

PRODUCT VERSUS PERFORMANCE SPECIFICATION FOR WHEELCHAIR RAMP CONSTRUCTION

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ABSTRACT

Wheelchair ramps at street intersections are a simple product of construction. In California, the standards for these ramps are established by the State Architect and are common to all agencies that own public streets and build pedestrian facilities in the state. There are 541 such street-owning agencies.

When 541 agencies produce a simple product to the same requirements, one might expect to find little difference in the cost of the product or the time taken to produce it. This proved not to be the case. A significant pattern of difference was found between the cost and time to produce ramps by the State Department of Transportation (DOT) as opposed to the cost and time to produce ramps by local cities. The differences appear to be rooted in historic practices which, in turn, are rooted in the procurement laws that govern to two types of agency. Those laws date back to 1875 and 1883 respectively, and they have led to the DOT adopting a more product-based form of specification while cities use specifications that emphasize performance. This difference in specifications drives the cost and schedule differences.

The paper illustrates the use of benchmarking between agencies and the "path dependent" influence of historic practices.

KEYWORDS

Theory, flow, set based design (SBD), product design, performance based design, transportation, wheelchair ramps.

INTRODUCTION

This paper considers a simple product of construction: wheelchair ramps at pedestrian crossings (Figure 1). These are the depressions in sidewalks that allow wheelchair riders to move from raised sidewalks into and across streets. Their engineering is simple. Structurally, they are made from an unreinforced concrete slab with a minimum thickness that is specified in US Customary Units at 3.5 inches (about 90 mm). This thickness is not determined through structural design calculations, but rather responds to experience of

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ground movement and growth of tree roots. Ramps and their adjacent sidewalks must accommodate movement of the underlying ground with a minimum of cracking. They normally carry minimal dynamic loads, e.g., a person on foot, or a person in a wheelchair.

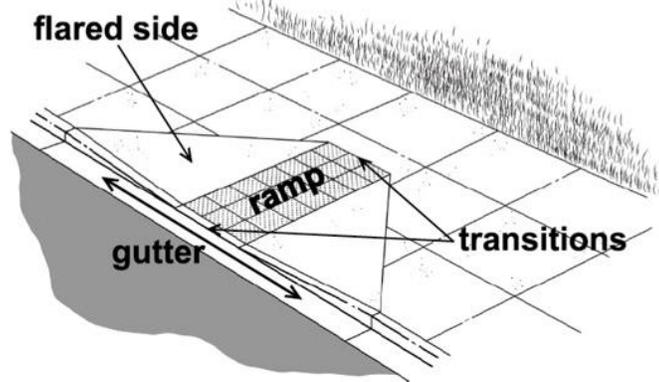


Figure 1: Wheelchair Ramp (US Dept. of Justice, Civil Rights Div. 2007)

In California, the State Architect establishes standards for such ramps. The state’s streets are owned and maintained by the State Department of Transportation (DOT), 58 counties, and 482 cities. Under the Americans with Disabilities Act (ADA) each of these 541 agencies is required to facilitate the movement of wheelchair riders and blind people. Accordingly, three elements, (1) wheelchair ramps, (2) sidewalks, and (3) signals, constitute the principal elements of ADA infrastructure on streets.

Table 1 lists the standards for wheelchair ramps. A ramp is considered to be non-compliant if any of these standards is not met. Exceptions are permitted only if compliance is technically infeasible or structurally impractical (Caltrans 2013). The specifications are written in US Customary Units.

Table 1: Wheelchair Ramp Standards (specified by the DOT in US Customary Units)
(Swanson 2012, modified by Value Management Strategies 2014)

<p><i>Width of Ramp: 48" (~1.22 m) min.</i></p> <p><i>Slope of Ramp: 8.3% max.</i></p> <p><i>X-slope of Ramp: 2% max.</i></p> <p><i>Flare Slope: 10% max.</i></p> <p><i>Gutter Slope: 5% max.</i></p> <p><i>Gutter Lip: Flush</i></p>	<p><i>Top Landing Length: 48" (~1.22 m) min.</i></p> <p><i>Top Landing Slope on Perpendicular Ramps:</i> <i>2% max.</i></p> <p><i>Top Landing X-Slope: 2% max.</i></p> <p><i>Gutter X-slope: 2% max.</i></p> <p><i>Truncated Domes: 36" (~0.91 m) deep x ramp width</i></p>
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The DOT has issued standard plans that conform to the State Architect’s requirements, and these plans are used by it as well as by counties and cities.

