A Dynamic Programming Approach for Determining Optimal E-Procurement Strategy

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Abstract

E-Procurement is the process of creating purchase requisitions by an internal customer by means of an electronic catalogue and using a software system based on internet technology for (a part of) the information flow and verifications in the operational purchasing process. A dynamic programming approach is presented to determine the most cost-efficient way to roll-out EP strategy based on expected costs and cost savings into an organisation, hence setting priorities by calculating the optimal order of implementation. In this paper greedy heuristics are used to calculate (near) optimal strategies. This paper using small scale examples with realistic values of the costs and cost savings the model shows that there can be a large difference in the total savings between the optimal roll-out strategy and other (random) strategies. This paper is first to present a good roll-out strategy in the successful implementation of EP.

Key words: Electronic purchasing, E-Procurement, Implementation, Dynamic programming.

1.   Introduction

E-procurement (EP), also known as electronic ordering through catalogue is the most established form of e-procurement nowadays, yet still in its infancy. Theoretically, changing from the "traditional" way of purchasing to EP can lead to huge cost savings. However the implementation (roll-out) of EP including many commodity groups and many departments is a large and costly task. In addition, not much experience on good roll-out strategies is available yet. Since the 80s automation has found its way into the purchasing process. Traditionally, the operational purchasing process involves a lot of administrative repetitive tasks that add little value: processing purchase requisitions, purchase orders, invoices and all sorts of reports.In the purchasing process computers

were first mainly used for data storage and simple spread sheet analyses. Later, Electronic Data Interchange (EDI) emerged, automating the interchange of business transactions between buyers and suppliers and thereby reducing the transaction costs per purchase considerably. Although a lot has been written about the advantages of EDI, EDI adaptation has been limited until now, mainly because of the large implementation costs of these dedicated (and therefore not so flexible) networks [3, 18, 8, 1]. With the Internet and Internet related technology it has become possible to communicate electronic data between and within companies based on standard global protocols. This has opened up a wide range of opportunities for business in general, e-commerce, and for purchasing in particular, e-procurement (early indications by [20], also see e.g. [16, 15, 13]. With this background the definition of e-procurement (or electronic procurement) by [4] is appropriate: "using Internet technology in the purchasing process."

In this paper we focus on the most established form of e-procurement nowadays. We define EP as: the process of creating purchase requisitions by an internal customer by means of an electronic catalogue and using a software system based on Internet technology for (a part of) the information flow and verifications in the operational purchasing process. This definition of EP is based on the definition of e-MRO by [4]: "the process of creating and approving purchasing requisitions, placing purchase orders and receiving goods and services ordered by using a software system based on Internet technology for MRO (Maintenance, Repair and Operations) supplies." This paper aims to address all purchases; hence the restriction to MRO is left out. Other common terms for EP with similar definitions are: e-catalogs[17], electronic catalog systems [7], Internet-EDI [1] and web-based procurement [5]. EP offers an opportunity to streamline administrative routines in operational purchasing both for product related (direct) purchases and for non-product related (NPR) purchases [5]. Currently many EP systems are available on the market. Major vendors are: Ariba, Baan, CommerceOne, PeopleSoft and SAP. Despite of the opportunities, companies still hesitate though. Recent research indicates that implementation of EP is still in its infancy. Many companies are planning to start a project in the near future, but only a few are actually implementing it now (80-90% versus 8% of the 5000 largest Indian companies[19].Selecting and implementing a new IT system such as EP requires an enormous effort and the (amount of) success depends on the way this implementation project is organised [19]. This paper aims to contribute to the decision making (setting priorities) of determining a good implementation strategy for EP in an organisation. A mathematical model is presented for determining the optimal EP roll-out strategy into an organisation based on maximisation of the total cost savings.

The paper is structured as follows. In the first section the effect of EP on the traditional operational purchasing process as described in literature is discussed more in depth. Section two focuses on the advantages of EP in terms of cost savings. The third section presents an overview of the setup and problem areas of implementing EP systems. The mathematical model is presented in the fourth section, describing the input data needed and describing the implementation process in a formal way. Section five deals with issues regarding the calculation of the optimal EP roll-out strategy. Also the model is illustrated with a numerical example in this section. Finally, conclusions are drawn in the last section together with suggestions for further research.

