# Productivity in the UK Engineering Construction Industry

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# PREFACE

The Departments for Business Enterprise & Regulatory Reform (BERR), and Innovation, Universities & Skills (DIUS) [now the Department for Business, Innovation and Skills (BIS)] commissioned this study as part of their joint review of productivity and skills in the engineering construction sector. The review will use this study and other input to formulate recommendations on ways to improve skills and productivity in the UK engineering construction industry, and to identify specific factors influencing success for UK-based companies bidding for UK and foreign engineering construction contracts.

The research documented in this report is a quantitative study that defines and measures productivity of the UK engineering construction industry and compares the UK productivity with productivity in Western Europe and the United States. The report assesses key drivers of engineering construction labour productivity that help explain differences between the UK and other regions.

Independent Project Analysis (IPA) completed this study, which draws from its existing database of process plant capital projects, under Contract for the Provision of Services to the Department of Business Enterprise & Regulatory Reform (BERR), executed on May 11, 2009. Through its Project Evaluation System (PES®),[1] IPA has developed a robust basis for project evaluation, system benchmarking and research. This analysis was conducted using IPA's Process Plants Database, which consists of more than 11,000 projects conducted by more than 350 companies in the oil, chemicals, consumer products, pharmaceutical, and other capital-intensive industries during the past 25 years.

A more detailed discussion of IPA databases and methodology is available in other reports. For more information, contact E. Merrow, emerrow@ipaglobal.com, K. Sonnhalter, ksonnhalter@ipaglobal.com, or in the UK, contact Andrew Griffith of IPA at agriffith@ipaglobal.com or +44 (0) 118 920 7800.

[1] PES is a registered trademark of IPA.

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## EXECUTIVE SUMMARY

This study explores engineering construction labour productivity in the United Kingdom for “engineering construction projects”, authorized between 1998 and 2008. These projects involve the construction or refurbishment of facilities in industries such as petroleum refining, chemicals manufacturing, power production, and the like. These projects generally require extensive engineering input and are usually heavy consumers of high skill crafts such as pipefitters and electricians.

Our data are drawn from 60 projects in the UK and compared with hundreds more from western European countries and the United States, especially the U.S. Gulf Coast (USGC), which is home to the world’s largest concentration of engineering construction projects. Twenty-three owners, companies who own the asset installed and are the client of the contractors selected, are represented in the UK projects, providing a good cross-section of the industry. Using a proven IPA-developed methodology for measuring engineering construction labour productivity, we assessed the engineering construction labour productivity for the UK projects and assigned each an index value, measuring the number of hours required to complete their scope versus that required on the USGC to complete very similar scopes of work on many other projects.

We find that the UK suffers an engineering construction labour productivity shortfall relative to both the USGC and Western Europe taken as a whole, although UK productivity is better than that found in some western European countries. The magnitude of the disadvantage is 11 percent versus the USGC and about 6 percent, versus Western Europe. At today’s exchange rates and wages, the UK suffers no cost disadvantage versus either of the two regions. It must be remembered, however, that exchange rates can fluctuate rapidly; productivity is more enduring.

We find evidence for poor productivity in UK projects being caused by a number of the practices followed by UK owners and contractors on the projects. It is important to realise that a third of the UK projects exhibited excellent productivity. These projects are distributed across owners and across the country. Other projects, drawing on essentially the same labour pool, obtained miserable productivity results. The difference is in the practices followed.

Whilst we identify eight practice areas that are important for engineering construction labour productivity and distinctly different than good practice, we mention only the key ones in this summary.

- The project execution plans for UK projects are not in accord with best practice, as determined by IPA research. Of particular note, the quality and depth of the schedules prepared prior to sanction were inadequate for the UK projects. Even the large projects failed to develop schedules with sufficient detail to generate good engineering construction labour productivity.
- The projects are intentionally overlapping engineering with construction far more than projects elsewhere and far more than accords with good engineering construction labour productivity. Engineering is then slipping substantially and resulting in insufficiently completed design to sustain field activities. What is particularly surprising about this result is that it is not a manifestation of desiring to accelerate the completion dates on the part of the owners. The contractors, who are actually producing most of the detailed schedules for UK projects, are fashioning aggressive schedules in execution that seriously erode field productivity.
- Finally, the project controls applied in the field are well behind best practice. The estimates are not being routinely validated by the owners, the basis for control is

often shaky, and comprehensive physical progress measurement is not being done routinely. Strong controls are a key component of good construction management.

Our evidence suggests that the three factors above are the biggest drivers of the UK's engineering construction labour productivity shortfall. Correcting these problems is entirely in the hands of UK owner companies. In some cases, the owners themselves must improve their practices; in others they need to prevail upon their contractors to improve. Either way, the owners shape the market.

# INTRODUCTION

## BACKGROUND

The Departments for Business Enterprise & Regulatory Reform (BERR), and Innovation, Universities & Skills (DIUS) [now the Department for Business, Innovation and Skills (BIS)] have launched a review of productivity in the “engineering construction industry”, which is defined as the sector that designs, constructs and maintains process plants in oil and gas, water, environmental, steel and metal, cement, glass, paper, brewing and distillation, food, power generation, nuclear waste reprocessing, pharmaceutical production, petrochemical and chemical sectors. The projects in these sectors are characterised by a large amount of engineering input and a relative absence of opportunities to standardise designs and therefore the construction work. The focus of this research report is on the productivity of craft labour employed to construct or maintain plants.

A recent dispute at the Lindsey Oil Refinery, where workers walked off the job in protest over issues related to posted workers from outside of the UK, highlighted concerns about engineering construction productivity and the possible effects on the UK economy and employment. The dispute involved a number of interconnected issues, including compliance with the National Agreement for the Engineering Construction Industry (NAECI), employment status of the foreign workers, and transparency of wages paid in the UK to foreign based workers. However, one additional issue raised as part of this dispute was the relative productivity of the UK engineering construction industry compared with other parts of the world.

Productivity in this industry is of central importance to the economic health of the UK economy. Overall, the construction industry represents approximately 6 percent of the UK economy and employs more than 1.3 million people nationwide.[2] The engineering construction industry is a major component of the overall construction industry, which plays a huge role in building and maintaining the UK’s manufacturing asset base. Because of the size of the industry, relative productivity performance and any changes within it have significant direct effects on the national productivity and economic well being.

## MEASURING ENGINEERING CONSTRUCTION LABOUR PRODUCTIVITY

We discuss three approaches to measuring engineering construction labour productivity, each of which has a different meaning and use. First is what we will call the Economist’s Approach. We explain the approach and then explain that it has limited application for our current problem. Second is the Construction Manager’s Approach, which measures engineering construction labour productivity at a task level. Finally, there is the Project Approach, which addresses engineering construction labour productivity with the whole project as the unit of observation. The third approach is what we employ here.

### The Economist’s Approach

In the most general sense, engineering construction labour productivity is the economic output per hour worked. In this approach to measurement, the number of hours required per item produced, e.g., per auto, per tonne of petrol, etc., is the measure of productivity. Within a given currency regime, the currency value produced by an hour of labour could be substituted for units. Therefore, engineering construction labour productivity

[2] UK National Statistics web site: http://www.statistics.gov.uk

in the UK could be measured as the project cost in pounds divided by the number of hours required to construct.[3] This economic formulation of productivity is useful to compare productivity across industrial sectors within an economy. When seeking to compare productivity across different currencies, this measure suffers from being heavily affected by changes in currency exchange rates. The problem this creates is that currency exchange rates are volatile in the short-run, while productivity surely is not.

By the economist's formulation, the labour productivity of engineering construction projects in developed economies has undoubtedly declined relative to many, and perhaps most, manufacturing industrial activities.[4] This is because the primary driver of labour productivity when measured in this way is the extent to which capital is substituted for labour. In this context, capital means construction machinery and information technology. IPA has evaluated engineering construction projects in OECD countries and finds no statistically significant difference in the substitution of capital for labour.[5] For example, we find no difference between the use of automated design systems in the UK than in the USA or Western European projects and no difference in the use other labour-substituting practices, such as shop fabrication of pipe spools.[6]

The substitution of capital for labour is especially difficult for engineering construction projects because these projects are largely "one-off" in character with designs tailored to the particular circumstances such as size, plot shape and layout, and integration with existing facilities. The "one-off" characteristic makes standardisation difficult, which in turn makes the application of machinery to do construction more difficult. This means that the labour component of engineering construction projects is generally high and much higher than most modern manufacturing. This in turn means that efficient labour efficiently applied is very important to the cost effectiveness of these projects. The underlying reason that standardisation is so difficult in these projects is that many of the projects refurbish and add-on to existing facilities in the OECD countries rather than build a standard new plant. Even relatively standard projects vary in capacity and other key characteristics that make full standardisation difficult.

## The Construction Manager's Approach

The Construction Manager's Approach involves the careful and very detailed measurement of work accomplished per hour at the gang or even individual labourer level. For example, the number of inches of acceptable weld of 4 inch alloy pipe per hour is a meaningful and useful measure of engineering construction labour productivity. This sort of measurement is the life-blood of strong construction management in the field and is used in estimating project costs at the bid stage. In principle, the individual measurements of productivity for each craftsman can be summed to arrive at a weighted productivity measurement for a whole project and could then be compared with other projects measured on the same basis. The problem with the approach is the sheer volume of data required. Consider the difficulties with our single example above. The amount of welding

[3] This ignores, of course, the hours required to engineer and manage.
[4] Teicholta, P. (2001), "Discussion of 'U.S. construction labor productivity trends, 1970-1998'." J. Construction Engineering Management, 127(5), 427-428.
Business Roundtable Report, "More Construction for the Money," Summary Report of the Construction Industry Cost Effectiveness Project, (1983).
[5] In countries with much lower construction wages, labour is frequently substituted for capital because it is efficient to do so. This has led many researchers to misunderstand the labour productivity in "third world" countries.
[6] Note that modularization is usually not associated with standardization. Rather, the modules for process facilities are usually one-off just as they would be on-site. It is important to understand that in normal circumstances, modular construction is not as cost-effective as "stick-build" construction. The exceptions tend to be cases in which labour access and supply are extraordinarily difficult and cases in which a skid-mounted bit of standard kit can be installed.

accomplished has to be somehow adjusted for the number of welds by the pipefitter that did not pass visual or X-ray inspection. Welding of alloy pipe cannot be compared with carbon steel pipe. Finally, pipe diameter is needed to normalise the productivity. As a result of the detail required, this micro approach cannot be used in the current study because the data would never be available.

## The Project Approach

To overcome the data challenges posed by the Construction Manager Approach while preserving most of its accuracy, IPA developed an alternative approach that leverages the size and breadth of our Process Plants Database. This database contains the hours worked, the wages paid, and detailed scopes of over 11 thousand process facilities built around the world. The database also contains details of how the projects were prepared on the front-end and managed in execution. As detailed below, the PPD information allows the development of an engineering construction labour productivity index and a labour cost index for each project by normalising for differences in scopes, locations, and other factors.[7] The database is drawn from exactly the industries that build engineering construction projects.

## Is Engineering Construction Labour Productivity Improving or Declining?

There is an ongoing debate in academic circles as to whether engineering construction labour productivity has been improving or degrading. This debate is largely an issue of definition and measurement. The debate only takes on substance when the methodologies for comparison across time are the same. In modern economies, the relative engineering construction labour productivity on complex project construction has surely declined relative to many other areas of manufacturing and industrial activity simply because engineering construction projects are inherently labour intensive activities, while many rapidly expanding areas of activity are less so. As mentioned above, substitution of machinery and other forms of capital for labour in construction is very dependent on standardisation. The nature of most engineering construction projects is that they are specially designed for the particular circumstance and application and therefore not amenable to capitalisation. At the same time, the number of labour hours needed to construct a given type of facility has likely improved slowly over the last two decades. That improvement has come from better practices applied to projects rather than changes in construction methodologies. Meanwhile, engineering construction labour productivity in places like China have been improving rapidly because the substitution of modern construction machinery has started to bring engineering construction labour productivity closer to the developed country norms.

[7] See E. W. Merrow and K.A. Brown, *A Statistical Methodology for Measuring Construction Labor Productivity*, Presentation to the Industry Benchmarking Consortium, March 2001, Independent Project Analysis, Inc.

# RESEARCH OBJECTIVES AND DESIGN

## RESEARCH OBJECTIVES

The objectives of this study are to provide robust evidence and analysis to inform the review and help the review group in making credible recommendations to improve the level and growth rates of productivity performance of companies operating on UK engineering construction sites. Specific study objectives include:

- Provide robust evidence that defines and measures the productivity of companies operating on UK engineering construction sites.
- Compare the productivity of companies on engineering construction sites in the UK to that achieved by companies on comparable sites abroad.
- Assess the key drivers of productivity of engineering construction on UK sites.
- Offer explanations for any significant differences in productivity.
- Identify the barriers to increased productivity performance on UK engineering construction sites.
- Identify factors affecting the competitiveness of UK-based engineering construction companies.

