City of Surrey Fire Service:
Reducing Uncertainty for Predicting Annual Staffing Costs

Len Garis[†], *Fire Chief*
Ron Price[††], *Assistant Fire Chief*
City of Surrey Fire Service

Fredrick Culbert[‡], P. Eng., *Consultant*
Louanne Wong[‡‡], M. Sc., *Consultant*
Banjar Management Inc.

April 2002

Abstract

Despite the fact new professional standards have improved fire safety for many communities, it is also true that their adoption has simultaneously increased operating costs for fire services. In this age of economic uncertainty and heightened concern to respond duly to unforeseen risk, direct adoption of new regulations without calculating short and long-term impact on budget is irresponsible. Implementation of accountability acts to ensure the right measures are executed at the right time.

This paper introduces the methodology developed by the Fire Service of Surrey, British Columbia, to forecast cost implications, and therefore, also cost savings. Probabilistic modeling of controlled variables provided the mechanism to predict fluctuations stochastically, while also allowing the adjustment of deterministic staffing parameters. Through modeling this approach, perceived system inflexibility is coupled with the ability to reconcile these same variables, illustrating a potential range of impacts on total annual budget. The results from these trials are discussed as case studies in consideration of broader policy implications.

***Key Words**: cost analysis, optimized personnel deployment, NFPA 1710, stochastic, probabilistic financial models, strategic staffing techniques*

† **Telephone:** 604.543.6701 **Email:** lwgaris@city.surrey.bc.ca
†† **Telephone:** 604.543.6701 **Email:** rwprice@city.surrey.bc.ca
‡ **Email:** fculbert@sfu.ca
‡‡ **Email:** louanne_wong@hotmail.com

1.0 Introduction

The recent passing of the NFPA 1710 has introduced improved professional standards for Fire Services worldwide. In North America, the standard has not only provided a gauge to measure the quality of services, but also has focused on the need to control the fiscal responsibility of individual Fire Services. The expectation to maintain performance in spite of greater competition between resources is complicated by the standards requiring increased levels of staffing. As a result, it is growing increasingly difficult to manage operating budgets within anticipated ranges while also explaining monthly fluctuations. Employing traditional ad-hoc methods is labourious, and often not easily replicated. This has pushed many Fire Departments to develop innovative tools to deliver services at a targeted, or lower annual cost.

In British Columbia, Canada, the City of Surrey Fire Service faces the same challenge. As the largest composite department located in one of Canada's fastest growing cities, the Fire Service is attempting to use empirical modeling and analysis techniques to help predict annual staff operating budgets.

Among the variables contributing to staff cost, absences due to sickness and work-related injuries ("Worker's Compensation [Board]" or WCB) are considered to have the most extensive uncertainties. In the past, uncertainties in the level of these absences due to these fluctuations were largely ignored. Instead, the level of absences was considered as "single point" or deterministic values in monthly and annual staff cost analyses.

With the use of interactive simulations, the development of a staffing tool served to capture the variables and characteristics of the staffing process while also institutionalizing senior management's knowledge. Following the preparation of an accurate four-year base of staffing information, the data was sampled probabilistically to limit statistical ranges.

As a main input, the staffing process was then parameterized with additional requirements and refined employing sensitivity test results. This produced a scalable, dynamic model of expected staff costs enabling Fire Service management to calculate scenarios, and compare the data to expected results. Moreover, the model provided a means to dynamically input requirements as dictated by the NFPA 1710 standards, with immediate understanding to cost and resource implications throughout the Service. In employing a repeatable model to manage staffing, not only can expenses be analyzed by shift, month and/or year, but the method is controlled and the results are documented.

2.0 Deterministic Model Development

The challenge to maintain four-person staffing on pump trucks while remaining within budget does not start with where the Service wants to be, but rather with where the Service is at the present time. Beginning with a situational assessment, modeling the process in situ helps to determine whether the model is functioning as anticipated.

Starting with base case development, both staffing processes and techniques residing within senior management was documented. This helped to visualize strengths and weaknesses of the existing process, while also preserving this information for inheritance by the Fire Service. Building these elements parametrically into the model introduced a method that connects decision-makers to decision-making tools. Moreover, with this knowledge transferred to a model, traditionally intuitive techniques became quantitative and institutionalized, therefore enabling them to be refined according to planned performance targets.

