Journal of Advanced Manufacturing Systems
Vol. 18, No. 3 (2019) 447–467
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DOI: 10.1142/S0219686719500240

Disassembly Scheduling for the Meat Processing Industry with Product Perishability

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The pork processing industry resembles a case of disassembly scheduling because a planner needs to decide the pig size and quantity to be supplied to the slaughtering house, as well as the amount of meat and meat size needed to process an order. The meat processing resembles disassembly scheduling for multiple products with parts in commonality. We extend the general disassembly model further to cover product perishability of the meat while allowing demand to occur in other levels of product hierarchy rather than the leaf product (products that are no longer being disassembled). We also allow the model to obtain outsource products to be processed if it achieves a more economical solution. In this study, we developed a mathematical model to determine the quantity and size of pig supplies (root items) and meat cuts (parent/child items) to be processed for an order to minimize the total cost. Computation time and cost of generated test problems are obtained. The application of pork processing plan is demonstrated.

Keywords: Disassembly scheduling; pig supply chain; pig size; meat industry; mathematical model.

1. Introduction

Typically, disassembly is a process in which used products or end-of-life products are separated into parts, components or other groupings with necessary sorting operations.[1] Hence, disassembly scheduling can be defined as the problem of determining the quantity and the timing of disassembling end-of-use/life products to satisfy the demand of their parts or components. In other words, from the solution of the problem, we can determine which products or subassemblies, how many, and when to disassemble used or end-of-life products to satisfy the demand of their parts or

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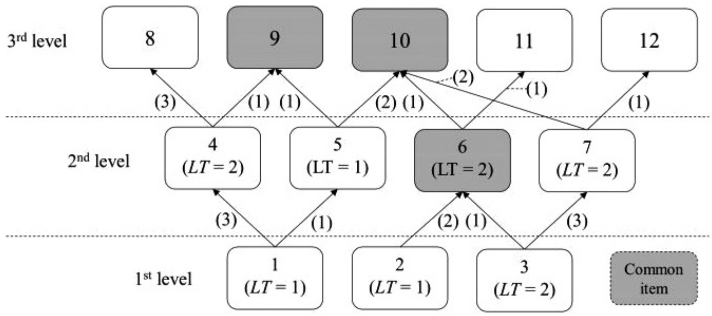
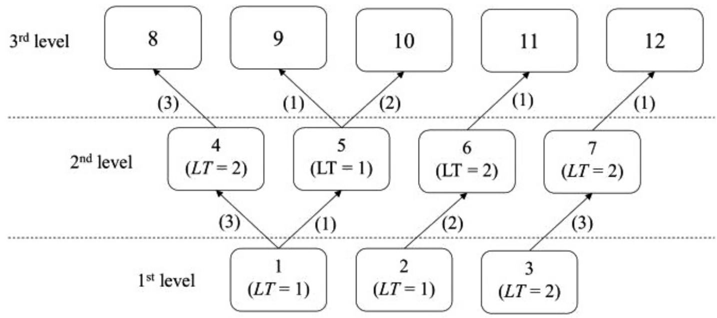
components. From the theoretical point of view, disassembly scheduling is known to be a reversed version of the lot-sizing problem in assembly systems.[2]

Gupta and Taleb[3] were among earlier works that considered the basic case of disassembling single product type without parts commonality. Later, the model has been modified by introducing capacity constraints[1] and multiple products with parts commonality.[4] More intensive reviews of the disassembly problem can be found in Refs. 2 and 5. In general, the disassembly products are structured in the root item (1st level) representing the product to be disassembled, as well as the leaf item representing any item that cannot be further disassembled (3rd level). Between the root and the leaf items, product hierarchy can be disguised according to a child item representing any item that has a parent at the next higher level and a parent item representing any item that has at least two child items at the next lower level.[4] The examples of these structures of multiple products with parts commonality and without commonality are as shown in Fig. 1.

In response to these stated general structures, integer programming has been developed. The objective for the general disassembly concept for used/end-of-life products is to minimize the sum of purchase, set-up, inventory holding, and disassembly operation costs. The objective function allows time-varying purchase costs



(a)



(b)

Fig. 1. Examples of disassembly structure.

for the root item. The assumption of the general disassembly model, stated in Ref. 4, can be summarized as follows: (a) there is no shortage of the root items; (b) demands for leaf items are given and deterministic; (c) backlogging is not allowed; hence, demand should be satisfied on time; (d) disassembly processes are perfect; hence, no defective parts or components obtained from disassembly exist; (e) disassembly lead time of each parent item is given and deterministic; and (f) inventory holding costs are computed based on the end-of-period inventory. For capacity constraint, Lee *et al.*[1] added capacity constraint to the general disassembly case of a single product structure in a form processing time. In the general disassembly structure, the purchase costs incurred only for the root item during set up, and disassembly operation costs are only for the leaf items; finally, inventory holding costs are for all items. Likewise, demand occurs at the leaf item.

The meat cut industry is also a special case for disassembly scheduling that addresses how to decompose a product into multiple sub-products with different demand sources of each component (meat cut). In this study, the customer's order of meat, pork in particular, is placed in terms of specific multiple co-products, components, and meat cuts: ham, shoulder, collar, loin, tender loin, and belly. To be more specific, the orders are usually specified in terms of cuts and division sizes (i.e., ham can be ordered as whole, halved, quartered and sliced; loin chops can be ordered in various thicknesses, such as 0.5, 0.75, 1 and 1.25 inches). A planner converts orders of cuts within the planning horizon into the size and quantity of primal cuts and, thus, the quantity of each pig size to be procured. When a pig is slaughtered, six primal cuts result, though with different sizes depending on the size of the pig. For example, when slaughtering 110 and 120-kg live pigs, the final weight of the carcasses is approximately 85 and 92 kg, respectively, after removal of most internal organs, legs and the head. These carcasses are split into two sides, each of which consists of approximately 16.41, 9.80, 5.20, 7.88, 1.28 and 11.93% of carcass weights for ham, shoulder, collar, loin, tender loin, and belly, respectively. Hence, the 110 kg pig would yield approximately 13.95 kg and 6.70 kg of whole ham and loin, respectively, whereas the 120 kg pig would yield 15.10 kg and 7.25 kg, respectively. In addition, when the different sizes of primal cuts are processed into a particular cut, the process involves different yield losses. In conventional practice, processors match the demand and meat cuts with pig sizes supplied in a trade-off between slaughtering and dressing the existing cuts into desired pieces depending on orders. Thus, selecting which primal cut to process into a meat cut is another critical, cost-saving point for a meat processor.

Though, the concepts of both selecting meat with the lowest yield loss and slaughtering the right size of a pig resembled a disassembly problem, there are some specific characters of agriculture products that are perishability. Moreover, demand in the meat cuts can occur at any level, not only for the leaf items. Hence, in this study, we modify a general structure of the disassembly model to match the characters of the meat processing industry. In this light, the model is used to determine the quantity of each pig size to be supplied to the processing plant and the sizes of primal cuts to be processed for an order such that the total cost of production, inventory, and outsourcing is minimized.

2. Problem Formulation

In our case, the root items are the pigs of each size, and the leaf items are the meat cuts of each size. Additionally, the meat cut type/product (i.e., whole, halved, quartered, and sliced ham and 0.5, 0.75, 1 and 1.25 inches of loin chops) is the child item of the primal cut (i.e., ham, shoulder, collar, loin, tender loin, and belly). Selecting which primal cut to process into a meat cut generates different product cost that makes this meat cut. Demand for meat occurs at any levels of meat cuts. Due to the perishable properties of the meat cut, it is required that the chilled carcass has to be processed into the meat cuts within a certain period (i.e. 2 days). The expired cut should be refrained from being processed further. For capacity of the processor, usually, it is defined as the number of carcasses processed within a day. Hence, our model is developed under the following assumptions: (a) there is no shortage of the root items; (b) demands are given and deterministic; (c) backlogging is not allowed; hence, demand should be satisfied on time; (d) disassembly processes are perfect but has a different cost of dissembling, and no defective parts or components obtained from disassembly exist. The cost of yield loss due to disassembling different cut sizes takes into account the form of disassembly cost; (e) the disassembly lead time of each parent item is given and deterministic; (f) inventory holding costs are computed based on the end-of-period inventory; (g) the items possess a certain shelf-life and have to be processed/disassembled prior to the expiration period; and (h) there is a processing capacity defined in a form of the root item.

