geq CmaxProduct_{ij} + (IncSequence_{ikj} - 1).M \qquad \forall i,j\in p^{50},k \qquad (22)$$

Eq.(17) inserts the product *j* into the incubation sequence if product *j* is produced on line *l* on day *i*. Eq.(15) and eq(16) ensures that each product is processed once and must have a predecessor and successor. Eq.(18) provides that the incubation sequence has at most one first product, (*i.e.*, one product sequence). Eq.(19) calculates the number of products lots regarding to maximum capacity of incubation room. Eq.(20) and Eq.(21) are balance equations.Completion time of production on day *I* must be greater than or equal to end of prior packaging and incubation operations, respectively. Eq.(22) presents the timing between packaging and incubation operations. It provides that the packaging operations are finalized just before incubation operation.

$$RTime_i + overtime_i \leq MaxTime_i \qquad \forall i \qquad (23)$$

$$CmaxProduct_{ij} - Rtime_i \leq overtime_i.M \qquad \forall i,j \qquad (24)$$

$$CmaxProduct_{ij} \leq overtime_i + RTime_i \qquad \forall i,j \qquad (25)$$

Eq.(23) limits the total working time Eq.(24) limits the maximum completion time on day *I* Eq.(25) shows that the maximum completion time on day *I* is limited with maximum working time consisting of regular hours and required overtime.

Lot-sizing:

$$\sum_{dl} x_{ijld} \leq MaxLot_j \cdot \sum_{k\in P^{so}:j\neq k} binsetup_{ikjl} \qquad \forall i,j \qquad (26)$$

$$\sum_{dl} x_{ijld} \geq MinLot_j \cdot \sum_{k\in P^{so}:j\neq k} binsetup_{ikjl} \qquad \forall i,j \qquad (27)$$

Eq.(26) and Eq.(27) defines minimum and maximum production lot-sizes by the value of the binary variable as equal to 1 if and only if product j is produced on line.

Integrality and non-negativity constraints which define the domain of the decision variables.

$$x_{ijld}, y_{jda}, inv_{ij}, PT_{ij}, FT_{ij\in P^{so}l}, overtime, UnmD_{jda}, CmaxLine_{il}, CmaxProduct_{ij\in P^{so}}, Z \qquad \forall i,j,l,d,a$$

$$IncNb_{ij} \geq 0 \text{ and integer} \qquad (28)$$

$$Insequence_{ijk},\ binsetup_{ijkl} \in \{0, 1\} \qquad \forall i,j \in P^{S0},k \qquad (29)$$

5. MODEL

The integration includes a big bucket planning and a small bucket scheduling grid. The basic idea of the proposed solution strategy is to handle these different time horizons by dividing the entire model into two distinct sub-models.

Big bucket planning sub-model

A MILP sub-model addresses the planning sub-problem. The big bucket planning sub-model, the planning part of the integrated model is simplified to obtain production targets with a solution which is likely to be sub-optimal. Then, the scheduling sub-model is fed with an input of planning decisions. The planning sub-model is formulated as follows and the corresponding parameters and decision variables are listed in the nomenclature.

5.1. Objective Function

The same monetary objective function *Z* in Eq.(1), which aims at minimization of total costs, is used to be comparable with the integrated model Eq.(2), Eqs.(3), (4) Eqs.(5), (6) and (7), Eq.(8), Eq.(19), Eq.(25) are used in the planning sub-model.