Supplementing the process with accurate, empirical staffing details, the model was provided with all the necessary inputs to generate its first deterministic scenario. The results from the deterministic model appeared favourable, reflecting past and current circumstances. As the conditions and data in the model were known, and the results fell within expected budget parameters, doubts regarding the model's tenability were relieved. In changing the basic way in which staffing is forecasted and budgeted, the means to substantiate results is dynamic, easily replicated, and understood.

3.0 Probabilistic Model Development

Once the results from the deterministic trials were considered satisfactory, the model was used to predict proposed future scenarios. Building onto the deterministic model, probabilistic elements were added to use the historic data to simulate future operational patterns. Development of the probabilistic model required identification of the stochastic inputs to the staffing process. Attention was concentrated upon those variables that can be predicted through pattern detection and probability, as staffing process activities cannot be determined by static information alone.

Absences due to sickness and work-related injury were selected. Due to the unavailability of staffing data for years prior to 1998 and following 2001, this data was sampled using Monte Carlo[1] simulation techniques and Poisson distribution[2] random generation to develop probabilistic values for staff absences. Among the variables contributing to staff cost, absences due to sickness and work-related injuries are considered major uncertainties. Probabilistic values are used for these absences, while deterministic values controlled a range of other staffing parameters. Other factors such as bereavement and family leave are not individually significant, but have an impact on staffing levels. As an uncertainty, these factors have conventionally been considered an uncontrolled qualitative value that is not predictable.

In the past, uncertainties in the level of these absences due to these fluctuations were largely ignored. Instead, the level absences were considered as “single point” values in monthly and annual staff cost analyses. Once viewed in terms of “seasonality”, patterns of absences became much more apparent and helped managers justify the reallocation of resources based upon month and also shift. This included peak months of events such as sickness. Escalating values over time and situation provided new analysis tools for managers to predict and assess the financial impact of changed operational staffing. This tool provided a means to empirically measure the impact of incorporating new professional standards and policies, including four-person staffing dictated by NFPA 1710. The model translated intangible intuition into a defined, collective impact on the existing system.

From the outset it was clear that an accurate, store of data was necessary not only to bind the (potential) fluctuation of statistic ranges, but also to ensure the integrity of the output results. The historic data tables allowed repeated evaluation of particular aspects within the model, with assurance of the reliability of the base data. In addition, inclusion of Monte Carlo simulation techniques in the model accounts for variability, such as minimum and maximum anomalous values and events. As the deterministic model utilized the same base (static) staffing absence information, these trials are first-run sensitivity tests validating the data’s soundness. Gradual supplement of the staffing data with new, available information will further increase the model’s accuracy.

With the staffing process parameterized and the staffing absence predictions in place, a scalable, dynamic model to predict operational staffing costs was available. The model enabled managers to calculate scenarios, and compare the data to expected results. Increasingly, the effect of specific actions upon resource relationships became more evident through systematically varying input (cells/formulas) and evaluating their results. Decision-makers began to gain critical new insight on the expected cost of resources, allocations, shifts and utilization of the performance of each of the four teams in the Fire

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[1] **Monte Carlo Approach**

Monte Carlo simulation is a statistical method used to directly model complex physical phenomena, events, or systems. This unique simulation technique generally assumes that the behaviour of a physical system is described using a probability density function (PDF), such as the Poisson Distribution. Once a PDF is known, then the Monte Carlo simulation proceeds by randomly sampling resultant PDF values by performing a large series of trials. A final result is derived from the average and range of these trials, providing insight into the predicted average, uncertainty and variance.

[2] **Poisson Distribution**

The Poisson Distribution is discrete and is associated with the generation of a count for unique events over a specified continuous interval. It is used when subintervals have specific characteristics that include:

i. the probability that a count may be zero;
ii. the probability of one occurrence being the same for all counts and proportional to the length of the count; and
iii. the occurrence of an event within a given subinterval having no effect upon the occurrence of another event in a non-overlapping subinterval.

The independence of a subinterval and an event from each other, or its discrete characteristic, is key to this sequencing technique.

