Product Launch Decision Making for Non-preemptive Product Development Process

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Abstract

This paper presents a method of addressing the resource-constraint problem associated with non-preemption in product development (PD) process. In this work, we specifically consider the development of multiple products across a planning horizon where development personnel and development durations are the main constraints that delay product launch. Relevant PD parameters were employed in defining the problem, and the problem was modelled as a contiguous-cells transportation problem with the objective of minimizing the "lost revenue" associated with the re-scheduling of PD processes due to unavailability of product development personnel. A hypothetical problem of scheduling six products across ten development quarters was then used to demonstrate the applicability of the model which yielded favorable results for product development schedules with minimal lost revenues. The result obtained shows that the method is effective and can be adopted by researchers and professionals to aid decision making in product development.

Keywords:
Product development, Non-preemption, Contiguous-cells transportation problem.

1. Introduction
Profitability has always been the focus of manufacturing organizations. However, for any manufacturing organization to remain sustainable and competitive, attention must be given to innovations, particularly in the direction of developing new products to meet customer needs (Kogabayev and Maziliauskas, 2017; Silinevica et al. 2016). Launching a new product at the right time is essential to the success of the product, and this has become the focus of many production firms. This is because the earlier the product gets to customers, the higher the chances of the product amassing the largest market share. However, this is not the case in many real-life situations due to several factors that cause delays in product release. One major factors that is responsible for delays in product launch is the unavailability of development personnel. This issue may occur in cases where the firm relies on external teams for the PD process where the external development team may be engaged in other projects at the scheduled PD time. The problem becomes critical in situations when there are multiple products to be developed and the PD process is one that cannot be interrupted due to the nature of the products, or the setup cost associated with the PD process. In such a situation, there is every possibility of re-scheduling the development process of some products, thereby reducing the likelihood of the products to meet up with the expected time to market and leading to revenue losses. Fortunately, some products may have better market performance than others. Thus, one practical solution to this problem lies in making the decision to ensure that the most marketable products are developed and launched so as to mitigate the effects of unavailability of development personnel. The non-preemptive nature of the problem as described is one which is similar to the contiguous-cells transportation problem. Hence, this study focuses on adopting the contiguous-cells transportation model of solving non-preemptive scheduling problems to address the non-preemptive personnel-constrained problem associated with the PD process. The motivation for this study is based on a previous work on the contiguous-cells transportation problem which has been found useful in solving non-preemptive scheduling problems (Adewole et al. 2020).

1.1 Objectives

The objectives of the research are stated as follows:

1. To define the non-preemptive new product development problem as a contiguous-cells transportation problem.
2. To identify all the parameters of the problem, state model assumptions and develop a mathematical model of the problem.
3. To develop an algorithm for solving the problem.
4. To demonstrate the application of the model using a realistic case example.

2. Literature Review

According to Bhuiyan (2011), the PD process consists of the activities carried out by firms when developing and launching new products. Also referred to as New Product Development (NPD), the concept focuses on formulating methods for guiding all the processes involved in getting a new product to market which in turn generates revenue for business owners. To further buttress the importance of the PD process, Kazimierska and Magdalena (2017) stressed that the PD process is essential for the creation of products intended to satisfy the needs of customers and to create competitive advantage for product manufacturers in the market.

The PD process comes with many challenges. Recent trends in PD suggest that there has been significant decline in PD productivity, where the level of output is not commensurate with business investments (Cooper and Edgett, 2008; Rankin and Mintu-Wimsatt, 2017). Major challenges such as *trade-offs*, *time pressure* and *product development economics* are usually encountered, and are not favorable to the success of the product. Researchers have thus contributed to developing methods to address the wide range of problems that hinder the PD process. Cooper and Edgett (2008) gave an outline of principles such as spiral development approach and portfolio management techniques to aid in improving the performance of the PD process. The work of Zhao and Yassine (2020) focused on applying convex optimization methods to address the problem of budget and performance constraints in the PD process. Li et al (2019) emphasized the need for a data-driven approach in PD by integrating the *knowledge discovery and data mining* (KDDM) process with the traditional NPD process to improve the performance of products to meet customer needs particularly during the concept development stage of the product.