Lot-sizing;

$$\sum_{dl} x_{ijld} \leq MaxLot_j \, .bin_{ijl} \qquad \forall i,j,l \qquad (30)$$

$$\sum_{dl} x_{ijld} \geq MinLot_j \, .bin_{ijl} \qquad \forall i,j,l \qquad (31)$$

Eq.(30) and Eq.(31) define minimum and maximum production lot-sizes with the value of the binary variable corresponding with production decision. The lot-sizing restrictions are adopted from Eq.(26) and Eq.(27). Since the planning sub- model considers planning issues and takes the scheduling information from the scheduling sub-model, it is enough to decide only on allocation of the products to the packaging lines and to the production days instead of determination of sequencing.

$$\sum_{djl} x_{ijld} \leq Capacity_i \qquad \forall i \qquad (32)$$

Eq.(32) is a linkage constraint and limits the capacity produced quantity for each day by taking the capacity values from the heuristic as a parameter.

x_{ijld}, y_{jad}, inv_{ij}, PT_{ijl}, $overtime_i$, $UnmD_{jda}$, Z, $\forall$I,j,l,d,a (33)

$IncNb_{ij} \geq 0$ and integer, $bin_{ijl} \in \{0, 1\}$

The small bucket scheduling problem is to assign each packaging operation to the parallel lines, such that make span is minimized. Two alternative sub-models which are the MILP and CP formulation are introduced for the scheduling sub-problem.

The objective is to minimize the completion time of the production and the constraints are adopted from the scheduling constraints of the integrated MILP model by removing the redundant *I* day indices, since the scheduling corresponds to small bucket time horizon.

$$\min Cmax \qquad (34)$$

The objective function of the scheduling MILP model aiming at minimization of makespan.

Constraints

Sequencing of parallel packaging machines:

$$\sum_{j \in P^{so}, l: j \neq k} binsetup_{jkl} \leq 1 \qquad \forall k \qquad (35)$$

$$\sum_{j \in P^{so}: j \neq t} binsetup_{jtl} - \sum_{k \in P^{so}: k \neq t} binsetup_{tkl} = 0 \qquad \forall t,l \qquad (36)$$

$$\sum_{k \in P^{so}} binsetup_{0kl} \leq 1 \qquad \forall l \qquad (37)$$

$$FT_{kl} \geq FT_{jl} + SetupTime_{jk} + PT_k + (binsetup_{jkl} - 1).M \; \forall l, j \in P^{S0}, k \qquad (38)$$

$$FT_{jl} \leq \sum_{k \in P^{so}: j \neq k} binsetup_{kj} \qquad \forall l,j \qquad (39)$$

$$FT_{jl} \leq CmaxLine_l \qquad \forall l,j \qquad (40)$$

Eq.(35) and Eq.(36) ensures that each product is processed maximum once and must have a predecessor and successor. Eq.(37) ensures that each machine has at most one first product Eq.(38) calculates the product completion times Eq.(39) enforces the finishing time *j* on line *l* to zero, if no corresponding production operation is performed. Eq.(40) defines the maximum completion time of line *l*.

Sequencing of incubation operation

$$\sum_{t \in P^{so}: j \neq t} IncSequence_{tj} = \sum_{k \in P^{so}.t.k \neq t} binsetup_{kjl} \; \forall j \qquad (41)$$

$$\sum_{j \in P^{so}: j \neq k} IncSequence_{jk} \leq 1 \; \forall k \qquad (42)$$

$$\sum_{j \in P^{so}: j \neq t} IncSequence_{jt} - \sum_{k \in P^{so}: k \neq t} IncSequence_{tk} = 0 \; \forall t \qquad (43)$$

$$\sum_{k \in P^{so}} IncSequence_{0k} \leq 1 \qquad (44)$$

$$IncNb_j \geq \sum_{ld} x_{jld}.\gamma_j \,/\, IncCapacity \; \forall j \qquad (45)$$

$$CmaxProduct_k \geq CmaxProduct_j + IncTime_k.IncNb_{ik} + (IncSequence_{kj} - 1).M \quad \forall, j \in p^{50}, k \qquad (46)$$

$$CmaxProduct_j \geq \sum_l FT_{jl} + IncTime_j.IncNb_j \; \forall, j \in p^{50}, k \qquad (47)$$

$$\sum_l FT_{kl} \geq CmaxProduct_j + (IncSequence_{kj} - 1).M \qquad \forall j \in P^{S0}, k \qquad (48)$$

Eq.(41) inserts the product *j* into the incubation sequence if product *j* is produced on line *l* Eq.(42 and 43) ensures that each product is processed once and have a predecessor and successor. Eq.(44) provides that the incubation sequence has almost one first product). Eq.(45) calculates the number of products lots regarding to maximum capacity of incubation room. Eq.(46) and Eq.(47) are balance equations and Completion time of product Eq.(48) presents the timing between packaging and incubation operations.