Service. These lessons learned could then be employed immediately in the model to further optimize performance and limit annual expenses.

The model has provided a means to dynamically input requirements as recommended by Fire Services Review, with immediate understanding of the cost and resource implications throughout the Service. Dynamic modeling to manage staffing allows expenses to be empirically analyzed by shift, month or year, in a controlled environment.

4.0 Simulating Annual Cost in Context of the NFPA

In December 2000 the City of Surrey Surrey Council supported the recommendation of the Fire Services Review as it referred to staffing of pumper trucks, such that:

> *The recommended approach to resolving staffing shortages is a combination of hiring 12 new staff, 8 in the year 2001 and 4 in the year 2002 and the continuation of current programs. Due to the newness of the Attendance Leave Program, it is too early to measure its effectiveness. In addition, a further refinement of the vacation and holiday schedules and/or continued cancellation of vacations when there are acute staffing shortages could even out the fluctuations of staffing demands.*
>
> *City of Surrey, Council Resolution*

The objective to staff pumper trucks with four firefighters has increased pressure to better predict fluctuations in attendance to mitigate the impact on staffing and attempt to work within budget. The issue remained that the conditions which four-person staffing *consistently* maintained were uncertain. With the criteria parameterized within the model, it became possible to project staffing patterns and budgets. Moreover, it enabled the modeling of various staffing scenarios, identifying discontinuities and the predicted financial impact within a given confidence range. Quantified measurement of expenditures helped to identify variables competing to utilize the same existing staff and financial resources.

Traditionally, the City of Surrey Fire Service uses a staffing pool to fill vacancies in emerging staffing shortages. This static approach uses off-duty firefighters either as a “call-back” shift, or requesting a firefighter(s) return for a shift not originally scheduled, to fill staff absences due to sickness under certain restrictive conditions. Management concern over this approach results from the cost inefficiencies placed upon the system. The realization that vacancies are filled in this manner simply for absences due to sickness has revealed weaknesses in the staffing methodology. Implementation of (new) practices without regard to cumulative impact on budget dramatically increases risk and raises the question of system feasibility. This was effectively illustrated in the Base Case 1d model of four-person staffing shown in Section 5.0, where it was found retaining this level of staffing each shift is unworkable.

In cases where there are staff surpluses on shift, the overflow is assigned as a fifth member of a pump crew. Placing the fifth person on a pump is not an effective utilization of the resource. The average cost to the City for is approximately C$30 per hour or C$360 per twelve-hour shift. This cost is contingent upon a firefighter’s individual seniority.

Where the traditional staffing methods were static, the opportunity now exists to test conceptual ideas regarding scheduling techniques and implement user-defined rules as a learning mechanism. The modeling process was dynamic, such that adjustments were systematic, results duly recorded and new adjustments controlled. What resulted included a range of lessons learned, including new insight into the relationship between correlated variables, and *tested* budgeting efficiencies. More notably, the risk of implementing change is reduced following controlled modeling. Modifications to the system are absorbed, as mistakes made within a model are “free”, and can be corrected in subsequent analysis.

The City of Surrey Fire Service has either adopted or has identified the following scheduling techniques, identified and developed dynamically, to meet the Fire Services Review objective of four-person staffing on a pump while, at the same time, satisfying NFPA 1710 demands for safety. Several of the key issues encountered are shown in Table 1.0 below.

Table 4.0 Staff Scheduling Issues Identified

Problem statement	Issue identified by model?	Issue (resolution) simulated by model?
i. Inability to replace permanent staff vacancies due to retirement, in a timely manner.	No	Yes
ii. Inability to monitor cost of not immediately filling long-term staffing absences. Absences are a result of chronic illness, and/or maternity/paternity leave.	No	Yes
iii. Inability to manage varying call-back rates for absences resulting from work place injury (WCB) or sickness.	No	Yes
iv. Inability to determine total budget impact of dynamically changing rosters or schedules.	No	Yes
v. Inability to dynamically adjust/balance shift performance with staff from other shifts, while understanding absence patterns and cost implications.	No	Yes
vi. Inability to efficiently monitor the cost implications of inadvertently missed (not scheduled to a Firefighter) shifts.	No	Yes
vii. Inability to adjust rosters or schedules (understand cost implications of) based upon patterns of seasonality.	Yes	Yes
viii. Inability to adjust rosters or schedules (understand cost implications of) based upon patterns of shift efficiencies and absence levels.	Yes	Yes
ix. Inability to plan and apply *Scheduled Absence Stabilization Techniques*. Ad-hoc vacation scheduling through the year does not take advantage of cost efficiencies enabled through scheduling time-off on non-peak periods.	Yes	Yes