Construction of ADA infrastructure is sometimes included in larger projects, but many agencies issue specific contracts exclusively for ADA compliance. These specific contracts may be issued in response to lawsuits or threats of lawsuits for failure to comply with the ADA. We shall refer to them as “ADA projects.”

With many different agencies issuing contracts to provide a simple and standard product, an opportunity exists to compare and learn from their delivery processes. One

might expect such processes to be uniform and consistent, but our research has shown this is demonstrably not the case.

In the course of this research, we examined the bid documents and project costs data for 39 ADA projects completed by the DOT, and 9 ADA projects completed by four cities. In addition, cost data was obtained for 13 ADA projects completed by four counties, but their bid documents were not examined.

DIFFERENCES IN LAW AND DIFFERENCES IN PRACTICE

ADA projects in California are developed through a Design-Bid-Build process. The DOT, counties, and cities are all subject to the California Public Contract Code and must comply with the requirements of that code. However, different code sections apply to each:

For the DOT, Public Contract Code 10120 applies. “Before entering into any contract for a project, the department shall prepare full, complete, and accurate plans and specifications and estimates of cost, giving such directions as will enable any competent mechanic or other builder to carry them out.” This law was introduced in 1875 and revised most recently in 1981.

For counties, Public Contract Code 20124 applies. “The board of supervisors shall adopt plans, specifications, strain sheets, and working details for the work.” This law was introduced in 1883 and revised most recently in 1982.

For cities, Public Contract Code 20162 applies. “When the expenditure required for a public project exceeds five thousand dollars (\$5,000), it shall be contracted for and let to the lowest responsible bidder after notice.” This is another law introduced in 1883 and revised most recently in 1982.

The code that applies to the DOT is the most specific one of the three and it has been interpreted strictly. The code that applies to the cities is the least specific one and it has been interpreted flexibly. This becomes apparent when one examines the bid documents and payment methods of the various agencies. The DOT provides bidders with detailed plans and pays for ramps by unit volume of concrete. This requires a considerable amount of preparatory work. To prepare plans, a survey crew must create a map of each location and then employ a designer to design a suitable ramp. The designer must spend time calculating the surface area of each ramp. To obtain a cubic measure, this surface area is multiplied by the expected concrete thickness. After the ramp is built, the DOT’s inspector must measure the ramp and determine its volume for payment.

By contrast, cities provide no drawings to bidders. Three of the four cities studied provide bidders with lists of locations where the ramps are to be constructed. The fourth city merely states the number of locations. That city’s staff selects locations after the contract has been awarded and then provides the successful contractor with a list.

Table 2 lists the data provided to bidders by the DOT and cities and Figure 2 illustrates a DOT wheelchair ramp design provided to bidders.

Table 2: Data Provided to Bidders and Units of Payment used on ADA Projects

Agency	Provides a location plan	Provides a plan for each ramp	Lists locations with no plans	Unit of payment for ramps
DOT	Yes	Yes	No	Unit volume
City A	No	No	Yes	Each
City B	No	No	No	Each
City C	No	No	Yes	Each
City D	No	No	Yes	Each

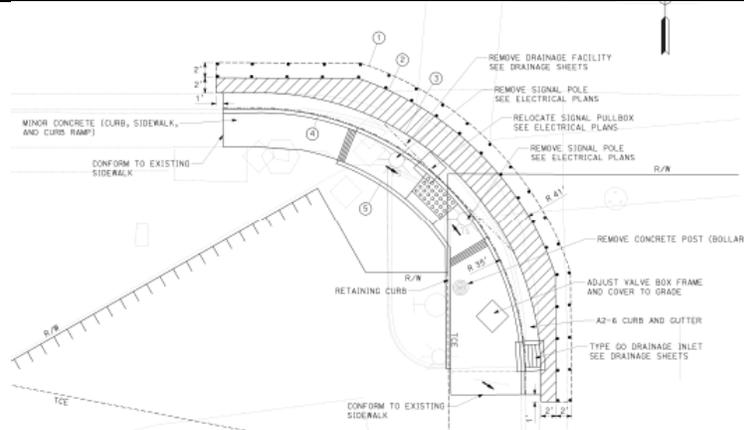


Figure 2: Example Wheelchair Ramp Design Provided by DOT to Bidders (Caltrans 2010)

EXPECTED COST FROM DOT DATA

This research began as an examination of the ADA project process in a single agency, the DOT. The goal was to determine how Lean principles and methods might improve that project delivery process. The comparison with county and city processes was added to stimulate ideas for improvement of the DOT's delivery process. The research then took a new direction when the researchers discovered how the city process differs from the DOT process. Although tangential at first, the comparison between the DOT and city processes became the principal focus of the research.

