國立雲林科技大學
九十三學年度博士班招生入學考試試題

所別：工程科技研究所
科目：工程數學 (甲)

1. (10%) Consider the following differential equations.

a) $\dfrac{d^2 y_1}{dx^2} + 3\dfrac{dy_1}{dx} + 2y_1 = 0$ subject to $y_1(0) = c_1$, $y_1'(0) = c_2$

b) $\dfrac{dy_2}{dx} + y_2 = 0$ subject to $y_2(0) = 1$.

Find constants c_1 and c_2 such that $y_1(x) = y_2(x)$ for all $x > 0$.

2. (10%) Consider the following ordinary differential equation.

$$\frac{d^2 y}{dx^2} + a\frac{dy}{dx} + by = \cos(10x) \quad \text{subject to} \quad y(0) = 1, \quad y'(0) = 0$$

in which a and b are real constants. Find all possible values of a and b such that the solution $y(x)$ remains bounded for all $x > 0$.

3. (15%) Define $f(x) = \begin{cases} 0, & -\pi \le x < 0 \\ \pi - x, & 0 \le x \le \pi. \end{cases}$ Let $g(x) = k_0 + k_1 \sin(x) + k_2 \cos(x)$, in which k_0, k_1 and k_2 are constants. Find the values of k_0, k_1 and k_2 so that $\int_{-\pi}^{+\pi} (f(x) - g(x))^2 dx$ is minimized.

4. (15%) Solve $f(t) = 3t^2 - e^{-t} - \int_0^t f(\tau) e^{t-\tau} d\tau$ for $f(t)$.

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5. If $\vec{F} = xy\vec{i} + y^2 z\vec{j} + z^3\vec{k}$, evaluate $\iint_S \vec{F} \cdot \vec{n} dS$, where S is the unit cube defined by

$0 \le x \le 1 \quad 0 \le y \le 1 \quad 0 \le z \le 1$. (25%)

6. Solve the following PDE. (25%)

$$\frac{\partial u}{\partial t} = c^2 \frac{\partial^2 u}{\partial x^2} \qquad 0 \le x \le L, \quad t \ge 0$$

$$u_x(0,t) = u_x(L,t) = 0$$

$$u(x,0) = f(x) = \begin{Bmatrix} x & if\, 0 \le x \le L/2 \\ (L-x) & if\, L/2 \le x \le L \end{Bmatrix}$$

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1. (15%) Consider the $n \times n$ system of equations given by $\mathbf{Ax} = \mathbf{b}$, and let $\mathbf{C} = [\mathbf{A} \mid \mathbf{b}]$ be the augmented matrix for that system. If $\mathbf{G} = [\mathbf{M} \mid \mathbf{d}]$ is the reduced, row-echelon form of $\mathbf{C}$:

   (a) What will you see in **G** if the system is inconsistent?

   (b) What will you see in **G** if the system has exactly one solution?

   (c) What will you see in **G** if this system has infinitely many solutions?

2. (15%) Let **A** and **B** be similar matrices.

   (a) Prove that $\mathbf{A}^T$ and $\mathbf{B}^T$ are similar.

   (b) If $p(t) = a_n t^n + a_{n-1} t^{n-1} + \cdots + a_1 t^1 + a_0$ is a polynomial, show that $p(\mathbf{A})$ and $p(\mathbf{B})$ are similar.

3. (20%) Suppose there is a baseband signal $m(t)$ with its spectral spectrum

$$M(f) = \begin{cases} M(0)(1 - |f|/W), & |f| < W \\ 0, & |f| \geq W \end{cases}.$$

Please evaluate and draw the spectral spectrum of $m(t) \cdot \sum_{n=-\infty}^{\infty} \delta(t - nT_s)$.

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4. Find a general solution of the following differential equation:

$$y''' - 6y'' + 12y' - 8y = \sqrt{x}e^{2x} \qquad (15\%)$$

5. Find a real general solution of the following system of differential equations:

$$y_1' = -3y_1 - y_2 + 2y_3$$
$$y_2' = -4y_2 + 2y_3$$
$$y_3' = y_2 - 5y_3 \qquad (15\%)$$

6. (a) Evaluate $\iint_S (curl\vec{F}) \cdot \hat{n} \ dA$ by direct integration,

where $\vec{F} = \begin{bmatrix} y^2, & -x^2, & 0 \end{bmatrix}$, S the semicircular disk $x^2 + y^2 \le 4, y \ge 0, z = 0$.

(10%)

(b) Evaluate $\oint_C \vec{F} \cdot \vec{r}'(s) ds$ (clockwise as seen by a person standing at the origin) by Stokes's theorem, where, with respect to right-handed Cartesian coordinates for $\vec{F}$ and S in part (a) (10%)

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1. Find the general solution for the following linear system, (10%)

$$\begin{bmatrix} -1 & 1 & 3 \\ 0 & 3 & 2 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} -2 \\ 4 \end{bmatrix}.$$

2. Given a matrix, $A = \begin{bmatrix} -1 & 0 \\ 2 & 5 \end{bmatrix}$, find A^{200}. (10%)

3. Find the Fourier transform for the following function, (10%)
$f(t) = 2[H(t-2) - H(t-5)]$, where $H(t)$ is Heaviside function.

4. Find the inverse Fourier function of the following function, (10%)

$$F(\omega) = \frac{\exp(\omega - 3)i}{4 + (\omega - 3)i}.$$

5. Find the sum of the series (10%)

$$\sum_{n=1}^{\infty} \frac{(-1)^n}{(4n^2 - 1)}.$$

(Hint: Expand $\sin(x)$ in a cosine series on $[0, \pi]$ and let $x = \frac{\pi}{2}$)

6. (a) Let the Laplace transform of f(t) be $\frac{a}{s^2(s^2 + a^2)}$. Find f(t), (15%)

(b) Let f(t) be $\frac{1 - \cos(t)}{t}$. Find the Laplace transform of f(t), (15%)

7. Solve the system $y'' + 2ty' - 4y = 1$ when $y(0) = y'(0) = 0$, (10%)

8. Find the general solution of the below system, (10%)
$y^{(3)} - 4y'' + y' + 6y = x^3 - 4x + 2$

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請從後面兩個不同的附件中（附件 1 結構工程與材料領域：第 2 至 6 頁、附件 2 營建管理與建築領域：第 7 至 14 頁），選讀其中之一，然後針對所選讀的附件回答下列各問題。

選讀附件 1 者：

1. Sort the following developments in mathematics according to time: (a) solving the quartic equation; (b) solving the quadratic equation; (c) Pythagorean theorem; (d) solving the cubic equation. (10%)
2. For the three roots of the cubic equation expressed in Equations (52) to (54), indicate the one which is definitely real and explain. In addition, discuss how you can determine it is the case of three real roots or the alternative case of one real root with two complex conjugate roots according to these analytical formulas. (40%)
3. Use the procedures described in this article to solve the following two cubic equations:
   (a) $10x^3 - 77x^2 + 178x - 120 = 0$ (25%)
   (b) $x^3 + 15x^2 + 64x + 90 = 0$ (25%)

選讀附件 2 者：

1. 本文之背景與目的為何？ (25%)
2. 本文之研究方法為何？ (25%)
3. 本文之具體貢獻為何？ (25%)
4. 本文之缺點及限制為何？ (25%)

附件 1

Cubic Equation

Introduction

Knowledge of the quadratic formula is older than the Pythagorean Theorem. Solving a cubic equation, on the other hand, was the first major success story of Renaissance mathematics in Italy. The solution was first published by Girolamo Cardano (1501-1576) in his Algebra book *Ars Magna*. Shortly after the discovery of a method to solve the cubic equation, Lodovico Ferraria (1522-1565), a student of Cardano, found a similar method to solve the quartic equation.