As outlined by the Table 1.0, staff-scheduling issues exist, and have been identified either experientially or through testing the model. The process for determining whether an issue can be effectively solved is risky in absence of projecting the total annual cost through implementing such a change. It is difficult and irresponsible to exert judgement without the tools to assess potential impact. Using a case-by-case assessment approach, the model has enabled visualization of existing scenarios with comparison to proposed staffing scenarios. These trials are methodically repeated, to test and record adjustments according to shift characteristics, such as efficiency and scheduled time-off.

5.0 City of Surrey Fire Service: Case Study

The use of modeling as a tool to support operational planning, serves to substantiate conceptual techniques towards improved efficiency. Development of the base case scenario provided the existing context to compare subsequent analyses. In general, the intent of the Surrey Fire Service analysis was to ensure that all teams, A to D, were of balanced efficiency in terms of cost. In order to achieve this, the absence levels must be predictable, to the extent to allow for their movement and rescheduling. Use of historic values of absences supports pattern detection for the model. Erratic spikes or anomalous values should not be present. Moreover, to assess any unintended changes that might occur, the modeling process should be systematic, such that values are changed in a stepwise manner, recorded and then analyzed. Results from sample with parameter definitions/adjustments are shown below illustrating the range of annual cost outcomes.

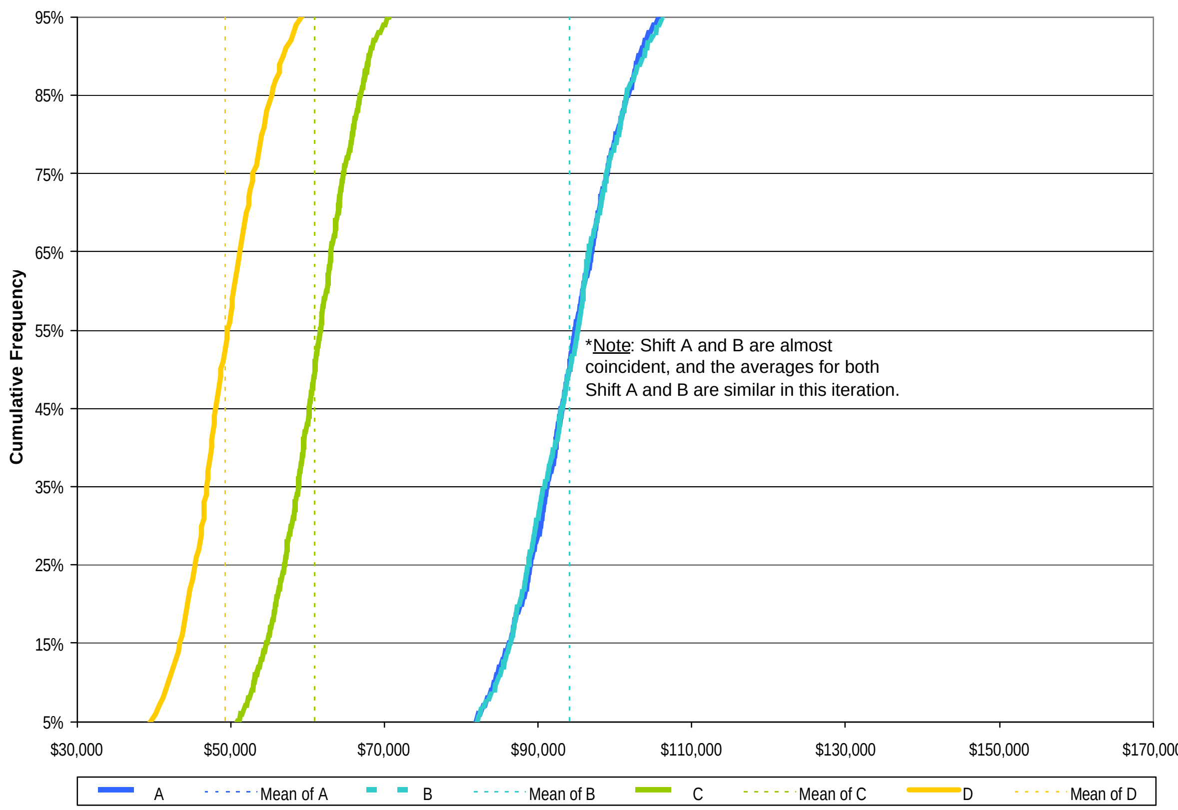
5.1 Base Case Simulation I