## Methodology

IPA has a deep understanding and extensive experience in working with the engineering construction industry. IPA's project databases include projects from several sectors of the engineering construction industry. In addition, IPA leads the Industry Benchmarking Consortium (IBC). The IBC is a voluntary association of owner firms in the chemicals, petroleum, consumer products, pharmaceuticals, and minerals processing industries that have employed IPA's quantitative benchmarking approach. The members have agreed to exchange data, information, and metrics to improve the effectiveness of their project systems. Through our ongoing work with industry companies, research, and work with the IBC, IPA continually updates and expands its capabilities in the engineering construction industry.

IPA's methodology provides a robust basis for capital project benchmarking and research. Its findings are based on actual industry data collected on a project-by-project basis. Using data collected directly from project teams, IPA builds carefully normalised project databases. Data collected on each project include cost history, schedule history, project scope and technologies, project team characteristics, and project management practices. Using these databases, IPA develops statistical models and builds comparison groups. These statistical tools make it possible to conduct quantitative analysis of individual projects.

IPA's primary data collection method is through direct face-to-face interviews with project teams. Over more than 20 years, IPA has developed structured data collection workbooks following standard survey research methods for survey design and pilot testing, prior to implementation. All of IPA's research analysts are extensively trained in survey research methods and then go through a period of mentoring where more experienced analysts attend project interviews to ensure consistency and quality before newer analysts are allowed to lead project interviews independently. Data on every project in IPA's current database were collected through face-to-face project interviews using IPA's structured data collection workbooks.

Data are collected from each project at multiple points in the project life-cycle. Typically, IPA collects project data at least once and often twice during the project definition phase prior to authorisation. We then interview the project team again after mechanical completion when the facility has started operations. The interviews conducted prior to authorisation are focused on technology, processes, team composition, and targets for the project. The final data collection is focused on understanding what took place during execution phase and on documenting the actual results such as cost, schedule, and safety performance. We find that conducting interviews at different stages improves the quality of the information collected.

### IPA Project Database

IPA's core projects database is its Downstream Process Plants Database. This database contains detailed information from actual capital projects executed worldwide. The database has the following characteristics:

- About 11,000 projects from the oil, chemical, pharmaceutical, consumer products, forest products, and minerals industries
- More than 350 companies represented
- Projects located in all regions of the world
- Average project started production design in 2000
- Database is detailed: up to 3,500 factors per project including technologies, cost and schedule history, team organisation, project definition practices, execution history, and operational performance after startup
- All parts of project cycle are covered, from R&D through operations
- All project types covered: greenfield to revamp
- Project sizes range from under US$100,000 to over US$5 billion
- Technical difficulty ranges from minimal to cutting edge
- New projects added constantly

### Normalisation of Project Costs

Project costs captured in the database are normalised to make "apples-to-apples" comparisons across different currencies and time periods. Projects' estimated and actual costs are converted to a single currency and adjusted to a single reference point in time. The adjustments are based on actual expenditure rates and historical currency exchange rates. IPA then adjusts all costs to a single reference point using published inflation rates. The escalation calculation uses different inflation rates for different cost categories. For example, major equipment has a different escalation rate than bulk materials; escalation is specific to each category of cost.

## STUDY DESIGN

This study was conducted using IPA's existing Process Plants Database of industry capital projects discussed in the previous section of this report. Using this database, we compiled a study database designed specifically to address the study objectives, developed different measures of productivity for each project in the sample, and then conducted detailed statistical analyses of the data testing hypotheses regarding differences in productivity and drivers of productivity. The specific steps followed were:

- Limit the sample of projects in the study database to:
  - Completed projects with actual project results
  - Projects authorised in 1998 or later
  - Projects located in the UK, Western Europe (Euroland) or US
  - Projects for which IPA has detailed cost and wage data
- Group projects according to process types and project types to minimise scope variations within each grouping.
- We then developed a Labour Productivity Index (LPI) value for each project in the dataset by comparing the number of hours needed to complete a project relative to the projects in the group of which the project is a member.
- We also then created a Labour Cost Index (LCI) by multiplying the LPI by the relative mean weighted hourly wage rate. Unlike the LPI, the LCI is very heavily influenced by currency fluctuations.
- We then statistically explored the differences in productivity between regions, to test hypotheses of drivers in productivity performance, and search for factors that may explain any observed differences in productivity performance.
- The last step in the research method is to summarise and document analysis, draw conclusions, report findings and make recommendations for improvements in productivity.

## STUDY DATABASE

### Total Study Database

Using the selection criteria discussed in the previous section, we developed a study database of completed projects that serves as the primary tool in this study. The final study database includes 1,011 completed capital projects from over 100 different owner organisations in the UK, US, and Continental Europe. All of the projects were authorised between 1998 and 2008 and the actual total of the projects is $3 million (US$ 2003) or greater.

**Figure 1**[8]

**Geographical Distribution of Projects**

| | |
|---|---|
| **United Kingdom** | **60** |
| Southern UK | 46 |
| Northern UK | 14 |
| **United States** | **692** |
| US Gulf Coast | 141 |
| **Continental Europe** | **259** |
| France | 67 |
| Germany | 65 |
| Netherlands | 59 |
| Other Europe | 68 |

Figure 1 above summarises the geographical distribution of the study sample. A majority of the projects are located in the US, but 30 percent of the projects are located in continental Europe or the UK. The 68 projects shown as Other Europe are located in Italy, Spain, and Ireland. The individual samples from these three countries were not large enough to support a country specific analysis. However, we have included these projects in the sample as part of a Continental Europe group.

[8] For this study the UK was divided into the Northern UK and Southern UK regions. For the purposes of this study Northern UK is defined as Yorkshire and Humber, Northwest England, Northeast England and Scotland and Southern UK is comprised of Wales, the Midlands and Southern England

**Figure 2**

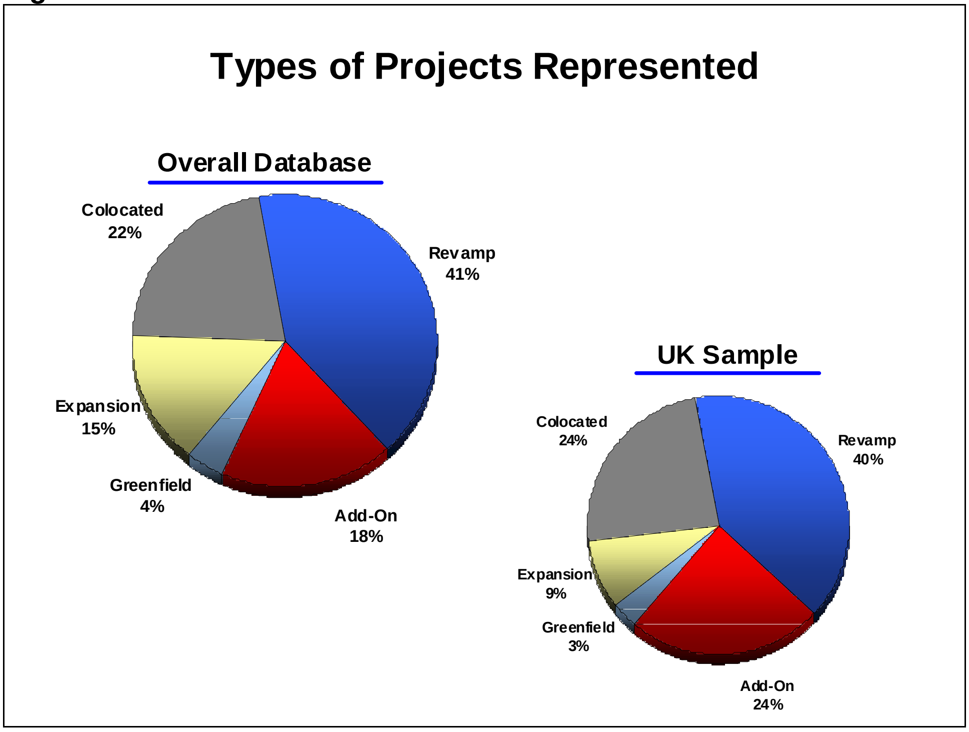



Figure 2 presents the types of projects included in the study sample. The distribution of projects executed within the UK is comparable to the overall study sample. The largest group of projects overall are "revamp" projects. These projects rebuild, refurbish, or debottleneck an existing operation. Revamps are particularly important in process industries in the US and Europe because relatively few new facilities are being constructed. Revamp projects are also more sensitive to good practices vis-à-vis labour than other types of projects. This is because revamps, by their nature, are constrained by the existing facilities.

Colocated projects make up the second largest group. These are projects located adjacent to an existing facility, but stand alone except for utilities and other infrastructure. Add-on projects are projects that add extra processing step(s) into or onto an existing processing facility. Expansion projects increase the capacity of an existing processing unit of the same type at the same site. Finally, greenfield projects are projects constructed on new, undeveloped sites.

**Figure 3**

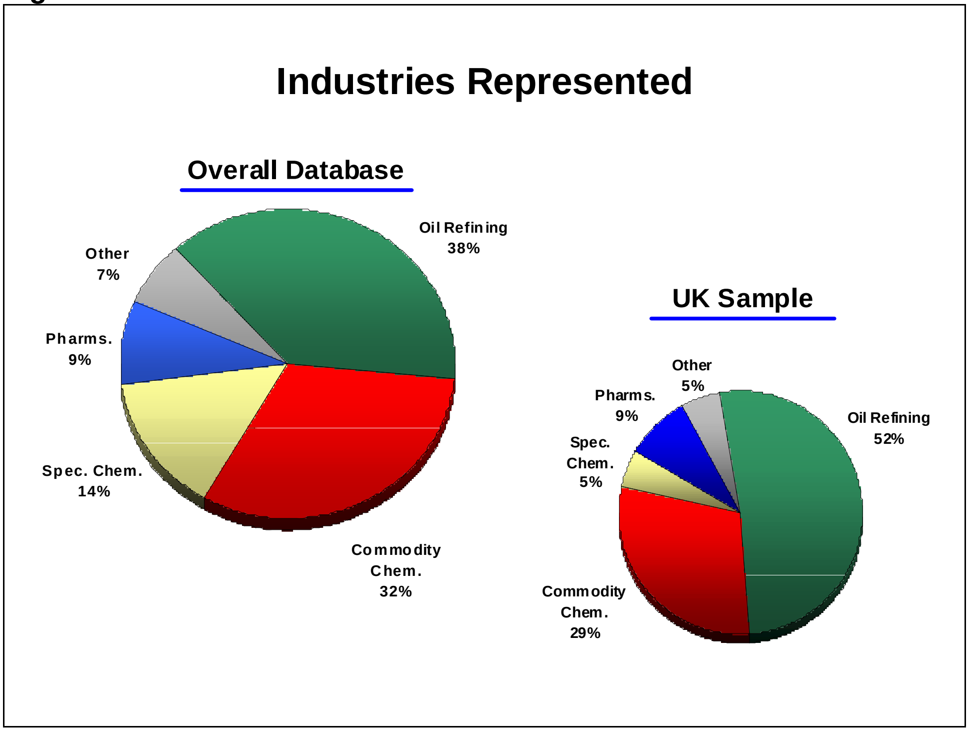



Figure 3 presents the industries represented in the study database along with the relative proportion. The industry with the largest sample is Oil Refining. These projects include core refinery projects such as vacuum towers, hydrotreaters, delayed cokers, and fluidized catalytic crackers (FCC). Commodity chemicals projects make up the second largest industry group in the study sample. These projects are focused on production of basic chemical products such as ethylene, polyethylene, and polypropylene. The next largest group is Specialty Chemical projects, which produce more specialised chemical compounds. The next group, Pharmaceuticals, includes projects for both primary and secondary pharmaceutical manufacturing. The last industry group is labelled "Other" and includes projects from diverse industries such as pulp and paper, steel or aluminium manufacturing, and mineral processing facilities.

