TPBOSCourier: A Transportation Procurement System (For the Procurement of Courier Services)

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Abstract

TPBOSCourier is the Transportation Procurement and Bid Optimization System (*TPBOS*) for Philips Electronics to automate and optimize its procurement of courier services. It was jointly developed by Red Jasper Limited and the Hong Kong University of Science and Technology, and has been successfully deployed in 2005. Philips typically procures courier services for more than 2500 shipping lanes annually and the use of the software has resulted in significant cost and time savings in analyzing and optimizing procurement decisions. This paper explains the development and design of the *TPBOSCourier*.

Introduction

Every year, household name, Philips Electronics, requires a considerable amount of transportation services throughout the world. Among the various types of transportation services, the courier service plays a very crucial role in satisfying urgent deals along every stage of Philips' supply chain operations. This is because Philips annually spends multi-million USD on purchasing courier services alone for more than 2500 lanes through a reverse auction with service providers including DHL, FedEx, UPS, TNT, etc.

Prior to jointly awarding the project to Red Jasper and the HKUST, Philips had conducted an exhaustive two-year worldwide search for such a system.

The quotation format for procuring courier services is significantly more complex than that for other transportation modes because prices of courier services vary greatly for different weights of shipments, for different lanes, and for different service levels. This inevitably leads to Philips requiring an enormous amount of data from service providers as input for Philips to make procurement decisions.

Previously, the task of selecting and allocating jobs to courier service providers was done through manual analysis with limited computer aid. It took several weeks for personnel in Philips' forwarding and distribution department (F&D) to conduct only a limited number of cases for scenario analysis. Consequently, processing errors were unavoidable, and the performances of the resulting schedules were impossible to measure.

Philips' problems occurred not only in the process of procuring courier services but also in sourcing sea and air freight providers. As a result, Philips Electronics sponsored the development of the Transportation Procurement and Bid Optimization System (*TPBOS*), an electronic procurement system with advanced scheduler and planner (Lim et al. 2006a, Lim et al. 2006b). When completed, the software is expected to automate Philips' entire transportation procurement process and to optimize the schedules of selecting service providers under different constraints and/or scenarios.

TPBOS, on the whole is currently under development. However, the courier procurement portion, *TPBOSCourier*, has been deployed and used to support decisions in the selection of courier service providers for the year 2005/2006.

This paper describes the steps involved in the development of *TPBOSCourier* from its conception to its completion, along with a breakdown of the inner workings of each portion of the software.

Procurement Process

The process of transportation procurement in Philips typically consists of the following stages:-

- Request for Information (RFI): the forward and delivery department (F&D) collects information of various business units to forecast the volume of transportation services requested for the coming year.
- Request for Quotation (RFQ): the F&D invites service providers to quote their shipping prices for different lanes, service levels, weights, etc.
- Analysis and Negotiation: the F&D analyzes the quotations from the service providers, and negotiate with service providers on their prices and conditions.
- Signing Contract: the F&D makes the decision to select service providers and to allocate the shipping tasks, and finalize the prices and conditions with service providers by signing the contract.

Since courier services largely deal with urgent and ad hoc requests, it is impossible for business units and the F&D to forecast its future requirements in day-to-day resolutions. Hence, the F&D aggregates shipping volumes monthly, according to historical records, and scales them properly by a seasonal factor to obtain the forecasted monthly volumes of courier services for the coming year. The seasonal factor represents the trends of the market, and it is above one if the market is optimistic, and below one if not.

After releasing the lanes of their shipping needs, Philips invites these courier service providers to quote their prices. Each service provider usually has its own zoning structure, and the shipping prices differ for different weights and service levels, as well as, for different zones of their sources and destinations. For example, DHL partitions cities as destinations into 9 zones (DHL 2005); FedEx has 16 zones (FedEx 2005), etc. The inconsistent zoning structures among different service providers inevitably complicate Philips' decision making processes when comparing and negotiating prices.

For this reason, Philips has proposed to service providers a standard zoning structure for all cities in the world, which consist of 24 zones and 55 countries. Each service provider only needs to quote shipping prices for each service with a certain level and weight along lanes from one country to one zone. This eases Philips' analyzing process, but increases the work of service providers as they have to project their cost structures to shipping prices based on the standard zoning structure.