At an early stage, a best-fit exponential curve was developed in order to identify outliers in the DOT data, using data from 39 DOT ADA projects that resulted in building a total of 976 ramps, about 1,500 m (4,797 feet) of sidewalk, and four audible traffic signals. A modified Cobb-Douglas formula was used (Douglas 1974). Through successive approximations in MATLAB, the following best-fit formula was developed:

$$\text{Expected Cost} = 232,940 + 62,711X_1^{0.2928} \cdot X_2^{0.1429} \cdot X_3^{0.3760} \cdot X_4^{0.0172} \cdot X_5^{0.1791} \quad (\text{equation 1})$$

Where X_1 through X_5 are the following numbers plus one (to avoid that any term in the equation would take on the value 0): X_1 the number of ramps, X_2 the linear feet of sidewalk (normally 1.24 m or 4 feet wide), X_3 the number of audible traffic signals, X_4 the dollar amount paid to property owners and utility companies for right-of-way (land, easements, and utility relocations), and X_5 the number of hours that DOT employees spent in obtaining right-of-way.

This formula had a correlation coefficient $R = 0.74$. The modified Cobb-Douglas converged quickly and provided an intuitively satisfying result. It indicates a fixed processing cost of \$232,940 per project, regardless of project size, and all the factors are positive.

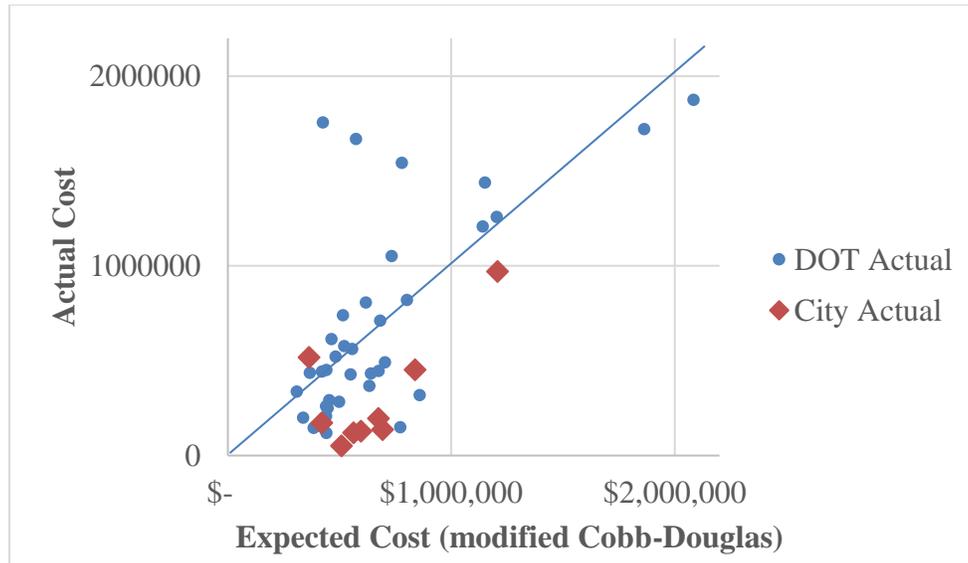


Figure 3: Expected versus Actual Project Costs

COST COMPARISON OF DOT VS CITY PROJECTS

Figure 3 illustrates the outcome of the Cobb-Douglas analysis. It compares the expected cost calculated with equation 1, on the horizontal axis, against the actual project cost on the vertical axis. A projects whose actual cost is equal to the calculated cost (expected cost) is shown by a point on the diagonal line. One that cost more than its expected cost is shown by a point above the diagonal. One that cost less than its expected cost is shown by a point below the diagonal. All but one of the city projects cost significantly less than their expected cost computer using DOT data. On average, each city project costs \$347,000 less than comparable DOT projects, that is, to produce the same scope as measured by the three ADA elements.

