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COST ESTIMATION METHODS OF TRANSPORT INFRASTRUCTURE PROJECTS

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Abstract

Since overhead costs, general and administrative expenses, and profit are usually added to costs as a percentage of direct transport project costs, it is imperative that estimate accuracy begin with precise estimates of the materials and labour hours required to the job. In many transport firms and infrastructure concession investors it is the materials and 'hands-on' labour that are estimated before any other peripheral costs are calculated even though these peripheral costs frequently exceed the original hardware costs. The paper describes the methods used to determine material quantities and costs, labour hours, some of the engineering activities, and 'factors' that affect these material and labour costs, and direct costs other than those that are normally classified as material and labour costs. The introduced cost estimation methodology can also be understood as a value analysis process for the assessment methodology. In this look, the described cost estimation process is an equivalent of the value engineering of the cost calculation.

Keywords: transport infrastructure, cost estimation, infrastructure establishment.

1. Estimating Basic Material Costs

The first step in estimating direct material costs is the determination of the material quantities required to the transport infrastructure project. The kilograms, cubic or square meters, litres, or linear metres of the required materials (like concrete, asphalt or iron) are usually obtained by determining or computing quantities directly from a 'bill of materials' or parts list; or from detailed drawings and specifications of the completed item with added sufficient percentage for waste and scrap. The next step is to apply the appropriate material unit price or cost to this quantity to develop the final material costs. The costs of procuring, handling, storing and maintaining materials stocks and supplies can be included in the material costs, or may be included in material overhead costs. Usually, materials are classed (together with another category of effort: subcontracts) as those items purchased rather than made by the transport developer.

The most precise means of determining the actual quantity of materials required for a section of a motorway as an example is the extraction or calculation of material quantities from drawings of the desired section or specifications for the building process or service. Calculation of material quantities involves such considerations as the anticipated method of establishing the infrastructure part or item, conducting the process, or delivering the final service (rarely used); the size or quantity of uniform purchase lots (e.g. stoplight-bulbs); and the anticipated scrap, waste, boil-off or leakage. Since the term ‘materials’ covers a wide range of substances varying from raw materials (e.g. bulk sand) to completed parts (e.g. junction control panels), there is often a delicate balance between the type, shape and kind of material purchased and the labour to be performed on it after its purchase.

Careful analysis of the drawings and specifications of the work output is required to determine (1) the best state or condition in which to purchase the material; (2) the optimum size or quantity of material bought; (3) the method of fabrication or establishment that will best use the full quantity of purchased material; and (4) the expected quantity of scrap or waste resulting from successful manufacture of the infrastructure part. The word ‘successful’ is used here, because the effects of accidents on material scrap or waste have not been considered yet. A certain amount of waste can be expected even from a successful building process, because the material units do not usually conform to the exactly needed amount for the completed part. Good building design, however, will make maximum advantage of available material units to minimise waste.

Once material quantities have been developed from drawings, specifications and parts lists, costs can be derived from material handbooks, supplier catalogues, or supplier quotes. Highly refined catalogues and handbooks are available for architectural building construction, which building sometimes belongs to the infrastructure itself (e.g. petrol stations). With rapidly changing prices and markets, it is always desirable to use the latest catalogue prices.

2. Estimating Engineering Activities

The design activity for any infrastructure includes conceptional design, preliminary design, final design and design changes. The design engineer must design prototypes in small or views (at least in the virtual reality), components for development or pre-production testing, special test equipment used in development or preproduction testing, support equipment and production hardware. Since infrastructure material testing has sometimes significant differences compared to the industrial one, special laboratories have been developed that are dedicated only to testing asphalt hardness or slithering, or to testing light-emitting transport signs. Design effort is highly dependent on the specific work output description, design hours must be estimated by a design professional experienced in the area being estimated [1].

Analysis goes hand-in-hand with design and employs the same general skill level as design engineering. Categories of analysis that support, augment or precede establishment design are thermal analysis, safety analysis, and maintainability analysis. Analysis is estimated by professionals skilled in analytical techniques.