After collecting the shipping prices from service providers, Philips conducts a concentrated research including benchmark calculations for prices, and scenario analysis for picking providers. The benchmark calculation is relatively simple, with only the lowest or second lowest prices being highlighted as a benchmark for each service. The benchmark may be fed back to service providers to help them decide their quotations for a second round of RFQ. Afterwards, Philips is able to properly scale the final benchmarks as the target prices for negotiations with service providers.

The scenario analysis for picking providers is relatively complicated and requires greater computational powers as aids. The F&D expects to know the minimum spending of courier services to satisfy the forecasted requests under several scenarios. A scenario is defined by certain constraints, which express the preferences of selecting service providers and the restrictions of the number of service providers for certain services that are requested. Based on the scenarios analyses, the F&D is able to gather a better understanding of its position and its target when negotiating with service providers. The scenarios analyses can also help F&D in deciding the final allocation schedule of service providers after prices have been settled in the negotiation.

After several rounds of negotiations and analyses, the F&D will decide on the selection of service providers and allocate them certain requests to serve. The shipping prices and other terms will be finalized and signed in the contract, which completes the purchasing period for the coming year. Finally, a number of reports are required to be documented and shared internally within Philips.

Figure 1 elaborates the operation flows of the transportation purchasing in Philips.

Problem Description

In order to support the scenario analysis, *TPBOSCouier* needs to solve a Service Provider Selection Problem (SPSP) to minimize the total spending by creating a schedule, such that a set of service providers is selected and allocated to consider certain courier services under restrictions that are configured as a scenario (Lim et al. 2006c). The instance of SPSP involves the following parameters.

- A set of ports *P*, and a set of *d* zones $Z=\{Z_1,\dots,Z_d\}$, while each Z_i is subset of ports;
- A set of *m* service providers, $SP=\{sp_1,\dots,sp_m\}$
- A set of business units, *B*
- A set of *n* service requests $R=\{r_1, \dots, r_n\}$, while each request r_i is defined by the following five elements:
  - s_i: the source in *P* of the lane;
  - d_i: the destination in *P* of the lane;
  - l_i: the service level;
  - w_i: the aggregated weights of shipments;
  - b_i: the business unit in *B* who owes the shipment;
- A set of quotation of prices $Q=\{q_{1,1},\dots,q_{m,n}\}$, while each quotation $q_{j,j}$ indicates the shipping spending for using service provider sp_i to serve request r_j. Notice that *Q* can be obtained directly from the data of the reverse auction, including the forecasting, the quotation of service providers, and the zoning structure.
- A set of constraints *C* to restrict the combinations of service providers to be picked for a certain subset of requests. For a subset of requests *R'*, two types of restrictions may be included:
  - Preference restriction: service providers are participated into three categories, IN(*R'*), EX(*R'*), and OTHER(*R'*), which indicates service providers that must be selected, must not be selected, and may be selected, to serve requests in *R'*
  - Scale restriction: two values, LB(*R'*) and UB(*R'*), are specified to indicate the minimum and the maximum number of service providers that are selected to serve requests in *R'*.

Hence, the SPSP is to decide an assignment of service providers to requests, which can be indicated by a set of binary variables:

- $x_{i,j}$: when equals to 1 if request r_j is served by service provider sp_i

A feasible solution to the SPSP is an assignment of values to all $x_{i,j}$ such that every constraint is satisfied and the requests are fulfilled. The SPSP aims to find the optimum feasible solution that minimizes the total spending. A special case of the SPSP is equivalent to the *k-median* problem, when only the total number of service providers is restricted to be *k* without considering other constraints. Since the *k-median* problem is *NP-Hard* (Garey and Johnson 1979), the SPSP is intractable as well in general.

However, the real-life SPSP for selecting the courier service involves a limited number of service providers, which is usually less than 20. This simplifies the complexities of the problem to some extent, but the SPSP with a constant number of service providers is still intractable because the constraints may be imposed on any subsets of requests (Lim et al. 2006c). Fortunately, the subsets *R'* related to constraints in *C* are defined by requests with similar properties. For example, *R'* may include requests starting from Hong Kong to ports in North America. This leads to a hieratical structure, which will be explained later, and makes it possible to generate exact optimum solutions to the SPSP in a reasonably short time.