Engineering costs on highway projects in the US are divided into Preliminary Engineering costs and Construction Engineering costs. Preliminary Engineering refers to engineering work that occurs prior to the award of a construction contract. The average cost of Preliminary Engineering for the DOT ADA projects in our sample is \$346,000 per project. The closeness of this number to the \$347,000 cost difference between DOT

projects and city projects is coincidental, but the order of magnitude is not. Cities save this money by avoiding virtually all pre-construction design effort on their ADA projects.

The total expected cost of the nine city projects, using the modified Cobb-Douglas formula, was \$5,865,185. The actual total cost of these nine projects was \$2,743,594, that is, 47% of the expected cost.

An expected outcome of investing time and money in the preparation of a detailed design in a Design-Bid-Build process is that the design will provide better information to bidders and thus result in savings from more competition in bidding as well as the avoidance of problems that might arise during the construction phase. The data for ADA projects indicates that these savings did not occur. Despite their minimal designs, the cities received construction bids that were similar in price to the construction bids received by the DOT.

SCHEDULE COMPARISON OF DOT VS CITY PROJECTS

Each city in the study prepares and awards an annual contract for ADA facilities. As indicated, their designs are minimalist. With very little of the project lifespan being dedicated to design, a city project therefore takes a year or less from start to finish.

DOT projects are funded from the State Highway Operation and Protection Program (SHOPP). This program has major project and minor project components. Minor projects are defined as those having a construction cost of less than \$1,000,000 (CTC 2005). The California Transportation Commission allocates funds for minor projects each year, normally in June, and these projects must be ready for construction within a year. These minor projects therefore typically have a lifespan of up to two years: one year for preliminary engineering and a second year for construction.

Projects over \$1,000,000 are in the “major project” portion of the SHOPP. This is a program of projects that are to be awarded with the next four years. Construction contracts that are awarded each year are for projects that are listed in the first of the four years. New projects are then added in the fourth year, creating a continuously rolling four-year plan. The lifespan of a major SHOPP project is therefore normally longer than five years as projects are listed in the program for four years before they are awarded, and then construction takes a year or more. These processes combined with anecdotal evidence indicate that DOT projects take considerably longer to complete than city projects. This would also mean that the DOT is less able than cities to respond quickly to citizen complaints about accessibility. Cities can respond within a year, and one city can respond almost immediately.

COMPARISON IN QUALITY OF DOT VS CITY PROJECTS

Swanson (2012) examined 91 recently-completed DOT wheelchair ramps and found that 39 of them did not comply with one or more of the standards listed in Table 1. This is a 43% failure rate.

The DOT commissioned a review of Swanson’s work. This found that Swanson had used outdated standards and had reported on ramps that were not part of the recently-

completed projects. When adjusting for these errors, the failure rate was reduced to 13% (Value Management Strategies 2014).

The cause of this poor compliance appears to be in the process used by the DOT. Designers produce detailed designs using location and topographic data provided by their surveyors. This data requires interpolation by the designer, which introduces a measure of imprecision that may not provide the precision needed to meet the exacting requirements of the wheelchair standards, where a few millimetres can make the difference between success and failure. The construction contractors are given detailed designs and are required to build to those designs. Their responsibility is to follow the design, not to satisfy the requirements of the standards. If they build to plan but the product does not meet the precise requirements listed in Table 1, either the designer has failed or the contractor has an excuse to blame the designer.

In contrast, the city process places responsibility for compliance squarely upon the construction contractor. The contractor receives the State's Standard Plans and is required to devise a solution that meets the standards. If the product does not meet any of the requirements in Table 1, the responsibility rests solely on the contractor.

The DOT has addressed the 2012 non-compliance by issuing new design and construction bulletins (Caltrans 2013 and 2014) and by introducing Standard Special Provision requiring the contractor to survey its work and report the results to the DOT.

In meetings with DOT personnel to discuss the research findings, it was suggested that there are scope differences between city and DOT ADA projects. References were made to conflicts with traffic signals, utilities, drainage and right-of-way widths. We asked in two e-mail messages for specific locations at which we might observe these problems, but received no location information. Our hope had been that we might observe these locations and determine whether similar locations exist in city projects. City facilities also do include traffic signals, utilities, drainage, and areas of limited right-of-way.