[Adapted from www.sosmath.com]

Derivation and Formula

The cubic equation is the closed-form solution for the roots of a cubic polynomial. A general cubic equation is of the form

$$z^3 + a_2 z^2 + a_1 z + a_0 = 0 \tag{1}$$

(the coefficient a_3 of z^3 may be taken as 1 without loss of generality by dividing the entire equation through by a_3).

To solve the general cubic (1), it is reasonable to begin by attempting to eliminate the a_2 term by making a substitution of the form

$$z \equiv x - \lambda. \tag{2}$$

Then

$$(x - \lambda)^3 + a_2(x - \lambda)^2 + a_1(x - \lambda) + a_0 = 0 \tag{3}$$

$$(x^3 - 3\lambda x^2 + 3\lambda^2 x - \lambda^3) + a_2(x^2 - 2\lambda x + \lambda^2) + a_1(x - \lambda) + a_0 = 0 \tag{4}$$

$$x^3 + (a_2 - 3\lambda)x^2 + (a_1 - 2a_2\lambda + 3\lambda^2)x + (a_0 - a_1\lambda + a_2\lambda^2 - \lambda^3) = 0. \tag{5}$$

The x^2 is eliminated by letting $\lambda = a_2/3$, so

$$z \equiv x - \tfrac{1}{3}a_2. \tag{6}$$

Then

$$z^3 = (x - \tfrac{1}{3}a_2)^3 = x^3 - a_2x^2 + \tfrac{1}{3}a_2^2 x - \tfrac{1}{27}a_2^3 \tag{7}$$

$$a_2 z^2 = a_2(x - \tfrac{1}{3}a_2)^2 = a_2x^2 - \tfrac{2}{3}a_2^2 x + \tfrac{1}{9}a_2^3 \tag{8}$$

$$a_1 z = a_1(x - \tfrac{1}{3}a_2) = a_1 x - \tfrac{1}{3}a_1 a_2, \tag{9}$$

so equation (1) becomes

$$x^3 + (-a_2 + a_2)x^2 + (\tfrac{1}{3}a_2^2 - \tfrac{2}{3}a_2^2 + a_1)x - (\tfrac{1}{27}a_2^3 - \tfrac{1}{9}a_2^3 + \tfrac{1}{3}a_1 a_2 - a_0) = 0 \tag{10}$$

$$x^3 + (a_1 - \tfrac{1}{3}a_2^2)x - (\tfrac{1}{3}a_1 a_2 - \tfrac{2}{27}a_2^3 - a_0) = 0 \tag{11}$$

$$x^3 + 3 \cdot \tfrac{3a_1 - a_2^2}{9}x - 2 \cdot \tfrac{9a_1 a_2 - 27a_0 - 2a_2^3}{54} = 0. \tag{12}$$

Defining

$$p \equiv \frac{3a_1 - a_2^2}{3} \tag{13}$$

$$q \equiv \frac{9a_1 a_2 - 27a_0 - 2a_2^3}{27} \tag{14}$$

then allows (12) to be written in the standard form

$$x^3 + px = q. \tag{15}$$

The simplest way to proceed is to make Vièta's substitution

$$x = w - \frac{p}{3w}, \tag{16}$$

which reduces the cubic to the equation

$$w^3 - \frac{p^3}{27w^3} - q = 0, \tag{17}$$

which is easily turned into a quadratic equation in w^3 by multiplying through by w^3 to obtain

$$(w^3)^2 - q(w^3) - \tfrac{1}{27}p^3 = 0 \tag{18}$$

The result from the quadratic formula is

$$\begin{aligned} w^3 &= \tfrac{1}{2}\left(q \pm \sqrt{q^2 + \tfrac{4}{27}p^3}\right) = \tfrac{1}{2}q \pm \sqrt{\tfrac{1}{4}q^2 + \tfrac{1}{27}p^3} \\ &= R \pm \sqrt{R^2 + Q^3}, \end{aligned} \tag{19}$$

where Q and R are sometimes more useful to deal with than are p and q. There are therefore six solutions for w (two corresponding to each sign for each root of w^3). Plugging w back in to (17) gives three pairs of solutions, but each pair is equal, so there are three solutions to the cubic equation.

Equation (12) may also be explicitly factored by attempting to pull out a term of the form $(x - B)$ from the cubic equation, leaving behind a quadratic equation which can then be factored using the quadratic formula. This process is equivalent to making Vièta's substitution, but does a slightly better job of motivating Vièta's "magic" substitution, and also at producing the explicit formulas for the solutions. First, define the intermediate variables

$$Q \equiv \frac{3a_1 - a_2^2}{9} \tag{20}$$

$$R \equiv \frac{9a_2a_1 - 27a_0 - 2a_2^3}{54} \tag{21}$$

(which are identical to p and q up to a constant factor). The general cubic equation (12) then becomes

$$x^3 + 3Qx - 2R = 0. \tag{22}$$

Let B and C be, for the moment, arbitrary constants. An identity satisfied by perfect cubic polynomial equations is that

$$x^3 - B^3 = (x - B)(x^2 + Bx + B^2). \tag{23}$$

The general cubic would therefore be directly factorable if it did not have an x term (i.e., if $Q = 0$). However, since in general $Q \neq 0$, add a multiple of $(x - B)$--say $C(x - B)$--to both sides of (23) to give the slightly messy identity

$$(x^3 - B^3) + C(x - B) = (x - B)(x^2 + Bx + B^2 + C) = 0. \tag{24}$$

which, after regrouping terms, is

$$x^3 + Cx - (B^3 + BC) = (x - B)[x^2 + Bx + (B^2 + C)] = 0. \tag{25}$$

We would now like to match the coefficients C and $-(B^3 + BC)$ with those of equation (22), so we must have

$$C = 3Q \tag{26}$$

$$B^3 + BC = 2R. \tag{27}$$

Plugging the former into the latter then gives

$$B^3 + 3QB = 2R. \tag{28}$$

Therefore, if we can find a value of B satisfying the above identity, we have factored a linear term from the cubic, thus reducing it to a quadratic equation. The trial solution accomplishing this miracle turns out to be the symmetrical expression

$$B = [R + \sqrt{Q^3 + R^2}]^{1/3} + [R - \sqrt{Q^3 + R^2}]^{1/3}. \tag{29}$$

Taking the second and third powers of B gives

$$B^2 = [R + \sqrt{Q^3 + R^2}]^{2/3} + 2[R^2 - (Q^3 + R^2)]^{1/3} + [R - \sqrt{Q^3 + R^2}]^{2/3} \tag{30}$$

$$= [R + \sqrt{Q^3 + R^2}]^{2/3} + [R - \sqrt{Q^3 + R^2}]^{2/3} - 2Q \tag{31}$$

$$B^3 = -2QB + \left\{[R + \sqrt{Q^3 + R^2}]^{1/3} + [R - \sqrt{Q^3 + R^2}]^{1/3}\right\}$$
$$\times \left\{[R + \sqrt{Q^3 + R^2}]^{2/3} + [R - \sqrt{Q^3 + R^2}]^{2/3}\right\} \quad (32)$$
$$= [R + \sqrt{Q^3 + R^2}] + [R - \sqrt{Q^3 + R^2}] \quad (33)$$
$$+[R + \sqrt{Q^3 + R^2}]^{1/3}[R - \sqrt{Q^3 + R^2}]^{2/3}$$
$$+[R + \sqrt{Q^3 + R^2}]^{2/3}[R - \sqrt{Q^3 + R^2}]^{1/3} - 2QB \quad (34)$$
$$= -2QB + 2R + [R^2 - (Q^3 + R^2)]^{1/3}$$
$$\times \left[\left(R + \sqrt{Q^3 + R^2}\right)^{1/3} + \left(R - \sqrt{Q^3 + R^2}\right)^{1/3}\right] \quad (35)$$
$$= -2QB + 2R - QB = -3QB + 2R. \quad (36)$$