Analysis usually includes computer time as well as working hours.

Engineering time costs should be derived from usual salaries or hour rates in the specific field. National organisations of construction engineers often define more cost levels in this field that can be used for estimation of engineering costs.

Table 1. Contents and total engineering time values for new documents

Function	*Man-hours per page*
research, liaison, technical writing, editing, supervision	5.7
typing and proof-reading	0.6
illustration	4.3
text setup	0.7
co-ordination	0.2
Total	11.5

3. Establishing and Production Engineering

The establishing and production engineering activity required to support a work activity is preproduction planning of test models and operations analysis. This differs from the general type of production engineering wherein overall establishing techniques, facilities, and processes are developed. Excluded from this categorisation is the design time of production engineers who redesign a test model unit in order to conform to establishing or user requirements, as well as time for designing special tools and special test equipment.

A large part of an engineer's time is spent to writing specifications, reports, contracts and engineering orders. Complexity of the engineering activity and specific document requirements are important determining factors in estimating the engineering labour hours required to prepare engineering documentation. The hours required for engineering documentation (technical reports, specifications and technical manuals of traffic control equipment) will vary considerably depending on the complexity of the transport infrastructure. However, average labour hours for origination and revision of engineering documentation have been derived based on experience, and these figures can be used as average labour hours per page of documentation. For new documentation the time values described in *Table 1* can be used as baseline. Similar tables are also available for other engineering activities, but their use is very circumstance-specific [2].

4. Estimating Establishing, Production, Assembly and Construction Activities

A key to successful estimating of building or construction activities is the process plan. A process plan is the listing of all operations that must be performed to establish an infrastructure element or to complete a project, along with the labour hours required to perform each operation. The process plan is usually prepared by an experienced foreman, engineer, logistic consultant or technician, who knows the builder's equipment, personnel and capabilities or by a process planning department hired to do all of the process planning. The process planner envisions the equipment, workplace and environment; estimates the number of persons required, and estimates duration of each step. From this information he derives the labour hours required. Process steps are numbered and space is left between operations listed to allow easy insertion or omission of operations or activities as the process is modified. Of course, in this case the critical path of the process may change and project total time may be modified [3].

The process plan is used not only to plan and estimate an establishing or construction process, but also it is often used as part of the manufacturing or construction work order itself. As such, it shows the construction personnel each step in the completion of the work activity. A typical example for using the process plan as a work order was the process plan of the Hungarian–Slovenian railway connection project. With more dozens of parallel branches, the process plan of the reconstruction work in the M7 motorway in 2001 is the other application of the method.

Different types of standards and estimating factors are used for each of construction works. The aim of this paper is to cover both manufacturing and construction works, since output of the classic manufacturing processes is used as element of the transport infrastructure system, while construction itself means the whole establishment of the project.

5. Manufacturing Activities

Manufacturing activities are broken into various categories of effort such as metal working and forming; welding, brazing and soldering; application of fasteners; plating; printing; surface treating and heat treating; manufacturing of electronic components (often needed for traffic control elements). The most common method of estimating time and cost required for manufacturing activities is the industrial engineering approach whereby standards or target values are established for various operations. The term 'standards' is used to indicate standard time data. All possible elements of work are measured, a standard time is assigned for their performance and are documented. When a particular job is to be estimated, all of the applicable standards for all related operations are added to determine the total time.

The use of standards produces more accurate and more easily justifiable estimates. Standards also promote consistency between estimates as well as among estimators. Where standards are used, personal experience is desirable or beneficial, but not mandatory. Standards have been developed over a number of years through the use of time studies and synthesis of methods analysis. They are based on the level of efficiency that could be attained by a job producing up to 1000 units of any specific work output. Standards are actually synoptical values of more detailed times. They are adaptations, extracts or benchmark time values for each type of operation. The loss of accuracy due to summarization or averaging is acceptable when total time for a system is being developed. If standard values are used with judgement and interpolations for varying stock sizes, reasonably accurate results can be obtained. Time relevance of classic manufacturing activities is to be found in handbooks for industrial movement analysis. For infactory material handling the AIM method was developed at the Budapest University of Technology and Economics.