**Figure 4**

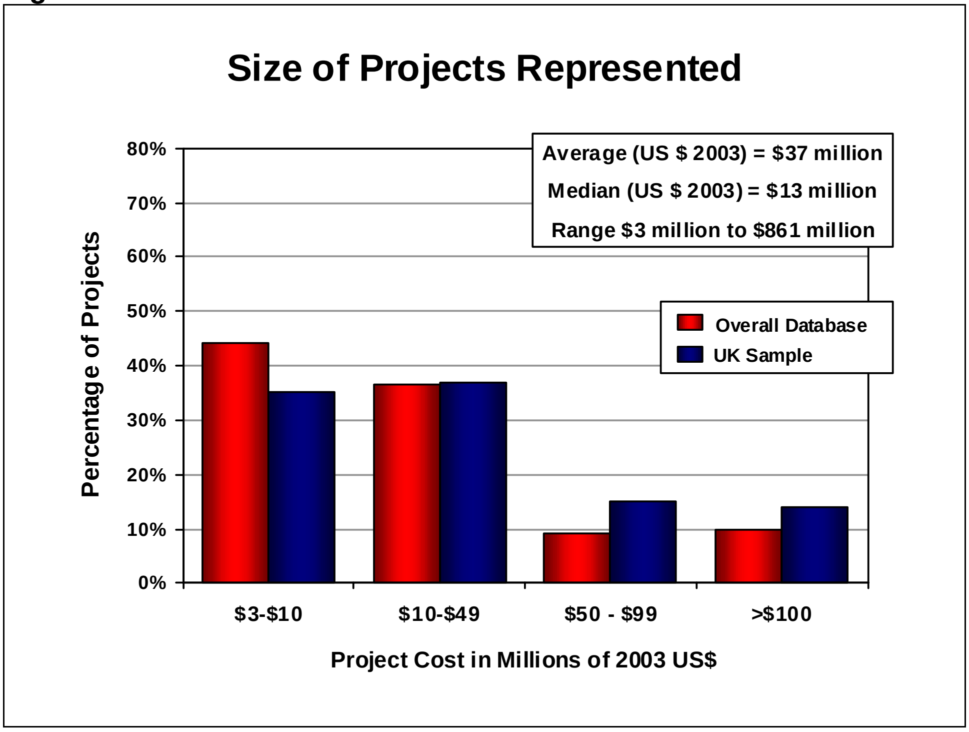



Figure 4 presents the size distribution of the projects in the study sample. The costs shown in the figure are anchored in US dollars normalised to 2003. As you would expect with any portfolio of capital projects, the largest group is smaller sized projects. The number of larger projects in the study group is less, but still significant. The box in the figure also reports the basic statistics regarding project size.

The study sample includes a wide range of recently completed projects from the countries of interest in this study. The projects represent a range of project types, industries, and project sizes. However, all projects in the study sample are engineering construction projects that involve the design and construction of process plants across a number of manufacturing sectors. The study sample does not include general building projects, heavy civil construction such as roads or bridges, or residential or commercial building construction.

## Sample of UK Projects

The 60 UK projects in the study sample are representative of the overall sample and provide a robust basis for comparison with the other regions. Twenty-three owner companies are represented in the UK sample along with 14 different primary contractor organisations and all contract types. Scores of subcontractors are represented. As shown above, the UK sample includes projects from most of the industries covered by the entire study sample. The average size of projects, $44 million (US$ 2003) is comparable to that of the overall study sample. In addition, the projects from the UK are well dispersed around the country with projects located in England, Wales, and Scotland. Finally, the composition of the UK sample in terms of project types is also comparable to that of the overall sample. Chemicals, petroleum refining, pharmaceuticals, and consumer products are included in the UK sample.

Confidentiality agreements with the companies that contribute to the IPA database prevent us from listing any details of individual projects. However, examples of UK based projects include:

- Coker furnace re-tubing
- Ultra low sulphur petrol unit
- Caustic waste handling facility
- Effluent treatment plant
- Benzene reduction modifications
- Fluidized catalytic cracker unit
- Crude blending
- Turbine condenser modules upgrade
- C3 reactor modifications
- Screening and bagging plant
- High pressure boiler
- Waste treatment plant
- High purity alcohol plant
- Ethylene expansion
- Acetate tow expansion
- Hydrogen recovery

## PROJECT GROUPINGS

We created groups of projects with very similar scopes: same process, same type of project (revamp, add-on, greenfield, etc.), and similar size of project to account for productivity differences associated with smaller projects. Each group provides a reasonable sample of like-for-like field work to be performed. We have excluded modular projects because a significant amount of engineering construction labour is completed offsite and labour costs are often grouped in a lump sum contract that includes materials and overhead. The in-ability to split these costs into the appropriate cost categories prevents us from accurately quantifying labour hours, which will distort productivity measures. Each grouping has a good geographical dispersion to avoid location bias.

In total, we created approximately 40 different subgroups of projects based on project scope and project type. This approach results in relatively homogeneous populations of projects that are then used as a basis to measure relative productivity across regions. Examples of the subgroups created include:

- Gas processing projects (separate groups for add-on/expansion, colocated, and revamp)
- Gas separation projects (separate groups for colocated and revamp)
- Bulk chemical/hydrocarbon processing liquids (separate groups for colocated, add-on/expansion, and revamps)
- Bulk chemical/hydrocarbon processing solids (separate groups for add-on/expansion, colocated, and revamp)
- Cracking
- Crude and Vacuum Distillation

- Primary pharmaceuticals (separate groups for add-on/expansion, colocated, and revamp)
- Hydrotreating (separate groups for add-on/expansion, colocated, revamp)
- Hydrogen Manufacturing (separate groups for colocated and revamp)
- Secondary Pharmaceutical
- Water treatment (separate groups for add-on/expansion and colocated
- Digital Control Systems

## PRODUCTIVITY INDICES

A critical step in the study was to develop different productivity measurements for each project that could then be used as dependent variables in the analysis phase. Table 1 is a summary of the two different productivity measurements generated per project.

**Table 1**
**Summary of the Three Different Productivity Measurements**

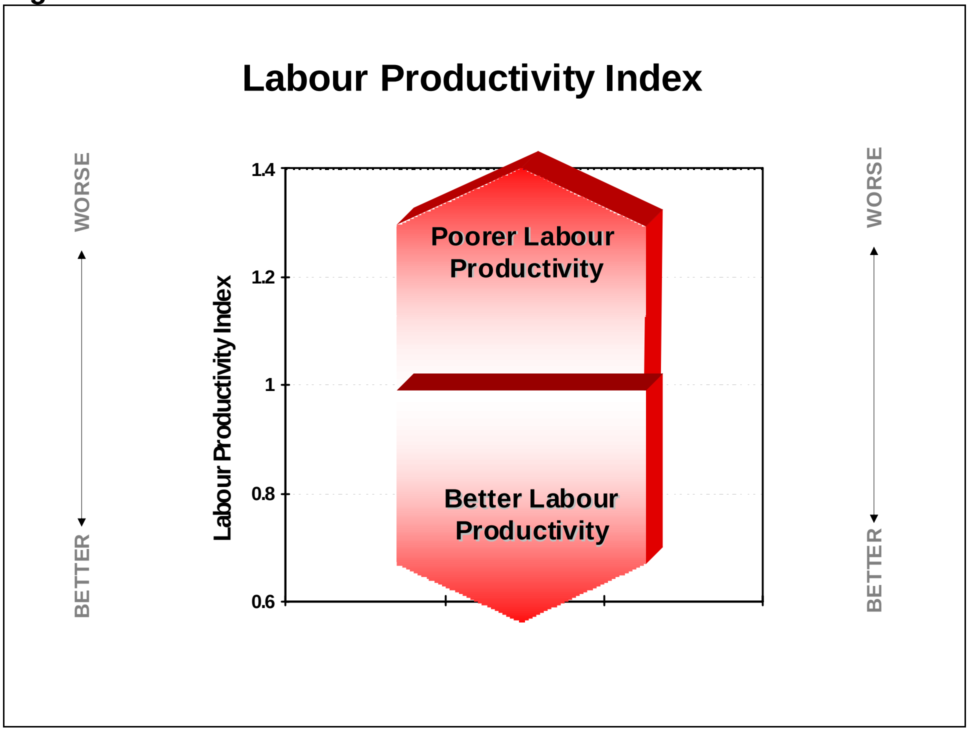
| Productivity Measure | Basic Ratio Equation | Characteristics |
|---|---|---|
| Labour Productivity Index | (Engineered Equipment Cost[9] / Total Field Labour Hours) / (Avg. [Equip. Cost / Field Labour Hours] of Subgroup) | Measure relative labour productivity to install a unit of major equipment |
| Labour Cost Index | (Labour Cost[10] / Engineered Equip. Cost) / (Average [Labour Cost/Engineered Equip. Cost] of Subgroup) | Measures relative effectiveness in terms of total labour cost to install a unit of major equipment |

- Labour Productivity Index – This index measures the relative labour hours to install a specific scope of work. The Productivity Index is created by adjusting the all-in wages to a constant US dollar basis and then calculating the ratio of total costs to total labour hours. As with the Labour Cost Index, we then build a non-dimensional index value by dividing each project's ratio by the average ratio for the anchor location (USGC) of comparable projects. This approach generates a Productivity Index that measures the relative number of hours required to install a common unit or scope of equipment.
- Labour Cost Index – The Labour Cost Index is a measure of the relative amount of money a project spent on field labour. The labour cost includes wages, benefits, small tools, subcontractor profits and fees and overtime premiums. The labour cost does not include major construction equipment, construction supervision or field engineering. However, we found no regional differences in the ratio of construction supervision costs relative to engineering construction labour. For the purposes of this analysis, we have normalised the data to a constant year and exchange rate to remove the effects of inflation. The Labour Cost Index throughout this report is based on the current exchange rate of both the Pound and the Euro relative to the US Dollar. The ratio of field labour costs is calculated for each project within a grouping of comparable projects. The index is then generated by taking each project's ratio of labour cost and dividing that by the

[9] Engineered Equipment Cost – The total cost of all engineered process equipment required to meet the given scope of work
[10] Labour Cost - The total cost of field labour to meet the given scope of work. Labour costs include all-in wages, benefits, small tools, subcontractor profits and fees and overtime premiums

average ratio for the anchor location (USGC). Since each project is indexed against comparable projects, the end result is a large sample of projects with index values showing the relative labour cost indices.

**Figure 5**




The LPI and LCI are non-dimensional index values that measure the relative labour productivity in terms of hours to complete a scope of work, compared with a common anchor location and total cost of craft labour respectively. In the case of this study, the common anchor location is the USGC. As shown in Figure 5, an index value greater than 1.0 indicates that the labour cost and/or productivity is worse (higher cost or more hours used) than the average for the anchor location. By contrast, a labour cost and/or productivity index that is less than 1.0 indicates that the labour productivity is better (lower cost or fewer hours used) than the average.

## ENGINEERING CONSTRUCTION LABOUR PRODUCTIVITY IN THE UNITED KINGDOM

The productivity of UK engineering construction projects in our sample is 11 percent poorer than our USGC, USA, base.[11] Almost a third of the UK sample had better than USGC productivity and about a third had productivity that was 35 percent worse than the USGC. The standard deviation around the mean UK productivity was ±30 percent.

Please recall that the USGC was selected as a "base location" simply for methodological reasons. The USGC has the highest concentration of complex process projects in the world. The USGC was not selected because productivity is particularly bad or good there. There are other places in the world and within the US with better average engineering construction labour productivity than the USGC. Due to the depth and breadth of our sample in the USGC, it is a stronger base location than any other. The methodology for calculating productivity is based on the careful matching of scopes. In other words, there is not a single USGC "base case" but rather a base case in the USGC area for each type of project represented in the sample of UK projects. For example, if one of the projects in the UK sample is the refurbishment and reworking of a petroleum refinery hydrotreater, it is compared against a set of very similar projects in terms of scope and size in the USGC area. This is possible because the density of engineering construction projects is so great there. Note also that our productivity results are not influenced by relative wage rates or currency exchange rates between the UK and other locations. That is because productivity is measured on an hours basis rather than a cost basis.[12]

The broad range of productivities found in the UK projects is important. Some projects enjoyed very productive labour whilst sharing the same general labour pool with those with significantly less enviable results. This situation and the factors discussed in the next section suggest that the issue is not so much the *labour* as the *management* of the project and its construction that accounts for the UK's relatively poor showing.

[11] US Gulf Coast (USGC) is defined as Greater Houston, Texas, USA area

[12] In a macro sense there is a relationship between productivity and wage rates. This effect, however, is seen in contrasting developed with less developed economies. Gross differences in education level and training will create differences in labour productivity. Although we do not have a direct measure of craft education and training between the UK and the US, our anecdotal view is that the differences are small. In general, union training programs in the US and the UK provide better trained labour than the usually non-union labour we find in the Greater Houston area.