For model comparison purposes, our model is structured similar to that of Lee *et al.*[4] by numbering all items in the disassembly structure in the topological order from bottom to top and from left to right, starting with the root item of $i = 1, 2, \ldots, i_r$, the parent items of $i = i_r + 1, 2, \ldots, i_l$, and the leaf item of $i_l + 1, 2, \ldots, I$.

Adapted from the general disassembly case stated earlier, the formulations and descriptions of the proposed mathematical model are provided below.

2.1. *Parameters*

- i Index of item, $i = 1, 2, \ldots, I$.
- k Index of item, $k = 1, 2, \ldots, K$.
- t Index of period, $t = 1, 2, \ldots, T$.
- t' Index of period, $t' = 1, 2, \ldots, T'$.
- $c_{i,t}$ Purchase cost of item i in period t.
- $d_{i,t}$ Demand for item i in period t.
- p_i Unit cost of disassembling item i.
- s_i Setup cost of disassembling item i.

h_i Inventory holding cost of item i.
v_i Cost of discarding perished item i.
a_{ki} Number of items i obtained from disassembling a unit of item k.
l_k Lead time of disassembling item k.
U_i Set of parents of item i.
N_i Maximum number of periods that item i could be held in the inventory storage after disassembly process.
i_r Number of root items.
i_l Number of items which are not leaf items ($i = i_l + 1$ is the index for the first leaf item).
$I_{i,0}$ On-hand inventory of item i (In this study, we assume that $I_{i,0} = 0$).
M A large positive number.
$C_{\max}$ Maximum capacity defined as a capacity of disassembling the root items.

2.2. *Decision variables*

$X_{i,t} \geq 0$ An integer representing number of items i disassembled in period t.
$Y_{i,t} \in \{0,1\}$ $Y_{i,t} = 1$, when item i is disassembled in period t.
$I_{i,t} \geq 0$ Number of item i held in inventory storage in period t.
$W_{i,t} \geq 0$ Number of item i which perished in period t.
$Q_{i,t,t'} \geq 0$ Number of item i obtained in period t that is either being assigned to be Disassembled or be delivered to customer in period t'.
$O_{i,t} \geq 0$ Number of items i obtained in period t from disassembly process and external sources.
$R_{i,t} \geq 0$ Number of item i obtained in period t from external sources.

2.3. *Mathematical model*

Minimize

$$\sum_{i=1}^{i_l}\sum_{t=1}^{T} p_i X_{i,t} + \sum_{i=1}^{i_l}\sum_{t=1}^{T} s_i Y_{i,t} + \sum_{i=1}^{I}\sum_{t=1}^{T} h_i I_{i,t} + \sum_{i=1}^{I}\sum_{t=1}^{T} c_{i,t} R_{i,t} + \sum_{i=1}^{I}\sum_{t=1}^{T} v_i W_{i,t}. \quad (1)$$

Subject to

$$O_{i,t} = X_{i,t} \qquad \text{for } i = 1, 2, \ldots, i_r, \ \forall t, \quad (2)$$

$$O_{i,t} = \sum_{k \in U_i | t-l_k} \geq 1 a_{k,i} X_{k,t-l_k} + R_{i,t} \qquad \text{for } i = i_r + 1, i_r + 2, \ldots, I, \ \forall t, \quad (3)$$

$$\sum_{t'=\max(t-N_i,1)}^{t} Q_{i,t',t} = X_{i,t} + d_{i,t} \qquad \forall i, t, \quad (4)$$

$$O_{i,t} = \sum_{t'=t}^{t+N_i-1} Q_{i,t,t'} + W_{i,t+N_i} \qquad \forall i,\ \text{for } t = 1, 2, \ldots, T - N_i, \tag{5}$$

$$I_{i,t} = I_{i,t-1} + O_{i,t} - \sum_{t'=\max(t-N_i,1)}^{t} Q_{i,t',t} - W_{i,t} \quad \forall i, t, \tag{6}$$

$$\sum_{i=1}^{i_r} X_{i,t} \le C_{\max} \qquad \forall t, \tag{7}$$

$$X_{i,t} \le MY_{i,t} \qquad \forall it, \tag{8}$$

$$X_{i,t} = 0 \qquad \text{for } i = i_l + 1, i_l + 2, \ldots, I,\ \forall t. \tag{9}$$

The objective of the model (1) is to minimize the total cost, which consists of the following: (1) disassembling cost, (2) setup cost, (3) inventory holding cost, (4) outsourcing cost, and (5) perishable cost. Constraint (2) defines the number of root items being disassembled in each period. Constraint (3) defines the number of parent and leaf items obtained from the disassembly process and external sources in each period. Constraint (4) defines the number of items obtained in period t and allocated to either be disassembled or be delivered to customer in period t'. Constraint (5) is production balanced constraint which ensures that the number of items obtained in period t must be allocated to the disassembly process and/or deliver to the customer between period t to period $t + N_i - 1$ and perished items are disposed if they are kept more than N_i periods (i.e. item i that obtained in period t will be perished in period $t + N_i$ unless the item is disassembled and/or delivered to the customer between period t to period $t + N_i - 1$). Constraint (6) is the inventory balanced constraint. Constraint (7) ensures that process must not exceed its maximum capacity of processing root items. Constraint (8) defines the relationship between variables $X_{i,t}$ and $Y_{i,t}$. That is, if item i is disassembled in period t (i.e. $X_{i,t} > 0$), then the setup of disassembly process set $Y_{i,t} = 1$. Constraint (9) guarantees that the leaf items are not be further disassembled.

In the general model of disassembly problem, as stated in Lee *et al.*,[4] the objective is composed of the disassembling cost, setup cost, and inventory holding cost. We add two more costs: procurement cost of procuring intermediate products from external sources to the decision-making process and the cost of discarding perished products into the objective function. Both Lee *et al.*[4] and Prakash *et al.*[6] state that procuring items from external sources do not incur costs because their problem is built within the sphere of remanufacturing and end-of-life products, in which the consumer may compensate the collecting cost. Hence, their models take into account mainly the separation (disassembly) cost, excluding the cost of outsourcing root items. For the pig processing case, we allow the model to consider the most economical way of obtaining intermediate items either by procuring the intermediate items (individual meat cuts) from external sources or by separating the root items (whole pig). Hence, procuring the costs of intermediate products from external sources is essential in the meat processing case, and $R_{i,t}$ is added in Constraint (3).

The last cost, the cost of discarding perished product, is similar to disposal costs, as stated in Ref. 7. However, in Ref. 7, the disposal option is stated again in the sphere of the remanufacturing case. Hence, the disposal options are such as landfills, incineration, or selling to secondary markets. When selling to the secondary markets is an option, the disposal cost may be negative for the objective of minimizing the costs.[7] The inventory balance constraint to address the disposal option, adapted from Ref. 7 is in Constraint (6), while adding perishability character of food product is in Constraint (5).

Though Constraints (4)–(6) are defined in a general form for all items, they can be modified to explain demand, inventory, and disposal options for each level of the disassemble structure. For example, N_i in Constraint (4) can be set according to the perishable time of each level. In the pig processing case, root items (live pigs) have to be slaughtered within one day of the arrival date. Hence, N_i for $i \leq i_r$ is 1 if N_i is defined in days, or it is the number of shifts if they are N_i. Additionally, inventory in Constraint (6) will be updated according to the policy level, as well. By applying the model, there will be no waste $W_{i,t+N_i}$ for $i \leq i_r$ because the model will decide the least number of root items to be procured under the demand constraint. Constraint (4) allows demand to occur at all levels. If, there, the processor does not allow selling live pigs (root items), $d_{i,t}$ is 0 and Constraint (4) becomes $\sum_{t-N<t'\leq t} Q_{i,t',t} = X_{i,t}$, for $i \leq i_r$, $\forall t$.

