

Research Article

The Number of Students Needed for Undecided Programs at a College from the Supply-Chain Viewpoint

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The objective of this study is to determine how to do forward-looking analysis to determine the future need for various professionals, so that educational institutes can produce an appropriate labor force for national development. The concept of component part commonality, which derives from research on effective inventory management using material resource planning (MRP), can also be applied to human resource planning and educational resource management in higher education systems. Therefore, this paper proposed a systematic method to analyze student recruitment numbers for future needs, based on the concept of MRP. The research studied the relationship between a curricular structure tree and the associated commonalities. It explored the relationship between the commonality of students and the aggregated level of student replenishment. Based on that, systematic guidelines for curriculum design can be established for undeclared programs at colleges. Two simple examples were used to illustrate the implementation of MRP in analysis of the replenishment levels (necessary safety stock levels) in an education system such as an engineering college.

1. Introduction

Technology can improve on conventional methods of allocating a nation's resources, including human resources. Meanwhile, international economic competition is increasing with the widening trade. Government protected industries, especially in newly industrialized countries, such as Taiwan and its neighbors, are encountering stronger competition than ever before. Therefore, these countries must join with foreign countries, even if involuntarily, to

open their domestic markets. To deal with this situation, these newly industrialized countries need to coordinate and integrate their limited resources to obtain optimal utilization. In other words, they should take steps to speed up technological research and development to increase their ability to compete. Success in these steps depends strongly on whether there are sufficient human resources in each professional area [1]. Therefore, a proper human resource policy is one of the determining factors for a national survival in light of this keen economic competition. Since educating a professional usually takes several years, a responsible government studies the future needs and develops policies, in advance, so that the education system can develop enough of the needed professionals [2].

In Taiwan, colleges or universities are the major institutes for training high quality workers. Qualified entrants have to fulfill strict curricular requirements before graduating. The study procedure in schools is analogous to the production process in industrial manufacturing. Thus, the concept of material requirements planning (MRP) can be applied to an education system. The very nature of an MRP system revolves around commonality, which means different final products still consist of some common components. An MRP system, based on the degree of commonality, determines the minimum aggregate safety stock levels needed to prevent out-of-stock situations and satisfy customer demands. If an undeclared programs were developed in universities, the designing of an appropriate curriculum for undeclared students needs to be prepared in advance. Curriculum decisions would be dependent on the undeclared program's student recruitment totals.

Nevertheless, a college student's major is determined by his score on the National Union College Entry Examination in Taiwan. A semigovernmental organization assigns prospective students to a department at a college or university according to their score on the examination and their choice list. Most students are assigned to a college by their examination scores, in spite of their interests. Meanwhile, in the second year of high school students are categorized into four groups according to their future majors. A type of professional streaming is premature for pupils, who are just fifteen or sixteen year-old. Early streaming reduces the breadth of a student's knowledge so that student may lack the capability to integrate related professional areas. Confucian concepts emphasize respect for the individual's will and educational interests. Therefore, students should be encouraged not to make any premature career decisions before gathering enough information and understanding their abilities and interests. Therefore, the Taiwanese Ministry of Education (MOE) has issued a proposal suggesting that the college education system should postpone professional streaming until the junior year of university. The government expects that the higher education system should be able to educate a professional with strongly integrated technological abilities by postponing professional curricular streaming [3]. Recently some Taiwanese universities, such as National Tsing Hua University and National Sun Yat-sen University, have provided undeclared programs for incoming freshmen. The primary objective of the program is to let each student develop an interest-oriented academic career and to broaden the recruitment pool for prospective student.

The objective of this study is to determine how to do forward-looking analysis to determine the future need for various professionals, so that educational institutes can produce an appropriate labor force for national development. According to the Ministry of Education proposal, universities should recruit students without major streaming at the college entry level. Recruited students can choose not to declare their major until they have finished a two-year common curriculum. Students are then assigned to a department based on their interests and capabilities as determined by their academic performance. This method is completely different from the current one, where a student's major is determined when they obtain

admission to a university. However, two problems arise from this proposal. First, a school's reputation would be the main consideration for a student instead of their major after the two-year common curriculum. This situation will worsen the current problem encountered by the Taiwanese education system, where most national universities are too crowded, while many private universities cannot recruit enough students, causing poor allocation of limited educational resources [4].