In the case of procuring courier services for 2005/2006, this involved five service providers to quote requests for more than 2500 lanes owed by seven business units to be scheduled under a pre-defined zoning structure. The purchasing period is from mid April to the end of June 2005, and two rounds of RFQs are conducted followed by a series of analysis and negotiations.

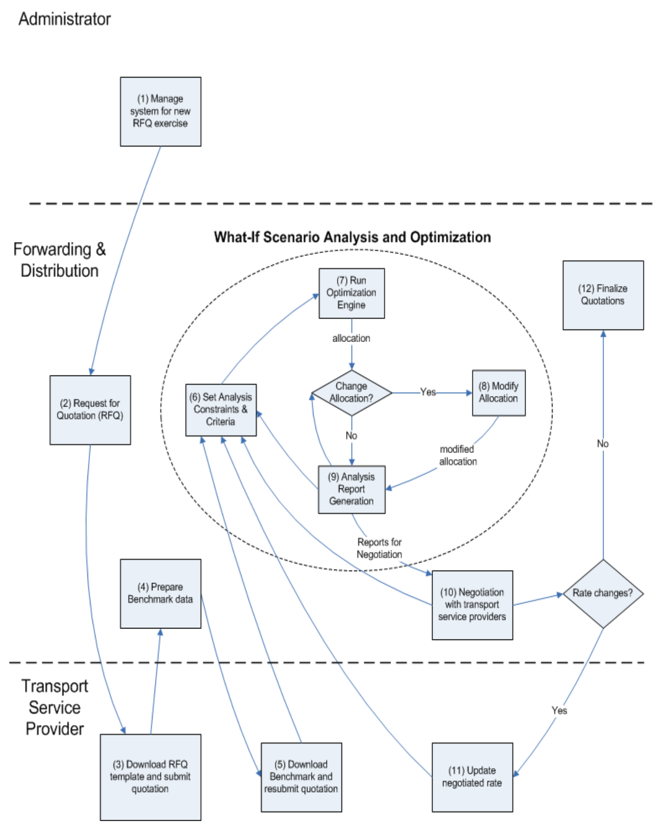

Figure 1: Flowchart of the transportation service purchasing in Philips

Application Description

The structure of the *TPBOSCourier* program needs to support personnel in F&D to work on different scenarios analyses simultaneously. Aside from the basic functions of user management, data entry, and optimization, facilities must be provided for data communication and sharing. Minor side-applications include creating the schedule of allocating service providers to service requests, and the generation of reports.

Hardware & Software

The system was coded in *Java 1.5* using the *Eclipse 3.1* software and *Oracle* databases. The central machine used was a Dell PC with a *Pentium-4 2.80GHZ* CPU and 1.00 GB RAM memory.

System Design

The *TPBOSCourier* system design is based on the 3-Tier architecture that is commonly used when building Client/Server applications. It keeps distinct the GUI, object oriented and data storage portions of our program. By separating the system into 3 tiers, they can be worked on independently (Reese, 1997).

TPBOSCourier is divided into the following 3 tiers as shown in Figure 2. The *View* tier involves the graphical user interface. The *Application* tier is composed of the modules in an object-oriented paradigm that manipulate the objects in the system. This includes the purchasing data manager, report generator, benchmark analyst, and scenario analyst, where the scenario analyst is supported by an optimization engine. Finally, the *Persistence* layer consists of the actual database access. Figure 1 shows the system design.

Parameter Definitions

TPBOSCourier contains several screens that enable the user to define all the variables of the SPSP problem, including:

- Information of service providers and business units
- Information of cities and the zoning structure
- Service request forecasting
- Price quotations of service providers
- Constraint definitions
- Policy definitions

Constraint Definitions

Of particular interest are the constraint definitions. It is imperative that the *TPBOSCourier* program allows the users to define the necessary constraints belonging to the following two categories.

The first category involves preference constraints, which express the preference of F&D on the selection of service providers for a certain subset of requests with similar properties of their sources and destinations. The following are two examples of preference constraints:

- For services from Asia to Europe, FedEx must be selected as a service provider, while UPS cannot be chosen.
- For services from Hong Kong, the service providers must be selected from UPS, FedEx, and TNT.