Table 2 below compares the engineering construction labour productivity for complex projects in Europe and the USGC from a previous IPA study completed in 2002,[13] exploring engineering construction labour productivity in high wage regions, with our current findings.[14] With the exception of The Netherlands, productivity in Europe has been quite stable over a long period. Historically, The Netherlands has demonstrated excellent engineering construction labour productivity that was apparently eroded by a surge of work in the past several years.[15]

**Table 2**
**Labour Productivity Index for Engineering Construction Industry**

| Region | IPA Study 2002 Labour Productivity Index Relative to USGC | Current Labour Productivity Index Relative to USGC |
|---|---|---|
| Authorisation Year | 1972-2001 | 1998-2008 |
| United States (USGC)[16] | 1.00 | 1.00 |
| United Kingdom | 1.11 | 1.11 |
| France | 1.13 | 1.20 |
| Netherlands | 0.96 | 1.08 |
| Germany | 1.13 | 1.05 |
| Continental Europe | Not Applicable | 1.06 |

Engineering construction labour productivity of the UK versus the USGC has remained nearly constant over the past decade at least at about 10 to 12 percent less productive.[17] The UK relative productivity lags Western Europe by an average of about 5 percent. A 5 percent difference would generate a difference in project cost of 1 to 2 percent if wages are assumed to be the same. The difference is statistically significant at about one chance in ten. If we contrast only non-revamp projects, however, the difference widens to 11 percent and the statistical reliability of the result jumps to about 2 chances in 100 of being random. This difference is generated by the fact that revamp projects are being done poorly in both the UK and Western Europe relative to performance in the US. The relatively poor productivity performance on revamp projects is important because these are a crucial class of projects in the US and Europe, where most manufacturing facilities are older (and therefore in need of refurbishment) and relatively few new greenfield facilities are being constructed. The reasons for the difference are discussed in the next section. Within

[13] E. Merrow, K. Sonnhalter, and K.A. Brown, *Understanding Construction Labor Productivity in High Wage Countries,* IBC, March, 2002

[14] Recall that there is little point in comparing construction labour productivity in a first world country such as Britain with a less developed country (LCD) situation. Because labour is very inexpensive in most LDCs, labour is freely substituted for capital. Therefore, construction is considerably less aided by machinery and more work is likely to be done on site rather than in fabrication shops.

[15] IPA's 2002 study for the Industry Benchmarking Consortium Conference put the Netherlands at 0.96. E. Merrow, K. Sonnhalter, and K.A. Brown, *Understanding Construction Labor Productivity in High Wage Countries,* IBC, March, 2002

[16] The Labour Productivity Indices for the Continental United States vary greatly from region to region and range from 0.95 to 1.25.

[17] Labour productivity tends to change only very slowly over time in the developed economies. There is relatively little opportunity to substitute new machinery for construction labour in engineering construction projects and the other big driver of productivity, skill levels, change only slowly. In a thin labour market, a surge of construction work may result in precipitous losses of productivity during a boom period. This did not occur on the USGC during its recent boom, although construction wages increased very rapidly. The USGC labour market is very large and US labour is highly mobile. Booms in Alberta, Canada, and in the Rotterdam area, however, were associated with significant drops in construction labour productivity for process plant construction.

Western Europe, only France stands out as distinctly different in terms of engineering construction labour productivity. At 1.20, French engineering construction projects suffer the poorest engineering construction labour productivity. The Western European average, however, is not much affected by the results in France because the number of observations in France is a small portion of the Western European total.

## Engineering Construction Labour Cost

Engineering construction labour Productivity is, of course, only an input (albeit an important one) into effective labour cost, which is the primary concern of project sponsors. When we adjust the productivity by the weighted average hourly wage paid, the comparative labour cost picture emerges in Table 3 below.

**Table 3**

| Region | Effective Labour Cost[18] | Relative Productivity |
|---|---|---|
| United States (USGC) | 1.00 | 1.00 |
| United Kingdom | 0.99 | 1.11 |
| France | 1.09 | 1.20 |
| Netherlands | 1.04 | 1.08 |
| Germany | 1.07 | 1.05 |
| Continental Europe | 1.05 | 1.06 |

The first thing to note is that lower average wages eliminate all of the productivity disadvantage of the UK versus the USGC and Europe *at current exchange rates (*Exchange rates as of July 10, 2009 1 USD = 0.72 € - 1 USD = 0.62 £). Note also that the variability in effective labour cost is considerably less than the variation in productivity. This is exactly what one would expect from an economic perspective in regions that are to any significant degree economically coupled. For example, if wages paid on the French projects were as high as those on the German projects, France would be such an expensive location within Europe that no rational company would choose to locate plant there unless absolutely essential. This is merely market mechanisms at work.

The convergence of the UK and USGC effective labour cost is the result of rapid increases in the craft wage rates in the US industry during the post Hurricane Katrina period. This convergence is important for owners when they are making decisions about siting facilities in the US or UK. This convergence is also heavily influenced by the current exchange rate between the pound and the dollar. Similarly, the relatively low current value of the pound versus the euro makes the UK quite competitive in terms of effective construction labour cost with Euroland.

## The Averages Can Mislead

If the average national productivities faithfully represented most projects, there would be little controversy surrounding engineering construction labour productivity. While there are differences, the differences are not so large as to drive most siting decisions. The real problem—and the source of much of the controversy—is the large project-to-project variability in engineering construction labour productivity. The variability in engineering construction labour productivity overall and within every region considered in this study is

[18] Based on the exchange rates as of July 10, 2009 1 USD = 0.72 € - 1 USD = 0.62 £

***±30 percent on a single standard deviation***. This variability by project overwhelms the variability by nation or region.

The project-to-project variability is frequently and inappropriately ascribed to the nature of the labour force or other location-related issue such as work rules, “work ethic”, etc. Without doubting the possibility of such things being influential in some cases, the fact that the variability is project-related rather than related to region or nationality strongly suggests that the variability is driven by the individual practices employed on the project rather than factor related to the locale.

Whilst evaluating more than 11,000 completed projects, IPA has noted a tendency to mis-attribute engineering construction labour productivity problems on a given project to labour union practices, work ethic of the labour pool, national or union work rules, regulations, and the like. This tendency is understandable. If an owner and their contractors on a project experience very poor productivity, it is unlikely that they will jump to attribute it to their own incompetence. By contrast owners and contractors on projects that experience brilliant productivity rarely ascribe it to the labour involved but rather to their excellent preparation of the project and fine management of the labour. One needs to recall that this is not just cynicism at work. Contractors who can be shown to have mismanaged projects are often liable financially. Owner project managers have their careers at stake.

## UNDERSTANDING ENGINEERING CONSTRUCTION LABOUR PRODUCTIVITY IN THE UNITED KINGDOM

As we saw in the previous section, labour productivity for engineering construction projects in the UK lags the USGC and Western Europe as a whole, although appreciably better than that in France. We also saw that at current exchange rates, the lower wage in the UK more than offset that liability. But that still begs the question of why UK engineering construction labour productivity should be lower at all, especially against the USGC where the difference is quite sizeable. The main factors influencing productivity are skills, innovation, competition, investment and enterprise.[19] These and a wide range of sub-factors which could potentially affect productivity have been considered. Only some of these can be adequately analysed with the data available. For example, there is little that can be concluded about the skill levels of craft workers because the survey methodology does not test this in detail. Others that could not be tested with the data available or were tested and have shown no significant correlation are outlined in the Annex of this report. Our analysis does, however, reveal a number of factors which significantly affect productivity and these are discussed in detail in the following sections.

In this section we will discuss the following practices:

***Front-End Activities***

- Owner team building activities
- Project execution planning and scheduling
- The schedule strategy, especially the amount of design completed when field work begins

***Execution Activities***

- The project controls strategy, including over-reliance on contractors for controls
- The amount of construction supervision provided
- Difficulties with the use of “travellers”
- Contracting strategy and contractor selection criteria
- The appropriate involvement of craft in pre-task planning

These eight practices have two things in common: (1) they are important to engineering construction labour productivity, and (2) they are significantly different in the UK projects versus those done on the USGC. They sometimes differ from European practice as well.

## FRONT-END ACTIVITIES

By “front-end” we mean the period of preparation for projects up to full-funds sanction. The quality and thoroughness of these early activities, which we call “front-end loading” (FEL), are the best predictors of all major project outcomes: construction safety, cost effectiveness, cost growth, schedule effectiveness, and schedule slip. But even before FEL, comes putting the owner team together to prepare the project.

[19]UK Government document: http://www.hm-treasury.gov.uk/d/bud06_productivity_513.pdf

**Team Development** starts with ensuring that all of the necessary owner competencies are on the owner team during FEL. We call this "team integration." There are substantial differences in the rate of team integration between the UK and other regions:

- UK 55 percent (of teams)
- W. Europe 69 percent
- USGC 78 percent

When key owner competencies are not present on the team during FEL, the quality of the FEL work is degraded. But not all competencies are equally important for engineering construction labour productivity. Most important are operations representation and the owner construction manager. When the operations representative is not present, operations will often force changes to be made to accommodate their requirements when the project is in construction. Changes during construction disrupt the construction sequencing and result is markedly decreased engineering construction labour productivity. When the construction manager is not present on the team, the value of constructability reviews—one of the most important practices to drive a smooth field—is almost completely negated. Unfortunately, the two positions that are most likely to be absent when UK teams are not integrated are construction management and operations. This is unlike Europe and the USGC, where business representation is the most commonly missing element.

When we modelled UK engineering construction labour productivity statistically, we find that missing owner functions, that is, the failure to integrate the owner team, is the most important single driver of engineering construction labour productivity in the UK even after controlling for all other statistically relevant factors.[20] These factors include:

- Project execution planning
- Use of resource loaded schedules
- Owner developed project control plan
- Owner validated estimate
- Comprehensive physical progressing
- Overlap of engineering and construction activities
- Use of travellers

It is very important to understand that the owner team members do not substitute for the contractors' personnel. The contractor cannot supply some of the key functions, such as operations and maintenance representation, and cannot supply others early enough in the project development cycle to be of maximum utility. For example, the owner construction manager is needed early in the definition period to review the Basis of Design and confirm that it is constructible at the particular site. The owner construction manager, who should know the owner's site fully, is in a position to rectify problems with the proposed plot plans and equipment arrangements when they are preliminary, rather than when detailed engineering is underway, or worse still, when construction has already begun. The frequency of missing personnel on owner teams in the UK suggests very strongly that UK owners have lost fundamental project competencies, perhaps in the mistaken belief that contractor personnel are adequate substitutes.

[20] In the regression model, the t-ratio for team integration is 3.92, which is significant at 0.001.

Although there is no one universal approach, design contractors are involved in the FEL phase of most engineering and construction capital projects. A typical example is to contract with a design contractor on a reimbursable basis to assist with the project definition. It is during this phase when it is critical to have appropriate participation of both the client and the contractor. In many cases, the contractor is then contracted to continue with detailed design after the project is authorised. This second contract may be reimbursable or lump-sum and it may include procurement and construction, or it may be design only. But in other cases, after completing project definition, the client will then award the detailed design (often with procurement and construction) to a different contractor. There are many variations in terms of contracting strategies and types, but most projects have active support of design contractors during the project definition phase prior to authorisation.

**Execution Planning and Scheduling**

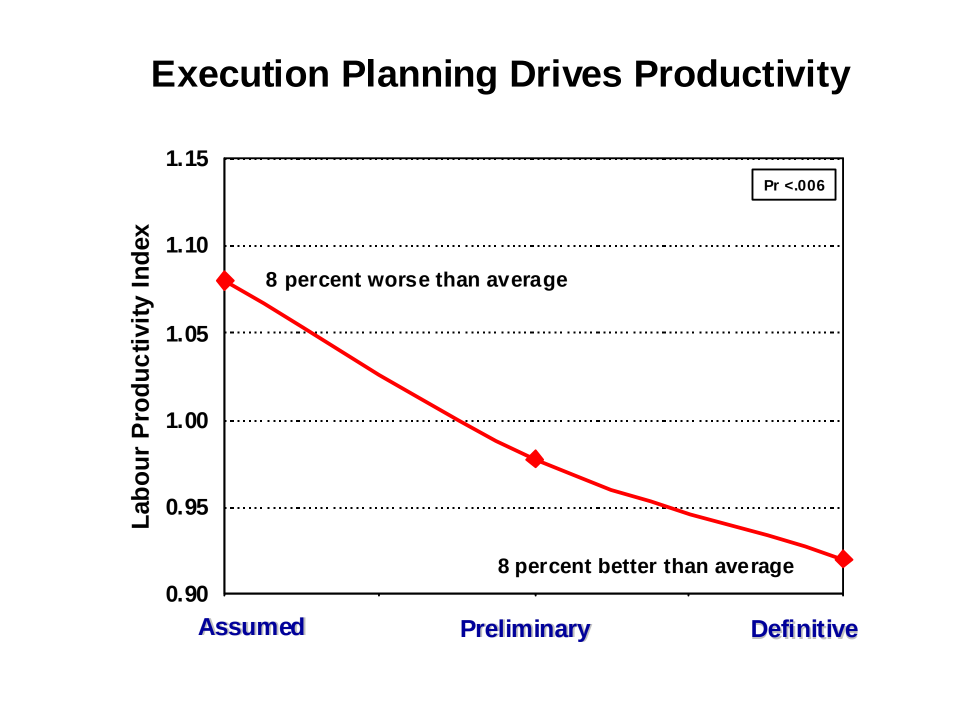
We measure the quality and completeness of FEL with a numerical index. The FEL Index is composed of three equally weighted factors. The first of the three factors is broken down further into four equally weighted subfactors:

1. The completeness of work on a set of site-specific items
    - Plot plans and unit configurations
    - Soils and hydrology work
    - Site-specific environmental regulatory requirements[21]
    - Site-specific health and safety requirements
2. The status of project engineering for the facility
3. The status of project execution planning

The overall FEL Index is obtained by a weighted aggregation of the factors and their components. The UK projects slightly lag the USGC projects in every category of FEL. The area of FEL that is an especially strong driver of engineering construction labour productivity is execution planning, which includes the scheduling. Figure 6[22] below shows the relationship between execution planning and engineering construction labour productivity. Achieving definitive execution planning is a key element of a labour-effective project.