5.2. The CP sub-Model

The CP methodology is chosen as useful modeling technique overcoming the computational limitations for the scheduling problem. The activities represent an interval of time during which an operation is performed. Each of the intervals is characterized by a start time, an end time and duration between these times. Additionally, the intervals can be considered as optional by using alternative constraints. In the proposed model mainly two activities are presented; Production activities (*i.e.,* $Task_j$, $OptTask_{jl}$ with size of $Duration_j$) and Incubation activities (*i.e.,* Inc_j with size of $IncDuration_j$). The sequence of these activities is decided with a sequence variable $Schedule_l$

The scheduling CP sub-model is formulated as follows and the corresponding parameters and decision variables are listed in the nomenclature

Minimize

$$\max(\text{endOf}(Inc_j) : j \in J^S) \qquad (49)$$

Eq.(49) illustrates the objective function of the scheduling CP model aiming at minimization of makespan. *End Of* is an expression used to access the end time of the given interval. The maximum of the incubation intervals corresponding to job *j* represent the make span value of the schedule.

Constraints

$$\text{alternative}\ (Task_j\, OptTask_{jl}) \qquad \forall j \qquad (50)$$

Eq.(50) provides an alternative constraint between each of $Task_j$ intervals and a set of $OptTask_{jl}$ intervals. This constraint specifies that if the $Task_j$ interval is presented in the solution, then exactly one interval variable of the $OptTask_{jl}$ set exists in the solution. $Task_j$ starts and ends together with this chosen $OptTask_{jl}$ interval.

Overlap prevention:

$$noOverlap(Schedule_l\, ,Setup) \ \forall l \qquad (51)$$

Eq.(51) presents a *no Overlap* constraint on the interval sequence variable *l Schedule* states that the sequence defines a chain of non-overlapping intervals,. It states that if a job is scheduled after another job in the sequence, a sequence dependent setup time must separate the end of the first interval from the start of the following second interval.

$$\text{startAtEnd}(Inc_j\, Task_j) \qquad \forall j \qquad (52)$$

$$\text{endBeforeTask}(Inc_{j-1}.Inc_j) \quad \forall j\ ,j>1 \qquad (53)$$

Eq.(52) and Eq.(53) are precedence constraints which ensure relative positions of intervals in the solution.

Presence:

$$\text{presenceOf}(Task_j) = 0; \qquad Duration_j = 0 \qquad (54)$$

$$\text{presenceOf}(Task_j) = 1; \qquad Duration_j \neq 0 \qquad (55)$$

Eq.(54) and Eq.(55) are precedence constraints ensure that the tasks which have duration values must be scheduled

5.3. Decomposition Algorithm

The algorithm includes a decomposition function and a search procedure. In the decomposition function, the planning sub-model is solved with given capacity limitations and the planning decisions are given to the scheduling sub-model. Then, the scheduling sub-model is solved to schedule planned productions for each day. The scheduling decisions are given to the planning sub-model to calculate the total cost of the proposed production plan and schedule. Note that, the planning sub-model is operated for the first iteration by giving an initial capacity. The initial solution should be large enough to satisfy the demand to start from a broad range of solution space. Hence, the initial capacity is chosen as sum of the demand data (*i.e,* $\sum_{jda} demand_{jda}$).