3. Case Studies

3.1. *General case to explore the logic of the model*

To demonstrate the logic of the developed model multiple products with parts commonality (Fig. 1(a)) and without commonality (Fig. 1(b)), they were compared in the case where perishable period N_i is 2 and 3. The case study product structures for both with and without parts commonality, as shown in Figs. 1(a) and 1(b), are converted to be an input of the mathematical model as shown in Table 1. It is interpreted as follows: Item 1 in the 1st level is disassembled into 3 and 1 units of Items 4 and 5, respectively, within one period production lead time. Assumed costs and demands for each item are as shown in Table 2. Planning horizon is 8 periods. Table 3 demonstrates the linkage among variables $O_{i,t}$, $X_{i,t}$, $I_{i,t}$, $W_{i,t}$, and $Q_{i,t,t'}$. For example, when $X_{1,1} = 10$ units of Item 1 is dissembled, we will be able to obtain 30 units of Item 4 in period 2, $O_{4,2} = 30$ (from $a_{1,4} = 3$ multiply by $X_{1,1} = 10$) and 10 units of item 5, $O_{5,2} = 10$ (from $a_{1,5} = 1$ multiply by $X_{1,1} = 10$). Of all these $O_{4,2} = 30$, it is used to be dissembled further into Items 8 and 9 for 25 units in period 4 and satisfy demand of Item 4 in period 3, $d_{4,3} = 5$ units ($Q_{4,2,2} = 25$, $Q_{4,2,3} = 5$, $O_{8,4} = 75$, $O_{9,4} = 25$). This is because production time to disassemble Item 4, l_4, is 2 and $a_{4,8} = 3$ and $a_{4,9} = 1$. Hence, to disassemble Item 4 in period 2, we will be able to obtain Items 8 and 9 in period 4. Note that $I_{4,2} = 5$ units was resembled from 5 (from $O_{4,2} = 30$ and $Q_{4,2,2} = 25$ thus 30–25 = 5) units of Item 4 in processed in period 2

Table 1. Examples of disassembly product structure.

Product level	Item	Lead time (period)	1st level			2nd level				3rd level				
			1	2	3	4	5	6	7	8	9	10	11	12
Obtained item from common product structure (unit)														
1st level	1	1				3	1							
	2	1						2						
	3	2						1	3					
2nd level	4	2								3	1			
	5	1									1	2		
	6	2										1	1	
	7	2										2		1
3rd level	8	—												
	9	—												
	10	—												
	11	—												
	12	—												
Obtained item from uncommon product structure (unit)														
1st level	1	1				3	1							
	2	1						2						
	3	2							3					
2nd level	4	2								3				
	5	1									1	2		
	6	2											1	
	7	2												1
3rd level	8	—												
	9	—												
	10	—												
	11	—												
	12	—												

have to be kept for 1 period to satisfy demand in period 3, $d_{4,3}$. Of all 10 units of Item 5 ($O_{5,2} = 10$) in period 2, only 8 units ($X_{5,2} = 8$) is processed further. Hence, 2 units is in kept in the storage $I_{5,2} = 2$. Because it is not being used, $I_{5,3}$ is also 2. The product perishes after 2 periods ($N_5 = 2$), therefore, it is discarded after 2 periods and $W_{5,4}$ is 2.

Note that in Table 4, comparing between with and without parts commonality using the product structure in Fig. 1 and the parameters in Table 2, the total number of the root items (Items 1–3) required to satisfy this set of demand for commonality case are 40 units ($10 + 20 + 5$ of items 1–3, respectively, in period 1 and 10 units of item 2 in period 3), while it is 61 units for the case without commonality. Likewise, perishable time is lengthier, so the model suggests combining the production in lesser batch to reduce set cost. For example, in the case of commonality part, for $N_i = 2$, it suggests to process Item 2 in two batches: one batch of 20 units in period 1 and the other for 5 units in period 3 while it suggests to process all 25 units in a batch when $N_i = 3$.

Table 2. Data used for problem illustration.

Product level	Item	Inventory holding cost	Setup cost	Perishable cost	Disassembly cost	Demand							
						Period							
						1	2	3	4	5	6	7	8
1st level	1	1.2	650	14	2.4								
	2	1.2	500	20	4.3								
	3	1.4	500	18.5	3.7								
2nd level	4	0.8	400	11	3.4			5					
	5	0.8	350	17	2.5								
	6	0.7	400	17	4.6				15				
	7	0.7	300	16	2.7								
3rd level	8	0.3	250	10.5	2.1				30	45			
	9	0.5	150	11	3.5					20			
	10	0.7	150	11	4.8			15	25	15			
	11	0.6	150	9	4.1					40			
	12	0.6	100	10.5	5					15			

The performance of the proposed mathematical model is demonstrated using 16 problem sets for the parts commonality with different combinations of 10, 15, 20, and 25 number of products (P) and 10, 15, 20, and 25 number of planning periods (T). For each problem set, 10 generated problems are tested. In total, 160 problems are tested. These and the other parameters used for evaluation process are summarized in Table 5. An optimization software, LINGO 13.0, linked with Microsoft Excel is used to solve the problems on a personal PC with a Core (TM) 2 Quad CPU, 2.33 GHz and 4 GB of RAM. The maximum runtime of the LINGO was set to 7,200 s. The average total cost and computational times are shown in Table 6. All optimal solutions for 10 periods and all four tested number of products are attained. When expanding the planning horizon to 15 periods, three optimal solutions for 25 products are attained; the rest of the three numbers of products (15, 20, and 25) is still attainable. None of the optimal solutions are found for the cases of 25 products and 20 periods, likewise for 15, 20, and 25 products and 25 periods. The results show that most small-to-medium sized test problems can be solved within a reasonable computational time. The gaps from lower bounds were very small, ranging from 0.73 to 6.33. For larger test problems, we construct cases of 60, 120, and 180 items with number of items in the 1st, 2nd, and 3rd levels as indicated in Table 7. Its results show that the gaps from lower bounds were very small, ranging from 0.81 to 4.27 indicating the capability of the model in solving industrial-size cases.

Note in Table 8 that the longer the perishable time, the lesser the costs of disassembly, although with a higher inventory cost. This is because the model avoids the higher cost of perishable items by buying intermediate or leaf products from other sources. When shelf life is short, by nature, it needs to disassemble more of the root products than with a longer shelf life. The lengthier perishable time allows the model to consider using more of the inventory items; hence, the cost of disassembly is

Table 3. Disassembly planning for the illustration case of $N = 2$ with parts commonality.

Decision variable	Product level	Item	Period							
			1	2	3	4	5	6	7	8
$O_{i,t}(X_{i,t})$	1st	1								
		2								
		3	5							
	2nd	4								
		5								
		6			5					
		7								
	3rd	8				75				
					8	25				
					16					
		11								
		12					15			
$I_{i,t}(W_{i,t})$	1st	1								
		2								
		3								
	2nd	4		5						
		5		2	2					
		6			5					
		7								
	3rd	8				45				
					8	33				
					1	16				
		11								
		12								

Decision variable	Product level	Item	Period														
			t	2		3		4		5		6		7		8	
			t'	2	2	3	3	4	4	5	5	6	6	7	7	8	8
$Q_{i,t,t'}$	1st	1															
		2					5										
		3	5														
	2nd	4			25	5											
		5			8												
		6						5									
		7					15										
	3rd	8								45							
							15		25		15						
		11															
		12									15						

Table 4. Disassembly planning of illustration case of under different product structures and perishable time length.

Product level	Item	Disassembly plan (N =2, with parts commonality)								Disassembly plan (N =3, without parts commonality)							
		Period								Period							
		1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
1st	1	10								10							
	2	20		5						25							
	3	5								5							
2nd	4		25								25						
	5		8								8						
	6		40								40						
	7			15								15					
3rd	8																
	9																
	10																
	11																
	12																
Product level	Item	Disassembly plan ($N = 2$, with parts commonality)								Disassembly plan ($N = 3$, without parts commonality)							
		Period								Period							
		1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
1st	1	28								28							
	2		28								28						
	3	5								5							
2nd	4		25								25						
	5		8	20							28						
	6			41								41					
	7			15								15					
3rd	8																
	9																
	10																
	11																
	12																

lower while incurring higher inventory cost. Knowing inventory level in advance also give an edge to the marketer for executing marketing strategies to exploit the inventory.

3.2. *The demonstration of disassembling plan of the meat processing case*

To demonstrate the disassembling plan of the meat industry, we use the same case as in Fig. 2. The tested problem composing of 60 product items: 5 sizes of live pig (root item). For each size of pig carcass, there are 6 primal cuts to be obtained ($5 \times 6 = 30$

Table 5. Parameters for generating problem sets.

Parameter	Symbol	Value
Number of items	I	[10,15,20,25]
Number of planning periods	T	[10,15,20,25]
Disassembly cost	p_i	U[1,3]
Setup cost	s_i	U[100,300]
Inventory holding cost	h_i	U[1,10]/10
Outsourcing cost	$c_{i,t}$	U[100,500]
Perishable cost	v_i	U[10,30]
Lead time	l_k	U[1,3]
Perishable period length	N_i	U[2,4]
Customer demand	d_i	U[1,100]

items of the 2nd level). And the number of leaf items in this case is 25. The part commonality is indicated by more than one arrow path from the precedent level (i.e. 37, 38, 40). The input of the model (demand and costs) are shown in Table 9. The disassembly costs of the product are set to be higher for larger live pigs and hence its corresponding meat cuts.