In the Simulation I Base Case, it is evident that teams A to D vary from most efficient (Team D) to most inefficient (Team A and B), as shown in Figure 5.1.

Parameters:

Personnel Required per Shift *(by month)*[3]	57
Staff Absence Adjustment *(by month)*[4]	No
Staffing Offset by Shift *(by month)*[5]	No

Figure 5.1 Base Case Simulation I: Total Team Performance



In other words, the greater the spread between teams, the greater the variance in individual total annual cost. The average annual performance cost in this simulation is C$300,000, with a standard deviation of C$27,000. These results are highly correlated to past performance histories. The good performance of Team D (C$49,000) is a direct result of historically low absences. Alternately, the most inefficient performers are Teams A and B, which had historically high absences and an average cost of C$94,000 annually.

In the next simulations, adjustments to the model attempt to have the teams perform in a more balanced and more cost-effective manner.

[3] **Personnel Required by Shift (by Month)**
Staff required by shift, adjustable by month. This variable allows monthly adjustments (January-December) based upon the number of shifts available in a given month.

[4] **Staffing Absent Adjustment (by Month)**
Staff scheduling based upon calculated values of average number of staff scheduled to be absent on a given shift. This variable allows monthly adjustments (January-December) for staff scheduling. In each absent adjustment (for teams A, B, C or D), a negative adjustment must be offset by an equal and opposite adjustment in another.

[5] **Staffing Offset by Shift (by Month)**
Staff scheduling for absences (holiday, training, miscellaneous time off) adjustable by month. This variable allows monthly adjustments (January-December) based upon the number of shifts available in a given month.