Plugging B^3 and B into the left side of (28) gives

$$(-3QB + 2R) + 3QB = 2R, \quad (37)$$

so we have indeed found the factor $(x - B)$ of (22), and we need now only factor the quadratic part. Plugging $C = 3Q$ into the quadratic part of (25) and solving the resulting

$$x^2 + Bx + (B^2 + 3Q) = 0 \quad (38)$$

then gives the solutions

$$x = \tfrac{1}{2}[-B \pm \sqrt{B^2 - 4(B^2 + 3Q)}] \quad (39)$$
$$= -\tfrac{1}{2}B \pm \tfrac{1}{2}\sqrt{-3B^2 - 12Q} \quad (40)$$
$$= -\tfrac{1}{2}B \pm \tfrac{1}{2}\sqrt{3}\,i\sqrt{B^2 + 4Q}. \quad (41)$$

These can be simplified by defining

$$A \equiv [R + \sqrt{Q^3 + R^2}\,]^{1/3} - [R - \sqrt{Q^3 + R^2}\,]^{1/3} \quad (42)$$
$$A^2 = [R + \sqrt{Q^3 + R^2}\,]^{2/3} - 2[R^2 - (Q^3 + R^2)]^{1/3} + [R - \sqrt{Q^3 + R^2}\,]^{2/3} \quad (43)$$
$$= [R + \sqrt{Q^3 + R^2}\,]^{2/3} + [R - \sqrt{Q^3 + R^2}\,]^{2/3} + 2Q \quad (44)$$
$$= B^2 + 4Q, \quad (45)$$

so that the solutions to the quadratic part can be written

$$x = -\tfrac{1}{2}B \pm \tfrac{1}{2}\sqrt{3}\,iA. \quad (46)$$

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Project Management Actions to Improve Design Phase Cost Performance

John A. Kuprenas, M.ASCE[1]

Abstract: Over 270 engineering design projects are analyzed to assess the impact of the use of project management processes on design phase cost performance. Frequency of design team meetings and frequency of reporting of design phase progress were found to reduce design phase costs. Project manager training and the use of a project management based organizational structure were found not to create statistically significant lower design costs. Calculation of regression lines for the meeting and reporting frequency variables against design costs is shown to be a method to quantify the potential savings to be obtained by application of each process.

DOI: 10.1061/(ASCE)0742-597X(2003)19:1(25)

CE Database keywords: Project management; Cost control; Design.

Introduction

Project management is well established as a means to improve cost, schedule, and quality performance of design and construction. Past research has shown that management of the design phase is particularly important, because decisions made in this phase of a project often have the greatest impact on the eventual total project cost (Paulson 1976). Little research, however, has been conducted to quantify the impacts of specific project management actions on design phase performance. This paper presents the results of a case study to statistically correlate and quantify selected management action impacts on project performance. This work provides an analysis of over 270 completed projects and examines the impacts of the use of a project management based organizational structure, project manager training, frequency of design meetings, and frequency of design reports on design phase cost performance.

Research literature has established the influence of management actions on project performance. Specifically, project success factors have been of interest to the engineering design and construction research community for many years. Work by Might and Fisher (1985), Pinto and Slevin (1987), Savido et al. (1990), Jaselskis and Ashley (1991), Parfitt and Savivido (1993), Anderson and Tucker (1994), Heath et al. (1994), and many others successfully created a comprehensive list of management factors that when present, increase the likelihood of design and construction project success (typically measured through schedule and budget). Specific research to quantify the impacts of success factors has been limited, particularly with respect to design performance.

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Note. Discussion open until June 1, 2003. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on October 10, 2001; approved on March 8, 2002. This paper is part of the *Journal of Management in Engineering*, Vol. 19, No. 1, January 1, 2003. ©ASCE, ISSN 0742-597X/2003/1-25–32/$18.00.

Some research, however, has begun to study the impacts of project management processes on design performance, specifically:

- Baldwin et al. (1999) found that by a better understanding of the flow of information among project participants, the management of design may be improved. Baldwin also found that nonexistent or ineffective design management results in extended design timescales and may also produce conflicting construction details that result in delays and problems during construction.
- Research by Ibbs and Kwak (2000a) attempted to determine the financial and organizational impacts of project management. Their work allowed an assessment of the effectiveness of project management efforts and the differentiation of performance enhancements based upon specific management processes. Additional research by Ibbs and Kwak (2000b) formulated and tested a procedure to allow managers to measure their return on investment for project management (PM/ROI). Initial study results found a relationship between project cost performance and project management maturity.
- Austin et al. (2000) established the importance of effective design management to facilitate a coordinated design within budget and to ensure the smooth running of the project. Their research proposed a planning methodology based upon information requirements to reduce work and optimize the design process.
- Communication (both formal and informal) was identified through a survey by Chua et al. (1999) as a critical success factor for project objectives of budget, schedule, and quality with design control meetings specifically identified as a key to budget performance.
- Pocock et al. (1997) found that projects with greater interaction between the project personnel performed better with respect to cost, schedule, changes, and design deficiencies (based upon a study of over 200 completed projects). Percentage of improvement varied based upon type/degree of interaction, but improvement was measured in cost growth and schedule growth percentages.
- Kog et al. (1999) specifically examined the impact of the number of meetings a project manager holds with other project

personnel on schedule performance. The research found that "good" schedule performance can be achieved through frequent (four to six) meetings per month.

- Manavazhi and Xunzhi (2001) identified a causal taxonomy to assess costs of design revisions based upon the cause of the revision. The work suggests the use of a tool to assess the health of a project and as a tool to determine designer resources needed for a particular revision.

This work attempts to advance the existing level of knowledge by quantifying the influence of project management actions/processes on design phase cost performance through a case study at a large public engineering design organization.

Data Collection

The study data is from the City of Los Angeles, Department of Public Works, Bureau of Engineering, a 1000-employee engineering organization that is responsible for the planning, design, and construction management of capital improvement projects for the city. Two hundred and seventy-two projects including municipal facilities, stormwater, sewer, and street projects were studied in this analysis of project management impacts. The construction costs of the projects ranged from $25,000 to $25 million and completion dates were between July 1993 and June 2000. The projects all had multidiscipline design requirements (civil engineering and other), and all established project teams to design the work. The teams consisted of the primary discipline design squad (typically civil engineers), additional discipline designers, oversight program managers, and client agency contacts.