2. The effect of EP on ordering procedures

The procedure of ordering items is one of the basic procedures in purchasing and it is the heart of the operational purchasing process. Therefore the ordering procedure always received a lot of attention: every general textbook on purchasing describes a way how this procedure should be arranged and this description does not differ a lot between them. Adapted from several textbooks [12, 6, 14] below the necessary steps for the ordering procedure are given:

1. purchase requisition from internal customer: this could be an actual request from a person within the company, but also it could be an automated request from an ERP system.

2. authorisation of purchase: checking with company regulation and / or obtaining the authorisation from the appropriate person(s)

3. sending the purchase order to the supplier (and retaining a copy for administration) supplier: delivery together with good delivered note

4. inspection of goods, checking it with the goods delivered note (and sending a copy to administration)supplier: sending invoice (could also arrive before the delivery)

5. clearing invoice: checking invoice with copies of the purchase order and goods delivered note, checking compliance with contract terms

6. payment to supplier

The description above only applies to repetitive purchases. It is assumed that the specifications are clear and that there is a contract with a supplier, so extra steps regarding those issues can be left out of the procedure. The purchasing department only takes care of the ordering and other administrative units take care of the registration of orders, notes and invoices. The administrative organisation could have slightly different arrangements in practice though, for instance a separate unit for carrying out the actual payments.

The majority of the repetitive purchases following this ordering procedure have little value. They are located in the routine and bottleneck quadrants of the Kraljic matrix [11]. Reducing this administrative burden would free more time to be spent on value adding activities such as tactical and strategic purchasing especially related to the strategic and leverage quadrants.

Although the procedure above can be performed manually without any automation, the advantages of using computers and the automated flow of information are also indicated in the textbooks on purchasing mentioned earlier [12, 6, 14]. These advantages can be summarised into two aspects: automation of data storage (maintaining records, standardised forms, etc) and automatic communication (EDI with suppliers, automatic

matching and other possible information flows within the organisation). Both aspects help to reduce the administrative tasks, hence reducing labour costs and streamlining and speeding up the process.

With the definition of EP in the previous section the changes resulting from using EP in the ordering procedure above can be derived. In step 1 this means that the purchase requisition by the internal customer will be done by using an electronic catalogue and the requisition will automatically be sent to the purchasing department.

Having only this change in place, it can already be considered as having an EP system. In this case the incoming requisitions would be printed out by the purchasing department and the other steps of the ordering procedure would be performed in the traditional way. Extending the EP system then means that other steps are also handled electronically. For steps 2,3,5 and 6 this could be done, only inspection of goods (step 4) will be difficult to do electronically. With this one can speak of the different functionality levels of an EP system. The system could include only step 1, or for instance step 1,2 and 3 or step 1,3 and 6. Note that when authorisation and the purchase order are done automatically, basically the purchasing department is circumvented and is not involved in the order anymore. If all steps for which it is possible are fully automated, there is no human interference in the purchasing department and the administrative unit blocks. Human involvement will still be necessary though, not as administrator in the process, but as controller of the process: to handle exceptions and input data such as: content management, setting authorisation levels and contract data.

3.   Potential costsavings of EP

Using the description of the differences between the "traditional" ordering procedure and EP the advantages of EP with respect to the traditional ordering procedure related to cost savings can be explained. Two advantages are the most important: reducing transaction costs and reducing maverick buying.

The transaction costs of a purchase are the total internal costs to complete a purchase from requisition to payment. Reducing transaction costs is achieved by reduction in the average time spends by (administrative) personnel on a transaction, reducing clerical errors and therefore also reducing the average lead time. A survey by CAPS among 169 Indian organisations showed that for MRO purchases the costs for an average transaction is still more than US $75, which is more than the average MRO invoice [10]. Quotes from [7] indicate that transaction costs with EP can typically be reduced from on average more than US $100 to about US $30 or less per purchase order.