For the part commonality, it implies that assigning a larger size of primal meat to cut into the antecedent level is more expensive than the smaller ones. In this case, the outsourcing cost of each item is assumed to be 3 times higher than using the raw material within its own supply chain. When this condition is stated, it infers that outsourcing the live pig (root item) to the third party is not an economical choice. Also, to mimic the practice of the industry, obtaining the leaf items (finished goods) from a third party is refrained. Therefore, a constraint refraining outsourcing of the finished goods, $R_{i,t} = 0$, $i_l + 1, 2, \ldots, I$ (where in this case, it is Item 36–60) is added to the model. For the waste cost, the perished meat is assumed to be sold at 40% discount.

To better reflect the meat industry, note that the general disassembly model commands that the disassembling decision, $X_{i,t}$ be an integer. To the disassembling of an electronic product, it is a straight forward logic. Disassembling an electronic product will certainly retrieve a fixed number of parts. However, for the meat product, one meat cut can be dissected into different smaller cut sizes (items). Applying the general approach instead of assigning one precedent cut into one antecedent cut. The planner has to determine first the proportion of the cut to be allocate to the next level. For example, in Table 10, Item 1 (live pig size 1) is disassembled into 6 primal cuts of Item 6–11. And these items and can be dissected further into 4 cuts each. The model will determine the optimal way to utilize these four pieces of each item without having to assign the whole primary cut to one leaf item. We can decide whether to use the whole or some of the pieces to satisfy the demand, or disassemble them further. Also notice that Item 45 demonstrates broadly the parts with commonality case that the item can be processed from a certain primal cut of all pig sizes, though with different costs.

Table 6. Result comparisons.

(a) Performance of the mathematical model.

Number of items	Number of periods															
	10				15				20				25			
	Opt*	Gap**			Opt*	Gap**			Opt*	Gap**			Opt*	Gap**		
		Avg.	Min.	Max.		Avg.	Min.	Max.		Avg.	Min.	Max.		Avg.	Min.	Max.
10	10	0.00	0.00	0.00	10	0.00	0.00	0.00	10	0.00	0.00	0.00	6	1.57	0.55	3.35
15	10	0.00	0.00	0.00	10	0.00	0.00	0.00	8	0.72	0.67	0.76	0	1.36	0.28	5.31
20	10	0.00	0.00	0.00	10	0.00	0.00	0.00	2	1.08	0.22	2.09	0	2.81	1.10	4.31
25	10	0.00	0.00	0.00	3	0.73	0.32	1.35	0	1.26	0.14	3.97	0	3.73	1.07	6.33

(b) Comparison of computation time (in seconds).

Number of items	Number of periods											
	10			15			20			25		
	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.
10	1.10	<1	3	17.20	4	88	56.20	5	169	3254.40	95	>7200
15	2.50	1	8	70.00	11	312	2433.10	42	>7200	>7200	>7200	>7200
20	21.40	2	77	1352.60	20	6560	6251.10	1793	>7200	>7200	>7200	>7200
25	26.40	7	77	6051.40	885	>7200	>7200	>7200	>7200	>7200	>7200	>7200

Notes: * Number of problems (out of 10 problems) that gave the optimal solutions.
**Percentage deviation of the best solutions from the lower bound (averaged over problems that optimal solutions are not obtained).

Table 7. Performance of the mathematical model for meat processing industry.

Number of items	Number of items			%GAP			Runtime (s.)
	1st Lv.	2nd Lv.	3rd Lv.	Avg.	Min.	Max.	
60	5	30	25	2.47	1.36	4.27	300
120	10	60	50	1.12	0.66	1.72	600
180	15	90	75	0.81	0.49	1.36	900

Table 8. Sensitivity analysis for increasing perishable time.

Cost	Scenario					
	Without commonality			With parts commonality		
	$N = 2$	$N = 3$	$N = 4$	$N = 2$	$N = 3$	$N = 4$
Disassembly cost	6,962.00	5,430.67	4,442.67	6,210.67	4,521.33	3,648.00
Setup cost	3,580.49	3,611.58	3,516.35	2,847.88	2,659.93	2,577.58
Inventory holding cost	1,871.77	2,609.04	3,167.61	2,494.93	3,287.54	4,121.91
Outsourcing cost	23,845.67	21,105.00	18,470.33	35,323.00	28,329.67	25,690.00
Perishable cost	12,176.67	11,500.00	13,053.33	8,720.00	11,856.67	13,283.33
Total cost	48,436.59	44,256.29	42,650.29	55,596.48	50,655.13	49,320.82
Computation time (s.)	8.25	7.00	9.28	32.90	80.46	105.12

Notes: 30 problems, 15 problems with uncommon item structure and 15 problems with common item structure, were generated.
Perishable period length was set to 2–4.
Total 90 problems, number of items (I) and number of periods (T) are 15, were solved.

Applying the proposed model to the case study, the disassembly plan is obtained as shown in Tables 11–13. The first level indicating the quantity of live pigs and sizes to be slaughtered in each planning period. In period 1, the model recommends slaughtering 222 live pigs (63, 84, 60, and 15 of Items 1–3, and 5, respectively).

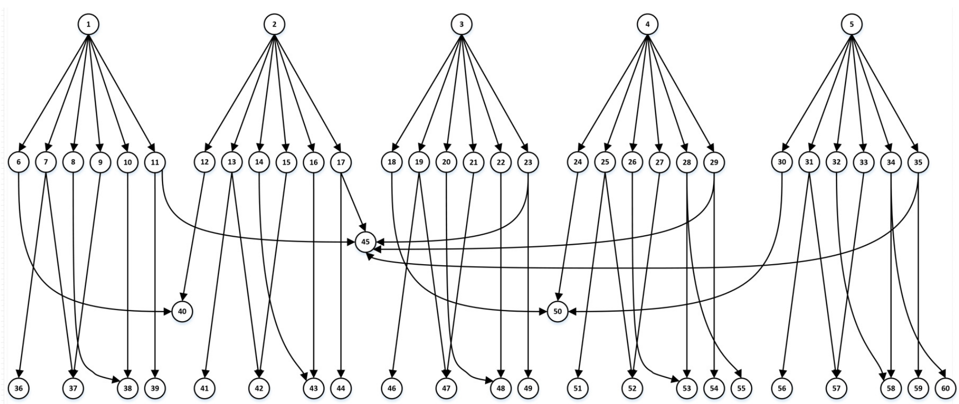


Fig. 2. Examples of disassembly structure for swine case study.

Table 9. Input data for swine industry.