Project Management Processes

The use of project management processes varied across these projects. Four different traditional project management processes (identified through past research as project management success factors) either were or were not used on these projects (Anderson and Tucker 1994; Chua et al. 1999; Kog et al. 1999). These four process were as follows.

1. Organization in a project management structure. With several large bond-funded construction programs in the planning stages, the Bureau of Engineering executive staff and the Board of Public Works mandated an organizational shift to improve project delivery to restore public and city government confidence in the Bureau's ability to manage these future programs. Hence, in February 1997, all of the nonwastewater Bureau divisions were shifted from a traditional functional organization into program-based matrixes with a project manager being the focus for project delivery with project conception-to-conclusion responsibility. These two organizational structures are shown in Fig. 1. The data for the case study included projects completed under both organizational structures with 198 projects completed under the functional organization and 74 under a program based matrix organization.
2. Completion of project management training. In March 1998, the City of Los Angeles, Bureau of Engineering completed a 9-month training effort of over 30,000 h Project Management training for over 1,000 employees. The Bureau's training program had three elements: (1) system optimization; (2) project management tools; and (3) human relations/organizational development. Fig. 2 shows the courses and hours offered within each element of the training. The data for the case study included projects designed by staff that had and had not been trained in these three areas. Of the 272 projects of the study, 208 projects were completed by staff that had not been trained, and 64 projects were completed by staff that had completed the project management training.
3. Frequency of design team meetings. As the awareness and emphasis on project management increased, and depending upon the particular project manager and lead design section for each project, the frequency of design team meetings increased. Hence, there was wide variation from project to project in the number of team meetings held. This success factor was measured as the average number of design team meetings (defined as a project manager lead meeting with key designers and stakeholders to review issues, cost, schedule, and progress) per month of the design phase of the project (varies from 0.25 to 1.0).
4. Frequency of design status reports. Again, as the awareness and emphasis on project management increased and depending upon the particular project manager and lead design section for each project, the frequency of design status reports varied. Hence, there was also wide variation from project to project in the number of reports issued. This success factor was measured as the average number of design status reports (defined as an issues, cost, schedule, and progress status check and printout) issued per month of the design phase of the project (varies from 0.1 to 1.0)

Design Cost Performance Measurement

The only project management performance measure for the 272 project data set was design phase cost performance data. Design phase cost performance is defined through a cost performance index (DCPI) computed as

$$DCPI = ACDWP/BCDWP \tag{1}$$

where BCDWP = budgeted cost of the design work performed and ACDPW = actual cost of the design work performed. A DCPI value of one means the design cost was as planned (at the budget value); a DCPI value above one means the project exceeded its budget; a DCPI of less than one means the project was below its budget.

The BCDWP for all projects in the case data set was based upon preestablished budget templates—historical estimates of dollar costs (expressed as a percentage of estimated construction cost) for every task/element required in the design of a Bureau project. For example, a template would indicate that for a library with an estimated construction value of $1 million, the total design effort is expected to cost 18.6% of the estimated construction cost (or $186,000). The complete templates for the library design include costs (expressed as percentages) for all tasks/elements of the design (with a total of 18.6%).

The Bureau has 21 templates—6 street design templates, 5 stormwater templates, and 10 municipal facilities templates. The values for each template are shown in Table 1. The different templates were created to differentiate projects by type (a library as opposed to a new sewer installation) and by size (a library project with a construction cost of $1 million or a library project with a construction cost of $5 million). When design work on a project in the case study began, the appropriate (based on project type and size) template was recalled from a database. After a review and adjustment period to correct the template design budget esti-

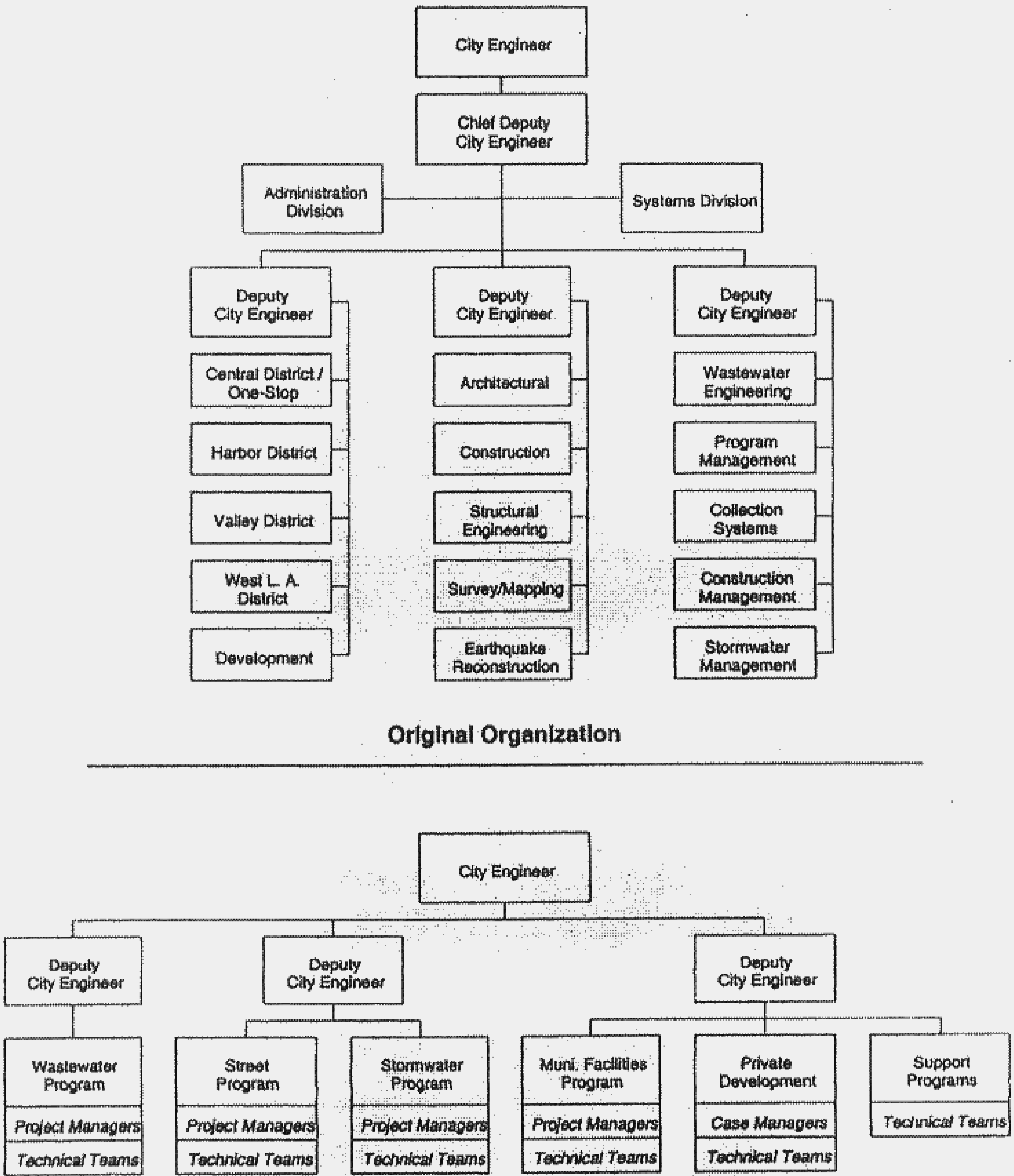

Fig. 1. Organizational forms

mate values for any specific project particularities, the design costs agreed upon became the BCDWP values from which the design performance was measured.