LEAN ISSUES AND LITERATURE REVIEW

LEAN

A wide body of literature attests to the importance of empowering the front-line worker. This is particularly true of Lean literature, beginning with Ohno (1988:1 and 1988:2). The essence of Toyota's implementation of kaizen is to empower front-line workers to stop the line and get help from their supervisors to resolve problems. It might reasonably be argued that the empowerment of front-line workers (and other workers in the organization) is a core distinctive of Lean. The city process is consistent in this regard by empowering contractors to "do what is needed to deliver a project to standard."

The city process is also consistent with set-based design, in which designers keep several alternatives in play and design decisions are deferred to the last responsible moment (e.g., Parrish 2009). In the wheelchair case, cities transfer location-specific design decisions to the contractor, leaving open a set of design options for the contractor to choose from.

The usefulness of deferring decisions to the "last responsible moment" was argued by Lane and Woodman (2000), who coined the term. By effectively leaving the final design

to the contractor, the cities are deferring this decision. In contrast, the DOT makes early design decisions that may be sub-optimal. When decisions are deferred, the later decisions generally produce better results because the decision makers have more complete, contextual information.

BEST VALUE

The cities' approach is also affirmed in the "Best Value" approach advocated by Kashiwagi et al. (2010). This approach advocates that decisions be made by the contractors wherever possible. Kashiwagi et al. say, "decision making by buyer's project managers [is] a risky, inefficient, and transaction causing exercise." We consider that this position is overstated: The contractor is not always the entity in the best position to make decisions but there is, nevertheless, truth to projects possibly being better off overall when designers avoid making decisions based on assumed or partial data, and defer decision making to contractor in the field, who have ready access to all pertinent data. In our example, the argument is two-fold: (1) the design of wheelchair ramps is not so complex that it must be detailed in the office by a designer and (2) a number of site-specific contextual considerations that are hard to identify a priori, may affect wheelchair ramp construction.

DESIGN INCOMPLETE AT BID

A fallacy in the Design-Bid-Build process is referring to the plans that accompany the bid documents as the "Final Design." Pietroforte (1997), building on earlier work by Hayes et al. (1988) points out that design is not complete until construction is complete. No matter how detailed the design may be at bid time, it continues to be refined or altered in construction. To go out for bid, the designer should produce a product that indicates the desired performance, that is biddable and buildable, and that will promote fair competition. In the case of the city's wheelchair ramp bid documents, this is achieved. The desired performance is that the ramp must meet the standards set by the State Architect. Many configurations at any given street corner could satisfy these standards. The mere provision of the State's Standard Plans and a location is sufficient.

The law requires that the DOT provide a bid package that can be executed by a "competent mechanic." On large projects, such as the multi-billion dollar San Francisco-Oakland Bay Bridge, this concept of a competent mechanic has been understood to include the ability to design and execute some extremely complex engineering feats. It would make no sense to suggest, then, that a competent mechanic cannot design a wheelchair ramp. The design of a wheelchair ramp does not entail any complex engineering calculations and such ramps are routinely designed and built by contractors who may not have a professional engineering registration.

CONCLUSIONS

Differences between the laws written for the California State Government and California cities in the late 1800s have led to considerable differences in DOT vs. city approaches to the delivery of equivalent products, in this study: ADA wheelchair ramps. The differences reflect the phenomenon of "path dependency," in which early decisions become enshrined in practice and limit the options available to later decision makers so that, after the passage

of time, it becomes extremely difficult, and often very costly, to revisit and reverse the early decisions. Such path-dependency has been described by Morrey et al. (2012), who discuss the path of practices in a construction company that has been in business since 1890. The path dependencies in our case are of a similar vintage. Morrey et al. state that, “only when they [the path dependencies] are identified and understood can they be overcome, enabling new paths to be created.” Although the paths between the DOT and cities have diverged for so long, the cities’ model could—in our opinion—easily be adopted by the DOT. Adoption could encounter institutional resistance, but that should not be insurmountable.

This research began with a goal of finding lessons from projects in a single agency that could be applied to other projects in the same agency. It transpired, however, that the more useful and significant comparison was to similar projects in other agencies rather than within the single agency. The paper illustrates the use of benchmarking as a version of the Lean practice of *genchi genbutsu* (“go and see for yourself”). This practice normally refers to visiting, observing, and learning from events on the shop floor. Here, however, we found it useful to observe two different groups of projects producing essentially the same products and to learn how each can provide useful lessons to the other.

The DOT has indicated that if city contracts are not subject to the same third party review that is applied to DOT projects, it is incorrect to presume that city curb ramps are being constructed in compliance with the ADA.

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