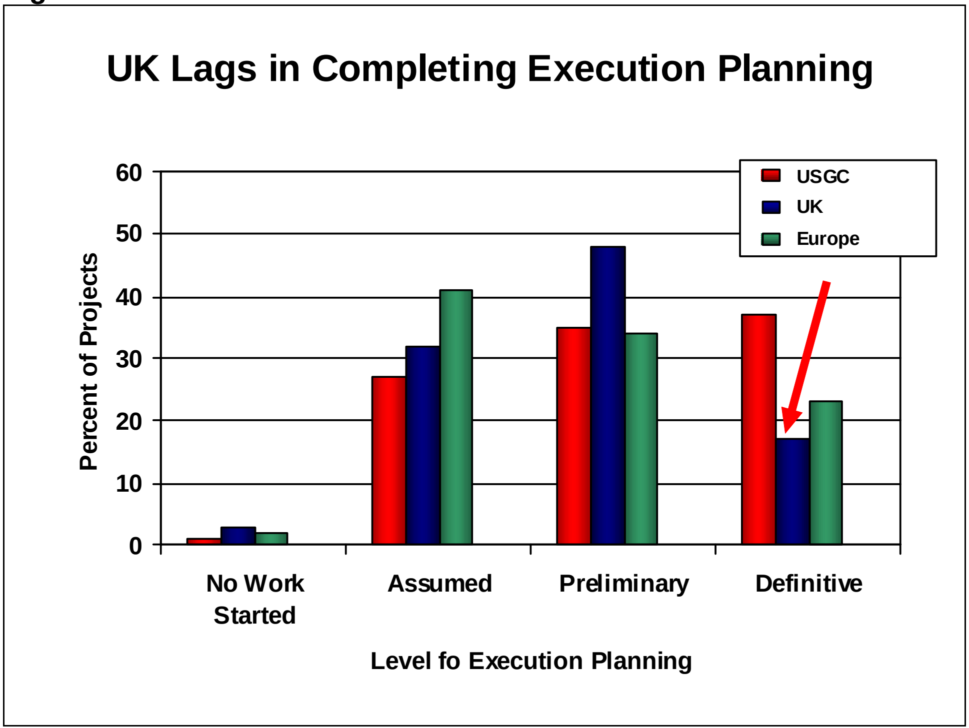
[21] A surprising 34 percent of UK projects had not yet applied for their environmental permits when the project was sanctioned. These projects had markedly poorer productivity. By contrast 87 percent of USGC projects had completed all environmental permit applications prior to sanction.
[22] Significance determined by ordinary least squares regression

**Figure 6**




Unfortunately, projects in the UK are typically not achieving best practice in execution planning, as shown in Figure 7. Whilst 38 percent of the USGC sample is achieving Definitive execution planning prior to sanction, only 16 percent of UK projects achieve it.

**Figure 7**




The bit of execution planning that is most telling for engineering construction labour productivity is the depth of the schedule for the project**. Milestone schedules** are very high level Gantt charts that sketch out the expected durations of major activities, such as procurement, detailed engineering, and construction.[23] Milestone schedules involve little detailed analysis and virtually no analysis of construction activities. Generally, only small projects are sanctioned with milestone schedules. **Critical-Path Schedules** add a very important level of detail and analysis to the schedules: an analysis of the items that should ultimately determine, at a minimum, how long the project will require to complete. The critical-path activities are those that, should they slip, the entire project will slip accordingly. While critical-path schedules are a major improvement over milestone schedules, they tell us little or nothing about the construction labour requirements.

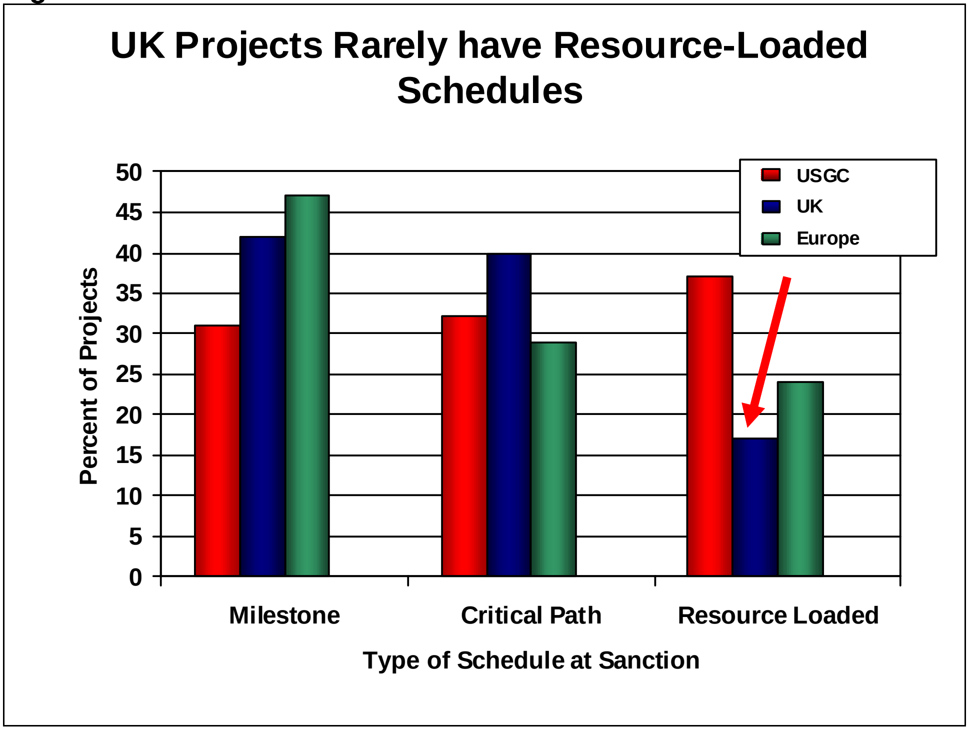
To achieve an understanding of the labour requirements for a project and therefore prepare to manage that level of staffing, a **Resource-Loaded Schedule** is essential. A resource-loaded schedule breaks the engineering and construction activities into discrete tasks, estimates the duration of the tasks, estimates the number of people required to complete the tasks and their required skill sets, and then networks (connects) the tasks into a comprehensive schedule for the project. The resource loading has a number of features that support engineering construction productivity:

- A realistic picture develops of when engineering deliverables will be available for fabrication and construction activities. This is essential to knowing when it is appropriate to start construction activities.
- The resource-loaded schedule enables planning by craft in time. This means that a profile of labour requirements can be developed and then used to address whether the needed numbers of craft can be secured. If not, then the schedule will have to be relaxed or additional resources secured.
- The resource-loaded schedule enables intelligent cost/schedule tradeoffs to be made. If accelerating the schedule beyond a given point will increase the peak labour requirements sharply, the project will pay a very high cost penalty for the acceleration.

Figure 8 below shows how badly UK projects lag others in completing resource-loaded schedules prior to sanction. Fewer than 20 percent of UK projects completed a resource-loaded schedule as part of FEL activities. Even on large projects—those over $40 million—UK projects were resource loaded only a third of the time at sanction. This constitutes a competitive disadvantage.

[23] There is no compositional bias in this comparison

**Figure 8**




### The Schedule Strategy

One of the most important drivers of engineering construction labour productivity and effectiveness is the timeliness and quality of detailed design. The types of projects explored in this study are quite engineering-intensive. The construction tasks depend on the engineering to be completed far enough in advance so that all materials will be available in the right size and quantity and available for installation and so that the construction can be planned at the construction task level. Therefore, the time scheduled between the start of detailed engineering and the start of construction, measured by installation of first foundations, is crucially important to engineering construction labour productivity. UK engineering construction projects are starting construction significantly earlier than projects in the USGC and Europe as a matter of plan.

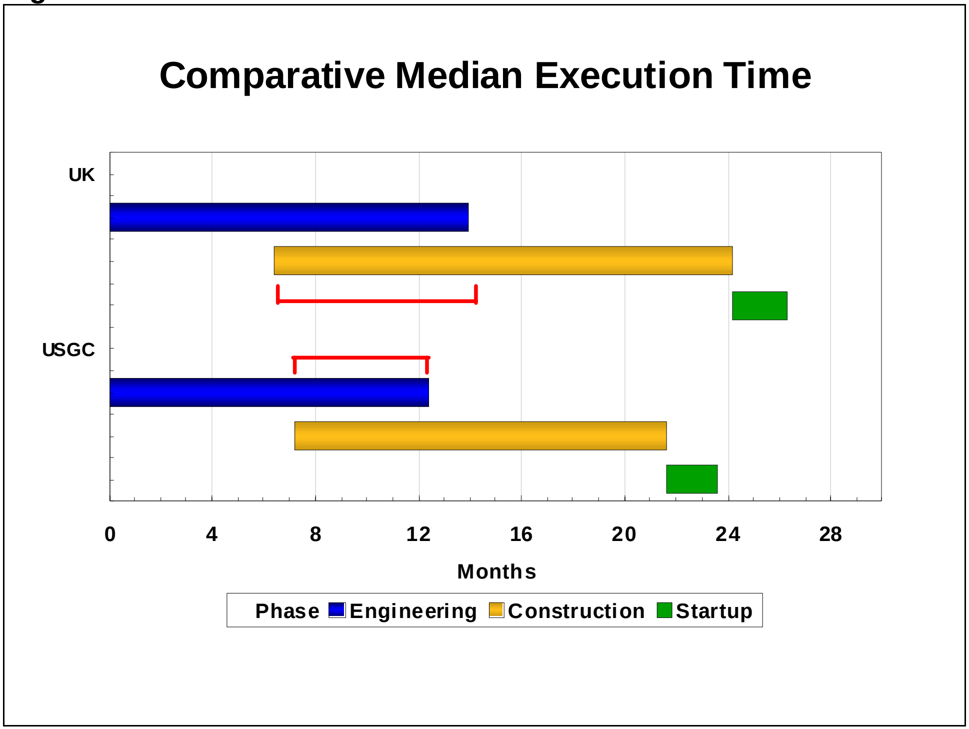
The chart on the following page in Figure 9 shows the average UK project schedule versus that of a similarly sized USGC project ($45 million in 2003 terms). The graph shows three primary phases of the execution phase: detailed engineering, construction, and startup. Detailed engineering begins with the start of production detailed design work and ends when the last construction drawings are released to the field. Construction begins with first foundations work (excluding site preparation and piling programs) and ends with mechanical completion. Startup begins with mechanical completion and ends when the facility is in steady-state operations (not necessarily reaching nameplate capacity). The bottom scale shows the number of months starting with detailed engineering work. Remember, detailed engineering work typically begins near the end of FEL and often coincides with the formal authorisation of the project.

First, notice that the UK engineering times are longer. This is a function of slip, not plan. The UK projects have a median slip in engineering of 25 percent versus 14 percent for the USGC projects.[24] Second, notice that start of construction is earlier on for the UK

[24] We report the median here because the average UK engineering slip is a stunning 48 percent. Because the distribution is skewed, we report the median where half of the projects are less and half more.

projects than the USGC projects. Normally, a large overlap in project stages is a product of the urgency of completing the project. But the great majority of the UK projects are *not* schedule-driven. Only 22 percent of the UK projects reported schedule as being top priority, about half the number in the USGC. We are at a loss to understand why the engineering contractors, who are clearly setting the project schedules, are deliberately increasing the overlap of engineering and construction, particularly in light of their track record of suffering significant slip in the production of engineering deliverables. The result is unmistakable: UK projects are attempting to progress construction with too little engineering completed and are suffering productivity losses as a result. Unless this peculiarity is corrected, it will be very difficult to improve engineering construction productivity on these projects.

**Figure 9**




## EXECUTION PHASE PRACTICES

In this section, we explore the key execution phase drivers that demonstrate a significant relationship with project outcome performance for their relative impact on Labour Cost and Productivity. Each driver is described, and the findings for that driver relative to engineering construction labour productivity and cost are presented. We start with project controls and then move on to construction supervision, the use of travellers, and finally construction strategy and contractor selection.