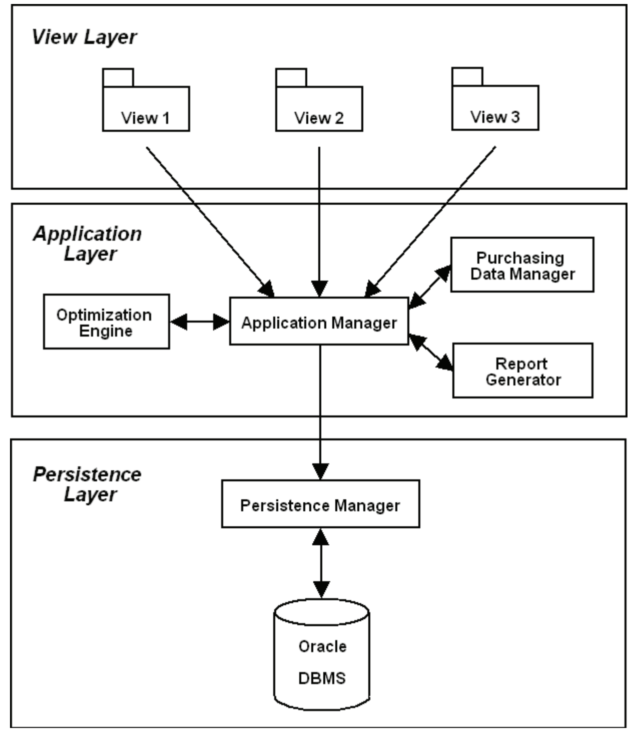

Figure 2: TPBOSCourier System Architecture

The second category of constraints involves scale constraints, which express the restriction of the minimum and the maximum number of service providers that serve a certain subset of requests with similar properties of their sources and destinations. The followings are two examples of scale constraints:

- For services inside America, at most two service providers can be used;
- For services from China, two or three service providers can be used.

With regard to the interest of Philips, the subset of services that is related to the above constraints always belongs to one of the following five categories:

- all services in the world;
- services from a certain continent to all ports in the world/continent;
- services from a certain zone to the world/ /continent/zone;
- services from a certain region to the world/ /continent/zone/region;
- services from a certain city to the world/region/country/region/city;

Here, the world, zones, continents, regions, and cities are five levels defined in the zoning structure, as shown in Figure 3 for example.

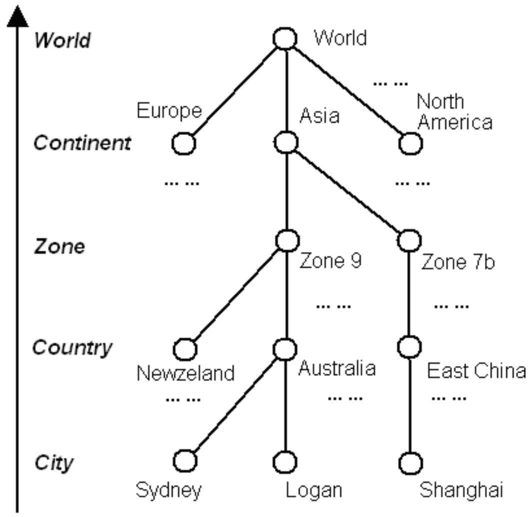

Figure 3: TPBOSCourier Zoning Structure

The *TPBOSCourier* system provides a template file for the F&D to express the constraints. As shown in Figure 4, each row of the template corresponding to the constraints on a subset of services with the same properties of their sources and destinations. In the figure SPs stands for service providers. The figure and the names of zones and service providers are distorted due to reason of confidentiality.

	A	B	C	D	E
1	Origin	Destination	No. of SPs	Must include SPs	Must Exclude SPs
2	GLOBAL	GLOBAL	4		
3	ZONE_A	ZONE_A	2	SP1	
4	ZONE_A	ZONE_B	2		
5	ZONE_A	ZONE_C	2		
6	ZONE_B	COUNTRY_A	2		SP2
7	ZONE_B	ZONE_A	2	SP1	
8	ZONE_B	COUNTRY_A	2	SP2	SP5
9	ZONE_C	ZONE_C	2		
10	ZONE_C	COUNTRY_B	1		SP1, SP5

Figure 4: Constraint Definition Template

Policy Definition

TPBOSCourier supports two possible policies for the optimization engine to decide the selection of service couriers in the scenario analysis.

- Unbiased policy: where minimizing the total spending is the only objective under the restriction of constraints;
- Biased policy: where a particular service provider is highly preferred to be selected. For services that the preferred service providers cannot cater to, others are selected to minimize the remainder of the spending amount.

