Hotel Room Allocation for Sales Channel by Dynamic Programming

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Abstract

This paper describes the sales channels decision problem on balancing opportunity loss and supply surplus. Service industries which sell limited, perishable inventories such as flight tickets and hotel rooms through multi sales channels are constantly faced with the problem how to allocate their inventories for getting the optimum total revenues because a high profitable channel has weak sales power and a low profitable channel has strong one. In order to solve this problem timely and reasonably, this paper formulates an original problem as dynamic programming where the decision factors are induced from the past sales records. Achieving numerical simulation, this paper also shows the availability of the strategy with Dynamic Programming is shown.

1. Introduction

Resource allocation has been a typical and important task for the most companies. Especially, in competitive industries, a wrong allocation will be fatal issues. Then, the problem exists not only in financial management, human resource management but also in supply chain management. The supply chain management includes how to sell them, in other words which sales channels work well for getting revenue [1][7].

Sales channels allocation for airplane tickets, hotel rooms, and renal cars are typical examples because high profitable direct sales channel can have the limited amount of customers while low profitable agent sales channel have the wide range of customers. Such trade off makes problems difficult. This kind of problem is referred to business risk management or business yield management because there are uncertainties [2]. If they allocate their inventories along a wrong strategy, they would suffer serious damage such as dead stock and opportunity loss.

While there are varieties of computer support for decision making, the final allocation strategy has been suggested by a human expert (for example, see [3]). However, such decision is too objective and intuitive to be reliable. Further, in the case that the expert retires from the organization, the quality of decision should be degraded. Therefore, the objective and reasonable decision algorithm is required. If the algorithm works well, then the organization needs not a highly paid expert.

This paper suggests a new strategy with dynamic programming [4] to solve such problems. The background of our proposal is that there are volumes of sales records in database and these can be clue for the strategy. First, comparing the proposed decision framework to the traditional framework, we define a sales channel problem where the hotel room reservation and sales are examples. Next, in order to formulate the problem solving, we introduce a new strategy with dynamic programming which is based on principle of optimality. Then, we carry out the experimental simulation. Finally, we discuss some future research issues.

2. Hotel Room Allocation Problem

Let us start describing the sales channel problem. We should pay attention on the relation between the amount of deliverable rooms and the expected profit. If the amount is small, the effective strategy is to deliver all rooms to the most profitable channel. However, the

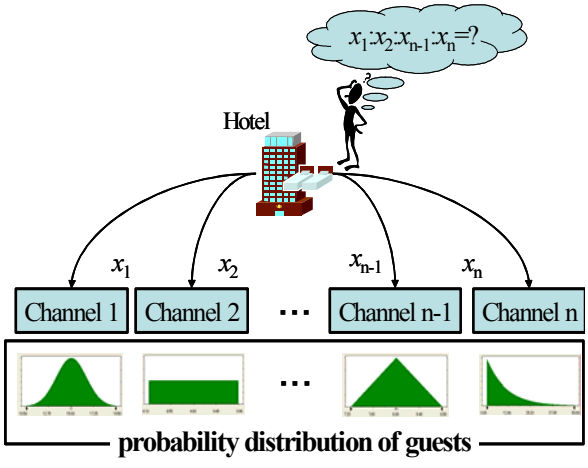


Figure 1. Hotel Room Allocation for Channels

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profitable channel has limited sales force. Some channels may become profitable if the amount of deliverable room exceeds the threshold. It is known as scale merit. Further, other channels may have complex profit matrix amount because they provide a group tour or something like this. Therefore, in the sales channel problem, the company has to find effective scheme on resource allocation to earn high revenue.

As introduced, these problems were included in the area of business yield management. The purpose of yield management is very simple: "Sell the right resource to the right type of customer at the right time and for the right price". The purpose is equal to maximizing total revenue to allocate limited resource efficiently. However, many companies have used their old scheme.

Old scheme of distribution is based on a decision by an expert. The expert should have heavy load to consider not only the features of channels but also the competitors' strategy, customers' preference, the coming events and so on. Sometimes, he is required to change his strategy time by time. Therefore, this old scheme is not always reliability and reasonable.

Today, most companies including hotels stores sales records in their transaction database. To increase their revenue, they are interested in using database for customer relationship management (for example, see [5]). The database can be also clue for the channel allocation strategy and here is our concern.