Second, since students in the same institute would have a common curriculum, their professional training would have a high degree of commonality. Although student choices among various professional majors would be more flexible, it can be predicted that most students would gravitate to popular departments, even if they were not interested or capable. This will lead to a problem where some departments will not be able to recruit as many students as under the present curricular streaming system. Moreover, each university will invest most of its budget in popular departments to attract more students without considering the social costs. From a long-term point of view, the planning and training of the professional labor force may be distorted, and some resources for certain professions could be diluted [5]; this will surely have educational and social costs.

The dropout rate, especially in the upper years, is high in private universities. The phenomenon leaves the fewer college students, especially in the upper years, and it has been a problem in Taiwan for a long time. The higher education system deals with this problem by recruiting transfer students from the technical education system (High schools in Taiwan are categorized into two groups: the so-called ordinary schools, where students are educated to enter colleges, or technical schools, which provide practical vocational training, so students can be employed by industry upon graduation or go to technical colleges. However, due to convention, most students from technical schools would rather compete with students from ordinary high schools to enter ordinary universities, instead of technical colleges. This phenomenon totally distorts the authority's original plan for the higher education system.) This approach lacks an integrated view and forward-looking consideration of future industrial needs and resource allocation. Since educational resources are being drained and curricular streaming is going to be postponed, how to allocate the limited resources efficiently is an important matter for Taiwanese educational authorities. Moreover, Taiwan's MOE subsidizes universities by the number of students recruited, but penalizes universities with dropout or vacancy rates that are too high. Under such circumstance, accurate estimation student number is crucial for curriculum design. This paper proposes a systematic method for analyzing student recruitment numbers to meet future needs based on commonality of academic content if streaming were postponed until the junior year.

2. Research Approach

Material requirement planning (MRP) [6] has been applied to inventory control management manufacturing in recent years and can likewise be applied to determining educational needs. This approach calculates the total supplies of product components at various manufacturing stages based on the commonality of each component part among the manufactured products, the product structures, and lead-time factors, such as ordering, manufacturing, and delivery. In other words, it uses the relationship between commonality and material costs, production, ordering, and delivery lead-time offsets, to consolidate and transfer the final products demanded during different time periods into the needed subassemblies of components. The objective of this approach is to combine independent orders for final products and maintain the quantity of orders at the highest possible level, so a factory can maintain raw materials

and component stocks at lower levels since it is economical. This approach reduces total costs by minimizing the cost per unit and setup costs. The commonality of component parts among different products has a significant impact on inventory levels for components and subassemblies. As commonality increases, the same component can be placed in many different products. When demand for a final product changes, the inventory of the lowest common component used must be properly adjusted to accommodate the change and avoid waste. Hence, the determination of the inventory level must be based on a global view so that limited resources can be utilized efficiently and flexibly to satisfy variations in the quantity of final products ordered.

The concept of component part commonality derives from research on effective inventory management using MRP. However, the concept can also be applied to human resource planning and educational resource management in higher education systems. In MRP, the master production schedule (MPS) must be established first according to predictions about end-product needs. This ensures that varying demand over different time periods can be met by production capacity. Similarly, MPS concepts can also be applied to long-term human resource planning, where the future demand for various professionals dictates the skills needed by the talent pool. The education and production processes are very similar as value-added processes. The fulfillment of curriculum requirements by a student is analogous to the production process of any industrial product. College freshmen, like raw material, are prepared for various professions through different core courses taken during the learning process. Alumni with different majors can be viewed as different end products. Hence, a learning process which trains the freshmen for different professions is analogous to the assembly process in a production line. Like MRP where the end product can be represented by the bill of materials (BOM), the training of a student can be represented by a similar hierarchical structure.