The unbiased policy could suggest to Phillips a lower bound of its total purchasing spending, while the biased policy empowers the F&D with the knowledge of potential improvements for the negotiation with every service provider.

Output

Various reports can be created for reference by the program. These include the assignment of courier service providers to requested services, the CPI report, the service provider ranking report, and the simulation report on spending based on historical transactions. Such reports are generated in excel files so that the F&D can further manipulate the data through MS Excel.

Figure 5 gives a segment of reports about the schedule of service provider allocations, which is generated for the courier service purchasing in year 2005/2006. It reports the allocation of services providers for lanes from countries to zones. The names of countries, zones and service providers are distorted due to reason of confidentiality. The color scheme highlights the usages of each service provider.

	A	B	C	D	E
1	FROM\TO	ZONE_A	ZONE_B	ZONE_C	ZONE_D
2	COUNTRY_A	SP1	SP1	SP2	SP2
3		SP2	SP3	SP3	SP3
4					
5	COUNTRY_B	SP4	SP4	SP4	SP4
6		SP2	SP2	SP3	SP3

Figure 5: Scheduled timetable output

Optimization Engine

The heart of the program is the optimization engine, which generates the optimum assignment of service providers to the requested services, under the restriction of constraints and polices that are specified by F&D. The interface for running the optimization engine is shown in Figure 5, while the details of the optimization algorithm are given in the next section.

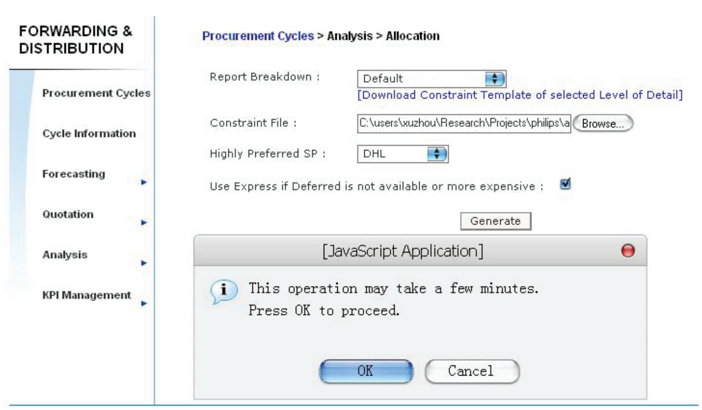

Figure 5: Interface of running optimization engine

Uses of AI Technology

The major objective of *TPBOSCourier* is to solve the *SPSP*, by selecting a subset of courier service providers and allocating them the requests to serve in a minimized total spending but restricted to certain constraints. To achieve the objective, the following three tasks need to be accomplished:

- Selection of service providers
- Allocation requests to the selected service providers
- Satisfying the constraints

Since it is possible that the F&D input constraints might lead to conflicts or infeasibility, the optimization actually deals the constraints in a soft way. Whenever a constraint is broken, a penalty is occurred and counted in the spending. As long as the penalty is large enough, we guarantee constraint satisfaction will have a higher priority than the spending minimization. When the schedule output is generated, the system will highlight unsatisfied constraints and guides the user to modify its constraints.

When a candidate set of service providers are selected, the service allocation to them can be accomplished by a dynamic programming algorithm (Lim et al. 2006c). It leverages the hierarchical structure of constraints and calculates the optimum allocations from leaves to the root recurrently. The dynamic programming algorithm can guarantee an optimal allocation that minimizes the total spending; however, it has a polynomial time and space complexity only when the size of the candidate set is bounded by a constant. In the case of courier services, the F&D always restricts the number of service providers to be small, usually 4 at the most. This is for the consideration of a smoother and controllable cooperation with selected service providers. Therefore the size of the candidate set is small, and the optimal assignment can be obtained through dynamic programming algorithm in a reasonably short time. Actually, dynamic programming can handle the instance where the scale of the candidate set is up to 30 according to the complexity analysis and numerical experiments. Since the number of service providers invited to attend the reverse auction hosted by Philips is only 5 in year 2005/2006, the dynamic programming algorithm can handle this case very comfortably.

Although the dynamic programming algorithm in *TPBOSCourier* handles the procurement of courier services for Philips in year 2005/2006, we still need to extend our method to handle much lager scale instances of the service provider selections problem (SPSP), so that Philips is allowed to invite more service providers to give their quotes (Lim et al. 2006c).