Apart from the afore-mentioned challenges faced by the PD process, one major factor that decides the success of any new product is timeliness. Also referred to as *time-to-market*, it is the tendency of the product to be the first to get into market, among other competing products serving similar purpose. The capability of TTM in evaluating product success rests on the fact that the success of any new product is directly tied to how much revenue it draws in upon its release. TTM has now become a yardstick for measuring product success and has gained attention from researchers and professionals. Jaifer et al. (2020) addressed the problem of cost and time overruns in PD projects by developing a framework for identifying and analyzing the most important time and effort drivers. Their work identified factors such as “degree of change in design” and “technology maturity” as complexity drivers, while factors such as “team skills” and “risk management” were classified as proficiency drivers. Ogura et al. (2019) focused on reducing production lead time by applying convex optimization methods to optimally allocate resources for product development projects having multiple dependencies. Sun et al. (2017) proposed a robust data-analytics tool, using *CRISP-DM* to aid in the management of product lifecycle, in a view to reduce manufacturing lead times for make-to-order manufacturing firms. All these evidences suggest a connection between timeliness has some monetary impact on the PD process and the sales life of any new product.

In PD process, timeliness is usually affected by limitations in development resources ranging from development funds to materials, personnel, etc. Several attempts have been made by researchers to address the variants of issues arising from resource allocation in PD process. A *performance generation model* (PGM) was presented by Nitindra et al. (2001) to develop best strategies for activities utilizing limited number of resources whilst considering performance and meeting up with product deadline. Wang et. al (2002) introduced a continuous flow model which incorporates resource interchangeability and simultaneous resource sharing in NPD processes and went further to develop a dynamic rule-based algorithm for finding optimal resource utilization in processing multiple activity. Jeremy and Stylianos (2010) developed a normative model for selecting the best resource allocation process, considering asymmetry of information between stakeholders and organizational norms affecting managerial choices. While there is evidence of research being conducted with regards to improving timeliness in PD, extensive review of literature reveals that not much attention has been given to the problem of scheduling the development of multiple products to meet up with their respective deadlines, in a personnel-constrained situation. This problem is more frequently encountered in cases where the development process cannot be interrupted, making it a non-preemptive PD problem. Fortunately, the contiguous-cells transportation model is one model that can handle cases of non-preemptive scheduling with applications in resource-constrained maintenance scheduling (Adewole et al. 2020; Charles Owaba et al, 2015). Hence, addressing the personnel-constrained non-preemptive NPD process using the contiguous-cells transportation model is the focus of this study.

3. Methods

Problem Definition

The non-preemptive NPD problem using contiguous-cells transportation method is stated as follows: Given M distinct products to be developed and T periods available for development, (in which development is carried out without preemption); determine the set of contiguous periods y_{ij} (i.e., contiguous-cells) required for developing each product, which minimizes the total lost revenue, whilst simultaneously satisfying the constraints of personnel capacity and development duration.

Model Assumptions

The following assumptions are set to develop the model:

1. The total numbers of periods (T) are fixed and contiguous.
2. A product is either on queue or in for processing at any given period.
3. Ready time for developing each product is known.
4. A product that is ready for processing has its activities commencing only when resources are available. Otherwise, it waits.
5. The problem parameters are known.
6. The lost revenue for each product spans over contiguous periods.
7. The length of a period may be in any unit of time (i.e., seconds, hours, days, month, quarters, etc.).
8. When a product is ready, activities commence at the beginning of the period while completion is at the end of the period.
9. Preemption is not allowed (i.e., once development begins on a product, it runs until completion without interruption).
10. Total production and development cost does not change over time

Model Notations

Notations used in the general model formulation are as follows:
i : Index indicating the product to be developed
j: Index indicating the time (period) of contiguous cells
M: Total number of products to be developed
T: Total number of periods in planning horizon
B_i : Number of periods required to develop product i
t_i : Number of periods product i stays in the system
H_i : Period in which development was completed on product i
k_i : Period in which product i is ready for development
s_i : Period in which development commences on product i
Dp_i : Development personnel required for product i
T_{mij} : Time to market for product i
D_{ij} : Due date for product i
N_i : Sales life of product i
r_{ij} = Lost revenue of product i in period j
A_j : Available development personnel at period j
y_{ij} : A contiguous variable for set of periods spent on actual development of product i

$$y_{ij} = \begin{cases} B_i\,,\ \ number\ of\ contiguous - cells\ commencing\ from \\ \quad (j - B_i + 1)th, \quad if\ cell\ j\ is\ the\ last\ cell\ among \\ \ \ contiguous - cells\ assigned\ for\ the\ development \\ \\ -, \qquad otherwise \end{cases}$$