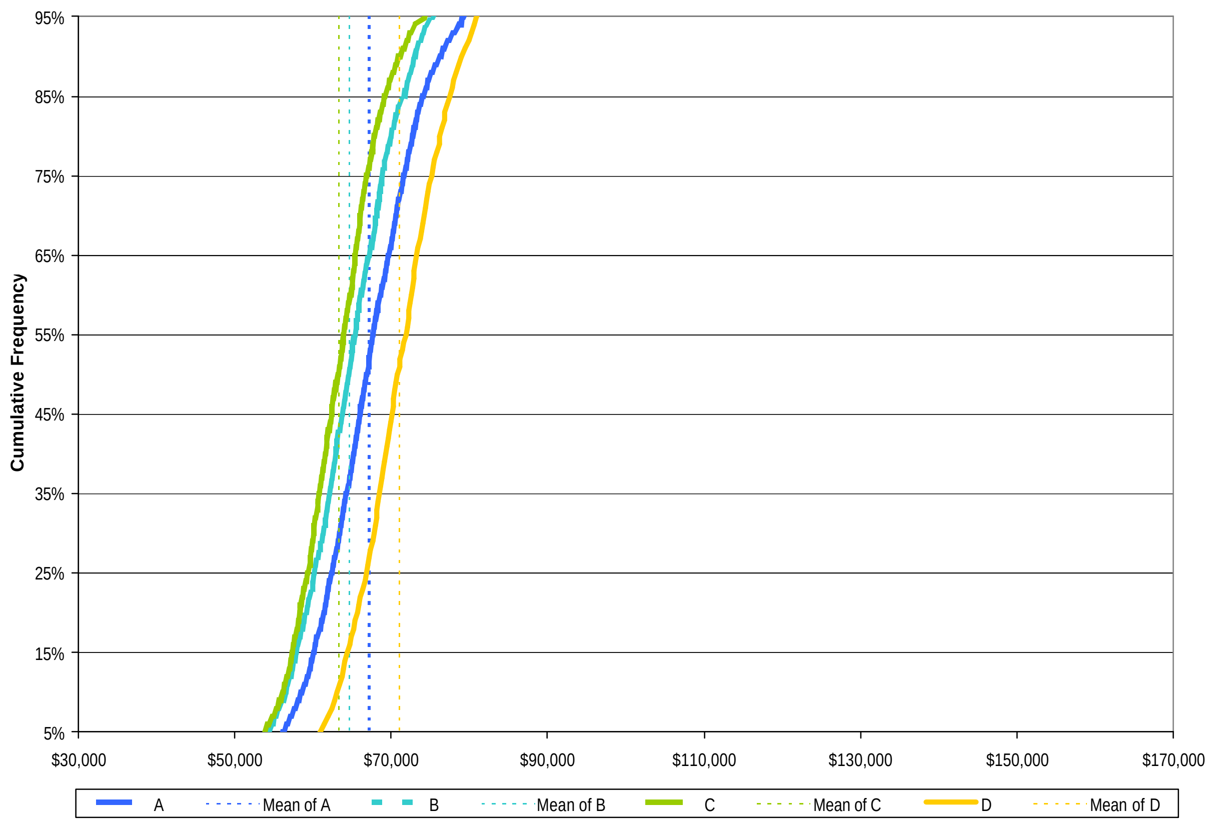
5.2 Base Case Simulation II

Parameters:

Personnel Required per Shift *(by month)*	57
Staff Absence Adjustment *(by month)*	Yes
Staffing Offset by Shift *(by month)*	Yes

In this case, Figure 5.2 illustrates the spread between the teams decreasing, such that the variance for an individual team's annual performance is decreasing

Figure 5.2 Base Case Simulation II: Total Team Performance



The average annual performance cost is C$266,000, with a standard deviation of C$26,000. Individual performance of teams has become more levelled with offsetting the time of year in which Firefighters take leaves with the historical seasonality of absences. These results show a projected annual cost savings of approximately C$34,000 without hiring additions to the roster.

Where Team D was formerly the best performer, it is now the poorest because of the adjustment (C$71,000), where a Firefighter from Team D was moved to Team A. Conversely, Teams A and B are performing closer to the cluster, with costs totalling C$67,000 for Team A and C$65,000 for Team B respectively. This indicates efficiency is becoming levelized. Resource consumption is therefore more often closer to the average, as shown by the clustering of data.

The next adjustment will attempt to improve cumulative team performance to test for variables for reduction of annual cost.

With an understanding of how adjustments to the model affect results under the Service's specific conditions, the next adjustment simulates the implementation NFPA 1710 requirements for four Firefighters on a pumper truck, as shown in Figure 5.3.

5.3 Base Case Simulation III

Parameters:

Personnel Required per Shift *(by month)*	57 + 2 = 59
Staff Absence Adjustment *(by month)*	Yes
Staffing Offset by Shift *(by month)*	Yes