The ACDWP is the sum of the actual dollar expenditures for every bureau staff person involved in any particular project. Individual time charges accrued as design on each project progressed. When each project was completed, each individual's total charges were downloaded from the city timekeeper's database and matched to each particular case study project by a unique project work order number recorded on each staff person's timesheets. Adding all of the time charges for every staff person who worked on each particular project provides the ACDWP. It is important to note that for all projects included in this study, all design work was done by Bureau of Engineering personnel. No subcontracted design services were used for any of these projects; hence, the DCPI calculation is based upon all-inclusive budgeted amounts and all-inclusive actual amounts. Similarly, the cost basis for the budget measures (with respect to labor burdens and indirect costs) is identical to the cost basis for the actual measures.

Check of Project Schedule and Quality Performance

One consideration in the entire effort to measure the cost effectiveness of project management is to check that just because the cost of a design effort is reduced (i.e., a lower DCPI), the design quality and design schedule are not adversely influenced. A lack of data beyond the cost data described above makes this assessment of quality and schedule performance difficult for these Bureau of Engineering projects.

A portion of the projects within the data set did, however, have construction cost data. To confirm that the design cost reductions did not adversely influence design quality, a check of the construction change order percentage (measured as total change order cost divided by total project final construction cost) for the subset of the data set projects verses all of bureau projects completed over the same time period was done. The purpose of the comparison was to check whether the designers "rushed" their work to achieve a lower DCPI at the expense of design coordination or fully thinking out a design (thereby creating change orders when

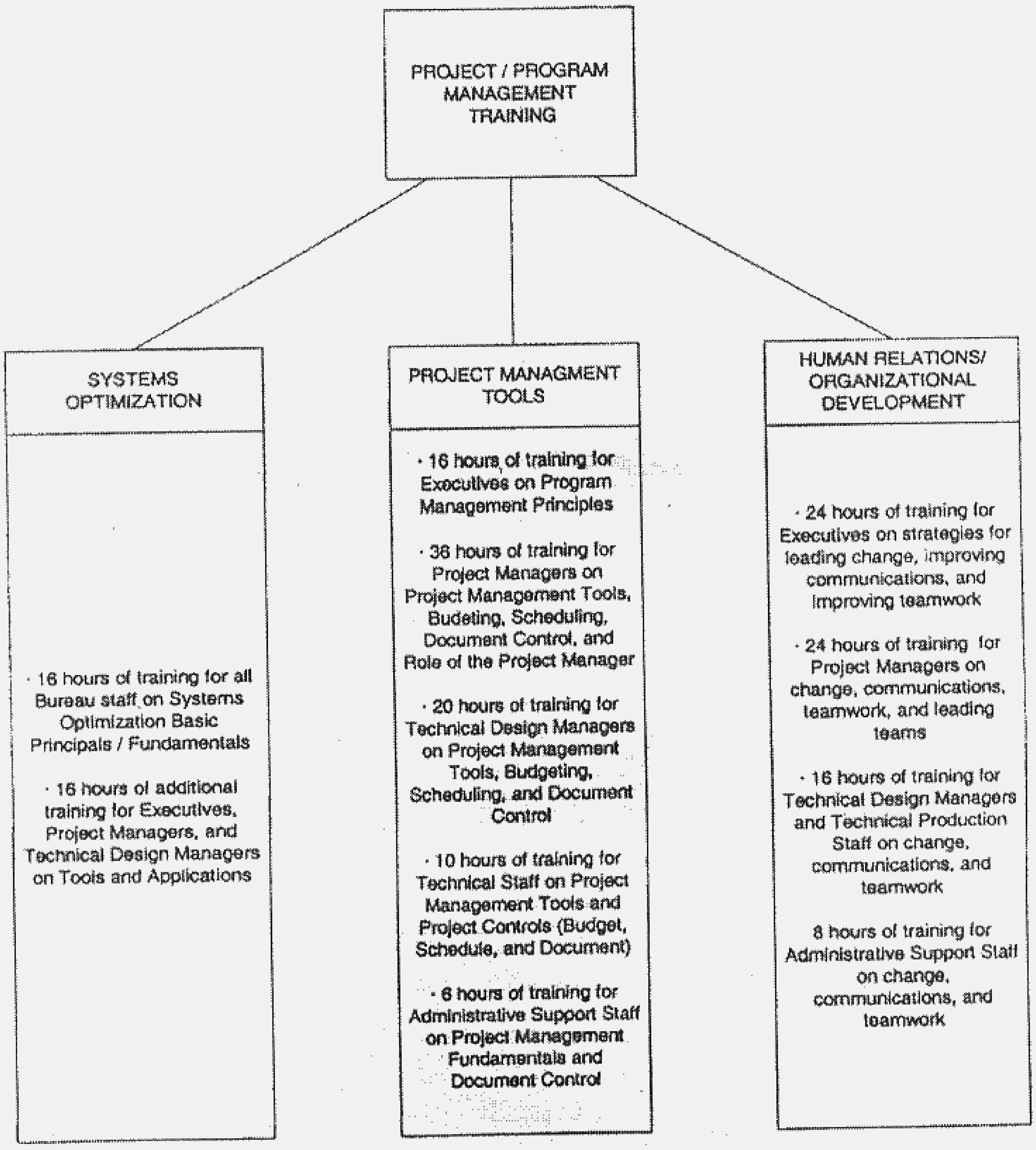

Fig. 2. Training program components

the project went into construction). Table 2 shows that over all years of the study, the projects of the data set had a lower change order percentage than the other Bureau projects. More importantly, as the project management processes were used with greater frequency over the years of the study, the change order percentage also became lower. Therefore, the project management effort to reducing design costs did not influence design quality (as measured through change order percentage).

The check that the project management processes did not adversely impact schedule performance is again difficult because of a lack of schedule performance data. Schedule performance for the entire design effort, however, can be measured through the number of completed design projects by group by calendar year (annual work program). For the years of study in which the data set was collected in which the project management processes were applied, the bureau's annual work program has increased the number of design projects completed for groups from which the data was obtained while maintaining or reducing the number of staff in the group. Hence, the projects have taken no longer to be completed—schedule performance has not suffered at the expense of a lower DCPI. Unfortunately, a lack of data for both of these checks (schedule and quality) does not allow a statistical analysis of the results as does follow for the DCPI.

Project Management Impacts to Design Cost Performance

Quantification of the impacts of the four project management processes identified above across their degree of application was done through three steps of analysis:

1. Comparison of summary statistics of design performance (DCPI) measured across variation in each of the four management processes.
2. Proof of statistical significance of any differences identified in analysis step 1.
3. Calculation of a least squares regression line of a plot of design performance measurement versus amount/application of project management as a means to quantify management influence to design phase cost performance.

The results and conclusions from each of these three analysis steps are explained in the sections below.