During the learning process, college students have a high degree of commonality after they have completed the basic courses. Once students begin to take the core courses in their major; however, even though some core courses are common to different majors (curricula), the streaming process begins. During the streaming process, students' core courses follow a predetermined order. Those who fail a prerequisite course must retake the course before they can proceed to advanced courses. Some students may be forced to change their major or drop out if they continuously fail in core courses. This process is just like the production process, where defective products must be reworked or repaired before they can be processed onto the next stage of manufacturing. Those with serious defects which cannot be repaired have to be scrapped. Hence, from the operational viewpoint, the learning process is very similar to the production process.

In MRP, to satisfy the demand for the end product, it is necessary to have some safety stock to compensate for unavoidable waste during production. The safety stock is a cushion for production variations; it ensures that raw materials and components can be supplied in time without shortage. Due to limited resources, the amount of safety stock must be planned from the aggregate viewpoint to reduce unnecessary costs and to increase production efficiency. Similarly, the safety stock concept can be applied to the education process; some students drop out of the system during the process and cause a shortage that can usually be replenished by enrolling more transfer students or freshmen. However, graduate quotas are based on the individual program requirements; that is, each program decides how many supplementary transfer students or freshmen it needs without considering the replenishment of students from an aggregate viewpoint. This is deemed a waste of precious resources. The problem of not satisfying the preset target for professionals can be resolved by means of

the commonality concept in MRP, which uses an aggregate student replenishment scheme to solve the unavoidable problem of a shortage of students.

Since similarities exist between the education process and the production process, it is possible to implement an MRP and commonality models in the education system. This paper studied the relationship between a curricular structure tree and the associated commonalities. Two simple examples were used to illustrate the implementation of MRP in analysis of the replenishment levels (necessary safety stock levels) in an education system such as an engineering college.

3. Model Analysis

This paper describes how to apply the MRP method to analysis of student replenishment and demonstrates that the MRP concept can be suitably implemented in an education system [7]. The compatibility of implementation between manufacturing systems and education systems can be observed from the MRP structure trees for a product and curriculum. In a manufacturing system, the MRP structure tree of a product represents the relationship among final products, semiproducts, and components. This hierarchical structure is composed of components at the lowest level, semiproducts and final products at the highest level. Similarly, the common and advanced courses in a curriculum can be used to construct an MRP tree based on a predetermined sequence, as shown in Figure 1.

In Figure 1, each node (element) denotes a course, which a student should take to gain essential knowledge. From another viewpoint, each node also represents the learning (training) status of a student. Therefore, for the purpose of illustration, in this paper, it was assumed that a node, that is, a course offered, also represented a student whose learning status has reached this course's level. Therefore, the inventory control method in MRP can also be applied to analyze student recruiting in an education system. The following example shows how the concept of commonality between products can significantly affect the safety levels of inventory required. MRP can be used to analyze how the commonality among qualified students in different disciplinary curricula affects the number of supplementary students.

3.1. Degree of Commonality

The degree of commonality index, DCI, denoted a measurement of commonality, the degree of difference among some products [8–10]. It was expressed as $C = \sum_{j=1}^d \phi_j / d$, where ϕ_j was the number of parents of course j in the curricular structure tree; d was the number of prerequisite courses, which had any ancestor; the index range was $1 \leq C \leq \sum_{j=1}^d \phi_j = \beta$. For example, in Figure 2, the DCIs were evaluated.

In other words, the DCI is a ratio between the number of prerequisite courses at the lower levels and the total number of their parents (related upper year courses). It can be used to represent the degree of commonality between students through different curricular disciplines [11, 12]. If two curricula in a college were independent, then $C = 1$, as shown in Figure 3.