The second major advantage is the reduction of maverick buying (purchases done without using available company contracts). Research indicates that maverick buying could be more than 50% for certain commodity groups resulting in an average higher price (typically 10-20%, [19]. IBM reported in their Annual Report 2000 a reduction in the maverick buying on average from 45% to less than 1% from 1994 to 1999 using e-procurement.

Besides the two main advantages mentioned above there are also other positive side effects. First, with EP system information about the purchase volume, frequency, etc. can be more easily extracted. Also reducing the maverick buying will increase the purchase volume per supplier, making the opportunity even better (reductions of 5-20% in spends through EP according to [19]. Secondly, as already mentioned, implementing an EP system is only done with a limited number of suppliers, because of the implementation costs. Finally, introducing an EP system (especially for several steps of the ordering procedure) means that there has to be a clear understanding of the tasks to be performed in that step in order to be able to automate it.

4. Implementation of EP

For most purchases it is possible to realise cost savings with an EP system based on the advantages in the previous section. However these savings should outweigh the effort and costs of implementing an EP system. Deciding to go ahead with the implementation of an EP system will be based on the analysis of the return on investment (ROI) and often a comparison takes place between the different possible IT investments [9]. We focus on this ROI analysis.Before going into the details of this analysis, note that selecting the proper EP system is also not straightforward. The system has to be able to handle the company-specific information flows, the dimensions of the system and also good compatibility with the existing IT systems of both the company and most of the suppliers would be an advantage. Attaran[2] recognises a number of these pitfalls or attention areas to be addressed before the start of the implementation: the content management, the necessary expertise and the organisational change. The last two apply to implementing IT systems in general; content management is specific for EP: maintenance and updates of the electronic catalog (new items, obsolete item, new prices, etc). Padmanabhan[17] defines three approaches to this issue: content management can be done by the buying organisation, the suppliers or by a third-party. The best solution will depend on the in-house expertise, the costs and expectation regarding control, response time and security, in case the second or third option is chosen.

For the ROI analysis it has to be identified for which commodity groups and for which suppliers of those commodities it is profitable to do the implementation and also for which parts of the organisation (for which employees or on a higher level for which departments / divisions / business units). The costs and the benefits of implementing EP also depend on the functionality level of the EP system. The functionality level of the EP system is defined as the tasks to be performed by the EP system, e.g. does it allow for searching a catalog only, or ordering too, authorisation degree, level of interaction with financial systems at the supplier and the buyer's side, payment etc. The implementation costs have to be assessed per commodity group, per department and per functionality level and the same holds for the cost savings. The implementation costs of adding a supplier catalog can differ a lot between suppliers depending on the experience with Internet technology a supplier has and the compatibility of his current IT systems to the EP system of the buyer. Furthermore making catalogs means making clear specifications of each item in the catalog, which will give more or less difficulties depending on the

commodity group. Also, the number of suppliers required to cover all items in a commodity group differs.

Costs related to adding employees (departments) to the EP system include determining business rules (authorisation limits), training of employees and compatibility issues regarding IT systems which could differ between departments. Last but not least, for all implementation costs apart from the one-time implementation costs update or maintenance costs can occur. Cost savings will only occur if both the commodity group and the department have been added to the EP system (with a certain functionality level). To gain more detailed knowledge about the size of the cost savings of all commoditydepartment combinations information has to be collected on the following:

   (i)   Spend per commodity per department.

   (ii)   Number of transactions per commodity per department.

   (iii)   Average maverick buying percentages per commodity (before and after implementation).

   (iv)   Average higher price when maverick buying.

   (v)   Average transaction costs (before and after implementation).

With the detailed information on the costs and possible cost savings an ROI can be calculated. Then for the EP system the (most) profitable combination of:

   (i)   commodity groups and suppliers;

   (ii)   departments / division / business units to be given access;

   (iii)   functionality level of the EP system;

can be determined.

As implementing EP is a huge task and still relatively new, common practice is to start with a pilot, typically implementing EP for one commodity group (a few suppliers) only available for a small number of employees (for example one department). The reason is to become familiar with the technology, to see if the promised benefits actually occur and to recognise possible pitfalls for successful implementation.