Table 1. Bureau Budget Templates

Type of work	Subtype of work	Size	Design cost template (Percent of construction cost)
Municipal facilities	Offices, fire/police stations, libraries	Under $2M	18.60
Municipal facilities	Offices, fire/police stations, libraries	$2M to $10M	15.98
Municipal facilities	Offices, fire/police stations, libraries	$10M to $20M	14.77
Municipal facilities	Parking structure, maintenance yards, warehouses	Under $100k	20.55
Municipal facilities	Parking structure, maintenance yards, warehouses	$100K to $200K	19.15
Municipal facilities	Parking structure, maintenance yards, warehouses	Over $200K	17.34
Municipal facilities	Underground storage tank	Under $50K	50.00
Municipal facilities	Underground storage tank	$50K to $100K	41.00
Municipal facilities	Underground storage tank	$100K to $200K	37.00
Municipal facilities	Underground storage tank	Over $200K	24.00
Stormwater	Storm drain	Under $50K	65.00
Stormwater	Storm drain	$50K to $100K	45.00
Stormwater	Storm drain	$100K to $200K	35.00
Stormwater	Storm drain	$200K to $500K	28.00
Stormwater	Storm drain	Over $500K	20.00
Street	Street reconstruction	Under $100K	50.00
Street	Street reconstruction	$100K to $250K	45.00
Street	Street reconstruction	$250K to $600K	40.00
Street	Street reconstruction	$600K to $1.5M	35.00
Street	Street reconstruction	$1.5M to $5M	30.00
Street	Street reconstruction	Over $5M	25.00

Summary Statistics

Table 3 shows a comparison of the summary data statistics for the entire sample versus the four management process measures of this study; the four measures are divided as follows.

- Training—subdivided into projects in which all team members completed training on project management and projects in which all of the team members did not complete the training.
- Organizational structure—subdivided into projects in which the design team was organized in a matrix organizational structure and projects in which the design team remained organized in a functional organization.
- Meeting frequency—subdivided into projects in which one or more design team meetings were held per month and projects in which less than one design team meeting was held per month.
- Reporting frequency—subdivided into projects in which one or more design status reports were issued per month and projects in which less than design status report was issued per month.

The summary data statistics for each subdivision of the four processes are shown in Table 3. The summary data statistics used are the sample mean, median, standard deviation, and sample size.

Table 2. Change Order Frequency Comparison

Year of completion of the project	All Projects Within the Bureau: Change order (%)	All Projects Within the Bureau: Count	Projects Within the Data Set: Change order (%)	Projects Within the Data Set: Count
1997	15.81	6	NA	0
1998	22.16	24	17.22	7
1999	24.68	47	19.31	12
2000	19.39	31	9.65	9

A comparison of summary data statistics across the presence or absence of these management practices give a first indication of the importance of project management to design success. Table 3 shows:

- The mean DCPI, median DCPI, and DCPI variance are lower for projects in which one or more design team meeting was held per month than for projects in which less than one design team meeting was held per month. Therefore, application of this management tool appears to enhance performance [mean DPCI reduced from 1.751 to 1.133 (35.3%)].
- The mean DCPI, median DCPI, and DCPI variance are lower for projects in which one or more design status report was issued per month than for projects in which less than one design status report was issued per month. Again, application of this management tool also appears to enhance performance [mean DPCI reduced from 1.567 to 1.342 (14.4%)].
- The mean DCPI, median DCPI, and DCPI variance appear to be almost identical for projects in which all team members completed training on project management and for projects in which all of the team members did not complete the training. Application of this management tool may minimally enhance performance [mean DPCI reduced from 1.549 to 1.452 (6.3%)]. Note, however, there is no correlation to this DCPI measurement and a measure of training effectiveness. It is possible that the skills trained were not understood and truly used by the bureau staff, or it is possible that the bureau staff already knew the skills of the training program. Either of these conditions with respect to the training program would cause the DCPI to behave as it did.
- The mean DCPI, median DCPI, and DCPI variance appear to be almost identical for projects in which the design team was organized in a matrix organizational structure and for projects in which the design team remained organized in a functional organization. Application of this management process actually

Table 3. Data Summary for Project Management Process

		PROJECT MANAGEMENT PROCESSES							
		Number of Meetings per Month		Number of Reports per Month		Project Management Tools Training		Organizational Structure	
Statistical measure	Entire sample	Less than one	One or more	Less than one	One or more	Not completed	Completed	Functional	Matrix
Mean	1.526	1.751	1.133	1.567	1.342	1.549	1.452	1.517	1.549
Median	1.132	1.361	0.958	1.141	1.093	1.153	1.087	1.144	1.113
Standard deviation	1.115	1.265	0.619	1.155	0.895	1.138	1.040	1.118	1.113
Count	272	173	9	223	49	208	64	196	74

appears to minimally hinder performance [mean DPCI increased from 1.517 to 1.549 (−2.1%)].

- The bureau's projects are running over budget with a mean DCPI for all projects of 1.526. The overall DCPI would be expected to closer to 1.0. The template values used to establish the baseline values appear to be too low. Comparison between subgroups of projects is still possible, because the entire sample uses the same templates.

All of these findings, however, need to be proven to be statistically significant.

Statistical Significance

There is enough data in the study to perform a test to determine if the study results are statistically significant. Table 4 shows the results of a one-tailed small sample hypothesis t-test for the population mean divided based upon degree of project management process use across the four project management process studied (training, organizational structure, meeting frequency, reporting frequency). The four processes are all tested based upon a null hypothesis (H_0) that the mean DCPI of the projects with the project management processes in use are not lower than the DCPI of the remaining projects. All four hypothesis tests are based upon $\alpha = 0.05$ and assume a normal distribution for the DCPI population (because t-test is used). The table shows the following results:

- H_0 is false for the frequency of the meetings during the design phase. The process of meeting more than one time per month is statistically very significant with the mean DCPI reduced by meeting more than one time per month as compared to meeting less than one time per month (with very strong p value of 7.577E-08).
- H_0 is true for the frequency of the reports during the design phase, but the p value of 0.067 shows marginal significance. Hence, the process of reporting more than one time per month may create a lower mean DCPI than reporting less than one time per month, but additional data is needed.
- H_0 is true for the use of training and the shift to a matrix organization. Hence, these processes do not create a statistically significant lower mean DCPI by their use.

The final step of the analysis is to attempt to quantify the impact of the statistically significant management processes through a plot of a least squares regression line.

Regression

Based upon the statistical significance of reporting and meeting frequency on design phase cost performance, a simple linear regression and correlation analysis was conducted. Two steps were used in the analysis process:

1. Calculation and plot of a least squares regression line (and 95% confidence intervals for plot line slope, b_1, and intercept, b_0).
2. Calculation of the coefficient of determination (R^2) for each plot of step 2 to test the strength of the regression relationship.

It is through these steps that a quantification of management impacts on project performance can be determined.