Once a feasible solution has been reached, the heuristic enters a search procedure that aims to improve the current solution. The decomposition function is embedded in the search procedure to evaluate the other suitable capacity limitations by a simulated annealing algorithm. In the search procedure, the capacity limitations tighten the solution space iteratively to achieve strong results and, continuously updated for each day of the entire planning horizon using the decomposition function, repeatedly. Thereby, each replication supports a sufficient change to make the planning decisions feasible and close to optimal. Neighborhood solutions are generated by a move strategy multiplying the current capacity with a random number for each day. The cooling strategy is a geometric sequence in which the temperature at each step decreases with a certain ratio. The cost-efficient results are kept track and the solution with the minimum cost is presented after the stopping criterion is satisfied. The algorithm stops, if the best solution found does not improve in a limited number of consecutive changes in temperature. The following pseudo code in Algorithm 1 is adopted by adding the decomposition function into the generic simulated annealing algorithm presented by Alizamir *et al.* (2008).

Decomposition Function

Step-1: Solve the big bucket planning sub-model

Step-2: Transfer the planning decisions to the small bucket scheduling sub-model

Step-3: Solve the small bucket scheduling model for each day

Step-4: Transfer the scheduling decisions to the big bucket planning model

Step 5: Calculate the objective value

Planning Decisions

The planning decisions are outputs of the planning MILP sub-model which serve as inputs of the scheduling sub-models. The equations calculating the transferred planning decisions differ in modeling approach of the scheduling sub-model as follows;

$$CmaxLine_i = CmaxLine_{il} \quad \forall i \quad (56)$$

$$CmaxProduct_j = CmaxProduct_{ij} \quad \forall i \quad (57)$$

$$binsetup_{jkl} = binsetup_{ijkl} \quad \forall i \quad (58)$$

Eqs.(56) and (57) provides the transfer the completion times of lines and products, respectively. Eq.(58) provides the transfer of sequence of production and changeovers.

$$Duration_j = \sum_i pt_{ijl} \quad \forall I,j \quad (59)$$

$$IncDuration_j = IncNb_{ij}.IncTime_j \quad \forall i,j \quad (60)$$

Eq.(39) provides that duration of product j is equal to process time of product j and Equation (40) calculates the incubation duration multiplying the number of incubation operation and the incubation times.

Scheduling Decisions

The scheduling decisions are outputs of the scheduling sub-model which serve as inputs of the planning MILP sub-model. The equations calculating the scheduling decisions differ in modeling approach of the scheduling sub-model as follows:

For the scheduling MILP sub-model, the solution values for the decision variables of scheduling MILP sub-model retransferred by the proposed algorithm using Eqs.(56), (57) and (58).

$$CmaxLine_{il} = Schedule_l.end \quad \forall i,l \tag{61}$$

$$CmaxProduct_{ij} = endOf(Inc_j) \ \forall i,l \ ; \ endoftask_j \leq maxtime_i \tag{62}$$

$$binsetup_{ijkl} \begin{cases} 1, & OptTask_{jl} \rightarrow OptTask_{kl} \text{ in } Schedule_i \\ 0, & \text{otherwise} \end{cases} \quad \forall i,l,k \tag{63}$$

For the scheduling CP sub-model, the solution values for the decision variables of scheduling model (i.e., $Schedule_l$, Inc_j, $Task_j$, $OptTas_{jl}k$) are compiled by the proposed algorithm using Eqs.(61), (62) and (63), then given the MILP model as parameter values of $CmaxLine_{il}$, $CmaxProduct_{ij}$, $binsetu_{ijkl}$.

Eq.(61) ensures that the end of schedule for line *l* is equal to completion time of line *l* on day *i*. Eq.(62) guarantees that the end of the incubation operation of product *j* is equal to completion time of product *j* on day *i*. Eq.(63) shows that the binary setup variable is equal to 1 if product *j* precedes product *k* on schedule of line *l* and, otherwise equals 0.