After successfully finishing the pilot the next step is a major one: rolling out the EP system into the entire organisation. Given the dimensions of the EP system, priorities need to be set on the commodity groups, departments and functionality level. For instance given a basic EP system with the commodity group and department with which the pilot started, should first more commodities be added or more departments or should the

functionality be extended? Experience with EP roll-out strategies is still lacking, again because the first EP implementations just started very recently.

To answer this question in the next section a mathematical model is presented to determine the most cost-efficient way to roll-out EP into an organisation, hence setting priorities by calculating the optimal order of implementation.

5.   Modelling the EP roll-out

To make a mathematical model of the electronic purchasing roll-out, input data has to be defined and the implementation process has to be structured. An explanation of the mathematical model follows below, in Appendix A all notation used is listed for reference.

5.1   Input data

We assume that there are *jmax* commodity groups j and that there are *kmax* departments (divisions, business units) k for which EP has to be implemented. Also in this first modelling attempt we assume there is only one level of functionality in the EP system.

For the implementation costs we assume that they can be determined beforehand. We assume fixed costs and variable costs. The fixed costs I are the costs of the EP system itself without any customisation. There are two types of variable costs: CC_j are the implementation costs for adding commodity group j to the EP system and similarly DC_k are the implementation costs for department k. We use one fixed amount for the implementation costs. For calculating this amount one could include several components: the initial implementations costs and update costs lasting for (and perhaps discounted over) several years. We assume that these components are not dependent on anything else except for the specific implementation; hence they can be aggregated into one amount. As indicated in section 3 adding a commodity group to the system means the items of that group are available for all departments that already have been added. Also, adding a department means that all commodity groups that already have been added become available to that department.

Other input data needed are the costs savings or revenues of the implementation. Note that cost savings will only occur for a commodity group in a department if both the commodity group and the department have been added to the EP system. We denote with R_{jk} the costs savings per commodity group j per department k. Again for the cost savings we take one fixed amount using the same reasoning as for the implementation costs. Components of these costs savings will include savings through reduced maverick buying and through reduced transaction costs. Furthermore, these savings are structural. To be able to relate them to the implementation costs one has to take into account the savings for a number of years. This can be done in several ways like: multiplying by a fixed number of years, discounting the savings over time with or without a time horizon.

5.2 Modelling the roll-out

At the start of the implementation project we assume for simplicity but without loss of generality that nothing has been implemented yet. We could also have started with an EP system where already some commodity groups and / or departments have already been added. The implementation process is then modelled as follows:

(i)   The process consists of N periods. The commodity groups and departments are added to the EP system one by one. In other words, in each period t (1...N) EP is implemented for one commodity group or department, hence $N = jmax + kmax$.

(ii)   In period t the implementation costs being either CC_j or DC_k have to be paid. The fixed costs I are paid at the start of the implementation.

(iii)   The revenues (cost savings) in period t are the new revenues generated by the commodity or department added in period t. Hence these revenues are dependent on what already has been connected to the EP-system.

(iv)   Costs and revenues are discounted (depreciated) with factor β ($0<\beta<1$) between each period. By giving costs and revenues that occur earlier in time a higher value, priorities can be determined in the order of implementation. Also β is assumed constant for now, by which we implicitly assume that the implementation period is the same for all commodity groups and departments.

For notation purposes we introduce the variables c_j and d_k with values either 1 or 0, indicating if commodity group j and department k respectively has or has not been added to the EP system. So all c_j and d_k are 0 at the start of the implementation and 1 at the end.

Now the best EP roll-out strategy can be reformulated as the strategy (the order of implementation) for implementing all commodity groups and departments that maximises the total profit (the total revenues minus the total costs) given the depreciation of the revenues and costs in time. Defining de total profit as v the objective can be formulated as:

$$\max \quad v = -I + \sum_{t=1}^{N} \beta^{t-1} \cdot P_t\left(i_{t-1}, z_t\right) \tag{1}$$

With the following definitions of the variables:

(i) i_t is the state of the EP system at the end of period t. This state consists of the values of c_j and d_k in period t and it depends on the state at the end of the previous period i_{t-1} and decision made in period t. Furthermore, i_0 is the initial state (all c_j and d_k are 0).