The first step of the analysis calls for the creation of a scatter plot and calculation of a least squares regression line (and 95% confidence intervals for plot line slope, b_1, and intercept, b_0) for each of the two management variables under study (meeting and reporting) and DCPI. Fig. 3 shows the scatter plot and least squares regression line for design phase meeting frequency versus

Table 4. Results of T-Test for Project Management Process Impact to Design Cost

	PROJECT MANAGEMENT PROCESSES							
	Number of Meetings per Month		Number of Reports per Month		Project Management Tools Training		Organizational Structure	
Statistical measure	Less than one	One or more	Less than one	One or more	Not completed	Completed	functional	matrix
Mean	1.751	1.133	1.567	1.342	1.549	1.452	1.517	1.549
Variance	1.600	0.383	1.335	0.801	1.296	1.081	1.250	1.239
Observations	173	99	223	49	208	64	191	74
Hypothesized mean difference	0		0		0		0	
Degrees of freedom	265		87		113		132	
t stat	5.396		1.507		0.638		−0.209	
t critical one-tail	1.651		1.663		1.658		1.656	
$P(T<=t)$ one-tail	7.577E-08		0.068		0.262		0.417	

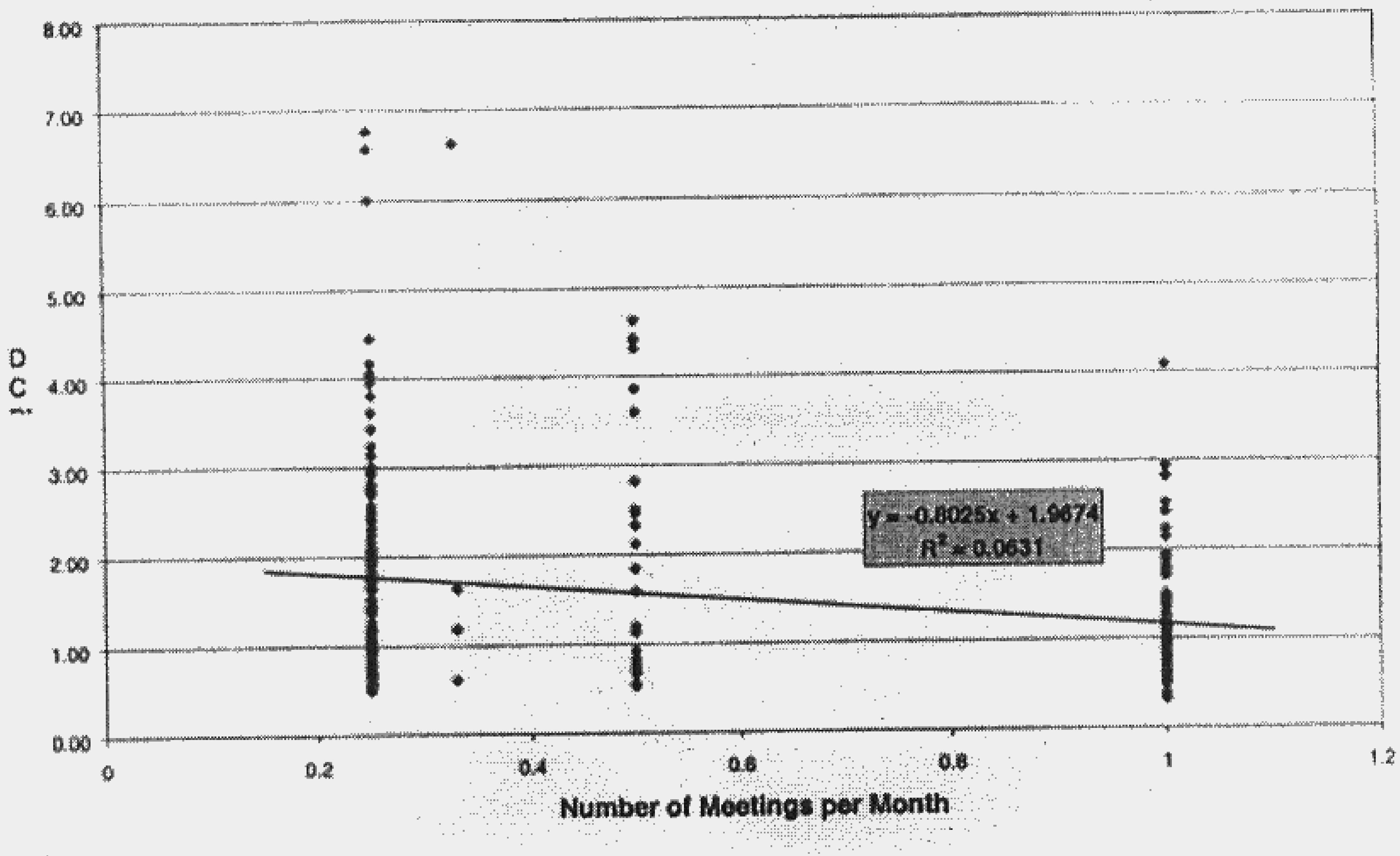

Fig. 3. DCPI versus meeting frequency

DCPI. Fig. 4 shows the scatter plot and least squares regression line for design phase reporting frequency verses. Table 5 shows the statistics for each regression equation slope, b_1, and intercept, b_0, and 95% confidence limits for the regression parameters. The table shows very low p values for all variables (less than 0.05) indicating very strong confidence in the equations of Figs. 3 and 4. The negative slopes (b_1) of the meeting ($b_1 = -0.802$) and reporting ($b_1 = -0.407$) frequency regression lines, along with the calculated intercept points, quantify the impacts of the application of each of these project management processes. For example, increasing the frequency of design team meetings from every other month to every month can be shown to improve DCPI by 25% (DCPI reduced from 1.6 to 1.2).

The second step of the analysis is a calculation of the coefficient of determination, R^2, for each regression plot. As shown in Fig. 3, the coefficient of determination for the meeting frequency versus DCPI regression is only 0.0631. A shown in Table 5, the coefficient of determination for the reporting frequency versus DCPI regression is only 0.0169. These low R^2 values show that variables other than meeting or reporting frequency also influence