Machining operations make up a large part of the manufacturing costs of many transport infrastructure projects, when special elements are needed, which cannot be obtained from regular producers. These machining operations are usually divided into set-up times and run times. Setup time is the required time to establish and adjust the tooling, to set speeds, and feeds on the metal removal machine, and to program for the manufacture of one or more identical or similar parts. Run time is the time required to complete each part. It consists of certain fixed positioning times for each item being machined as well as the actual metal removal and cleanup time for each item.

6. Construction Activities

Fabrication of bridges, dams, and public transport facilities as well as the track/road line itself and the neighbouring transport-related buildings belong to the construction activities. One of the most structured, documented, and well-thought-out activities that estimators deal with is transport infrastructure construction [4]. Reason for this is that transport infrastructure has usually an effect on more hundreds or maybe millions of inhabitants, costs and deadlines often have politic results. Almost from beginning of recorded history, man has had to provide structures for travel. Despite a wealth of information on the construction process, there are still evidences of cost overruns and underestimates due to factors such as inadequate planning, escalation and inflation, unforeseen natural disasters, and growth in complexity or content of transport construction projects. The key to avoiding many of these cost increasing factors is to take maximum advantage of the structured planning, scheduling and estimating process. It is important to recover and to include adequate labour hours and materials for each step in the construction process, and to meticulously lay out and identify each construction activity. Because construction activities at the site where the structure or public utility is needed, construction activities differ considerably from the manufacturing and assembly activities covered earlier in the paper.

The need for physical access to the construction element being performed at a given time dictates a general flow of activities for the construction process. The unique feature of an integrated on-site manufacturing and assembly process performed by diverse skills, makes it particularly important to lay out the flow sequence of construction as a prerequisite to estimating labour hours and materials.

Transportation construction includes the construction of airports, bridges, bus terminals, canals, docks, railroads, roads, train terminals, and tunnels. Each category and subdivision has its own background and experience, a specific labour skill mix, and, usually, a well-thought-out and experience-proven planning, scheduling and estimating methodology.

In the fields of transport infrastructure planning alone, there are nearly 3000 categories of material and labour. Many construction labour standards are tied to the item being installed or material being used. Within each category the labour hours required often vary with the specific type and brand name of item or material being installed. There are estimating standards for new construction and for remodelling and repair, and overall square-meter cost relationships are available for residential, commercial and industrial transport infrastructure. Construction estimating manuals usually include average wage modification factors that adapt these wage rates for various construction skills and trades, wage modification factors that adapt the wage rates for various geographical areas, and material and labour costs associated with each construction activity. For a simpler and quicker method of estimating transport infrastructure costs, Euro per kilometre values can be used at different transport modes. Euro per kilometre figures are empirical in nature and must be modified to conform to the prevailing costs in a given geographical area, and to the quality of the structure.

7. Testing

Testing usually comprises three categories:

- development testing,
- qualification testing and
- production acceptance testing.

Rules of thumb are difficult to apply for estimating development testing because testing varies with the complexity, uncertainty and technological content of the work activity. The best way to estimate the cost of development testing is to produce a detailed test plan for the specific project and to cost each element of this test plan separately, with careful consideration of all skills, facilities, equipment, and material needed in the development test program.

Qualification testing is required in most commercial infrastructure and on all military infrastructure projects to demonstrate adequately that the new construction will operate or serve its intended purpose in environments far more severe than those intended for its actual use. Transport infrastructure products must often undergo severe and prolonged tests under high shock, thermal and vibration loads, as well as heat, humidity, cold, and salt spray environments. These tests must be meticulously planned and scheduled before a reasonable estimate of their costs can be generated.