Product level	Item	d(i,t) Period 1	2	3	4	5	6	7	8	9	10	11	12	13	14	p(i)	c(i,t)	v(i)	h(i)	s(i)	l(k)	N(i)
1st (Live pig)	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4,250	12,750	1,700	340	15,000	1	3
	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5,000	15,000	2,000	400	15,000	1	3
	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5,750	17,250	2,300	460	15,000	1	3
	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6,500	19,500	2,600	520	15,000	1	3
	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7,250	21,750	2,900	580	15,000	1	3
2nd (Primary cuts)	6	-	-	-	-	70	-	190	30	-	-	-	40	-	-	266	797	106	21	10,000	1	3
	7	-	70	200	-	-	-	-	-	-	-	120	200	-	-	266	797	106	21	10,000	1	3
	8	-	140	160	20	-	200	200	-	180	80	-	-	-	-	170	510	68	14	10,000	1	3
	9	-	10	60	20	50	190	160	-	20	80	150	-	-	-	117	351	47	9	10,000	1	3
	10	-	-	50	-	50	-	60	60	-	-	80	-	-	-	106	319	43	9	10,000	1	3
	11	-	-	-	150	-	170	-	30	80	190	140	-	-	-	53	159	21	4	10,000	1	3
	12	-	-	-	80	-	140	-	100	90	50	130	-	-	-	313	938	125	25	10,000	1	3
	13	-	40	10	-	90	180	-	130	-	110	50	-	-	-	313	938	125	25	10,000	1	3
	14	-	-	-	40	90	140	10	-	-	60	200	150	-	-	200	600	80	16	10,000	1	3
	15	-	140	40	130	30	160	-	-	-	10	-	-	-	-	138	413	55	11	10,000	1	3
	16	-	-	-	-	180	-	40	-	60	-	-	-	-	-	125	375	50	10	10,000	1	3
	17	-	-	-	80	190	-	-	-	60	-	120	-	-	-	63	188	25	5	10,000	1	3
	18	-	40	180	140	-	30	-	150	-	80	90	-	-	-	359	1,078	144	29	10,000	1	3
	19	-	-	-	130	120	200	180	190	170	200	-	150	-	-	359	1,078	144	29	10,000	1	3
	20	-	-	-	50	100	120	-	-	-	-	-	120	-	-	230	690	92	18	10,000	1	3
	21	-	-	-	200	-	120	-	-	-	30	90	50	-	-	158	474	63	13	10,000	1	3
	22	-	120	200	-	190	70	-	-	-	30	-	70	-	-	144	431	58	12	10,000	1	3
	23	-	50	40	-	40	170	200	-	110	-	-	-	-	-	72	216	29	6	10,000	1	3
	24	-	-	-	120	10	190	40	120	200	-	160	170	-	-	406	1,219	163	33	10,000	1	3
	25	-	-	-	90	-	120	-	80	-	-	-	-	-	-	406	1,219	163	33	10,000	1	3
	26	-	-	-	-	130	-	-	-	-	-	180	-	-	-	260	780	104	21	10,000	1	3
	27	-	-	-	-	40	110	-	110	170	10	-	140	-	-	179	536	72	14	10,000	1	3
	28	-	40	10	90	-	-	-	-	90	10	150	90	-	-	163	488	65	13	10,000	1	3
	29	-	140	20	-	180	-	10	-	-	20	-	80	-	-	81	244	33	7	10,000	1	3
	30	-	60	360	-	20	60	20	-	-	50	70	-	-	-	453	1,359	181	36	10,000	1	3
	31	-	10	460	160	-	80	-	40	-	200	190	-	-	-	453	1,359	181	36	10,000	1	3
	32	-	50	190	-	-	-	-	-	40	190	-	-	-	-	290	870	116	23	10,000	1	3
	33	-	-	60	10	-	140	-	-	-	120	-	-	-	-	199	598	80	16	10,000	1	3
	34	-	-	-	120	180	10	-	10	-	110	180	130	-	-	181	544	73	15	10,000	1	3
	35	-	10	420	150	30	150	-	40	-	110	70	80	-	-	91	272	36	7	10,000	1	3
3rd (Finished product)	36	-	-	-	-	160	-	500	370	260	-	240	-	-	-	-	398	53	11	-	1	3
	37	-	-	210	310	-	-	130	330	120	240	-	-	-	-	-	266	35	7	-	1	3
	38	-	-	270	340	390	90	-	140	-	470	300	410	-	-	-	128	17	3	-	1	3
	39	-	-	-	-	260	360	80	-	-	-	240	300	-	-	-	80	11	2	-	1	3
	40	-	-	370	-	-	260	40	500	170	110	460	-	-	-	-	199	27	5	-	1	3
	41	-	-	450	180	-	40	290	90	160	390	330	-	-	-	-	469	63	13	-	1	3
	42	-	-	-	450	480	-	170	-	-	50	-	-	-	-	-	313	42	8	-	1	3
	43	-	-	500	420	430	-	-	-	-	-	80	430	-	-	-	300	40	8	-	1	3
	44	-	-	230	-	-	400	500	-	60	310	-	-	-	-	-	63	8	2	-	1	3
	45	-	-	220	-	290	-	230	360	-	-	100	-	-	-	-	53	7	1	-	1	3
	46	-	-	-	-	-	-	220	460	-	-	90	390	-	-	-	539	72	14	-	1	3
	47	-	-	340	-	420	-	-	190	400	-	30	-	-	-	-	539	72	14	-	1	3
	48	-	-	120	310	-	120	340	60	-	-	10	380	-	-	-	345	46	9	-	1	3
	49	-	-	-	-	260	-	120	-	270	360	-	240	-	-	-	108	14	3	-	1	3
	50	-	-	200	-	340	370	-	420	-	170	-	-	-	-	-	539	72	14	-	1	3
	51	-	-	-	-	20	40	200	-	180	210	-	110	-	-	-	305	41	8	-	1	3
	52	-	-	-	110	480	310	-	210	350	60	120	360	-	-	-	406	54	11	-	1	3
	53	-	-	-	-	-	-	-	270	210	-	-	430	-	-	-	195	26	5	-	1	3
	54	-	-	90	-	-	200	-	100	-	-	490	-	-	-	-	122	16	3	-	1	3
	55	-	-	-	360	-	410	90	370	70	290	50	180	-	-	-	260	35	7	-	1	3
	56	-	-	220	70	310	70	-	450	-	-	50	-	-	-	-	340	45	9	-	1	3
	57	-	-	-	260	-	430	220	-	280	20	-	-	-	-	-	680	91	18	-	1	3
	58	-	-	-	-	-	180	360	90	-	-	440	270	-	-	-	435	58	12	-	1	3
	59	-	-	-	-	-	-	-	220	230	70	300	-	-	-	-	91	12	2	-	1	3
	60	-	-	-	330	-	310	-	-	60	-	230	-	-	-	-	181	24	5	-	1	3

$O_{6,2}$ is 252 (obtained from the product of 63 pigs of $X_{1,1}$ and 4 pieces of a_{16}). Of all 252 pieces of Item 6, $X_{6,2}$ and $Q_{6,2,2} = 93$ was processed in period 2 and $I_{6,2}$ 116 is kept as inventory. For the rest, $Q_{6,2,4}$ is processed again in period 4 for 43 pieces while the, $W_{6,5}$, 116 expired cuts are sold at a discount price. For the outsourcing plan as shown in Table 11, as indicate earlier, there is no outsourcing of the root items (live pig) due to its cost advantage and, likewise, the leaf items (finished product) due to processor policy. Hence, the primal cut (2nd level) is lightly supplied by a trustworthy party.

To implement the proposed model, the output variable that is crucial for the planner are $X_{i,t}$, which for the first level is the number of live pigs of different sizes to

Table 10. Product structure for swine industry.

Product level	Item k	Item i																																																									
		1st (Live pig)					2nd (Primary cuts)																													3rd (Finished product)																								
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
1st (Live pig)	1	-	-	-	-	-	4	4	4	4	4	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	-	-	-	-	-	-	-	-	-	-	-	4	4	4	4	4	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	4	4	4	4	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	4	4	4	4	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	4	4	4	4	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2nd (Primary cuts)	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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	13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-
	19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	2	-	-	-	-	-	-	-	-	-	-	-	-	-
	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-
	21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
	22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-
	23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-
	24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-
	25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	3	-	-	-	-	-	-	-	-
	26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	3	-	-	-	-	-
	27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-
	28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	3	-	-	-	-	-
	29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-
	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-
	31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	2	-	-	-
	32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-
	33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-
	34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	3
	35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-

Table 11. Decision variables ($X_{i,t}$, $R_{i,t}$, $O_{i,t}$).