It should be noted for Eqs.(56) to (63) that the same scheduling sub-model is called by planning MILP sub-model recursively for each day (*i.e.,* the variables of the scheduling CP sub-model (*i.e., $Duration_j$*, *$IncDuration_j$*, *$Schedule_l$*, *Inc_j*, *$Task_j$* and *$OptTask_{jl}$*) and the variables of the scheduling MILP sub-model (*i.e., $CmaxLine_l$*, *CmaxProduct* and *$_j binsetu_{jk}p$*) do not include of *i* production day indices.

6. CASE STUDY

The production and distribution network consists of a single plant and seven DCs. The production planning and scheduling is performed for a weekly planning. Regular working time of the plant is 8 hours among 5 working days of the week. If necessary, overtime can be afforded in addition to regular working times. Available working time is limited by maximum 16 hours for each working day. The daily demand of DCs for separate products is collected during working days. two packaging lines and one single room for incubation is considered. The products are operated on these identical parallel lines.

The processing time of a product depends on the produced quantity and the corresponding machine speed. In production, there is a natural sequence in which the various products are to be produced in an order. It stands to reason that each product has different fat consistency and ingredients. The changeover rules arranged with data. Product 1, 2 and 3 requires 120 min changeover time and 60000 rs cost between each other. The corresponding changeover time and cost are 30 min - 35000 rs for the rest of the products. In addition, to set the packaging lines between some certain products is time consuming and costly. The changeover time and cost between the product group of products 1, 2, 3 and the other products are either 30 min-35000 rs for product 4, 5, 6, 7 or 60 min - 45000 rs for product 8, 9, 10, 11. The setup matrix is designed symmetrically. The rest of the input data used is summarized here

Parameters Value(~ between)Unit

Monetary parameters

Cost of the decrease on shelf life	0.1 ~ 0.5 rs / lt per day
Variable production cost	0.09 ~ 0.16 rs / lt
Inventory cost	0.01 ~ 0.07 rs / lt per day
Operating cost of lines	0.3 rs / min.
Production waste cost	0.01 ~ 0.05 rs / min.
Operation cost of incubation room	360 rs per batch
Overtime cost	1 rs / min.
Transportation cost	0.120 ~0.300 rs/ lt
Unmet demand cost	1.4 ~ 2 rs / lt

Technical parameters

Shelf life of product	1 Week
Minimum shelf life required by the customers	66 %
Incubation time	180 ~ 240 min.
Packaging machine speeds	10 ~ 50 lt/min.
Maximum storage capacity	2000 boxes
Maximum incubation capacity	150 boxes
Minimum production lots	100 Lt
Maximum production lots	10,000 Lt
Factor converting quantities to storage unit boxes	0.1 ~ 0.05 boxes /lt

The analysis is performed with respect to changes in the demand. Since a short-term planning horizon of one week is considered,

These conditions are reflected by two scenarios which assume an average workload of 75 and 90% of the available total capacity, respectively. Moreover, since the demand is driven by customer orders of various sizes, the high demand scenario implies a large number of small-sized customer orders while low demand scenario is given by a comparatively small number of large-sized orders. In particular, in a high demand scenario the scheduling complexity is considerably increased because a comparatively large number of production lots have to be established. The demand figures are randomly generated

Determine X as the total number of available operating hours: X·8·5·1·2·80 hours based on 8 hours operating time per day, five days per week, a planning horizon of one week, and two production lines.

- Considering an average workload factor of 75% and 90%, respectively, and a capacity loss of 10 hours due to setup operations,
- The entire set of products can be produced on two lines and N·2·11·22 product-week assignments are achieved
- The average size of demand elements is $D \cdot Y\ n$ hours. In order to create a realistic degree of demand variability for each scenario, actual values of demand elements d are randomly drawn from the uniform distribution $d\cdot\ \{0.5 \cdot D,\ \ 1.5 \cdot D\}$.
- The demand intervals are selected Demand limits β_{max} is considered 1.3 times of average demand to 1 for each distributor and β_{min} 0.8 to 1 times average demand.