Figure 5.3 Base Case 1d: Total Team Performance

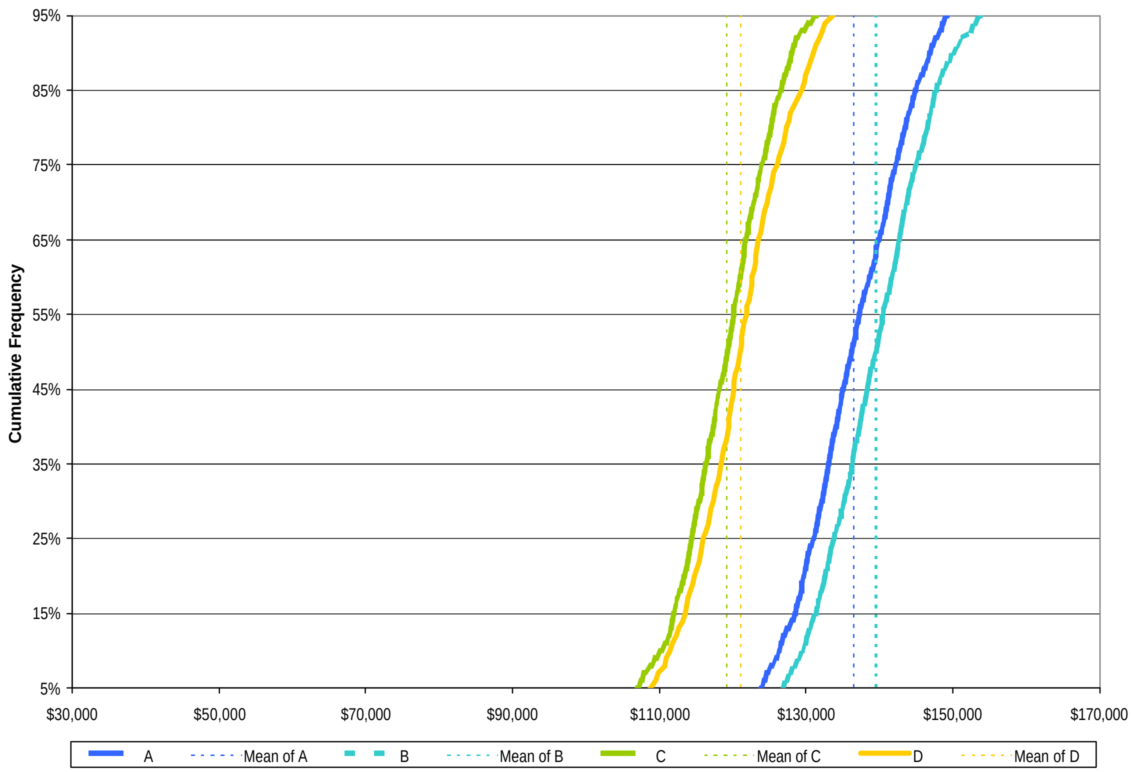


Figure 5.3 shows an enormous shift in the total annual cost, where all team averages have moved significantly. The average annual performance cost is C$516,000, with a standard deviation of C$31,000. These results indicate that direct addition of two (2) staff per shift is not cost effective. Staffing results from the model suggests the shifts currently have under-utilized resources. Where the total cost is not within expected rates, additional adjustments must be tested to determine how to best schedule and use resource consumption.

Of all the simulations, results plotted from the model is normally distributed, such that most of the results from the trials are close to the average, with relatively few results tending to one extreme or the other.

6.0 Conclusion

Fire Service Mangers will be or are now faced with the implementation of improved safety standards. The costs associated with consistently maintaining four person staffing on pumpers is largely unknown. The single, largest expense the fire department manages is staffing.

The staffing model statistically forecasts the potential range of cost impacts based upon the historical experience of sick and injury (WCB) usage with the Fire Service. Utilization of a staffing model statistically forecasts the potential range of cost impacts to reduce the risk of budget overruns.

The conditions, for which the techniques are applied and learned, will need to be applied stringently and dynamically to ensure cost remains within allocated budget. The risk of exceeding the allocated budget still exists if sick usage exceeds previous averages or the techniques identified are not carefully adhered to or applied.

Project Team

Len Garis is the Fire Chief for the City of Surrey, British Columbia. Len was formerly an Assistant Chief with the City of Surrey. Previous positions include Director of Protective Services and Fire Chief in Pitt Meadows, British Columbia and Program Coordinator for the Justice Institute of British Columbia Fire Academy.

Ron Price is an Assistant Fire Chief for the City of Surrey, British Columbia. He was formerly a Lieutenant and also a Training Officer with the City of Surrey Fire Services. Ron was instrumental in the design and implementation of various staff scheduling tools, and has expert knowledge of staffing techniques.

Frederick G. Culbert, P. Eng. is a consulting engineer specializing in economic and financial planning. He has a M.S. in Engineering-Economic Planning from Stanford University. Fred has 37 years of experience in public and private sector engineering-cost analysis in North America and Asia.

Louanne Wong, M. Sc. is a consulting planning analyst specializing in spatial modeling and developing decision support systems. Louanne has a Masters degree in Geographic Information Systems from the University of Huddersfield, United Kingdom.