Then our problem is: how to allocate rooms for the sales channel by using the past sales records under uncertainty. Another problem is to design a computer supported decision tool. This tool would be effective in resolving the traditional weaknesses.

This paper illustrates the case for the general problem that a hotel distributes its available rooms to multi sales channels. The rooms are sold through multi sales channels such as its front desk, web site and travel agencies (see **Figure 1**). Each sales channel has different features such as profit rate and sales force.

3. Approach for Solving Problem

3.1. Overview of Dynamic Programming

Dynamic Programming (DP) based on Richard Bellman's Principle of optimality [4] is a well-known approach developed to solve sequential or multi-stage decision problem. The main characteristic of DP is to solve decomposed small problems iteratively instead of solving one large problem.

The definition is as follows: an optimal policy has the property that whatever the initial state and initial decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision. This principle can be also applied to the sales channel problem.

DP is the way that multi-stage decision problem change into some single-stage decision problems. So the calculation is very simple. All kinds of scheme are found by one calculation process. For example, solving *N*-channels problem, not only a scheme of allocation for N-channel, but also scheme of allocation for *i*-channel (*i*=1,2,…,*N*-1) are found.

3.2. Applying DP to Hotel Room Allocation

Using an example shown in **Figure 2** where x is the amount of deliverable room and g_i is i-th sales channel, let us show how iterative calculation works for solving the sales channel problem. DP allows original 4-channel problem to decompose into stepwise (and simple) 2-channel problems. Step 1 calculates the optimal allocation for two channels. Then we can regard the optimal solution for two channels as a virtual channel (it is a scheme of distribution and expected profit vector $f_2(x)$).

Then Step 2 allocates rooms to next two channels, $f_2(x)$ and channel 3. This step is the same as Step 1 where $f_2(x)$ is a virtual channel which is the best distribution of original two-channel problem. Therefore, we consider the two-channel problem in Step 2 as the original three-channel problem.

Just as Step 2, Step 3 is also considered as the

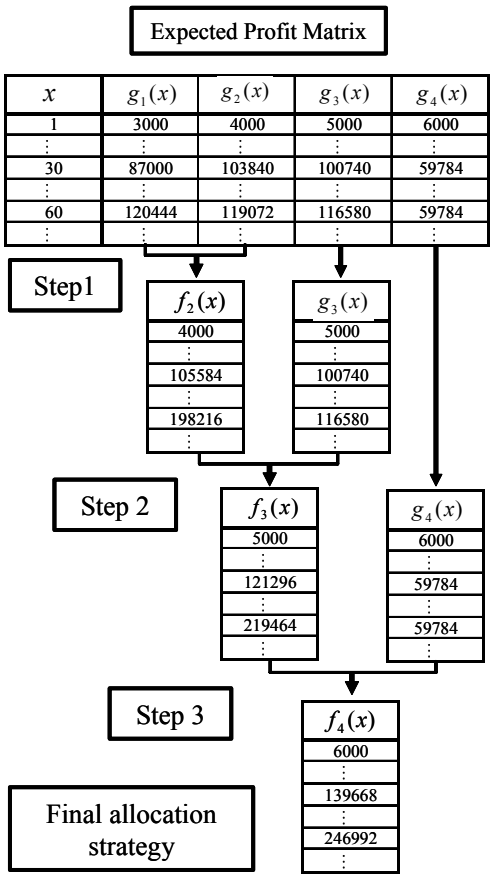


Figure 2. Multi-stage Allocation Rooms Problem.

Table 1. Example of step wise DP Solution.

	step 1		step 2		step 3	
x	$f_1(x)$	$g_2(x)$	$f_2(x)$	$g_3(x)$	$f_3(x)$	$g_4(x)$
1	1	0	1	0	1	0
2	1	1	2	0	2	0
3	2	1	3	0	2	1
4	3	1	4	0	3	1
5	3	2	5	0	4	1
6	3	3	5	1	5	1
7	4	3	6	1	6	1
8	5	3	7	1	7	1
9	6	3	8	1	8	1
10	7	3	9	1	8	2

Table 2. Example of Final DP Solution.

x	ch 1	ch 2	ch 3	ch 4
1	1	0	0	0
2	1	1	0	0
3	1	1	0	1
4	2	1	0	1
5	3	1	0	1
6	3	2	0	1
7	3	2	1	1
8	3	3	1	1
9	4	3	1	1
10	4	3	1	2

original four-channel problem. Finally, we can get the best distribution for four-channel problem. The formulation is borrowed from [4].