3.2. Curricular Commonality and the Number of Supplementary Students

Example 3.1. A simplified two-level curricular structure tree were used to represent the case where a college recruits students without postponing streaming, Figure 4(a). In this

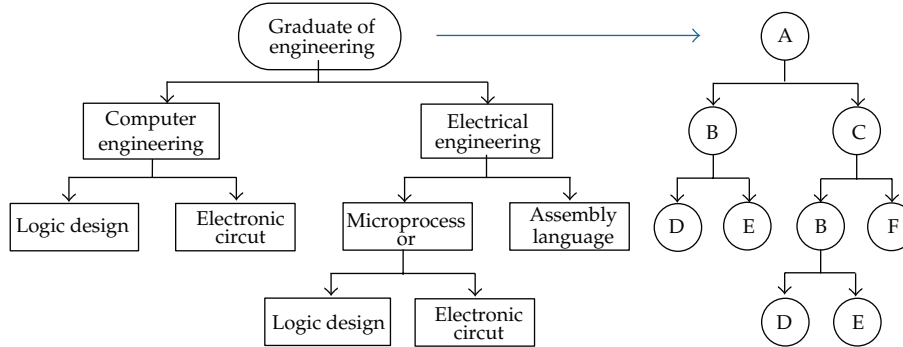


Figure 1: The curricular structure tree of an engineering college.

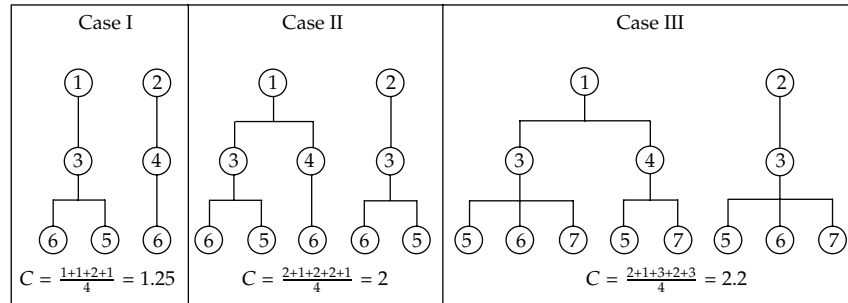


Figure 2: Examples for evaluating the degree of commonality indexes.

example, there are ten different curricula (majors) in a college. Students should take the course represented by the upper node after they fulfill the lower node course's requirements.

If the college postponed streaming, the freshman and sophomore students took the common core courses regardless of their future majors. Thus, most of the prerequisite courses at the lower level were aggregated, as shown in Figure 4(b), for example. The prerequisites (11...20) for these ten majors were merged into a common prerequisite (21). Using this example, the main effect resulting from increased commonality can be studied.

The DCI can be applied to any node or level in the curricular tree. Therefore, the students that reached a certain node, that is, who took the prerequisite courses (antecedents) for that node, were tagged by the DCI. For the course or subject j , the level of student replenishment S_j was equal to the value of the safety parameter k multiplied by the predicted standard deviation σ_j . If the actual demand y exceeded the expected demand u and was greater than the probability of student replenishment level, it can be expressed by Tchebysheff's inequality:

$$\text{Prob}\{(y - u) \geq k\sigma_j\} \leq \frac{1}{k^2 + 1}, \quad (3.1)$$

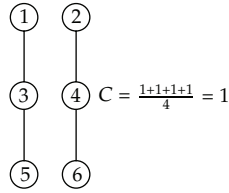


Figure 3: An example where there was no commonality between two curricula.

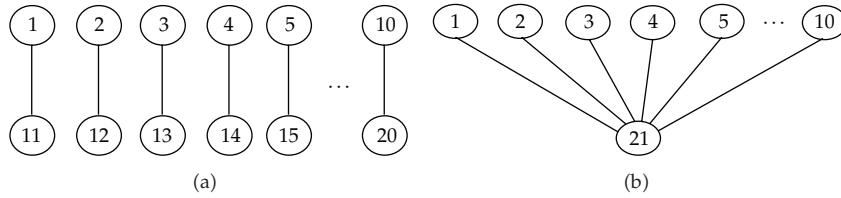


Figure 4: Two-level curricular structure trees.

where parameter k represents the upper bounds of the safety parameter. In the worst case, the probability of a student replenishment shortage at any level can be derived by substituting S_j/σ_j for k :

$$\Psi = \text{Prob}\{(y - u) \geq S_j\} = \frac{\sigma_j^2}{s_j^2 + \sigma_j^2}. \tag{3.2}$$