### Project Controls

The IPA Project Controls Index (PCI) measures the set of practices by which a project team plans to manage and then actually does manage cost and schedule performance during engineering and construction. The objective of project control is to establish and maintain a disciplined approach to managing work activities during execution so that planned project outcomes are achieved. Project controls involve establishing a cost and schedule baselines as part of FEL that are sufficiently detailed that actual progress in execution can be accurately measured against the baseline figures. Deviations from plan can be noted quickly and corrective action can be taken.

During FEL, project control focuses on establishing a cost estimate and schedule that are suitable not only as a basis for project decisions, but also as a basis for control of project work activities. A strong control basis supports the achievement of *Best Practical* FEL. During project execution, project control focuses on measurement and reporting of progress, forecasting, and change management. The PCI quantifies the strength of the planned or actual project control practices.

In a project completion analysis, measures of the actual practices used during execution are substituted for what was planned during FEL. Planning without follow-through during execution will not result in the project outcomes desired. Table 4 shows the components of the PCI for completion analyses.

**Table 4**
**Components of the Project Control Index for Postauthorisation or Closeout Analyses**

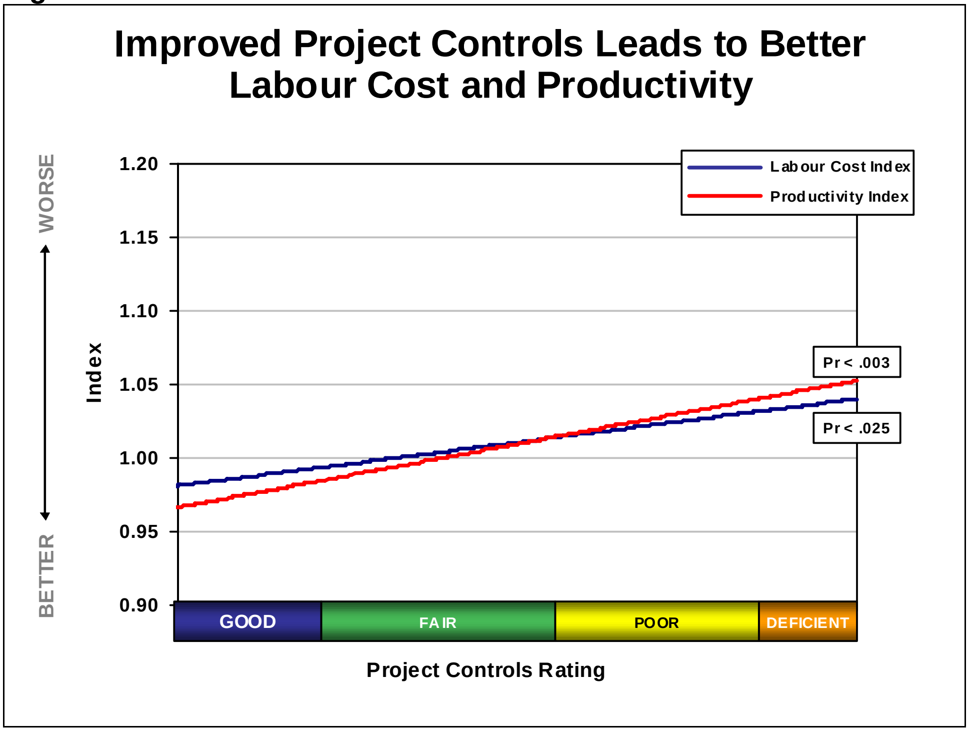
| PCI Component | Elements of Project Control |
|---|---|
| **Estimating for Control** | Estimating and Scheduling Methodology<br>• Definiteness of estimating methods (including contingency estimate)<br>• Level of detail for each cost category (including owner costs)<br>• Degree of cost and schedule integration<br>Estimate Validation and Review Process<br>• Extent of estimate review and quantitative validation<br>• Owner cost knowledge brought to review and validation practices |
| **Control During Execution** | Measurement of Progress<br>• Extent that physical progressing was performed<br>• Level of detail of measurements for each cost category<br>Reporting of Progress and Status<br>• Frequency that project progress and status were reported<br>• Level of detail of progress reporting for each cost category<br>Owner Participation in Project Control<br>• Involvement of owner project control specialists<br>Collection of Cost and Schedule Data at Closeout<br>• Extent and level of detail of historical database to support planning |

The PCI is rated at four levels: *Good, Fair, Poor,* and *Deficient*. A *Good* rating indicates that all of the elements for effective project control are in place or were used with fairly robust methods, detail, and so on. A *Fair* rating indicates that one or more of the elements is not in place or was not used or that the methods and detail employed were not robust. A *Poor* rating indicates that several of the elements for effective project control are missing or were not used. A *Deficient* rating indicates that the elements for effective project control are not in place or were not used.

As shown in Figure 10,[25] the PCI is positively correlated with both engineering construction labour productivity and cost realised by projects included in this study. As controls improve, effective corrective action to maintain plans in the field improves as well.

[25] Significance determined by ordinary least squares regression

**Figure 10**




Two of the factors that we explore in estimating for control addresses who is responsible for validating the estimate and who is responsible for controlling the estimate during execution. Figure 11[26] and Figure 12[27] clearly show that when owner personnel are assigned to these two functions, there is a marked improvement in the labour cost. Validation of the estimate by owner personnel provides for a realistic basis of control, whereas use of an owner cost control specialist not only ensures the project is spending as planned but also provides for another measurement of project progress.

[26] Significance determined by t-test
[27] Significance determined by t-test

Figure 11

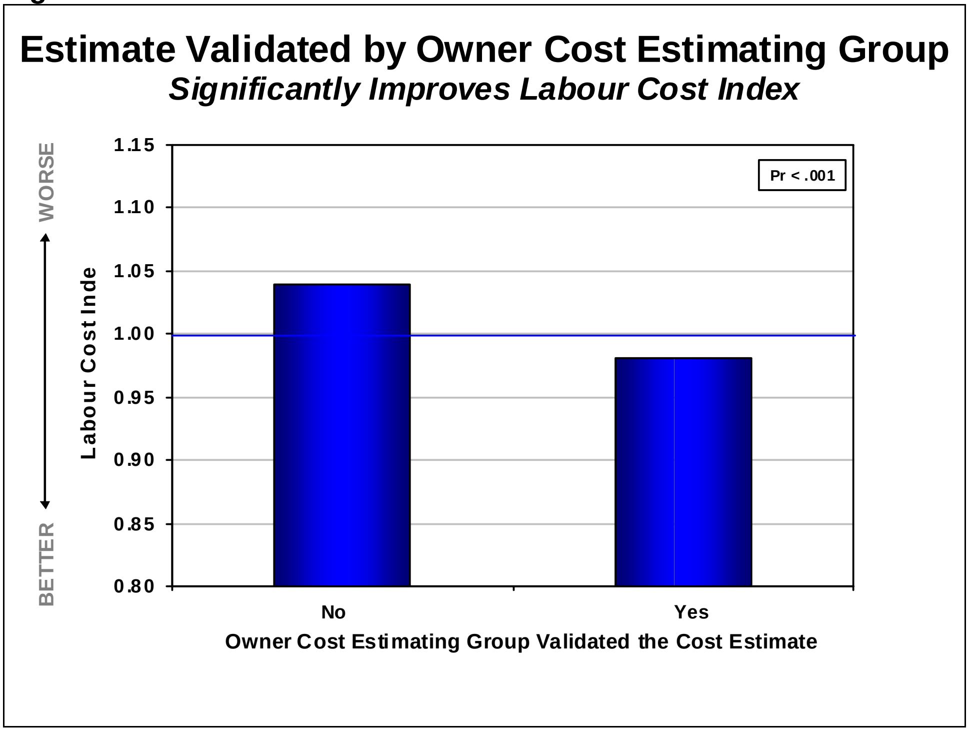
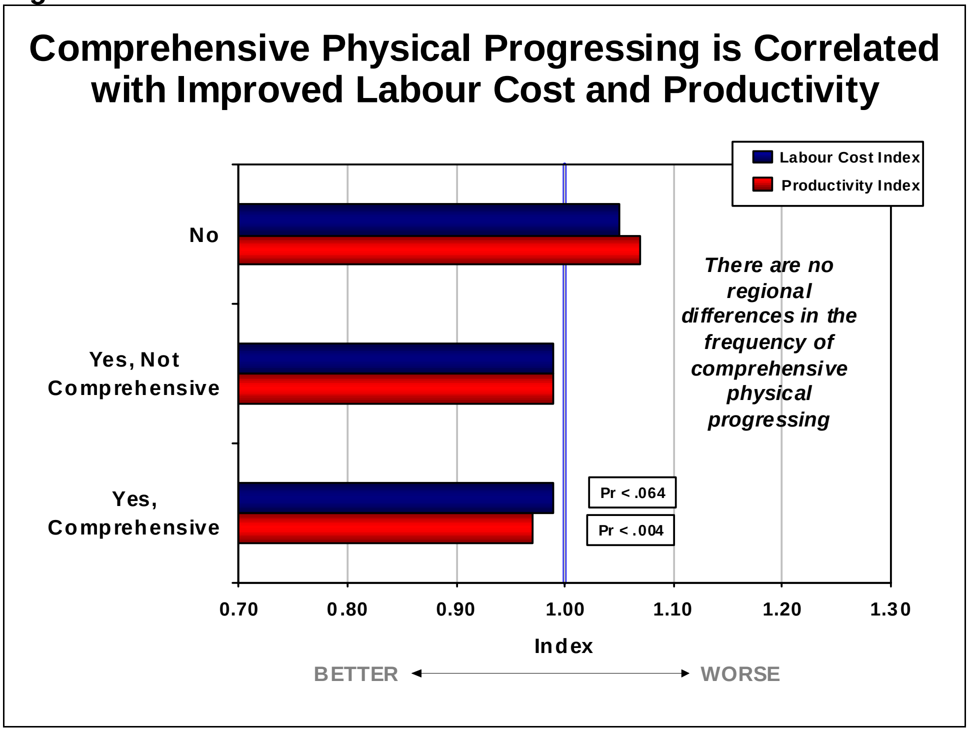



Figure 12


There is no statistical difference regionally in use of owner personnel to complete estimate validation and cost control. However, projects executed in the UK use owner control specialists on 57 percent of their projects, whereas projects executed on the USGC use an owner specialist on 77 percent of projects.

Control during execution is most commonly measured using some form of physical progressing. As depicted in Figure 13,[28] physical progressing is a component of the PCI that most strongly correlates directly with improved engineering construction labour productivity and cost.

**Figure 13**



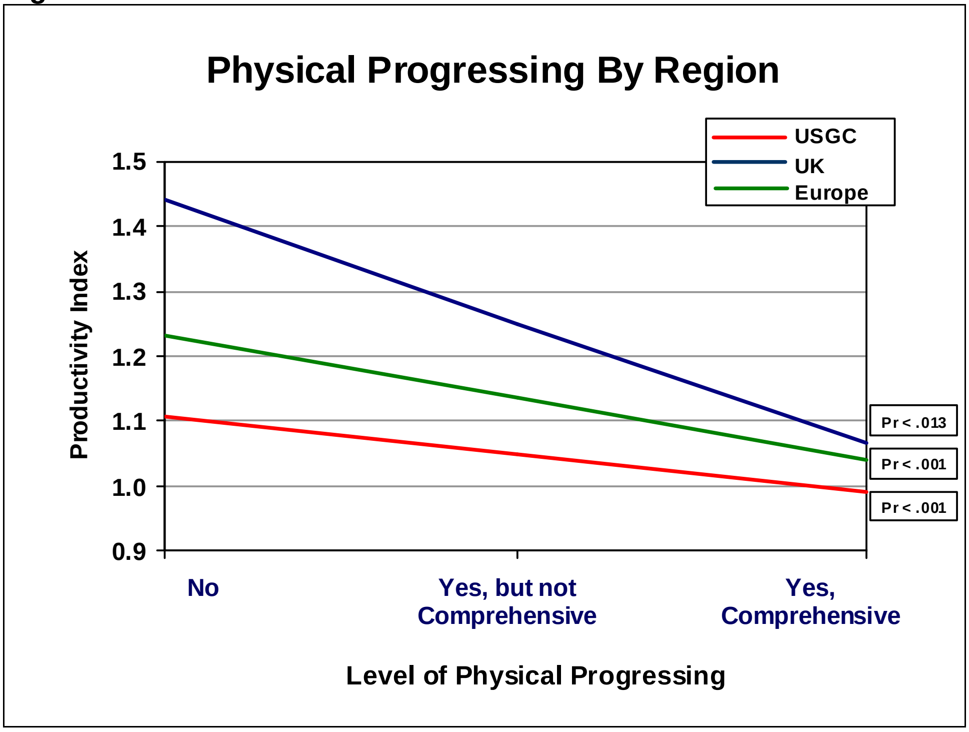

Although there are no differences in the rate of use of physical progressing between the UK and other regions, there is a very significant difference of *effect* of physical progressing,[29] especially on revamp projects, however our data lacks the detail to suggest the reason for the failure to monitor field progress more regularly in the UK. Referring to the graph on the following page in Figure 14,[30] on the USGC, the difference in productivity between no physical progressing, some, and comprehensive is about 6 percent improvement from category to category. Amongst the UK revamps, however, the improvement is 19 percent! Recall that UK revamps were quite poor in terms of engineering construction labour productivity. The failure to monitor the field progress of these revamp projects appears to be the primary reason for the significant problems. This result is very robust statistically. The pattern for Europe, which also suffers difficulties with the revamp projects, is 9 percent improvement per category.