Development of Lost Revenue Function

For contiguity, the lost revenue is evaluated as 'cumulative' over the set of contiguous periods. Hence, if D_{ij} is the due date for product i, H_i is any period in which processing is completed on product i (where D_i, $H \in T$); and R_{ij} is the cumulative value of the lost revenue, until the end of period H,
Then:

$$R_{ij} = \begin{cases} \sum_{j=D_{ij}+1}^{H_i} r_{ij}, & if\ H_i > D_{ij} \\ 0, & if\ H_i \leq D_{ij} \end{cases} \quad (1)$$

The structure of the contiguous-cells transportation tableau is as shown in Table 1.

Table 1. Structure of the Contiguous-cells Transportation Tableau

i/j	1	2	3	4	5	6	B_i
1		D_1	R_{13}				-
2			D_2	R_{24}	R_{25}		-
3	D_3	R_{32}	R_{33}	R_{34}			-
4	D_4	R_{42}	R_{43}	R_{44}	R_{45}	R_{46}	-
A_j	-	-	-	-	-	-	

From Table 1, the various R_{ij} are computed using equation 1 as follows:

$$R_{13} = \sum_{j=3}^{3} r_{1j}, \qquad R_{25} = \sum_{j=4}^{5} r_{2j}, \qquad R_{34} = \sum_{j=2}^{4} r_{3j}, \qquad R_{46} = \sum_{j=2}^{6} r_{4j}$$

Development of the Objective Function and Constraints

Let $\bar{R}_{ij}$ represent the value of the cumulative lost revenue for developing product i in any period j within the set of contiguous periods. Since R_{ij} is for all B_i contiguous cells, then $\bar{R}_{ij}$ is given by the expression:

$$\bar{R}_{ij} = \frac{R_{ij}}{B_i} \quad (2)$$

For product i across T periods, the 'actual' cumulative value of the lost revenue becomes:

$$Z(T, y_{ij}) = \sum_{j=1}^{T} \bar{R}_{ij}\, y_{ij} \quad (3)$$

For all M products across T periods, the lost revenue objective function becomes:

$$Z(T, M, y_{ij}) = \sum_{i=1}^{M} \sum_{j=1}^{T} \bar{R}_{ij}\, y_{ij} \quad (4)$$

The personnel capacity constraint is expressed as:

$$\sum_{i=1}^{M} \frac{y_{ij}}{B_i} \leq A_j \quad (5)$$

The development duration constraint which depicts non-preemption is given by the expression:

$$\sum_{j=1}^{T} y_{ij} = B_i \qquad (6)$$

Combining equations (4), (5) and (6), the contiguous-cells optimization model to cater for non-preemption in NPD is given by the expression:

$$minimize\ Z(T, M, y_{ij}) = \sum_{i=1}^{M}\sum_{j=1}^{T} \bar{R}_{ij}\, y_{ij}$$

Subject to:

$$\sum_{i=1}^{M} \frac{y_{ij}}{B_i} \le A_j \qquad (Personnel\ Capacity\ Constraint)$$

$$\sum_{j=1}^{T} y_{ij} = B_i \qquad (Non-preemption\ Constraint)$$

Model Algorithm

The contiguous-cells transportation algorithm (CCTA), which is similar to the conventional 'least cost' method of solving transportation problems is employed in solving the non-preemptive NPD problem. The algorithm will make use of "allocation by maximum average lost revenue", and is stated as follows:

Step 1 **Obtain** the values of the parameters of the problem (T, M, B_i, A_j, k_i, D_i, r_{ij}, Dp_i, N_i, T_{mij})

Step 2 **Using** equation (1), set up the contiguous-cells tableau for the lost revenue.

Step 3 For each product, select the R_{ij} value in the N_i^{th} period (i.e., the period that marks the end of the product's life) on the contiguous-cells transportation tableau, and divide the R_{ij} value by the total number of contiguous cells (i.e., counting from the D_{i+1}^{th} cell to the N_i^{th} cell), to obtain the average R_{ij} value.

Step 4 **Start** with the product having the highest average R_{ij} and allocate all the duration in that row (to satisfy the contiguity condition), whilst simultaneously meeting the personnel capacity constraint that can be met.