From the result of some pilot experiments, the initial temperature 0 *t* is pre-determined as 100. The temperature reduction factor is chosen as 0.90. The number of iterations *p* for each step *p* is equal to 10.The algorithm stops, if the best solution found does not improve in 100 consecutive changes in a temperature.

Table 1 75 % capacity scenario1 experiments result (rs)

	Heuristic		MILP/CP		MILP
S.No.	**Result**	**Time (s)**	**Result (rs)**	**Time (s)**	**Result (rs)**
1	34,68,000	350	37,98,600	1,400	35,20,100
2	25,81,000	1,700	27,87,400	2,000	24,28,300
3	37,63,400	900	41,50,400	1,534	38,70,800
4	27,75,300	1,200	34,03,100	1020	27,92,700
5	24,94,800	700	26,99,900	864	23,95,800
Avg.	**30,16,500**	**970**	**33,67,880**	**1,364**	**30,01,540**

Table 2 75% Capacity load scenario 2 experiments result (rs)

	Heuristic		MILP/CP		MILP
S.No.	**Result**	**Time (s)**	**Result (rs)**	**Time (s)**	**Result (rs)**
1	41,09,200	2,900	38,80,450	1,820	35,60,800
2	37,88,300	1,500	36,95,900	800	36,95,634
3	39,92,400	12,354	41,96,350	4,231	39,89,550
4	45,71,800	16,500	47,53,400	2,300	43,96,100
5	39,53,300	10,005	39,85,600	1,200	40,19,610
Avg.	**40,83,000**	**8,652**	**41,02,340**	**2,070**	**39,32,339**

Table 3 90% Capacity load scenario 1 experiments result (rs)

	Heuristic		MILP/CP		MILP
S.No.	**Result**	**Time (s)**	**Result (rs)**	**Time (s)**	**Result (rs)**
1	39,92,100	100	44,42,000	421	42,52,000
2	32,17,800	352	35,43,200	680	31,78,200
3	30,96,950	234	33,35,900	1,855	31,58,200
4	42,73,100	220	42,20,500	2,643	42,63,600
5	33,50,500	214	33,96,600	1,520	30,52,000
Avg.	**35,86,090**	**224**	**37,87,640**	**1,424**	**35,80,800**

Table 4 90% Capacity load scenario 2 experiments result (rs)

	Heuristic		MILP/CP		MILP
S.No.	**Result**	**Time (s)**	**Result (rs)**	**Time (s)**	**Result (rs)**
1	43,12,925	800	48,65,742	1,800	41,53,152
2	42,98350	10,432	46,74,800	2,735	39,33,810
3	43,26,580	17,580	47,59,600	1,953	36,96,671
4	47,80,564	18,560	52,15,600	2,475	43,95,850
5	41,34,500	17,345	42,45,432	1,800	36,85,430
Avg.	**43,70,584**	**12,943**	**47,52,235**	**2,153**	**39,72,983**

7. CONCLUSION

This paper addresses the integrated production planning and scheduling problem. The problem is motivated from a two-stage semi continuous production process and formulated as a comprehensive MILP model. The objective function of the MILP model aims at minimization of the cost. The key limitation of the overall MILP solution approach lies in the large computational times. The integrated planning and scheduling problem is divided into two distinct sub-problems. The sub-problems are solved by the decomposition heuristic. A hybrid MILP/CP hybrid approach is proposed. And it achieves reasonable solutions with short computational times. The proposed heuristic has given better solution in reasonable time compared to integrated MILP with complex calculation. The heuristic is solved using python software on Pentium i5 processor. MILP is solved using Lingo11.

The major advantages of the proposed approaches are their applicability to different dairy production processes (e.g., cheese, butter, ice cream). It is possible to extend the study in several ways, which can be suggested as future research areas, such as dealing with the non-identical packaging line considerations and dealing with the stochastic and dynamic nature of dairy supply chains and various key characteristics of sustainability issues are promising directions.

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