The *TPBOSCourier* program thus employs a stochastic search technique to select a candidate set of service providers. Since the total number of the selected service providers is usually restricted to be small, the dynamic programming algorithm can be used to provide the optimal service allocation for service providers in the candidate set. A simulated annealing mechanism (Rayward-Smith, et al. 1996) is adopted to guide the search for a good combination of service providers to form the candidate set, while the initial solution is chosen from a random sampling. We also implement a local search algorithm to improve the initial solution as a reference for performance comparisons.

Table 1 summarizes results of numerical experiments, where the test instances are generated based on procurement data for a hundred lanes in Philips. However, figures are distorted due to reasons of confidentiality. Here the objective value of a solution includes both the total shipping cost and the penalty cost for invalidating the preference constraints. The number of forwarders (*m*) varies from 5 to 100, and the total number of selected service providers varies from 3 to 10. The dynamic programming (DP) can produce an optimal solution as long as the number of forwarders is less than *20*, due to the restriction of time and space. Using simulated annealing (SA) can produce optimal solution for small instances, and can also produce near-optimal high quality solution. Compared with its initial solution (INIT) and a near optimal solution by a local search (LS), the solution produced by SA is significantly better. Especially when the number of forwarders is larger than 50, the heuristic objective value by SA is above 6% better than the initial solution and 2% better than the heuristic solution by LS. The details of the numerical results are reported in Lim et al. 2006c.

Table 1: Comparing Performances of Algorithms

m	DP		INIT	LS	SA
	Value[1]	Time[2]	Value[3]	Value[4]	Value[5]
5	9924.05	0.01	9924.14	9924.05	9924.05
10	7952.20	0.20	8169.00	7952.00	7952.20
15	10047.23	6.67	10442.60	10047.23	10047.23
18	10458.43	213.00	10684.06	10458.43	10458.43
20	–	–	8948.33	8360.09	8360.09
50	–	–	10629.40	10196.50	9904.67
100	–	–	10699.67	10223.64	10003.38

1: the objective value obtained by dynamic programming;
2: the time in seconds consumed by the dynamic programming;
3: denotes the objective value of the initial solution for the simulated annealing;
4: denotes the optimal objective value obtained by a local search with a 10-second time limit;
5: denotes the optimal objective value obtained by simulated annealing with a 10-second time limit;

In summary, *TPBOSCourier* optimally solves the median scaled instance of the *SPSP* through dynamic programming when the invited number of service providers is small. When the scale is larger, it adopts a simulated annealing meta-heuristic to select candidates and uses dynamic programming to generate the service allocation. Meta-heuristics can provide a near-optimal solution for larger scaled instances.

Application Use and Payoff

TPBOSCourier was used to create the selection schedule of service providers under different scenarios for the recently completed procurement exercise for the year 2005/2006. Based on the scenarios analyses, the F&D department of Philips has decided on the final allocation of requests to the service providers, and a total of four service providers have been selected. The shipping prices and other terms have already been agreed upon, and the contracts have already been signed as well.

Even though this is the first year that *TPBOSCourier* is being deployed in Philips, benefits of automating the procurement exercises and analyses are significant:

- Initial implementation of the program, data entries and constraint specifications were the most time-consuming part of the process. Massive amounts of historical shipping records were dug up and transferred to the database for forecasting. It took a further 2 weeks to settle the definition of zone structures, 4 weeks to conduct the first round of RFQ to collect the quotation from service providers, and another two weeks to figure out the constraints for various scenario analyses. However, subsequent years would require much less data entry since the zoning structure remains largely the same and the historical transactions are now imported automatically through other modules of the *TPBOS*. The analysis, once the data entry was completed, took less than 3 minutes for each scenario.
- When the service providers quote their prices, *TPBOSCourier* will filter out the illegal entries or abnormal entries that may be caused by typos. This reduces a great deal of effort for personnel in F&D to validate quotations with the service providers.
- *TPBOSCourier* also saves the F&D a considerable amount of time in their benchmark analyses (reducing the time from days to only several minutes), such that the F&D is now able to spend more time and resources on scenario analyses, which is a much more valuable exercise as it empowers the personnel the ability to improve the final purchasing decision.
- With the support of the intelligent optimization engine, a larger number of scenarios analyses can be conducted in a more complicated but accurate way. Before having *TPBOSCourier,* the F&D could only afford to do the cherry pick or other simple greedy methods to allocate the requests to the providers. It was even difficult sometimes, for personnel as they had to manually find a feasible schedule if constraints were imposed. Now in the case of year 2005/2006, *TPBOSCourier* is able to provide optimal schedules that minimized the total spending, and highlighted the unsatisfied constraints when no feasible solution was found. The speed of the system allowed F&D to do different scenarios analyses, which greatly helped them in determining a better final decision.
- *TPBOSCourier* also empowers different business units to do their own scenarios analyses and even suggests constraints to the F&D.
- The reduction of manual entry input and analyses time means a more efficient transference of labor and time resources to be used in strategic analyses and negotiations with providers. This translates to a substantial savings in efficiencies and spending.