Step 5 **Repeat** the procedure for other products if the duration in the row and personnel capacity in the column are satisfied for the scheduled product. But in case there is no personnel capacity to accommodate the duration for developing the product, move to the next available period that has personnel capacity for the duration on that row and schedule the product. (It should be noted that moving to the next period for any product connotes re-scheduling of the product, thereby changing the start period from k to s).

Step 6 **Using** the y_{ij} obtained from the transportation tableau, determine the lost revenue R_{ij} for each product, and the total lost revenue for all M products.

4. Data Collection

The data used to illustrate the application of the model in the following example has been carefully put-together to fully depict the realities of non-preemptive NPD processes.

Numerical Example

In this example, we consider a hypothetical non-preemptive NPD problem of 6 products (P1, P2, P3, P4, P5, P6), across a planning horizon of 10 quarters (Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q9, Q10) of product development. Typically, each product has a profile which provides information about its development and market performance. The profile for P6 is as shown in Table 2.

Table 2. Product Profile for Product P6

Start of Development	Quarter 1
Development Team	3 people/quarter
Expected Market Launch	Quarter 3
Product Development Time	2 quarters

Total Production Development Cost (PDC)	$30,000
Total Product Tooling Cost (PTC)	$20000
Quarterly Production Cost (PC)	$10,000 per quarter
Quarterly Overhead Cost (OC)	50% of Production Cost
Product Sales Life and Revenue	3 quarters; (Q1 = $120,000, Q2 = $110,000 and Q3 = $100,000)

The ideal cash flow diagram for P6 (assuming the ideal product launch in Q3, in thousands of dollars), throughout the product's sales life is as shown in figure 1.

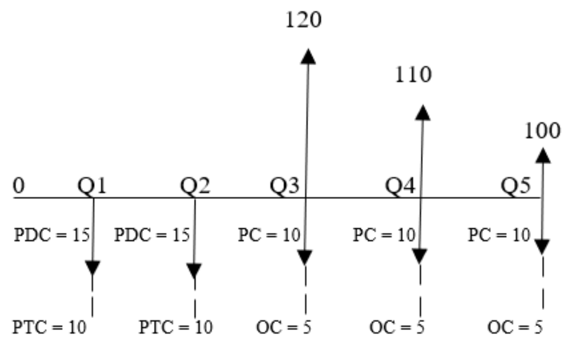

Figure 1. Cash Flow for Product P6

The cash flow for P6 in figure 1 can be represented as shown in figure 2:

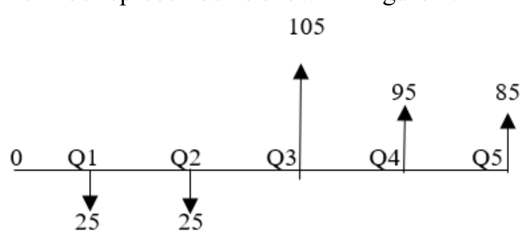

Figure 2. Cash Flow for Product P6

Considering time value of money, the present worth of P6 at the expected market launch (Q3), assuming 10% interest rate is computed as follows:

$$PW_{6,Q3} = 105 + \left(\frac{95}{1.1}\right) + \left(\frac{85}{1.1^2}\right) - \left(25(1.1^2) + 25(1.1)\right) = 203.85$$

Following a similar cashflow as above, the worth of P6 at Q4 and Q5 are given by:

$$PW_{6,Q4} = 95 + \left(\frac{85}{1.1}\right) - \left(25(1.1^3) + 25(1.1^2)\right) = 108.75$$
$$PW_{6,Q5} = 85 - \left(25(1.1^4) + 25(1.1^3)\right) = 15.12$$

Conversely, the quarterly lost revenue for P6 is computed as follows:
$r_{6,Q3} = PW_{6,Q3} - PW_{6,Q3} = 0$
$r_{6,Q4} = PW_{6,Q4} - 1.1\left(PW_{6,Q3}\right) = 108.75 - 203.85 = -115.4$
$r_{6,Q5} = PW_{6,Q5} - 1.1\left(PW_{6,Q4}\right) = 15.12 - 119.6 = -104.5$

Note that the negative values obtained for the r_{ij} indicate losses.

Given the above illustration for computing the lost revenue per period for each product, the model algorithm is now applied to solve the case of 6 products across a planning horizon of 10 quarters.