(ii) z_t is the decision what to add to the EP system in period t. Of course only commodities or departments for which c_j or d_k are still 0 in state i_{t-1} can be

added. Thus the decision z_t is to turn one of those from 0 to 1, hence changing the state. Note that at time $t = 0$ there are still *jmax + kmax* decision options, whereas for $t = N-1$ only one option is left.

(iii) $P_t(i_{t-1}, z_t)$ is the direct profit that is generated in period t. Like i_t it depends on i_{t-1} and the decision in period t. Note that the profit can be negative. The direct profit is calculated in the following way depending on whether a commodity or a department is added to the EP system:

$$P_t\left(i_{t-1}, z_t\right) = \begin{cases} \displaystyle\sum_{k=1}^{k\max}\left(d_k\left(i_{t-1}\right)\cdot R_{j^*k}\right) - CC_{j^*} & z_t : c_{j^*} := 1 \\ \displaystyle\sum_{j=1}^{j\max}\left(c_j\left(i_{t-1}\right)\cdot R_{jk^*}\right) - DC_{k^*} & z_t : d_{k^*} := 1 \end{cases} \tag{2}$$

Note that the fixed costs I is just a constant subtracted from the profit and therefore I has no influence on the optimal roll-out strategy.

5.3   Using dynamic programming

The number of possible implementation sequences is $N!$, making the calculation of all values of v nearly impossible task already for small values of N. However the problem (1) can be rewritten into a finite deterministic dynamic programming (DP) problem with backwards recursion. We define $v_t(i_t)$ as the maximum total revenues that can be obtained in state i_t at the end of period t. $v_t(i_t)$ can be calculated recursively:

$$v_t\left(i_t\right) = \max_{z_{t+1}}\left(P_{t+1}\left(i_t, z_{t+1}\right) + \beta \cdot v_{t+1}\left(i_{t+1}\right)\right) \tag{3}$$

At the end of period N there is only one possible state (all c_j and d_k equal to 1) and no decision options are left, hence:

$$v_N = 0 \tag{4}$$

There is also only one initial state i_0 and with the recursive relation above $v_0(i_0) - I$ will be the maximum total profit and the decisions z_t that give rise to this maximum value determine the optimal order of implementation.

The number of states at the end of period t is $\binom{N}{t}$ and there are $N - t$ decision options left. Thus for determining the maximum profit $\displaystyle\sum_{t=0}^{N}(N-t)\cdot\binom{N}{t}$ calculations have to be made, an expression that can be simplified:

$$\sum_{t=0}^{N}(N-t)\cdot\binom{N}{t} = \sum_{t=0}^{N}t\cdot\binom{N}{t} = \frac{1}{2}N\cdot 2^{N}$$

$$\text{(using } t\cdot\binom{N}{t}+(N-t)\cdot\binom{N}{N-t} = N\cdot\binom{N}{t} \text{ and } \sum_{t=0}^{N}\binom{N}{t} = 2^{N} \text{)} \qquad (5)$$

Above the restriction is used that all commodities and departments have to be implemented. Implementing certain commodities and departments could be non-profitable though, hence excluding them would increase the overall profit. Obviously this would be the case, when the implementation costs for a commodity j^{*} or a department k^{*} are larger than the revenues gained by adding j^{*} or k^{*} to the EP system:

$$\sum_{k=1}^{k\max}R_{j^{*}k} < CC_{j^{*}} \text{ or } \sum_{j=1}^{j\max}R_{jk^{*}} < DC_{k^{*}} \qquad (6)$$

All non-profitable implementations are found at the end of the optimal implementation order. Because of the discount factor losses are postponed. Hence, the profit is maximised when recursively all commodities and departments are excluded that are implemented from period t^{*} until N. This period t^{*} is determined by starting from $v_{N}(i_{N})$ and going backwards in the optimal order until $v_{t^{*}}\left(i_{t^{*}}\right)$ becomes negative. This leads to the optimal roll-out strategy without the restriction that all commodities and departments have to be implemented.

6.   Calculating the optimal roll-out strategy

Using the DP formulation of the previous section optimal EP roll-out strategies can only be calculated on a computer within reasonable time limits for values of N up to 25 or so. This means for problems with larger N, heuristics are required to determine a good approximation of the optimal strategy.