Then the sales channel problem can be formulated as follows:

$$f_k(N) = \max_{1 \le x \le N} [g_k(x) + f_{k-1}(N-x)] \qquad (1)$$

$f_k(x)$: Optimal profit for x rooms to k channels.
$g_i(x)$: The profit for x rooms to i-th channel.

Using **Table 1** and **Table 2**, let us introduce how to see the computational result. **Table 1** shows the optimal solutions of Step 1, Step 2, and Step 3 in **Figure 2** while **Table 2** shows the optimal allocation for four channels. For Step1, g_1 should have seven and g2 has three if the number of deliverable room is ten. Step 2 solves three channels problem. For ten deliverable rooms, the solution (f2, g3) is (9, 1). Then we get (g1, g2) = (6, 3) if the number of deliverable room is nine for the two channel problem.

Similarly, Step 3 solves four channels problem. **Table 2** shows that the solution in Step 3 for ten deliverable rooms is (8, 2). Then we check the solution for eight deliverable rooms in Step 2 and find the solution is (7, 1). Again, we check the solution for seven deliverable rooms in Step 1 and find the solution is (4, 3). Finally, we get the solution of four channel problem for deliverable rooms, (4, 3, 1, 2) as shown in **Table 1**.

3.3. Available Expected Profit Matrix

Basic premise under our approach is that there is the expected profit matrix which is induced from sales transaction data. The matrix indicates the relationship the amount of deliverable room and the expected profit for each channel. The example is shown in **Figure 2**.

This matrix implies that the allocation proportion among sales channels is not invariant for the amount of deliverable room. Therefore, we should have solution which depends on the amount of deliverable room. Then, let us describe how to generate the expected profit matrix of $g_i(x)$ from sales transaction records for training. The calculation method is follow:

$$g_i(x) = x \times \sum_{a=k}^{N} h_i(a) / \sum_{b=0}^{N} h_i(b) + g_{i-1}(x) \qquad (2)$$

p_i : Profit collected for one i-th channel sold.
$h_i(j)$: Frequency of j rooms sold through i-th channel.

4. Numerical Simulation

4.1. Premise for Simulation

In order to validate our approach, we are ready for numerical simulation studies as follows (See **Figure 3**):

(1) We prepare four virtual channels detail description on channels is presented later.
(2) We generate two kinds of sales transaction records by random variables artificially: One is for training and the other is for evaluation,
(3) Using the sales transaction records for training, we create an expected profit matrix,
(4) We work out the strategy using this matrix and dynamic programming in order to estimate the profit,
(5) Comparing the estimated profit by other strategies, we verify the proposed formulation.

<Problem Establishment>

1. Hotel has 120-guest rooms.
2. Each guest stays one night.
3. Reserved person does not cancel his stay
4. Reservation for a channel is independent from each other.

<Parameter>

1. 4-Channel Problem
2. Deliverable rooms numbers are (10,20,…,120)
3. Four benchmark strategies shown later
4. 1000-day simulation (One day corresponds to one case)

<Expected Profit Matrix>
In this simulation, we generate a past transaction data using Crystal Ball [6], as follows:

1. Assign probability distribution for guest frequency of each channel.
2. Use past 250-day booking data for training (see **Figure 4**)
3. make an expected profit matrix, using the data

Next let us describe what kinds of channels are prepared (see **Figure 4**). Channel 4 has a feature as a direct sale by hotel itself. It is expected that it has the highest revenue margin: however this channel's sales power is low. Channel 3 is supposed to be a travel agency with brand. Although this channel's sales power is high, it requires margin from hotel. Channel 2 has a feature as a Web travel agency. This channel's sales power is still middle today. However, this channel is powerful to reach wide area of customers and will fit to people's new lifestyles. Therefore, this channel's sales power will be higher in the near future. Channel 1 is a discount travel agency for group travelers. This channel's sales power is high.