[28] Significance determined by ordinary least squares regression

[29] Physical progressing is a method to measure the completion of work progress. Physical progressing is typically completed by assigning a weighted value to an activity or group of activities associated with some physical item or event. The measure of the degree of completion is achieved by counting items, quantities or events. The overall progress is determined by summing up the achieved or "earned" value for each item or event. The total physical progress complete is calculated by dividing the earned sum by the total value of all items to determine the percent complete.

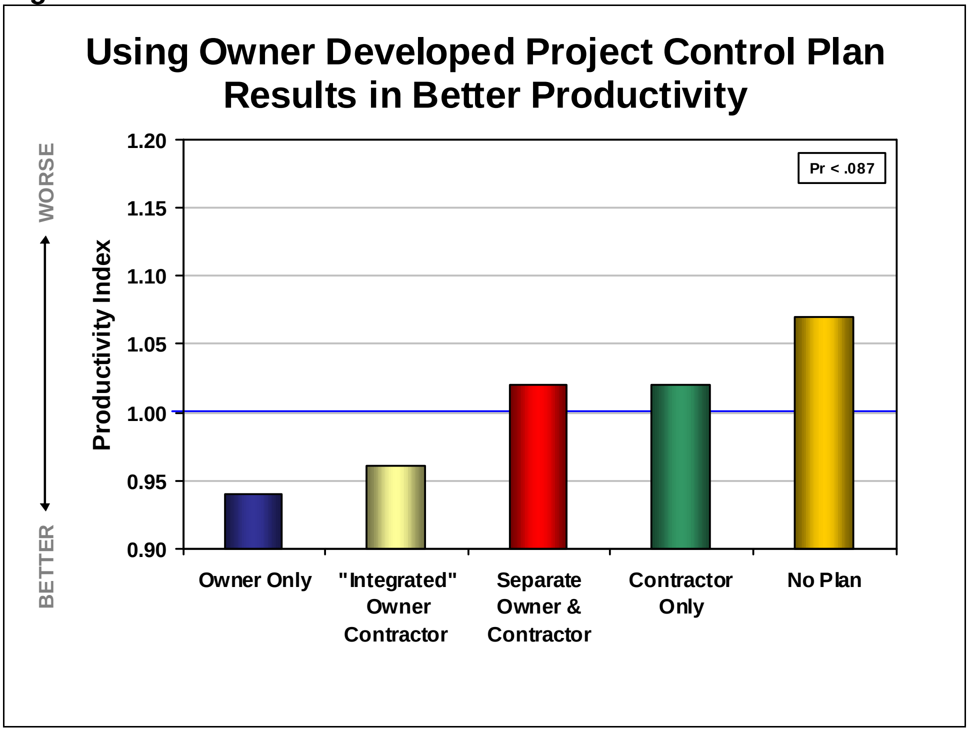
[30] Significance determined by ordinary least squares regression

**Figure 14**




In addition to physical progressing, the type of project control plan employed on a project can influence the productivity realised. Use of the owner control plan is correlated with better than industry average productivity, as indicated in Figure 15,[31] whereas, use of separate owner and contractor, or solely contractor control plans degrades productivity performance.

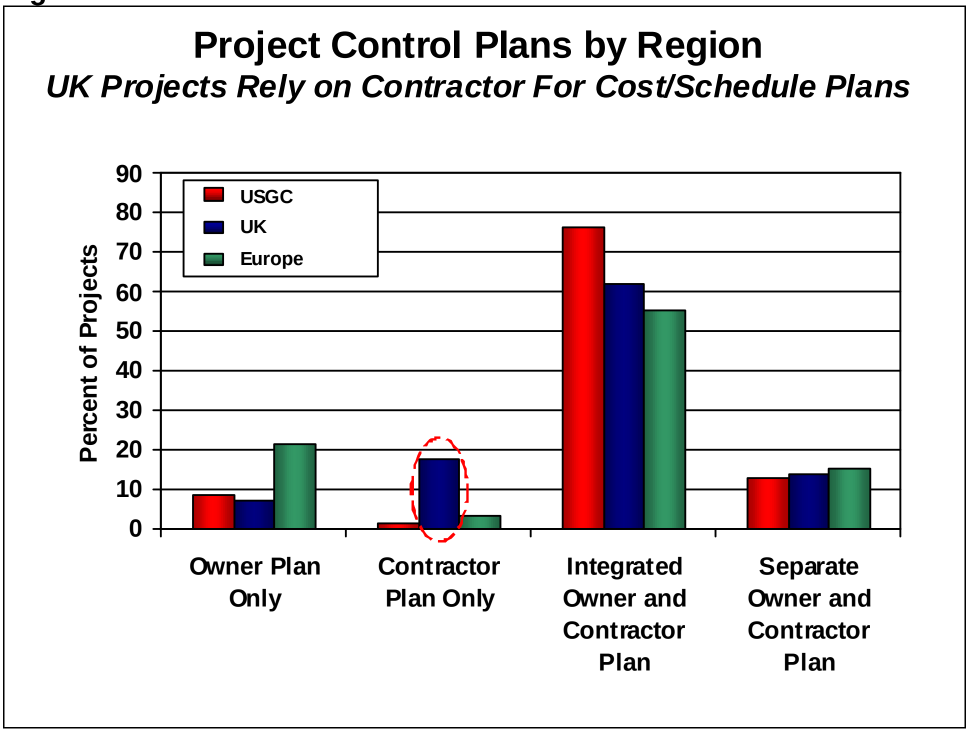
**Figure 15**




31 Significance determined by ordinary least squares regression

Previous IPA research has shown that when a project attempts to use separate owner and contractor plans, there is no clear control plan in place. As a result, the project experiences delays while disputes wait for resolution and the project works to determine whose plan takes precedence. Similarly, while a project may choose to use a contractor control plan at the time of sanction, the owner never fully hands over all risk to the contractor and therefore again introduces delays. Projects executed in the UK more frequently rely on contractor project control plans more than any other region.

**Figure 16**

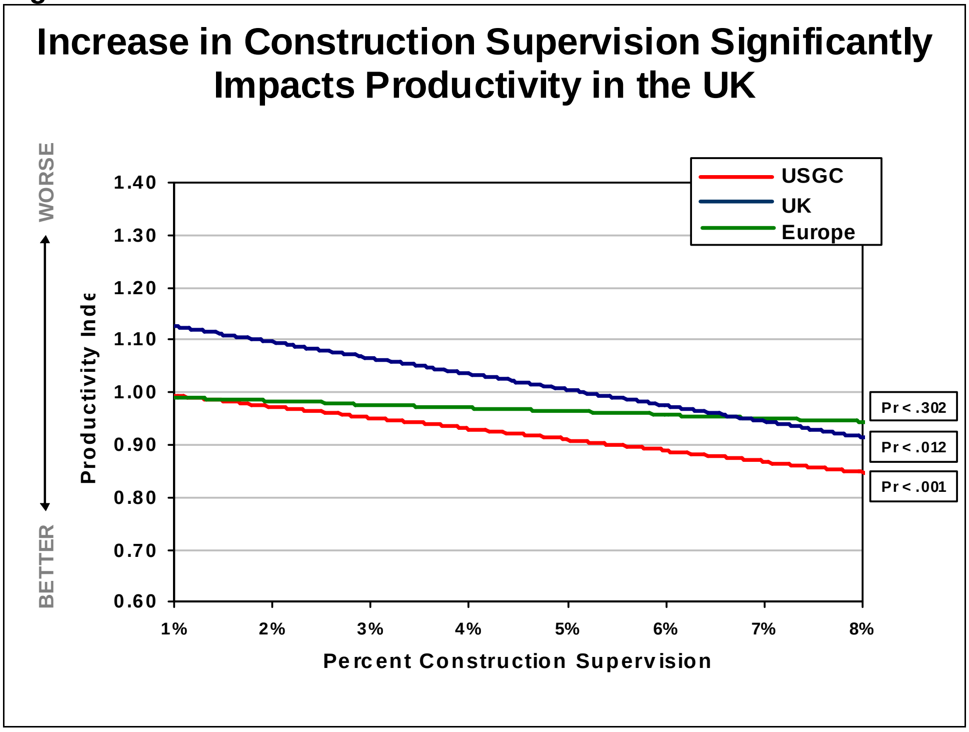



## Construction Supervision

In general, engineering construction labour productivity improves as more construction supervision is provided. The added supervision has the effect of reducing the construction gang sizes and is usually associated with better defined construction packages to be executed. The effects of added construction supervision are far from uniform across regions. Figure 17[32] below shows clearly how much more important construction supervision is to productivity in the UK versus the USGC or Western Europe. We do not fully understand the reasons for the differences, but they are large enough to strongly suggest that additional research would be fruitful.

[32] Significance determined by ordinary least squares regression

**Figure 17**




## The Use of Travellers

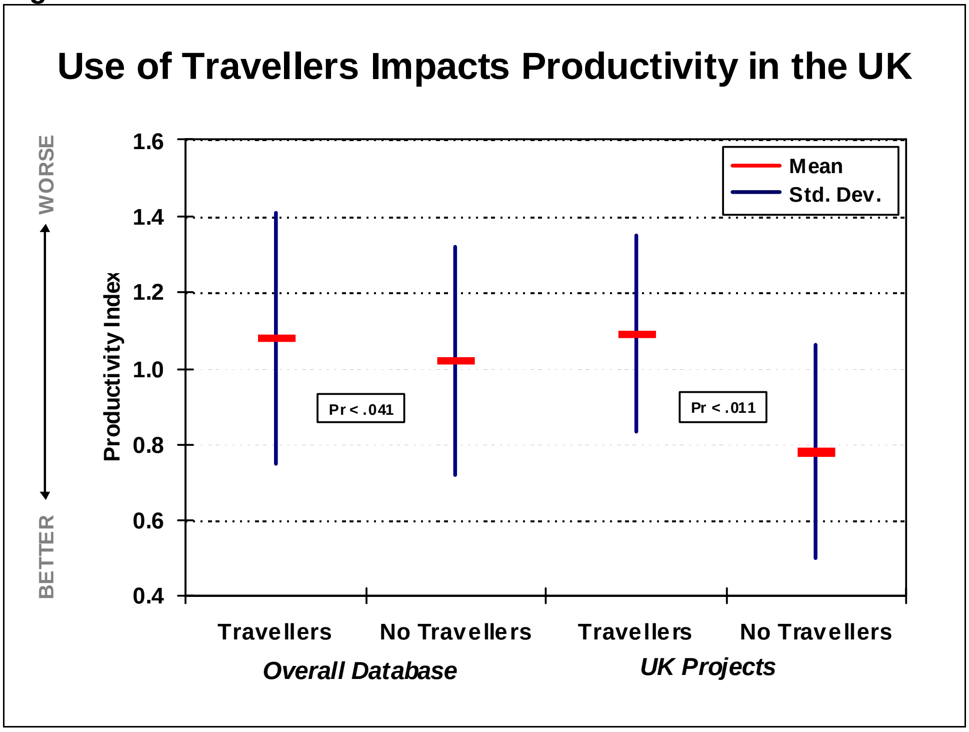
A "traveller" is a craft worker brought in to work on a project from a distance that makes daily commuting to and from home each day impractical. Travellers may be in-country nationals or foreign workers brought in for a specific job.[33] The use of travellers is common in engineering construction and occurred on nearly half of the projects in our sample. As shown in Figure 18,[34] in general, the use of travellers is associated with a small loss in overall productivity—about 5 percent. However, the extent of the loss in productivity varies greatly from region to region depending on local attitudes towards travellers, availability of adequate lodging nearby, and the skill levels of the traveller versus local workers.

We had data on the use of travellers for only 28 of the 60 UK projects in the sample. However, for the projects with the data, the difference in productivity between the projects that used and did not use travellers was extremely large. UK projects with travellers were over 30 percent less productive than those that did not employ travellers. Our data however, do not contain the granularity needed to further describe the cause of the loss in productivity associated with the use of travellers.