Step 1: (Problem Parameters): For all six products, the problem parameters are stated as follows:
Number of products (*M*) = 6 products (i.e., P1, P2, P3, P4, P5, P6)
Number of periods in the planning horizon (*T*) = 10 quarters (i.e., Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q9, Q10)
Ready times for product development (k_i) = {Q2, Q4, Q4, Q5, Q6, Q1}; {*i* = P1, P2, P3, P4, P5, P6}
Development personnel per product (Dp_i) = {5, 4, 3, 4, 3, 3}; {*i* = P1, P2, P3, P4, P5, P6}
Expected market launch (T_{mij}) = {Q6, Q7, Q6, Q8, Q8, Q3}; {*i* = P1, P2, P3, P4, P5, P6}
Product due dates (D_i) = {Q5, Q6, Q5, Q7, Q7, Q2}; {*i* = P1, P2, P3, P4, P5, P6}
Product sales life (N_i) = {5, 4, 4, 3, 3, 3}; {*i* = P1, P2, P3, P4, P5, P6}
Available development personnel per quarter (A_j) = {6, 9, 7, 10, 14, 12, 8, 7, 5, 4}; {*j* = Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q9, Q10}
Development duration (B_i) = {4, 3, 2, 3, 2, 2}; {*i* = P1, P2, P3, P4, P5, P6}
The lost revenue (r_{ij}) for all 6 products is as shown in Table 3.

Table 3. Lost Revenue r_{ij} (x10^3 dollars) per Period

i/j	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
P1	-	-	-	-	-	0	-271.8	-209.3	-223.7	-177.5
P2	-	-	-	-	-	-	0	-134.6	-137.5	-145.0
P3	-	-	-	-	-	0	-142.6	-137.4	-129.8	x
P4	-	-	-	-	-	-	-	0	-157.4	-169.1
P5	-	-	-	-	-	-	-	0	-126.8	-121.0
P6	-	-	0	-115.4	-104.5	X	X	x	x	x

The symbol "x" represents periods beyond the product sales life.

Step 2: (Computation of R_{ij} and developing the contiguous-cells transportation tableau): Equation 1 is used to compute the various R_{ij} values, and the contiguous-cells transportation tableau is as shown in Table 4.

Table 4. Contiguous-cells Transportation Tableau

i/j	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	B_i
P1	-	-	-	-	(D_{ij}) -	0	-271.8	-481.1	-704.8	**-882.3**	4
P2	-	-	-	-	-	(D_{ij}) -	0	-134.6	-272.1	**-417.1**	3
P3	-	-	-	-	(D_{ij}) -	0	-142.6	-280	**-409.8**	x	2
P4	-	-	-	-	-	-	(D_{ij}) -	0	-157.4	**-326.5**	3
P5	-	-	-	-	-	-	(D_{ij}) -	0	-126.8	**-247.8**	2
P6	-	(D_{ij}) -	0	-115.4	**-219.9**	x	X	x	x	x	2
A_j	6	9	7	10	14	12	8	7	5	4	

Step 3: (Determination of average R_{ij} value from the N^{th} period): From Table 4, the average lost revenue R_{ij} value for each product is given as follows:
Product 1 = (-882.3/5) = -176.4
Product 2 = (-417.1/4) = -104.3
Product 3 = (-409.8/4) = -102.5
Product 4 = (-326.5/3) = -108.8
Product 5 = (-247.8/3) = -82.6
Product 6 = (-219.9/3) = -73.3

Form step 3, the order of schedule based on "allocation by maximum average lost revenue" becomes: 1 – 4 – 2 – 3 – 5 – 6. Following steps 4 and 5, the final schedule is presented in Table 5.

Table 5: Final Schedule

i/j	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	B_i
P1	-	- (5)	- (5)	- (5)	- (5)	0	-271.8	-481.1	-704.8	-882.3	4
P2	-	-	-	- (4)	- (4)	- (4)	0	-134.6	-272.1	-417.1	3
P3	-	-	-	-	-	0 (3)	**-142.6** (3)	-280	-409.8	x	2
P4	-	-	-	-	- (4)	- (4)	- (4)	0	-157.4	-326.5	3
P5	-	-	-	-	-	-	-	0 (3)	**-126.8** (3)	-247.8	2
P6	- (3)	- (3)	0	-115.4	-219.9	x	X	x	x	x	2
A_j	6	9	7	10	14	12	8	7	5	4	

(▬) represents the periods allocated for actual development of the product.
The symbol "x" represents periods beyond the product sales life.
The numbers in parentheses in the cells represent the number of personnel required for developing each product in that period.