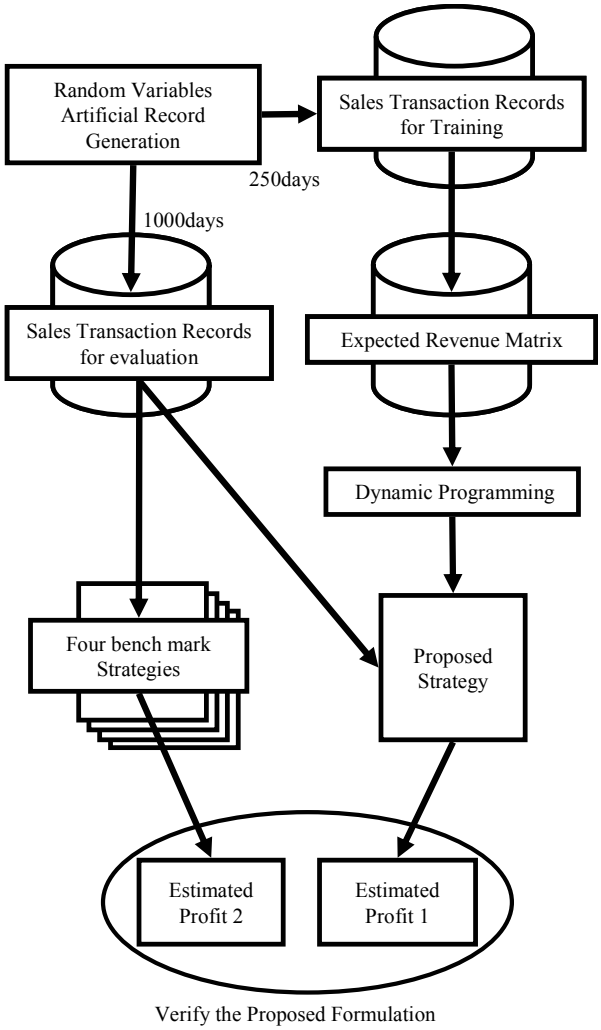


Figure 4. Simulation Model for Evaluation.

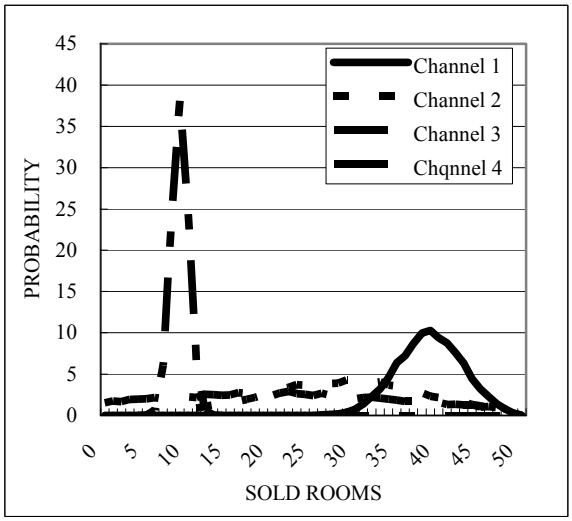


Figure 3 Setting Probability Distribution.

4.2. Simulation Strategies

We use five strategies in this simulation.

1. The strategy based on Dynamic Programming. (Dynamic Programming Based Allocation: DPBA)
2. the strategy based on a Highest Price channel (High Price Channel Based Allocation: HPBA)
3. the strategy based on a lowest Price channel (Low Price Channel Based Allocation: LPBA)
4. Divide up evenly among 4 channels (Uniform Allocation: UNIA)
5. Division based on the most likelihood point of

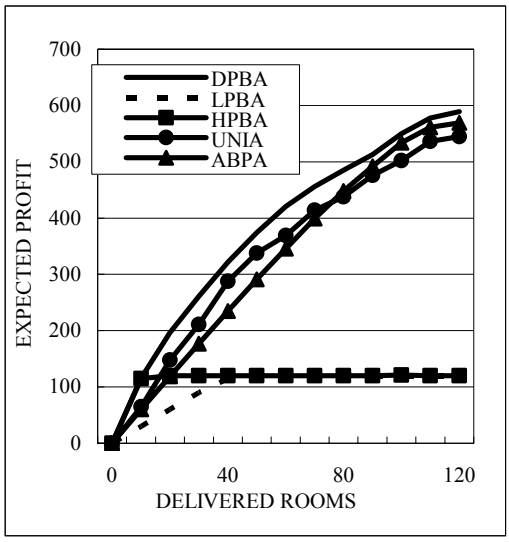


Figure 5 Expected Profit for All Cases.

each channel. In this simulation, this strategy is (ch 1: ch 2: ch 3: ch 4) = (4:3:2:1) (Average based Proportional Allocation: ABPA).