6.1   Heuristics

As an approximation we defined a "greedy m-step" heuristic: looking m steps ahead.

In this heuristic at the end of each period t the decision $z_{t+1}{}^{*}$ will be taken that maximises the profit w_{t}over m steps:

$$w_{t} = \max_{z_{t+1}}\left(P_{t+1}(i_{t},z_{t+1})+\beta\cdot\max_{z_{t+2}}\left(P_{t+2}(i_{t+1},z_{t+2})+\beta^{2}\cdot\max_{z_{t+2}}\left(...+\beta^{m-1}\cdot\max_{z_{t+m}}P_{t+m}(i_{t+m-1},z_{t+m})\right)\right)\right) \quad (7)$$

The total profit v will be:

$$v = -I + \sum_{t=1}^{N}\beta^{t-1}\cdot P_{t}\left(i_{t-1},z_{t}{}^{*}\right) \qquad (8)$$

Note that for the greedy 1-step heuristic (7) and (8) can be taken together:

$$v = -I + \sum_{t=1}^{N} \beta^{t-1} \cdot \max_{z_t} P_t\left(i_{t-1}, z_t\right) \tag{9}$$

This greedy 1-step heuristic is simply taking the best available option at every step, without looking at its consequences for further steps.

Naturally, it should hold that $1 \le m \le N$. It is proven that below a certain threshold value β_T of the discount factor β the greedy m-step heuristic provides the optimal solution.

The number of calculations needed for the heuristic in each period t is:

$$\left(N+1-t\right)\left(N-t\right)\cdots\left(N+2-t-m\right) = \prod_{i=0}^{m-1}\left(N+1-t-i\right) \tag{10}$$

For the total number of calculations it has been proven in Appendix C that:

$$\sum_{t=1}^{N}\prod_{i=0}^{m-1}\left(N+1-t-i\right) = \frac{1}{m+1}\prod_{i=0}^{m}\left(N+1-i\right) \tag{11}$$

For the 1-step heuristic this boils down to $\frac{1}{2}N\cdot\left(N+1\right)$ calculations and for the 2-step heuristic to $\frac{1}{3}\left(N-1\right)\cdot N\cdot\left(N+1\right)$ calculations. Note that for large m calculating the DP problem could be faster.

The 1-step heuristic has an obvious flaw, as in the first period no cost savings will occur (only having either a department or a commodity connected to the EP system), hence the commodity or department with the lowest implementation costs would be chosen. Here a large improvement can be made by looking two steps ahead, as in the second period the first savings occur. Considering reasonable calculation time the 2-step heuristic can be used for N even larger than 100, making it applicable for most practical situations. If not all commodities and departments have to be implemented, the non-profitable parts can be removed at the end of the implementation order found by the heuristic (as described at the end of section 4), hence increasing the maximum profit.

6.2   A numerical example

To illustrate how the model can be used for practical calculations a small scale example is given below with seven commodity groups and six departments to be connected to the EP system. The data in the examples is based on realistic values. Fixed costs of US $0.6 Million are assumed. Furthermore, the costs per commodity group are assumed to be in the order of US $ 100,000 and the costs per department around US $ 30,000. These amounts include discounted maintenance costs for five years. The variable costs are shown in Table 1. For the six commodity groups we assume around 15,000 transactions per year and spend of US $25 Million. Also, we assume around US $50 can be saved on

average per transaction, which means around US $0.75 Million per year. With an average of 25% maverick buying that will decrease to 5% with the EP system and assuming 10% higher prices with maverick purchases, the savings per year are around US $0.5 Million. With discounted summation over five years this leads to an estimate of US $6 Million in total cost savings and these savings have been divided over the savings per commodity group per department in Table 2. Finally, a discount factor per year of 0.8 was taken. Assuming projects of 3 months this leads to $\beta = 0.946$.

Table 3 shows the optimal roll-out strategy. The last two periods are put between brackets, as they are non-profitable and therefore should be excluded from the implementation. Table 4 gives a comparison of five roll-out strategies regarding: the profit, implementation order and the total implementation costs. They vary between the strategies as the costs are distributed differently over the total implementation period.