Receiving inspection, production testing, and acceptance testing can be estimated using experience factors and ratios available from previous similar work activities. Receiving tests are tests performed on purchased components, parts and/or subassemblies prior to acceptance by the receiving department. Production tests are tests of subassemblies, units, subsystems, and systems during and after assembly. Experience has shown generally that test labour varies directly with the amount of fabrication and assembly labour. The ratio of test labour to other production labour will depend on the complexity of the item being tested. *Table 2* gives percentages of direct fabrication and assembly labour for testing simple, average and complex items.

Table 2. Test estimating ratios

	% of direct labour		
	simple	average	complex
Fabrication and assembly labour base			
receiving test	1	2	4
production test	9	18	36
total	10	20	40
Assembly labour base			
receiving test	2	3	7
production test	15	32	63
total	17	35	70

Special-purpose tooling and special-purpose test equipment are important items of costs because they are used only for a particular job; therefore, that job must bear the full cost of the tool or test fixture. Testing equipment of this type often appears when testing transport infrastructure establishment (e.g. vibration test for a bridge, etc.). In contrast to the special items, general-purpose tooling or test equipment is purchased as capital equipment and costs are spread over many jobs. Estimates for tooling and test equipment are included in overall manufacturing startup ratios.

8. Labour Allowances

The ‘standard times’ assume that workers are well trained and experienced in their job, that use 100% of the time for the job, that never make a mistake, take a break, lose efficiency or deviate from the task for any reason. This, of course, is an unreasonable assumption, because there are legitimate and numerous unplanned work interruptions that occur with regularity in any work activity. Therefore, labour allowances must be added to any estimate that is made up of an accumulation of standard times. These labour allowances may accumulate to a factor of 1.5 to 2.5.

The total standard time for a given work activity, depending on the overall inherent efficiency of the activity, equipment and personnel, will depend on the nature of the task. Labour allowances are made up of a number of factors that are described in the following section.

Standard hours vary from actual measured labour hours because workers often deviate from the standard method or technique used or planned for a given operation. This deviation can be caused by a number of factors ranging from the training, motivation or disposition of the operator to the use of faulty tools, fixtures or machines. Sometimes shortages of materials or lack of adequate supervision are causes of deviations from standard values. These factors can add 5 to 20% to standard time values [5].

Personal times are for personal activities such as coffee breaks, trips to the restroom or water fountain, unforeseen interruptions or emergency telephone calls. Fatigue time is allocated because of the inability of a worker to produce at the same pace all day. Operator efficiency decreases as the job time increases. Delays include unavoidable delays caused by the need for obtaining supervisory instructions, equipment breakdown, and power outages or operator illness. Personal, fatigue and delay time can add 10 to 20% to standard time values. Although normal or routine equipment maintenance can be done during other than operating shifts, there is usually some operator-performed machine maintenance activity that must be performed during the machine duty cycle. These activities include adjusting tools, sharpening tools, and periodically cleaning and oiling machines. In processing operations (like concrete finishing) the operator maintains solutions and compounds, and handles and maintains racks and fixtures. Tooling and equipment maintenance can account for 5 to 12% of standard time values. The overall direct labour hours derived from the application of the preceding three allowance factors to standard times must be increased by additional amounts to account for normal rework and repair. Labour values must be allocated for rework of defective purchased materials, rework of in-process rejects, final test rejects, and addition of minor engineering changes. Units damaged on receipt or during handling must also be repaired. This factor can add 10 to 20% direct labour hours to those previously estimated.

For projects, where design stability is poor, where production is indicated prior to final design release, and where field testing is being performed currently with production, an engineering change allowance should be added of up to 10% of direct labour hours. Change allowances vary widely for different types of work activities. Even fairly well defined projects, however, should contain a change allowance.