Product level	Item	X(i,t)														R(i,t)														O(i,t)													
		Period														Period														Period													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1st (Live pig)	1	63	17	-	47	-	58	-	37	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	63	17	-	47	-	58	-	37	20	-	-	-	-	-
	2	84	-	45	-	25	-	-	41	37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	84	-	45	-	25	-	-	41	37	-	-	-	-	-
	3	60	20	80	55	-	-	45	-	35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	60	20	80	55	-	-	45	-	35	-	-	-	-	-
	4	-	32	-	57	-	-	21	45	-	23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	32	-	57	-	-	21	45	-	23	-	-	-	-
	5	15	114	-	-	49	-	22	-	70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15	114	-	-	49	-	22	-	70	-	-	-	-	-
2nd (Primary cuts)	6	-	93	-	75	-	-	168	-	142	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	252	68	-	190	-	232	-	148	80	-	-	-	-
	7	-	-	80	-	-	250	315	-	120	-	-	-	-	-	-	-	30	-	2	60	83	-	-	-	212	-	-	-	-	252	98	-	190	60	315	-	148	80	212	-	-	-
	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	10	-	-	-	-	-	-	-	-	-	252	68	-	190	10	232	-	148	80	-	-	-	-
	9	-	94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	2	-	-	-	-	252	68	-	190	-	232	-	148	80	2	-	-	-
	10	-	250	-	-	58	-	-	-	295	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	252	68	2	188	-	232	-	148	80	-	-	-	-
	11	-	-	-	350	-	-	-	-	270	-	-	-	-	-	-	-	-	180	-	-	-	-	-	110	140	-	-	-	-	252	68	180	188	-	232	-	148	190	140	-	-	-
	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	336	-	180	-	100	-	-	164	148	3	-	-	-
	13	-	315	-	160	-	130	-	-	360	-	-	-	-	-	-	19	10	-	70	210	-	130	196	-	12	-	-	-	-	355	10	180	70	310	-	130	360	148	12	-	-	-
	14	-	336	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	95	-	-	-	-	336	-	180	-	100	-	-	164	151	95	-	-	-
	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	336	-	180	-	100	-	-	164	148	-	-	-	-
	16	-	-	339	-	-	-	-	-	-	255	-	-	-	-	-	-	3	-	-	-	-	-	-	3	-	-	-	-	-	336	3	180	-	100	-	-	164	151	-	-	-	-
	17	-	77	-	179	-	141	-	-	104	-	-	-	-	-	-	-	-	-	10	41	-	-	-	-	-	-	-	-	-	336	-	180	10	141	-	-	164	148	-	-	-	-
	18	-	100	-	91	279	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	240	80	320	220	-	-	180	-	140	-	-	-	-
	19	-	-	-	110	-	230	-	45	-	195	-	-	-	-	-	-	-	-	-	-	110	55	170	255	150	-	-	-	-	240	80	320	220	-	110	235	170	395	150	-	-	-
	20	-	215	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	240	80	320	220	-	-	180	-	140	-	-	-	-
	21	-	340	-	200	-	-	-	40	-	-	-	-	-	-	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	340	80	320	220	-	-	180	-	140	-	-	-	-
	22	-	-	-	-	260	-	-	-	-	195	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	240	80	320	220	-	-	180	-	140	-	-	-	-
	23	-	-	-	190	-	135	-	180	-	120	-	-	-	-	-	-	-	-	-	-	-	-	110	-	-	-	-	-	-	240	80	320	220	-	-	180	110	140	-	-	-	-
	24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	36	20	-	238	-	-	-	-	-	128	-	228	-	4	120	200	-	330	-	-	-
	25	-	-	38	-	-	108	-	-	180	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	128	-	228	-	-	84	180	-	92	-	-	-
	26	-	-	90	-	136	-	-	-	174	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	128	-	228	-	-	84	180	-	92	-	-	-
	27	-	-	-	262	-	79	-	-	-	-	-	-	-	-	-	-	-	134	-	1	-	26	-	-	48	-	-	-	-	-	128	134	228	1	-	110	180	-	140	-	-	-
	28	-	-	31	-	-	177	-	-	-	-	-	-	-	-	-	40	-	3	-	-	-	-	-	-	-	-	-	-	-	40	128	3	228	-	-	84	180	-	92	-	-	-
	29	-	45	-	-	150	-	-	-	245	-	-	-	-	-	-	185	-	-	-	-	4	-	-	1	-	-	-	-	-	185	128	-	228	-	4	84	180	1	92	-	-	-
	30	-	-	-	79	-	116	-	85	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	60	456	-	3	196	-	88	-	280	-	-	-	-
	31	-	55	113	-	-	113	-	13	-	-	-	-	-	-	-	5	117	160	-	-	-	-	-	-	72	-	-	-	-	65	573	160	-	196	-	88	-	280	72	-	-	-
	32	-	-	-	-	-	121	-	78	-	135	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	60	456	-	-	196	-	88	-	280	-	-	-	-
	33	-	-	-	-	177	-	-	134	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	60	456	-	-	196	-	88	-	280	-	-	-	-
	34	-	-	110	104	-	-	-	142	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	52	-	-	-	-	60	459	-	-	196	-	88	-	280	52	-	-	-
	35	-	-	-	-	-	-	174	-	-	100	-	-	-	-	-	-	3	61	30	-	128	-	-	-	32	-	-	-	-	60	459	61	30	196	128	88	-	280	32	-	-	-
3rd (Finished product)	36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	160	-	-	500	630	-	240	-	-	-	-
	37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	282	240	-	-	750	945	-	360	-	-	-	-
	38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1,000	-	-	232	-	-	-	1,180	-	-	-	-
	39	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	700	-	-	-	-	540	-	-	-	-
	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	372	-	300	-	-	672	-	568	-	-	-	-
	41	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	630	-	320	-	260	-	-	720	-	-	-	-
	42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	945	-	480	-	390	-	-	1,080	-	-	-	-
	43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	672	678	-	-	-	-	-	-	510	-	-	-
	44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	231	-	537	-	423	-	-	312	-	-	-	-
	45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	366	-	2,157	450	828	522	540	1,857	660	-	-	-
	46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	220	-	460	-	90	-	390	-	-	-
	47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	340	-	420	-	460	-	130	-	390	-	-	-
	48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	430	-	-	520	-	-	-	-	390	-	-	-
	49	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	380	-	270	-	360	-	240	-	-	-
	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	200	-	340	558	232	-	170	-	-	-	-	-
	51	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	152	-	-	432	-	-	720	-	-	-	-
	52	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	114	786	-	561	-	-	540	-	-	-	-
	53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	484	-	544	708	-	-	696	-	-	-	-
	54	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	90	-	-	300	-	-	-	490	-	-	-	-
	55	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	363	-	408	531	-	-	522	-	-	-	-
	56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	220	452	-	-	452	-	52	-	-	-	-	-
	57	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	110	226	-	354	226	-	294	-	-	-	-	-
	58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	220	208	-	242	-	440	-	270	-	-	-
	59	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	522	-	-	300	-	-	-
	60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	330	312	-	-	-	426	-	-	-	-	-

Table 12. Decision variable ($Q_{i,t,t'}$).