If there were a demand for students (called differentiation-type students) who already took the various prerequisite courses, (11···20) in Figure 4, then these students could be replaced by students (called common-type students) who have taken the common course, for example, (21) in Figure 4. The variance of the independent variable C is

$$\sigma_c^2 = \sigma_1^2 + \sigma_2^2 + \dots + \sigma_d^2, \tag{3.3}$$

and the demand variance of prerequisite j is

$$\sigma_j^2 = \frac{1}{d} \cdot \sigma_c^2. \tag{3.4}$$

Substituting (3.4) into (3.2), the supplementary level of the j -type student is

$$S_j = \sqrt{\frac{1 - \Psi}{\Psi}} \cdot \sigma_c \sqrt{\frac{1}{d}}. \tag{3.5}$$

If there are d common-type students, then

$$\sum_{j=1}^d S_j = \sqrt{\frac{1 - \Psi}{\Psi}} \cdot \sigma_c \sqrt{d}. \tag{3.6}$$

The optimal number of supplementary students was assumed to be $S_c = \sqrt{(1 - \Psi)/\Psi} \cdot \sigma_c$ if the differentiation-type students were replaced by the affine common-type students. The total number of supplementary students was $1/\sqrt{d}$ of the accumulated number of differentiation-type students; that is, $S_c = 1/\sqrt{d} \sum_{j=1}^d S_j$.

Since $Cd = \sum_{j=1}^d \phi_j = \beta$ and we let $\beta = 1$, as in the case of Figure 4, d differentiation-type students were replaced by affine common-type students. Therefore, $d = 1, C = d/1$. And

$$S_c = \frac{1}{\sqrt{C}} \sum_{j=1}^d S_j. \quad (3.7)$$

Equation (3.7) expresses the relationship between the number of incoming common-type students and the number of replaced differentiation-type students. Due to the degree of commonality, the number of needed supplementary common-type students was less than that of differentiation-type students. From this example, it can be noted that

- (a) a simplified two-level structure tree was used. However, if the number of structure levels were more than two, the demand would not have been fully independent due to the correlation between the elements in the tree,
- (b) if N common-type students were needed and each of them was equivalent to d differentiation-type students, then the CDI was

$$C = \sum_i^N \frac{d}{N} = \frac{Nd}{N} = d, \quad (3.8)$$

and the total number of supplementary students was

$$\sum_{i=1}^N S_c = \frac{\left(\sum_{i=1}^N \sum_{j=1}^d S_j \right)}{\sqrt{C}}. \quad (3.9)$$

Example 3.2. From the above example, it was noted that the demand for supplementary students can be reduced if the degree of commonality increases. The other example, where there are two simplified two-level curricula, can be used to show how the common-type student demand and differentiation-type student demand interacted with each other.

Example 3.1 depicts a simple case where the differentiation-type students were replaced by common-type students. However, further study is needed on the situation where there are some partially common components. The following example assumed two professions were needed, and that the distribution of demand probability for both professions was uniform: $(0, b_1)$ for Profession1 and $(0, b_2)$ for Profession2. If $b_1 \geq b_2$ and (Z_1, Z_2) was a vector representing the demand for these professions, then the example describes the resolution of an optimization problem where the total cost of student replenishment should be minimized, subject to the service level. The aggregate service level, ASL, is the probability that all the demands will be satisfied [13]. ASL was assumed to be γ in this example.

Case 1. There was no commonality between the two curricula as shown in Figure 5.

It is a unique phenomenon in Taiwan that a college's desirability among senior high school students is strongly affected by the college's rankings in the previous year's entry

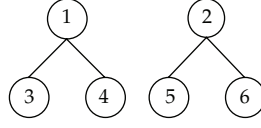


Figure 5: Two independent curricula.

examinations. Therefore, a college's department may become a low-priority choice based on the low scores of students recruited in the previous year. Meanwhile, too many colleges have been established in recent years and the population of potential students is decreasing dramatically due to the rapidly declining birthrates. Many private universities have suffered from lower student recruitment. Therefore many universities are working on strategies to raise their rankings on student priority lists by reducing the new student quota to ensure less vacancy during registration. Therefore, the problem can be formulated as follows:

$$\begin{aligned} \text{Minimize } T &= S_3 + S_4 + S_5 + S_6, \\ \text{S.T. } \text{ASL} &= \gamma, \end{aligned} \quad (3.10)$$

where S_i represents the number of i -type students; T is the total number of students.