Step 6: (Determination of variables and lost revenue): From the final schedule in Table 5, the development ready time, development start time, actual development periods y_{ij}, and the associated lost revenue R_{ij} are presented in Table 6.

5. Results and Discussion

5.1 Numerical Results

Table 6. Presentation of Results

i	k_i	s_i	y_{ij}	R_{ij}
P1	Q2	Q2	{Q2, Q3, Q4, Q5}	0
P2	Q4	Q4	{Q4, Q5, Q6}	0
P3	Q4	Q6	{Q6, Q7}	$142,600
P4	Q5	Q5	{Q5, Q6, Q7}	0
P5	Q6	Q8	{Q8, Q9}	$126,800
P6	Q1	Q1	{Q1, Q2}	0
Total Lost Revenue				$269,400

To examine the impact of development personnel on the lost revenue, we consider a progressive increase in the number of personnel per quarter by 1, starting from Q4, until P3 and P5 are non-preemptively accommodated without rescheduling. The following cases were examined, and the corresponding results were obtained as shown below:

Case 1: (A_j) = {6, 9, 7, 11, 14, 12, 8, 7, 5, 4}; R_{ij} = $269,400
Case 2; (A_j) = {6, 9, 7, 12, 14, 12, 8, 7, 5, 4}; R_{ij} = $269,400
Case 3; (A_j) = {6, 9, 7, 12, 15, 12, 8, 7, 5, 4}; R_{ij} = $269,400
Case 4; (A_j) = {6, 9, 7, 12, 16, 12, 8, 7, 5, 4}; R_{ij} = $0

From table 6, it is clear that products P3 and P5, which were ready for development at periods Q4 and Q6 were re-scheduled to start at periods Q6 and Q8 respectively. The reschedule was due to the unavailability of development personnel at their respective ready periods. The implication of this re-schedule led to their market launch period moving from Q6 and Q8, to Q8 and Q10 respectively, thereby leading to a revenue loss of $142,600 and $126,800 respectively. Both products were also idle for 2 periods.
From cases 1 to 4 as presented, it is also clear that the addition of 1 personnel at Q4 (case 2) would allow for development of P3 to begin. However, the development personnel at Q5 were not enough to continue the PD process in that period. Hence, P3 was rescheduled, consequently leading to a rescheduling of P5. The same situation and result

in case 2 were obtained in case 3 where the available personnel were increased by 1 at Q5. In case 4, we see that the addition of 1 personnel in Q5 not only allows for development of P3 to run non-preemptively to completion. The inclusion also frees up development personnel at Q6 and Q7 for the development of P5, ultimately bringing the revenue loss to zero.

It is also evident that "development personnel" is not the only parameter responsible for the final schedule and lost revenue. All other PD parameters (T, M, B_i, k_i, D_i, r_{ij}, Dp_i, N_i, T_{mij}) also contribute to the final schedule, and as such impact the behavior of the model. For instance, an increase in the development duration of any product while keeping its ready time constant will extend its market launch and possibly lead to loss of revenue. Furthermore, changes in market predictions during the PD process any product (as found in many real-life situations) may affect the sales life of the product. In such a situation, the "average lost revenue" which the contiguous-cells algorithm uses to determine the order of schedule may change. This change may distort the order of schedule, ultimately resulting to a change in lost revenue.

6. Conclusion

This paper proposed the contiguous-cells transportation approach to aid decision making for product launch in non-preemptive PD process. The approach considered parameters relevant to the PD process and the problem was successfully formulated with an algorithm proposed to solve the problem. The methodology and results obtained reveals that the availability of development personnel throughout the product development horizon is vital to the timely release of products particularly in cases where preemption is not allowed during the PD process, and this also contributes to the overall market performance of products as it helps to reduce revenue losses. In conclusion, organizations must adequately plan to ensure that product development personnel are available throughout the entire PD horizon.

Future works will focus on addressing real-life problems, considering stochastic ready times for product development and seek to extend the development resource constraints beyond development personnel to include other development resources relevant to the PD process.

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