Table 1: Implementation costs of the commodity groups a department
(in 1000 US dollars)

Commodity (j)	CC_j	Department (k)	DC_k
C1	185	D1	25
C2	100	D2	95
C3	95	D3	20
C4	145	D4	36
C5	92	D5	12
C6	60	D6	77
C7	145		

Table 2: Expected cost savings R_{jk} per commodity per department
(in 1000 US dollars)

Department (k)→ ↓Commodity (j)	D1	D2	D3	D4	D5	D6
C1	300	566	240	190	150	9
C2	200	180	235	130	190	6
C3	70	125	100	523	110	3
C4	250	365	325	122	140	5
C5	310	175	60	120	155	14
C6	115	40	32	70	365	8
C7	15	34	13	27	25	50

Table 3: Optimal roll-out strategy together with the revenues associated with each implementation period (in 1000 US Dollars)

Period	Optimal solution	Direct profit	Direct profit (discounted)	Cumulative profit
1	D2	-695	-695	-695
2	C1	381	360	-335
3	D1	275	246	-89
4	C4	470	398	309
5	D3	545	436	745
6	C2	515	390	1135
7	D4	406	291	1426
8	C3	723	490	1916
9	D5	578	371	2287
10	C5	728	442	2729
11	C6	562	323	3052
(12)	(C7)	(-31)	(-17)	(3035)
(13)	(D6)	(18)	(9)	(3044)

Table 4: Results regarding the expected profit (in 1000 US dollars) using various roll-out strategies

Method	Profit	Total investment	Implementation order
Optimal	3052	1295	D2,C1,D1,C4,D3,C2,D4,C3,D5,C5,C6
Greedy 1-step	2920	1232	D5,C6,C2,D1,C5,D3,C4,D2,C1,D4,C3
Greedy 2-step	3041	1282	D4,C3,D2,C1,C4,D3,D1,C2,D5,C5,C6
Greedy 3-step	3052	1295	D2,C1,D1,C4,D3,C2,D4,C3,D5,C5,C6
Worst case	2042	1481	C1,C4,C7,C2,C3,C5,C6,D6,D3,D5,D4,D1,D2

The worst case was found by minimising instead of maximising the total profit. In this case the maximum profit is 49% higher than the minimum profit. Furthermore, the greedy heuristics approximate the optimal solution quite well. One can see the value of looking two steps ahead instead of one by the profit difference between the 2-step and 1-step heuristics. The 3-step heuristic already provides the optimal solution here.

7. Conclusion

The advantages of EP seem undisputed regarding costs savings and administrative process automation. As implementation costs are lowering, EP is expected to be widely adopted by companies. At the moment EP is still in its infancy though. Pilot projects are under way, but companies still hesitate with the full roll-out of EP into their organisation, because the technology is new and not much experience exists yet about implementation strategy.

The mathematical EP roll-out model is a framework for providing a good roll-out strategy based on expected costs and cost savings. It determines the optimal order of implementation for commodity groups and departments, together with total cost savings

and how these savings will occur over time. For larger practical cases greedy heuristics can be used to calculate (near) optimal strategies. Using small scale examples with realistic values of the costs and cost savings the model shows that there can be a large difference in the total savings between the optimal roll-out strategy and other (random) strategies. A good roll-out strategy is therefore an important factor in the successful implementation of EP.

Although many aspects already have been incorporated in the model, it is possible to make some extensions. Different functionality levels of EP systems, different lengths of implementation periods can be incorporated easily. One could also think of learning curves for implementing EP systems. Stochasticity could also be included, as input values may not be easy to estimate in practice.

The applicability of the model with possible extensions still has to be verified with empirical evidence in the near future. For practical purposes it is good to emphasise that only financial aspects of EP implementations are optimised in the model. To implement EP successfully also other organisational factors may need to be considered. These factors could influence the preferred implementation sequence. However with the model at least the financial consequences of other roll-out strategies can be calculated.

References

[1]   Angeles, R., 2015, Revisiting the role of Internet-EDI in the current electronic commerce scene, *Logistics Information Management,* 13, 45-57.

[2]   Attaran, M., 2011, The coming age of online procurement. *Industrial Management & Data Systems,* 101, 177-180.