Since the number of supplementary students was equal to the difference between the total number of students and the expected demand, that is, the *safe supplementary level* = $T - (b_1 + b_2)$, minimizing the number of supplementary students is equivalent to minimizing the total number of students. Therefore, to satisfy all the constraints, the conditions $Z_1 \leq \min(S_3, S_4)$ and $Z_2 \leq (S_5, S_6)$ must exist. Let $S_3 = S_4$ and $S_5 = S_6$, then $\text{ASL} = \text{Prob}\{Z_1 \leq Z_3\} * \text{Prob}\{Z_2 \leq Z_6\} = S_3 S_6 / b_1 b_2 = \gamma$.

Meanwhile,

$$\begin{aligned} \text{Minimize } T &= S_3 + S_4 + S_5 + S_6 = 2(S_3 + S_6) \\ \text{S.T. } S_3 S_6 &= \gamma b_1 b_2 \\ S_3^* &= \gamma b_1, \quad S_6^* = b_2, \quad T^* = 2(\gamma b_1 + b_2). \end{aligned} \quad (3.11)$$

Table 1 lists the solutions for S_3 and S_6 in different ranges of ASL and T [8].

Case 2. There was some commonality between the two curricula as shown in Figure 6.

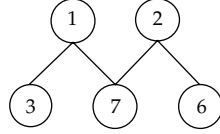
In this example, the common-type node 7 replaced the differentiation-type node 4 and node 5 from the previous example. The inequality of $S_7 \geq S_3$, $S_7 \geq S_6$, and $S_7 \leq (S_3 + S_6)$ must hold. Meanwhile, $\text{ASL} = \text{Prob}\{Z_1 \leq S_3 \text{ and } Z_2 \leq S_6 \text{ and } (Z_1 + Z_2) \leq S_7\}$. The shadow region in Figure 7 represents the probability of the ASL.

From Figure 7, the ASL was evaluated as $[(S_7 - S_3)(S_7 - S_6) + (S_3 + S_6 - S_7)(S_7 - S_3) + (S_3 + S_6 - S_7)(S_7 - S_6) + (S_3 + S_6 - S_7)/2] / b_1 b_2$. That is $[(S_7 - S_3)(S_7 - S_6) + (S_3 + S_6 - S_7)(3S_7 - S_3 - S_6)/2] / b_1 b_2$. The problem was reformulated as follows:

$$\begin{aligned} \text{Minimize } T &= S_3 + S_6 + S_7 \\ \text{S.T. } 2(S_7 - S_3)(S_7 - S_6) &+ (S_3 + S_6 - S_7)(3S_7 - S_3 - S_6) = 2\gamma b_1 b_2. \end{aligned} \quad (3.12)$$

Table 1: Solutions for S_3 and S_6 in different ranges of ASL and T .

ASL	T^*	S_3^*	S_6^*
$\gamma \leq \frac{b_2}{b_1}$	$\sqrt{(16\gamma b_1 b_2)}$	$\sqrt{(\gamma b_1 b_2)}$	$\sqrt{(\gamma b_1 b_2)}$
$\gamma \geq \frac{b_2}{b_1}$	$2[\gamma b_1 + b_2]$	γb_1	b_2

**Figure 6:** The two curricula overlapped.

Furthermore, $S_3 \leq \min(b_1, S_7)$, $S_6 \leq \min(b_2, S_7)$, and $S_7 \leq (S_3 + S_6)$. Using Lagrangian methods, the solutions in Table 2 were obtained.

Some conclusions can be drawn from the tables.