Product level	Item	1			2			3			4			5			6				7			8			9			10			11			12			13	14
		1	2	3	2	3	4	3	4	5	4	5	6	5	6	7	1	6	7	8	7	8	9	8	9	10	9	10	11	10	11	12	11	12	13	12	13	14	-	-
1st (Live pig)	1	63	-	-	17	-	-	-	-	-	47	-	-	-	-	-	-	58	-	-	-	-	-	37	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	84	-	-	-	-	-	45	-	-	-	-	-	25	-	-	-	-	-	-	-	-	-	41	-	-	37	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	60	-	-	20	-	-	80	-	-	55	-	-	-	-	-	-	-	-	-	45	-	-	-	-	-	35	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	-	-	-	32	-	-	-	-	-	57	-	-	-	-	-	-	-	-	-	21	-	-	45	-	-	-	-	-	23	-	-	-	-	-	-	-	-	-	-
	5	15	-	-	114	-	-	-	-	-	-	-	-	49	-	-	-	-	-	-	22	-	-	-	-	-	70	-	-	-	-	-	-	-	-	-	-	-	-	-
2nd (Primary cuts)	6	-	-	-	93	-	43	-	32	36	-	-	-	34	-	156	-	-	-	-	202	30	-	-	-	-	142	-	-	-	-	40	-	-	-	-	-	-	-	-
	7	-	-	-	70	182	-	98	-	-	-	-	-	-	190	-	-	60	-	-	315	-	-	-	-	-	120	-	28	-	80	-	12	200	-	-	-	-	-	-
	8	-	-	-	140	112	-	48	20	-	-	-	-	-	190	-	-	10	-	-	200	-	32	-	-	-	148	-	-	80	-	-	-	-	-	-	-	-	-	-
	9	-	-	-	104	60	2	-	18	50	-	-	-	-	190	-	-	-	-	-	160	-	20	-	-	-	-	-	148	80	-	-	2	-	-	-	-	-	-	-
	10	-	-	-	250	-	-	50	-	-	-	2	-	106	-	35	-	-	-	-	25	60	147	-	-	-	148	-	-	-	80	-	-	-	-	-	-	-	-	-
	11	-	-	-	-	-	252	-	68	-	180	-	-	-	170	-	-	-	-	-	-	30	202	-	-	-	148	-	-	190	-	-	140	-	-	-	-	-	-	-
	12	-	-	-	-	-	40	-	-	-	40	-	140	-	-	-	-	-	-	100	-	-	-	-	-	-	90	-	29	50	98	-	3	-	-	-	-	-	-	-
	13	-	-	-	355	-	-	10	-	-	160	20	-	70	-	-	-	310	-	-	-	-	-	130	-	-	360	-	-	110	38	-	12	-	-	-	-	-	-	-
	14	-	-	-	336	-	-	-	-	-	40	90	50	-	-	-	-	90	10	-	-	-	-	-	-	-	-	-	164	60	36	55	-	95	-	-	-	-	-	-
	15	-	-	-	140	40	40	-	-	-	90	30	60	-	-	-	-	100	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-
	16	-	-	-	-	336	-	3	-	-	-	180	-	-	-	-	-	-	40	-	-	-	-	-	-	-	60	104	-	151	-	-	-	-	-	-	-	-	-	-
	17	-	-	-	77	-	259	-	-	-	-	180	-	10	-	-	-	141	-	-	-	-	-	-	-	-	164	-	-	-	120	-	-	-	-	-	-	-	-	-
	18	-	-	-	140	100	-	80	-	-	231	89	-	190	30	-	-	-	-	-	-	-	-	150	-	30	-	-	-	50	90	-	-	-	-	-	-	-	-	-
	19	-	-	-	-	-	240	-	-	80	-	-	320	40	110	70	-	-	-	-	110	-	-	235	-	-	170	-	-	395	-	-	-	150	-	-	-	-	-	-
	20	-	-	-	215	-	-	-	-	-	50	-	-	100	120	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	120	-	-	-	-	-	-	-	-
	21	-	-	-	340	-	-	-	80	-	320	-	-	-	120	-	-	-	-	-	-	-	-	40	-	30	-	-	-	-	90	50	-	-	-	-	-	-	-	-
	22	-	-	-	120	120	-	80	-	-	-	300	-	150	70	-	-	-	-	-	-	-	-	-	-	155	-	-	-	70	-	70	-	-	-	-	-	-	-	-
	23	-	-	-	50	-	155	40	35	5	-	15	305	20	-	200	-	-	-	-	-	-	-	180	-	-	110	-	-	120	-	-	-	-	-	-	-	-	-	-
	24	-	-	-	-	-	-	-	120	8	-	-	-	2	190	36	-	-	-	-	4	-	-	120	-	-	200	-	-	-	-	-	160	170	-	-	-	-	-	-
	25	-	-	-	-	-	-	38	90	-	-	-	-	-	228	-	-	-	-	-	-	-	-	80	-	-	180	-	-	-	-	-	-	-	-	-	-	-	-	-
	26	-	-	-	-	-	-	90	-	38	-	-	-	228	-	-	-	-	-	-	-	-	-	-	82	-	92	-	88	-	-	-	92	-	-	-	-	-	-	-
	27	-	-	-	-	-	-	-	128	-	134	-	-	40	188	-	-	1	-	-	-	-	-	110	-	-	170	10	-	-	-	-	-	140	-	-	-	-	-	-
	28	-	-	-	40	-	-	41	87	-	3	-	-	-	177	-	-	-	-	-	-	-	-	-	68	-	22	10	148	-	-	-	2	90	-	-	-	-	-	-
	29	-	-	-	185	-	-	20	-	108	-	-	-	222	-	6	-	-	-	-	4	-	-	-	84	-	161	19	-	1	-	-	-	80	-	-	-	-	-	-
	30	-	-	-	60	-	-	360	79	17	-	-	-	3	-	-	-	176	20	-	-	-	-	85	-	-	-	-	-	50	70	-	-	-	-	-	-	-	-	-
	31	-	-	-	65	-	-	573	-	-	160	-	-	-	-	-	-	193	-	3	-	-	-	50	-	38	-	-	-	162	118	-	72	-	-	-	-	-	-	-
	32	-	-	-	50	-	-	190	-	-	-	-	-	-	-	-	-	121	-	75	-	-	-	3	40	45	-	-	-	280	-	-	-	-	-	-	-	-	-	-
	33	-	-	-	-	-	-	60	10	177	-	-	-	-	-	-	-	140	-	46	-	-	-	88	-	-	-	-	-	120	-	-	-	-	-	-	-	-	-	-
	34	-	-	-	-	55	-	55	224	180	-	-	-	-	-	-	-	10	-	152	-	-	-	-	-	88	-	-	-	22	128	130	52	-	-	-	-	-	-	-
	35	-	-	-	10	50	-	370	89	-	61	-	-	30	-	-	-	150	46	-	128	-	-	40	-	48	-	-	-	162	70	48	-	32	-	-	-	-	-	-
3rd (Finished product)	36	-	-	-	-	-	-	-	-	-	-	160	-	-	-	-	-	-	-	-	500	-	-	370	260	-	-	-	-	-	240	-	-	-	-	-	-	-	-	-
	37	-	-	-	-	-	-	210	70	-	240	-	-	-	-	-	-	-	-	-	130	-	-	330	120	-	-	-	-	240	-	-	-	-	-	-	-	-	-	-
	38	-	-	-	-	-	-	270	340	390	-	-	-	-	-	-	-	90	-	140	-	-	-	-	-	-	-	-	-	470	300	410	-	-	-	-	-	-	-	-
	39	-	-	-	-	-	-	-	-	-	-	-	-	260	360	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	240	300	-	-	-	-	-	-	-	-
	40	-	-	-	-	-	-	370	-	-	-	-	-	-	260	40	-	-	-	-	-	-	-	500	170	2	-	-	-	108	460	-	-	-	-	-	-	-	-	-
	41	-	-	-	-	-	-	450	180	-	-	-	-	-	40	280	-	-	-	-	10	90	160	-	-	-	-	-	-	390	330	-	-	-	-	-	-	-	-	-
	42	-	-	-	-	-	-	-	450	-	-	-	-	480	-	-	-	-	-	-	170	-	-	-	-	-	-	-	-	50	-	-	-	-	-	-	-	-	-	-
	43	-	-	-	-	-	-	500	-	172	420	258	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	80	430	-	-	-	-	-	-
	44	-	-	-	-	-	-	230	-	-	-	-	-	-	400	137	-	-	-	-	363	-	60	-	-	-	-	-	-	310	-	-	-	-	-	-	-	-	-	-
	45	-	-	-	-	-	-	220	-	-	-	-	-	290	-	-	-	-	-	-	230	-	-	360	-	-	-	-	-	-	-	-	100	-	-	-	-	-	-	-
	46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	220	-	-	-	-	-	460	-	-	-	-	-	-	90	-	-	-	-	390	-	-	-	-	-	-
	47	-	-	-	-	-	-	340	-	-	-	-	-	420	-	-	-	-	-	-	-	190	270	-	-	-	130	-	-	-	-	-	30	-	-	-	-	-	-	-
	48	-	-	-	-	-	-	120	310	-	-	-	-	-	-	-	-	120	340	60	-	-	-	-	-	-	-	-	-	-	-	-	10	380	-	-	-	-	-	-
	49	-	-	-	-	-	-	-	-	-	-	-	-	260	-	120	-	-	-	-	-	-	270	-	-	-	-	360	-	-	-	-	-	240	-	-	-	-	-	-
	50	-	-	-	-	-	-	200	-	-	-	-	-	340	-	-	-	370	-	188	-	232	-	-	-	-	-	170	-	-	-	-	-	-	-	-	-	-	-	-
	51	-	-	-	-	-	-	-	-	-	-	20	40	-	-	-	-	-	-	-	200	-	180	-	-	-	-	-	-	210	-	110	-	-	-	-	-	-	-	-
	52	-	-	-	-	-	-	-	-	-	110	-	4	480	306	-	-	-	-	-	-	210	350	-	-	-	-	-	-	60	120	360	-	-	-	-	-	-	-	-
	53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	270	210	-	-	-	-	-	-	-	-	430	-	-	-	-	-	-	-	-
	54	-	-	-	-	-	-	90	-	-	-	-	-	-	-	-	-	200	-	100	-	-	-	-	-	-	-	-	-	-	490	-	-	-	-	-	-	-	-	-
	55	-	-	-	-	-	-	-	-	-	360	-	2	-	-	-	-	408	-	-	90	370	70	-	-	-	-	-	-	290	50	180	-	-	-	-	-	-	-	-
	56	-	-	-	-	-	-	220	-	-	70	310	70	-	-	-	-	-	-	-	-	450	-	-	-	-	-	-	50	-	-	-	-	-	-	-	-	-	-	-
	57	-	-	-	-	-	-	-	110	-	150	-	76	-	-	-	-	354	-	-	220	-	6	-	-	-	274	20	-	-	-	-	-	-	-	-	-	-	-	-
	58	-	-	-	-	-	-	-	-	-	-	-	180	-	-	208	-	-	-	-	152	90	-	-	-	-	-	-	440	-	-	-	-	270	-	-	-	-	-	-
	59	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	220	230	70	-	-	-	-	-	-	300	-	-	-	-	-	-	-
	60	-	-	-	-	-	-	-	-	-	330	-	-	-	310	-	-	-	-	-	-	-	-	-	-	-	60	-	230	-	-	-	-	-	-	-	-	-	-	-

Table 13. Decision variable ($I_{i,t},\ W_{i,t}$).