Occasionally a cost estimate will warrant the addition of allowances for cost growth. Cost growth allowances are best added at the lowest level of a cost estimate rather than at the top levels. These allowances include reserves for possible misfortunes, natural disasters, strikes, and other unforeseen circumstances. Reserves should not be used to account for normal design growth. Care should be taken in using reserves in a cost estimate because they are usually the first cost elements that come under attack for removal from the cost estimate or budget. Cost growth with an incomplete design is a certainty, not a reserve or contingency.

9. Estimating Supervision, Direct Management, and Other Direct Charges

Direct supervision costs will vary with the task and company organisation. Management studies have shown that the span of control of a supervisor over a complex activity should not exceed twelve workers. For simple activities, the ratio of supervisors to employees can go down, but 1 to 12 ratio (8.3%) will usually yield best results. Project management for a complex can add an additional 10 to 14%. Other direct charges are those directly attributable to the project being accomplished but not included in direct labour or direct materials. Transportation, training, and reproduction costs as well as special service or support contracts and consultants , are included in the category of 'other direct costs'.

Two cost elements of 'other direct costs' that are becoming increasingly prominent are travel and transportation costs. Air, bus and rail fares as well as private conveyance costs are increasing at a rate higher than the general inflation rate because rapidly increasing fuel costs comprise a large part of the cost per passenger kilometre. For this reason a frequent check on public and private conveyance rates and costs is mandatory. Most companies provide a private vehicle mileage allowance for employees who use their own vehicles in doing company business. Rates differ and depend on whether the private conveyance is being used principally for the benefit of the company or principally for the convenience of the traveller. Regardless of which rate is used, the kilometre allowance must be periodically updated to keep pace with actual costs. Many companies purchase or lease vehicles to be used by their employees on official business, and sometimes personal travel. The decision as to the most cost-effective method of providing business-related employee transportation should be based on one of several types of investment analyses.

Per diem travel allowances or reimbursement for lodging, meals and miscellaneous expenses must also be included in overall travel budgets. These reimbursable expenses include costs of a motel or hotel room; food, trips, and taxes; local transportation and communication, and other costs such as laundry, mailing costs, and on-site clerical services. Transportation costs include the transport of equipment, supplies, and products as well as personnel, and can include packaging, handling, shipping, postage and insurance charges.

10. The Use of Factors in Estimating

Although the use of factors in estimating is not a recommended practice, it is becoming increasingly common, particularly in high-technology transport infrastructure (like high-speed railway tracks), and work outputs. One company employs an allocation factor, which allocates miscellaneous labour-oriented functions to specific functions such as fabrication or assembly. This company adds 14.4% to fabrication and construction hours and 4.1% to assembly hours to cover miscellaneous labour-hour expenditures associated with these three functions. It is also common to estimate hours for planning, tooling, quality inspection, production support, and sustaining engineering based on percentages of manufacturing and/or assembly hours. Tooling materials and computer tapes are sometimes estimated based on cost per tooling hour. Miscellaneous shop hardware (units, bolts, fasteners, cleaning supplies, etc.), otherwise known as 'panstock,' is estimated at a cost per manufacturing hour.

The disadvantage of the use of such factors is that inefficiencies can become imbedded in the factored allowances and eventually cause cost growth. A much better method of estimating the man-hours and materials required to accomplish these other direct activities is to determine the specific tasks and materials required to perform the job by man-loading or process planning methods. When the materials, labour hours, and other direct costs have been estimated, the basic direct resources required to do the job have been identified. The next step in the estimating process is to determine labour rates, indirect costs, administrative expenses and profit.

11. Summary

None of modern transport infrastructure is built without a careful cost estimation process. As the role of co-operation of public and private becomes more and more important, it is essentially to be in possession of the required estimation methods and tools. The paper summarised some of the most significant effects that influence the cost estimation process. As seen, non-regular costs in the form of allowances may increase the total estimation sum by a high ratio. In order to avoid inefficiencies, some of old methods have to be neglected, and new estimating should be used. An aim of the paper was to point out the many pitfalls of the simple cost estimating for transport infrastructure. Methods described above should be a help for decision-makers both at public and private side to increase the safety of cost estimation.

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