Application Development and Deployment

The Transportation Procurement and Bid Optimization System (*TPBOS*) project was jointly developed by Red Jasper Limited and the HKUST for Philips in late 2003 when it became obvious that the introduction of automation and intelligent techniques would make their procurement and analyses processes more efficient. At the time, the existing manual procurement process was exceedingly time-consuming, resulting in a dramatic escalation of shipping and purchasing costs. Philips has since funded the development of a complete decision support system for their transportation procurement, including sea freight, air freight, and courier services.

When all the data was obtained, preliminary experiments were conducted in optimizing the procurement of courier services based on incomplete data from historical quotations in year 2004/2005. The representatives of Philips had tested the system, and it turned out that the F&D may have configured certain constraints that led to conflicts and infeasibilities. Thus, it was decided that constraints could be dealt softly, and penalties could be added in the objective function if constraints cannot be fully satisfied.

Although the scenarios analyses was not ready before the first round of negotiations, the automated reports from the benchmark analyses on the quotations in the first round significantly helped Philips in terms of yielding more complete comparisons, more user-friendly report formats, and greater convenience to query information. Most importantly, it saved F&D a considerable amount of time in the preparation of documents for negotiations with service providers.

After obtaining the quotations in the second round of RFQ, the search engine was ready for different scenarios analyses. Based on the scenarios analyses, four service providers out of five in total were qualified. Philips then conducted the second round of negotiations on their quotations. After a further scenario analysis based on the new prices quoted by the four qualified providers, Philips finalized the allocation of services for the year 2005/2006.

As with all initial deployments of new software, teething problems are likely to occur that requires fine-tuning. For instance, the format to input constraints of scenarios analyses is through Excel files uploaded by F&D. In our view, it would be more user-friendly to provide a graphical view for F&D personnel to input. In another instance, Philips is requesting to allow configurations for broader constraints, by scaling their zoning structure into more levels or details. These issues are minor and are considered for improvement in subsequent upgrades of the software.

Maintenance

Currently, the hardware and software of the *TPBOSCourier* system is being handled by the development team as alterations to the program are being made as required. Control of the program will be handed over to Philips in a few months, once some final issues are ironed out. Since the program is simple and instinctive to use, minimal training is required. In fact, an on-site training program was conducted for the service providers before the first round of RFQ, and another remote one was conducted through conference calls for all F&D managers of Philips.

We remain committed in continually improving the intelligence of the *TPBOSCourier* system. For example, we are trying to involve other criteria, such as service qualities, lead time, shipping date, rather than prices only, in the formulation of the *SPSP*. We are confident that the *TPBOSCourier* program will be able to produce more powerful analyses and facilitate more efficient processes for the procurement of courier services for Philips for years to come.

Conclusion

This paper looks at what was required in the development of the courier-procurement portion of the transportation procurement and bidding optimization system, titled *TPBOSCourier*.

We described the size and complexity of the problem of scheduling the selection and the allocation of service providers for global manufacturer, Philips Electronics, in conducting reverse auctions to buy courier services to fulfill the requests of their mammoth but irregular volumes of urgent shipments. The program's design, features and scheduling approaches were also described.

Even though *TPBOS* has only been deployed for a year, the advantages of having automated and intelligent procurement and analyses processes are obvious and significant. Despite initial challenges encountered in its development process, this endeavor has been well worth the effort. We are confident that our work will inspire other global shippers in the near future to consider automating their transportation procurement processes as well.

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