4.3. Simulation Result and Discussion

Let us verify our approach by artificially generated data. We show the efficiency of the proposed approach, using expected profit, the amount of unsold rooms and upper probability 80% point.

4.3.1. Finding in expected profit

<Result 1 (see **Figure 5**)>

In twelve check points (deliverable rooms = 10, 20,…, 120), each expected profit of DPBA is the highest in five strategies. When the amount of allocated room is small (10 rooms or less), the expected profit of HPBP is also higher than other three strategies. Next, between 30 rooms and 60 rooms, the expectation of UNIB is close to the expectation of DPBA. However, the increment rate of UNIB comes down for 70 rooms and the higher. Then, in behalf of UNIB, the expectation of ABPA is close to DPBA. Finally, each strategy's profit is unspread. As the result, DPBA is the effective strategy and is regarded as a mixture of simple strategies, using past transaction data. (For example, when 10 rooms are allocated, HPBA is the base strategy of DPBA).

4.3.2. Finding in upper probability point of 80%

<Result 2 (see **Figure 6**)>

Upper probability point of 80% means threshold which removes twenty percent of low expected profit cases from others. So, using this statistic, we can check

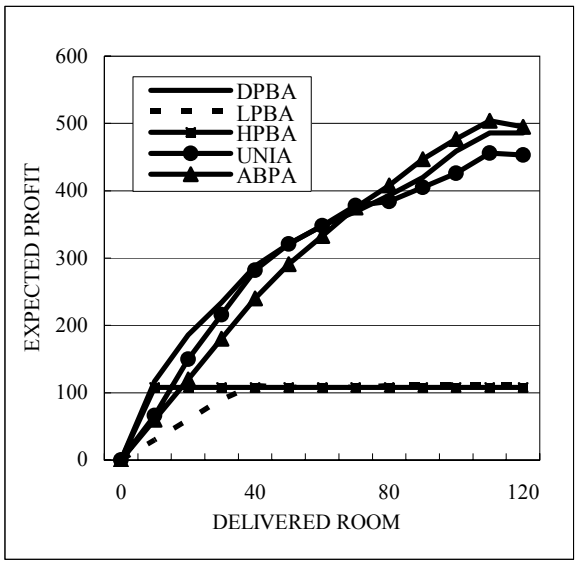


Figure 6 Expected Profit for Upper Probability 80% Cases.

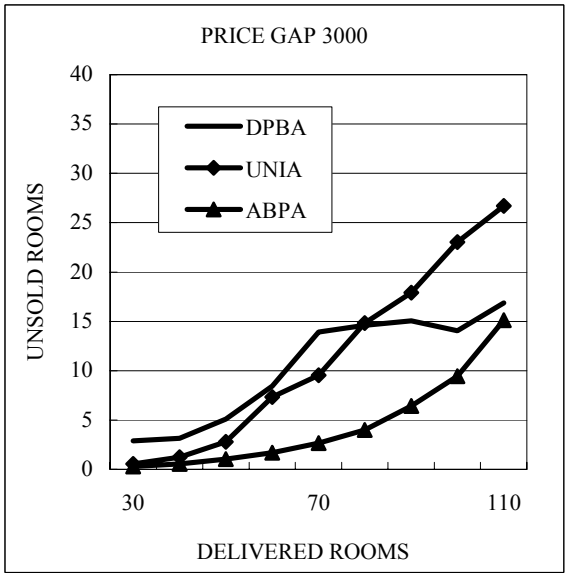


Figure 7 Average Amounts of Unsold Rooms.

whether a strategy is steady or not. To some degree, DBPA is the steadiest strategy. As the number of allocated rooms increases, however, ABPA is steadier than DBPA. This result implies that ABPA is steadier strategy than DBPA because this strategy is based on the most likelihood point of each channel. As the result 1, however, the expected profit of DBPA is the highest in all strategies. Next we will show why the expected profit of DBPA is the highest.

4.3.3. Finding in unsold rooms of three strategy, DPBA, UNIA, and ABPA

<Result 3 (see **Figure 7, Figure 8**)>.