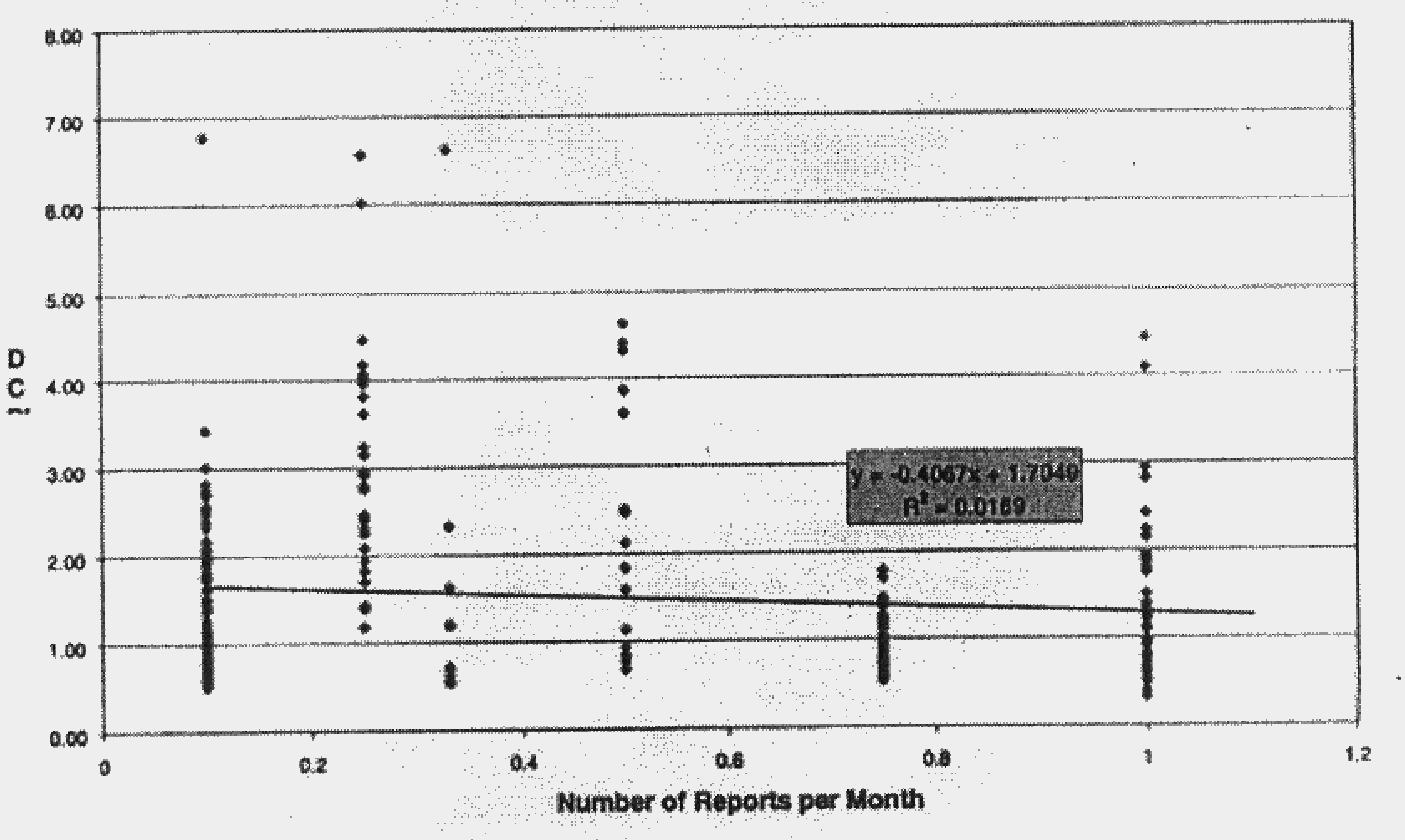

Fig. 4. DCPI versus reporting frequency

Table 5. Results of T-Test for Slope and Intercept Values

	PROJECT MANAGEMENT PROCESSES			
	Number of Meetings per Month		Number of Reports per Month	
Statistical measure	Regression slope b_1	Intercept b_0	Regression slope b_1	Intercept b_0
Value	−0.802	1.967	−0.407	1.705
t stat	−4.268	16.063	−2.157	15.985
t critical	2.000	2.000	2.000	2.000
$P(t \le t)$ one-tail	2.768E-05	3.276E-41	3.186E-02	6.242E-41
95% confidence interval (lower)	−1.173	1.726	−0.778	1.495
95% confidence interval (upper)	−0.432	2.209	−0.036	1.915

DCPI. As seen in the literature review portion of this study, past researchers have identified dozens of potential design cost influences (critical success factors); hence, these low R^2 values are not unexpected. Future research, however, should attempt to identify and quantify these additional influences and should devise methods to measure individual influence impacts (thereby moving the R^2 values closer to one).

Conclusions

This work has provided an analysis of over 270 completed municipal facilities, stormwater, sewer, and street projects within the City of Los Angeles, Department of Public Works, Bureau of Engineering, in order to assess the impact of the use of a project management based organizational structure, project manager training, frequency of design meetings, and frequency of design reports on design phase cost performance. Given a constant level of quality and schedule performance, the process of a design team meeting frequency was found to be statistically significant in reducing design phase costs with the mean DCPI reduced by meeting more than one time per month as compared to meeting less than one time per month. Similarly, given a constant level of quality and schedule performance, the process of written reporting of design phase progress more than one time per month resulted in a lower mean DCPI (with marginal significance) than reporting less than one time per month. The use of project manager training and a project management based organizational structure were found to be processes that do not create a statistically significant lower mean DCPI by their application.

Creation of scatter plots and calculation of least squares regression lines for the meeting frequency and reporting frequency variables against DCPI further confirmed application of these processes results in lower design costs. The negative slopes of the meeting and reporting frequency regression lines, along with the calculated intercept points, were shown to be a method to quantify the design cost impacts of the application of each of these project management processes. Both least squares regression lines had extremely low coefficients of determination, and as such, present numerous opportunities for future research, because other factors certainly influence DCPI. In addition to identification of these influences, future research should also investigate how schedule and quality performance of design phase work can be measured and whether the use of project management processes can also have a similar positive influence to these measures.

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國立雲林科技大學
九十三學年度研究所博士班招生考試試題

所別：工程科技研究所
科目：工程數學（丁）

1. (10%) Determine the independent variable, order, degree, linearity, and homogeneity of the following equations.

a) $\left[x+(y')^2\right]\ y''' - 3y'(y'')^2 = 0$

b) $(y''-xy)^2 = 1-(y')^2$

c) $\left[1+\left(\frac{dy}{dx}\right)^2\right]^{\frac{1}{3}} = 2\frac{d^2y}{dx^2}$

d) $st\frac{\partial^2 u}{\partial s^2} + t\frac{\partial^2 u}{\partial s\partial t} + \frac{\partial u}{\partial s} = 0$

2. (10%) Please solve the following ordinary differential equation:

$x^3y''' - 3x^2y'' + 6xy' - 6y = x^4 \ln x$

3. (10%) Solve the following ODE and use $\omega_0 = \sqrt{k/m}$ to simplify the solution, where m, c, k, F_0, and ω are constants and $c^2 = 4mk$.

$my'' + cy' + ky = F_0 \cos\omega t$

4. (10%) Solve the following boundary value problem. Assume D_f, k, K_s, S_s, L_f, X_f are constants and $K_s \gg S_s$.

$D_f\frac{d^2S_f}{dz^2} = \frac{kX_fS_f}{K_s+S_f}$, $S_f(0) = S_s$, $\frac{dS_f}{dz}(L_f) = 0$

5. (10%) Solve the following boundary value problem, where V, D_M, k_1, k_2, C_s, ℓ are constants.

$V\frac{dC}{dx} - D_M\frac{d^2C}{dx^2} = -k_1L + k_2(C_s - C)$, $C(0) = C_s$, $C(\ell) = C_s$

$V\frac{dL}{dx} = -k_1L$, $L(0) = L_0$

6. (10%) Consider the continuous probability density function $p_X(X)$=a $\sin^2$ mx for $0<X<\pi$.(a) What must be the value of a and m? (b) What is $p_X(x)$? (c) What is prob($0<X<\pi/2$)? (d)What is prob($0.5<X<2.1$) if m=1?

7. (10%) Let $p_x(x)$=0.25 for $0<X<a$. What is the distribution of Y=lnX? Sketch $p_Y(y)$.

8. (10%) Consider the probability density function given by

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$p_X(x)=\lambda_1/2$ $\quad$ $0<X<2$

$P_X(x)=(1-\lambda_1)/4$ $\quad$ $2<X<6$

This is a mixture of 2 uniform distributions. (a) Sketch $p_X(x)$ for $\lambda_1=0.5$. (b) Sketch $p_X(x)$ for $\lambda_1=0.1$. (c) Sketch $p_X(x)$ for $\lambda_1=0.333$. (d) In a random sample from $p_X(x)$, 60% of the values were between 0 and 2. What would be an estimate for the value of λ_1?

9. (10%) Estimate the parameter λ of the distribution $p_X(x)=\lambda e^{-\lambda x}$ for $X>0$ by the method of moments.

10. (10%) Find the maximum likelihood estimator for the parameter λ of the distribution $p_X(x)=\lambda e^{-\lambda x}$ for $X>0$.