- (i) The total number of students T^* decreases when there is commonality among the curricula.
- (ii) If the students who have taken course 7 replace the ones who should have taken courses 4 and 5, the number of common-type students is less than the number of differentiation-type students, that is, $S_7 < S_4 + S_5$.
- (iii) When commonality among the professional curricula increases, the number of differentiation-type students who have taken courses 3 and 6 also increases.

Since the number of supplementary students is equal to the difference between the total number of students and the expected demand, the number of supplementary students is proportional to the total number. The above comments actually describe the relationship between the number of supplementary students and the total number. When streaming is postponed, common courses must replace some professional courses. It means that some commonality exists in the curriculum. In order to satisfy industrial demand, the student recruiting policy must be flexible. To maintain the necessary overstock level, for safety, transfer students are the primary resource to replenish programs, especially in schools with high quality controls, where some students may leave for failure to fulfill the curricular requirements. If a school wants to go with the streaming postponement policy and replenishment is needed, the number of transfer students who have been streamed should be increased. In other words, if a college needs to recruit transfer students to maintain the safety stock level, it should take transfer students in their junior year. In addition, it can establish systematic guidelines to curriculum design for undeclared programs at colleges.

4. Conclusion

The direction of higher education is to allow more people have opportunities to attend college. However, as the government budget for education is shrinking, the need to expand private contributions has grown. Despite pressure from a limited budget, high quality education still needs to be maintained while costs are minimized. From the economic point of view, the optimal balance among cost per student, governmental support, and self-generated

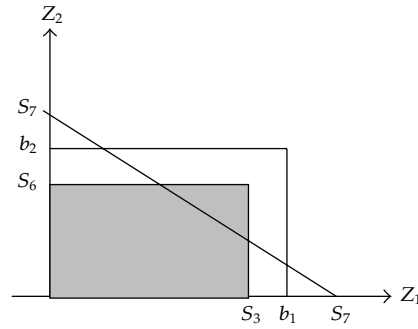


Figure 7: The probability of the aggregate service level.

Table 2: Solutions obtained by Lagrangian methods.

ASL	T^*	S_3^*	S_6^*
$\gamma \leq \frac{7b_2}{8b_1}$	$\sqrt{(14\gamma b_1 b_2)}$	$\frac{2}{7}\sqrt{(14\gamma b_1 b_2)}$	$\frac{2}{7}\sqrt{(14\gamma b_1 b_2)}$
$\frac{7b_2}{8b_1} \leq \gamma \leq 1 - \frac{b_2}{8b_1}$	$2\gamma b_1 + 7\frac{b_2}{4}$	$rb_1 + \frac{b_2}{8}$	b_2
$\gamma \geq 1 - \frac{b_2}{8b_1}$	$2(b_1 + b_2) - \sqrt{(2(1-\gamma)b_1 b_2)}$	b_2	b_2

income would lead to effective management of resources. This is also a good index for planning and controlling the number of students enrolling in a school with undeclared status. In accordance with the current interest of undergraduates maintaining undeclared majors until their upper years and the need to maintain a certain level of professionals in training, many universities have proposed a variety of curricular programs to broaden the recruitment pool of prospective students. The proposed approach is based on the commonality among college level curricula. By decreasing the total number of students recruited from different departments, this program can reduce costs. For schools with student recruiting problems, their enrollment depends on transfer and extension students. The proposed program is more cost-effective because recruitment takes place at the college level rather than at the department level. At the same time, advanced students who have declared their majors can be recruited. In other words, students can transfer during all four years of their undergraduate program.

This paper also proposes a quantified model of commonality and recruitment planning for appropriate curriculum design. Two simple cases are used to illustrate the method, which can be divided into two phases—before undeclared students declare majors and after. However, with the challenges higher education is facing with majors, general education, and professional programs, our model still needs more research into quantity and quality. The future direction of the proposed quantification model is two-fold. First, optimization of resource allocation needs to be studied when the commonality changes depending on different types of professional training. Secondly, in order to satisfy the needs of the system, methods for controlling student distribution need to provide for transfer student quality, and appropriate and a sufficient curriculum needs to be offered accordingly.

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