[3]   Bergeron, F.andRaymond, L., 2013,Managing EDI for corporate advantage: A longitudinal study, *Information & Management,* 31, 319-333.

[4]   Boer, L. de, Harink, J.H.A.andHeijboer, G.J., 2011,A conceptual model for assessing the impact of electronic procurement.*European Journal of Purchasing & Supply Management*, 2, 346-362.

[5]   Croom, S.R., 2013,The impact of web-based procurement on the management of operating resources supply,*Journal of Supply Chain Management*, 2, 4-13.

[6]   Dobler, D.W.andBurt, D.N., 1996,*Purchasing and supply management: text and cases*, sixth edition , McGraw-Hill.

[7]   Harink, J.H.A.,1999,*Excelling with e-procurement*, PriceWaterhouseCoopers, Netherlands.

[8]   Kaefer, F.andBendoly, E., 2012,The adoption of electronic data interchange: a model and practical tool for managers,*Decision Support Systems,* 30, 23-32.

[9]   Kim, S.H., Jang, D.H., Lee, D.H.andCho, S.H., 2011,A methodology of constructing a decision path for IT investment.*Journal of Strategic Information Systems*, 9, 17-38.

[10]   Kolchin, M.G.andTrent, R.J.,2013,Reducing the transactions costs of purchasing low-value goods and services, CAPS focus study,*Harvard Business Review*, 23, 453-471.

[11]   Kraljic, P.,2014, Purchasing must become supply management,*Harvard Business Review*, 1, 109-117.

[12]   Leenders, M.R.andFearon, H.E., 1993, *Purchasing and materials management*, Tenth edition, Irwin, Boston.

[13]   Long, B.G., 2011, Ten E-Commerce Questions All Purchasing Managers Must Answer, *Harvard Business Review*, 2, 342-361.

[14]   Lysons, K., 1996,*Purchasing*, Fourth edition, Pitman Publishing, London.

[15] McIvor, R., Humphreys, P.andHuang, G., 2013, Electronic commerce: re-engineering the buyer-supplier interface, *Business Process Management Journal,* 6, 122-138.

[16]   Min, H.andGalle, W.P.,2009,Electronic commerce usage in business-to-business purchasing,*International Journal of Operations & Production Management*, 19, 909-921.

[17]   Padmanabhan, S., 2011,Electronic catalogmanagement, *Purchasing Today*, 1, 60-81.

[18]   Segev, A., Porra, J.andRoldan, M.,2014, Internet-based EDI strategy,*Decision Support Systems*, 21, 157-170.

[19]   Sherrill, F., Anthony, T., Danish, S. andChrist, K., 2015,E-Procurement: the promise and reality, *Harvard Business Review*, 1, 234-261.

[20]   Telgen, J.,2015, Revolution through electronic purchasing,*Harvard Business Review*, 2, 238-263.

Appendix A

The notation used :

Indices:

      j : denoting the commodity group (1...*jmax*)

      k : denoting the department (1...*kmax*)

      t : denoting the period (1...*N*)

Here *jmax* and *kmax* is the respectively the number of commodity groups and the number of departments to be added to the EP system. *N* is the number of implementation periods and therefore equal to *jmax + kmax.*

Input data:

      I : Costs of the uncustomised EP system itself.

      CC_j : Implementation costs of EP for commodity group j (≥ 0).

      DC_k : Implementation costs of EP for department / division k (≥ 0).

      R_{jk} : Costs savings (revenues) obtained when commodity group j and department k have been added to the EP system (≥ 0).

      β : Discount / depreciation factor ($0 < \beta < 1$).

Variables:

      c_j : Value 1 or 0 if commodity group j respectively has or has not been added to the EP system.

      d_k : Value 1 or 0 if department / division k respectively has or has not been added to

    the EP system.

      i_t : The state of the EP-system at the end of period t, consisting of the values of c_j and d_k at the end of period t.

      z_t : Decision what to add to the EP-system in period t (turning one c_j or d_k from 0 to 1).

      P_t : Direct profit in period t.

      $v_t(i_t)$: Maximum profit in period t for state i_t.