Product level	Item	*I(i,t)*														*W(i,t)*													
		Period														Period													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1st (Live pig)	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2nd (Primary cuts)	6	-	159	227	152	156	156	30	-	6	86	86	40	-	-	-	-	-	-	116	-	-	-	-	-	-	6	40	-
	7	-	182	-	-	190	-	-	-	28	108	200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	8	-	112	20	-	190	-	32	32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	9	-	148	156	136	190	-	72	72	200	148	-	-	-	-	-	-	-	-	86	-	-	-	-	52	-	-	-	-
	10	-	2	20	22	100	82	254	147	-	80	-	-	-	-	-	-	-	-	2	18	-	47	-	-	-	-	-	-
	11	-	252	320	-	188	18	250	202	-	-	-	-	-	-	-	-	-	-	-	-	-	18	-	-	-	-	-	-
	12	-	336	336	436	140	100	100	-	74	172	45	-	-	-	-	-	-	-	296	-	-	-	-	-	-	45	-	-
	13	-	-	-	20	-	-	-	-	-	38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	14	-	-	-	140	50	10	-	-	164	255	150	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	15	-	196	156	206	60	-	-	-	164	302	302	138	-	-	-	-	-	-	116	-	-	-	-	-	-	164	138	-
	16	-	336	-	180	-	100	60	60	104	-	-	-	-	-	-	-	-	-	-	-	-	-	60	-	-	-	-	-
	17	-	259	259	180	-	-	-	-	-	148	28	28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	28	-
	18	-	100	-	89	30	-	-	30	30	90	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	19	-	240	320	400	500	70	-	-	-	-	150	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	20	-	25	105	375	470	270	-	180	180	320	140	20	-	-	-	-	-	-	25	80	270	-	-	-	180	-	20	-
	21	-	-	80	-	220	100	100	140	140	250	50	-	-	-	-	-	-	-	-	-	-	100	-	-	110	-	-	-
	22	-	120	-	320	90	20	-	180	180	95	70	-	-	-	-	-	-	-	-	-	20	-	-	-	25	-	-	-
	23	-	190	230	360	505	200	-	-	-	20	20	20	-	-	-	-	-	-	35	-	-	-	-	-	-	-	20	-
	24	-	-	128	8	226	36	-	-	-	-	170	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	25	-	-	90	-	228	-	-	4	4	4	92	92	92	-	-	-	-	-	-	-	-	-	-	-	4	-	-	92
	26	-	-	38	38	-	-	-	84	90	90	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-
	27	-	-	128	-	188	-	-	-	10	-	140	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	28	-	-	87	-	228	51	51	84	174	164	90	-	-	-	-	-	-	-	-	-	-	51	-	-	16	-	-	-
	29	-	-	108	108	6	6	-	84	19	-	92	12	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12
	30	-	-	96	17	-	20	-	3	3	233	160	160	-	-	-	-	-	-	-	-	-	-	-	-	3	-	160	-
	31	-	-	-	-	-	3	3	38	38	118	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	32	-	10	276	276	266	75	75	85	45	-	-	-	-	-	-	-	-	-	10	266	-	-	-	-	-	-	-	-
	33	-	60	456	446	209	56	56	10	-	160	160	160	-	-	-	-	-	-	60	209	-	-	10	-	-	-	160	-
	34	-	60	409	185	-	186	186	122	88	258	130	-	-	-	-	-	-	-	5	-	-	-	34	-	-	-	-	-
	35	-	50	89	-	-	46	-	48	48	118	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3rd (Finished product)	36	-	-	-	160	-	-	-	260	-	240	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	37	-	-	72	2	2	-	620	1,235	1,115	615	120	120	-	-	-	-	-	-	-	2	-	-	-	620	495	-	120	-
	38	-	-	730	390	-	142	142	2	-	710	410	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-
	39	-	-	-	-	440	80	-	-	-	540	300	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	40	-	-	2	2	302	40	-	172	2	460	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-
	41	-	-	180	-	320	280	250	160	-	330	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	42	-	-	945	495	495	-	220	220	220	1,030	1,030	1,030	-	-	-	-	-	-	-	495	-	-	-	220	-	-	1,030	-
	43	-	-	172	430	-	-	-	-	-	-	430	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	44	-	-	1	1	538	137	60	60	-	2	2	2	-	-	-	-	-	-	-	1	-	-	-	-	-	-	2	-
	45	-	-	146	146	2,013	2,317	2,915	1,210	1,300	2,559	2,957	2,417	560	-	-	-	-	-	-	146	-	1,867	450	598	162	540	1,857	560
	46	-	-	-	-	220	220	460	-	90	90	390	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	47	-	-	-	-	-	-	460	270	-	-	360	360	360	-	-	-	-	-	-	-	-	-	-	-	-	-	-	360
	48	-	-	310	-	-	400	60	-	-	-	380	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	49	-	-	-	-	120	120	270	270	360	-	240	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	50	-	-	-	-	-	188	420	-	170	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	51	-	-	-	152	132	92	232	232	52	510	510	400	-	-	-	-	-	-	-	-	92	-	-	52	-	-	400	-
	52	-	-	-	4	310	-	561	351	1	480	360	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
	53	-	-	-	484	484	1,028	1,252	982	228	696	696	266	-	-	-	-	-	-	-	-	484	-	544	228	-	-	266	-
	54	-	-	-	-	-	100	100	-	-	490	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	55	-	-	-	3	3	1	441	71	1	232	182	2	-	-	-	-	-	-	-	-	1	-	-	1	-	-	2	-
	56	-	-	-	382	72	2	452	2	54	52	2	-	-	-	-	-	-	-	-	-	2	-	-	2	-	2	-	-
	57	-	-	110	76	76	-	6	6	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	58	-	-	-	220	428	248	90	-	440	440	270	-	-	-	-	-	-	-	-	-	40	-	-	-	-	-	-	-
	59	-	-	-	-	-	-	-	302	72	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-
	60	-	-	-	-	312	2	2	-	366	366	136	-	-	-	-	-	-	-	-	-	-	2	-	-	-	136	-	-

be supplied to the processor in each planning period, and the next level is the primal cut i to be disassembled in period t; the outsourcing plan, the time and quantity of each cut to be retrieved from the third party; and the waste and inventory of each cut in each period. Learning the quantities of waste and inventory of each cut in advance enables the marketing and sales department to effectively search for proper channels to distribute the inventory in time to command the highest possible price in advance. For the costs, the accuracy of the cost elements (disassembling, setup, inventory holding, outsourcing, and perishable costs) are crucial for the effectiveness of the model and the decision to reflect the processor policy. In this light, the activity-based costing method similar to those suggested by Kabinlapat and Sutthachai[8] in particular for meat industry may be necessary.

4. Conclusion

In this paper, the problem of determining the ordering and disassembly schedules of the meat industry is developed while satisfying the demand of items over a given planning horizon. The model is extended from the general disassembly more in Ref. 4 by adding some specific characters of agriculture products, which is perishability, and demand in the meat cuts can occur at any level, not only for the leaf items. Therefore, in this study, we modify a general structure of disassembly model to match the characters of the meat processing industry. The model takes into account the disassembling, setup, inventory holding, outsourcing, and perishable costs. Similar to the general disassembly model, the proposed model is with the objective of minimizing the number of root items to be disassembled. There are, in total, 160 problems tested (16 problem sets each with ten generated problems). The model is able to obtain the optimum solutions fairly well for the case of the 25 number of products and 10 planning periods. Other trade-off mechanisms among inventory cost, perishability cost, disassembly cost, and outsourcing cost are revealed through the results of the test problems, as well. The larger size of the problem with 60, 120, and 180 items were also tested and the results indicate the mathematical model perform reasonable well with a small gap between solutions and lower bounds. In the last section, the structure of the part commonality representing the meat industry is reviewed. We demonstrate the applications of the model to facilitate the meat processing plan from procuring live animals, the decision to process each meat cut, the decision to purchase intermediate items from the third party, and the decision to sell the inventory of meat cuts that is not in the processing plan to the market. Though we use pork cuts to state the case, the concept itself is applicable to other meat industries as well as other perishable products.

Acknowledgments

The authors acknowledge Betagro Hybrid International Company Limited and Betagro Science Center Company Limited for help in collecting data, for providing invaluable guidance and for making this research possible. The research was funded by Faculty of Economics, Khon Kaen University.

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