Judging from **Figure 5** and **Figure 6**, HPBA and LPBA are not good strategy. On the contrary, other three strategies (DPBA, UNIA, and APBA) worked out. Using **Figure 7,** we show the difference among three strategies.

The amount of DPBA's unsold rooms is more than that of ABPA. This gives that ABPA is the strategy to eliminate unsold rooms for getting high profit. On the contrary, DPBA is the strategy to allocate more rooms for high risk channels than ABPA do. Judging from result 1 and this result, to increase occupancy ratio is not always the best way to increase revenue.

Next let us consider the difference between DPBA and UNIA. DPBA line is different from UNIA line at 70 delivered rooms. The increment rate of UNIB comes down from the same point (result 1). This means that a low risk strategy is effective when the amount of delivered room is large.

4.3.4. Finding in the Flexibility of DPBA

Finally, let us show the flexibility of DPBA. As found in result 3, DPBA takes much resk than ABPA. However, DBPA can control the risk with increasing price gap among channels. In **Figure 8**, as decreasing price gap, the difference between DPBA and ABPA becomes small. This means that DPBA can adapt the strategy to the situation.

5. Conclusion

We have presented hotel room allocation for sales channels. Notifying that the sales transaction records are clue for the expected profit, we defined the problem in allocating deliverable rooms to multi sales channels. In order to solve this problem iteratively, reasonably and quickly, we designed a new decision strategy based on dynamic programming. Through the numerical simulation, the proposed strategy, DPBA is of benefit for solving multi-sales channel problem.

The real problem is more complex. For example, the pricing is rather flexible. How to define the period for training the expected profit matrix is also an issue. And the benchmark strategies were simple. So we shall compare DPBA to other computational approach. The presented approach will be the first step for such issues.

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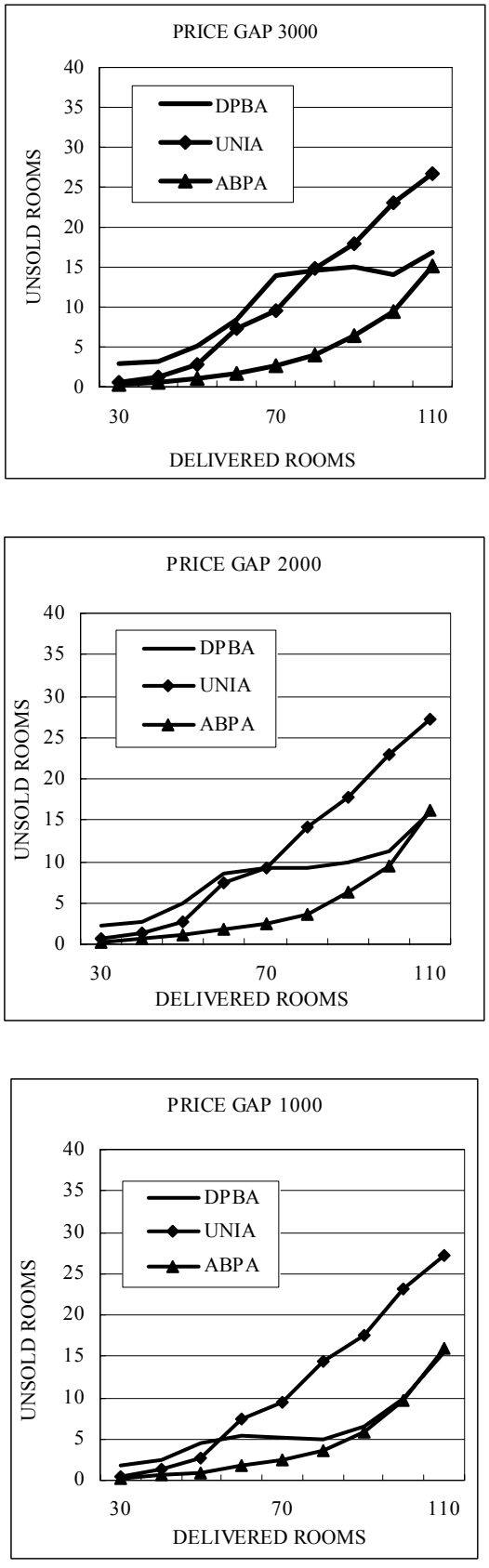


Figure 8 Unsold rooms graph (price gap 3000, 2000, and 1000)