[33] We do not, unfortunately, know the precise origin of travellers; our qualitative knowledge of the projects suggest the majority of the travellers for UK projects were in-country nationals

[34] Significance determined by t-test

**Figure 18**

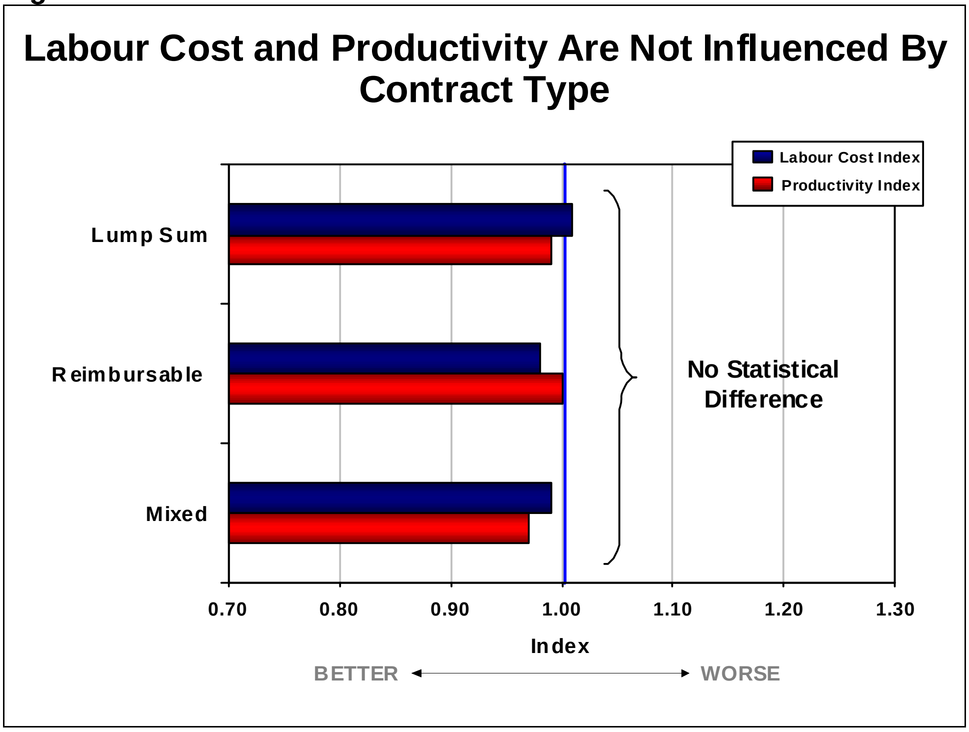



## Contracting Strategy

The contracting strategy selected by a project team is a second-order issue to the establishment of good project drivers and strong execution phase practices. In this section we explore the relationship of contracting strategy on engineering construction labour productivity and cost. Furthermore, we identify whether there are practices related to contracting that can influence productivity and dispel some commonly held hypothesis relating to contracting and productivity outcomes.

## Contract Type

**Figure 19**

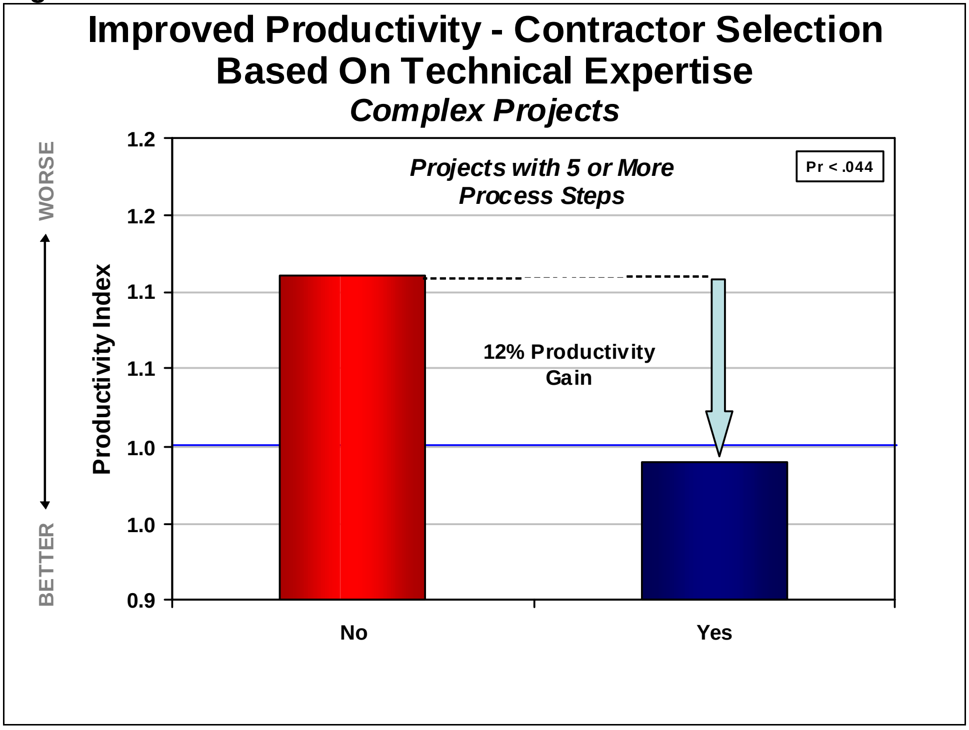



There is a commonly held belief that the contracting strategy used on a project can influence the productivity achieved. As indicated in Figure 19 above, there is no reliable relationship between the type of contracting strategy used and the labour cost or productivity Index. This non-relationship holds true regardless of project location, project type, process and global region.

Although there is no relationship between contracting strategy and labour cost and productivity outcomes, the criteria for contractor selection can play a role in the productivity realised by a project. For large complex projects, defined as projects greater than 6 million Pounds, with more than 5 five process steps the basis of selection of the construction contractor can be very influential. As shown in Figure 20,[35] our research has shown that for these large complex projects, including technical expertise as a contributor to the selection criteria, can gain nearly 12 percent in productivity performance. As projects gain in complexity, technical competence becomes more critical to success. Therefore, failure to include technical expertise as a requirement for these contractors could introduce a risk to the owner in terms of cost and schedule delays. Owners appear to be making appropriate value decisions when they select on technical expertise for complex projects.

[35] Significance determined by t-test

**Figure 20**

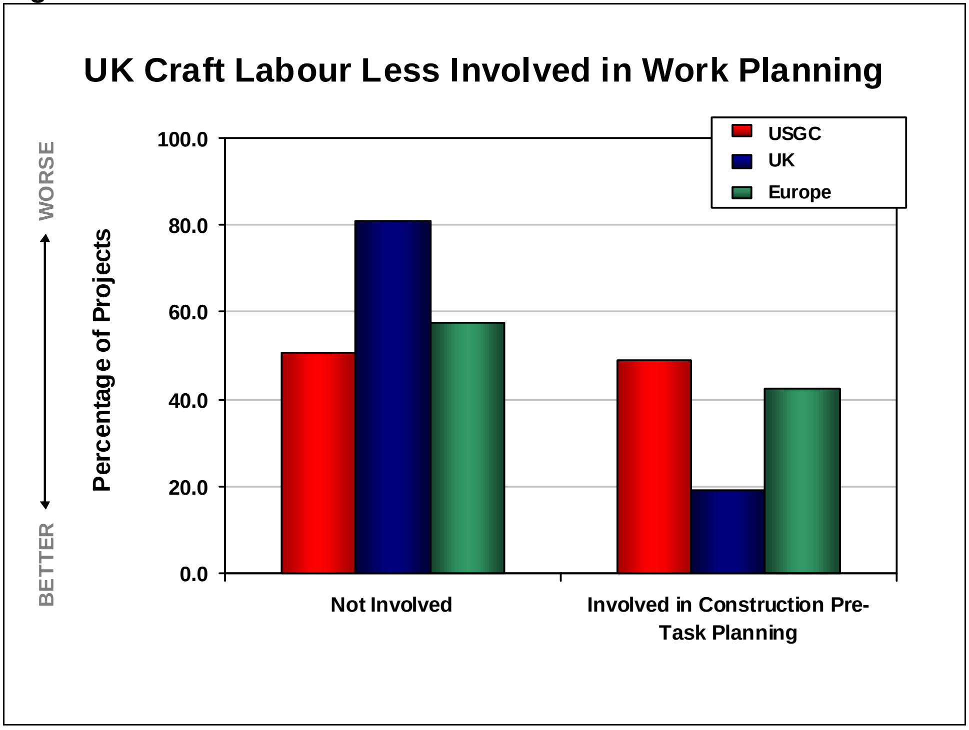



## Involving Craft Labour in Task Planning

Beyond contracting strategy and selection criteria, our research explored how the contractor manages the project once it is mobilised in the field. There is a clear relationship between involvement of the construction labour in pre-task planning[36] and productivity. To further clarify, when the individuals involved in the execution of a specific scope of work are personally involved in the planning of that work, the work is executed up to 6 percent more efficiently in terms of hours required. There is also a significant difference in the percent of projects that use pre-task planning regionally. As shown in Figure 21, projects executed in the UK involved construction labourers in pre-task planning less than 20 percent of the time, whereas nearly 40 percent of projects executed in Continental Europe use this practice and more than 50 percent of projects executed in the US. Involving craft workers in planning the work results in better planning, higher motivation, and fewer labour relations issues.

[36] Construction task planning is the working through of exactly what work will be conducted on a particular day or half-day by each construction gang. Task planning involves walking through what needs to be done, what tools will be required, what permits will be needed, and what the safety and personnel protection requirements will be for the task. Best practice in task planning includes the planning of a back-up task for each gang with tools and safety planning, especially if there is any concern about the feasibility of executing the primary task at the appointed time.

**Figure 21**




## OTHER CORRELATES AND NON-CORRELATES OF UK PRODUCTIVITY

As previously suggested, there are several plausible factors that influence engineering construction labour productivity including skills, innovation, competition, investment and enterprise. For the factors we were able to evaluate there is a weak, but statistically significant (p|t|<.05), tendency for larger projects in the UK to display better productivity after controlling for all other statistically relevant factors. Without controlling for practices, the larger projects actually display poorer productivity because key practices (e.g., team integration) on UK projects are better for *smaller* projects.

Of the three sectors with substantial representation in the UK sample, the pharmaceutical sector has the best average productivity while the petroleum refining sector displays the poorest average productivity. The commodity chemicals sector is in between the two. The results by sector are not statistically significant, but the t-test for the oil refining sector approaches significance at (p|t|<.08).

No particular type of project stands out as more or less productive. For example, revamp (refurbishment) projects are no different that others (p|t|<.53). This result should not be extended to include turnarounds (also call planned shutdowns). We do not have a sufficient sample of turnarounds in the UK at this time to evaluate their productivity.

## CONCLUSIONS

Productivity in the UK for the construction of complex engineered facilities lags somewhat behind its competitors in the US and Western Europe. While the disadvantage is slight vis-à-vis Europe, it is substantial when compared to the USGC. Based on this and a prior study completed eight years ago, the results of which are presented in Table 2 of this report, we conclude that the disadvantage has been present for a long time.

At current exchange rates (July 2009) the UK suffers no cost disadvantage for labour versus the USGC and is actually advantaged versus Western Europe due to the weakness of the pound against the euro. However, a productivity disadvantage that is only adjusted by lower effective wage rates is small comfort to either the wage earner or the economy as a whole. It is a serious disadvantage.

We find that engineering construction labour productivity for complex facilities in the UK is highly variable from project to project, varying from very good to very poor using essentially the same labour pool in the same area at the same time. This fact points us straight to the manner in which projects are being prepared and organised by owners and contractors. When we turn our attention to these practices, we find ample support for our direction.

### Practices Requiring Improvement

If engineering construction labour productivity in the UK is to improve, it must be because the practices followed by owners and contractors that generate the productivity change for the better. We outlined eight areas that needed improvement, three prior to sanction in the FEL process and five in execution. There is an overall theme that ties most of the needed improvement together: owners must stop ceding control of projects to their contractors.

This tendency to overly rely on the contractors was seen in a number of the weak practices that encourage poor productivity:

- The owners' project teams are often missing key functions such as operations and construction management. This is the single most important defect in the UK projects. When a key owner function is missing during the project development and definition period, it generally results in changes during execution. Changes during execution are an immediate cause of loss of productivity.
- The owners are failing to develop detailed schedules for engineering and construction as part of their FEL process and are instead relying on the contractors to develop such schedules if they are developed at all. This is true even on large projects.
- The contractors are then scheduling the projects in ways that are not entirely rational if one is desiring good engineering construction labour productivity. Although 4 of 5 UK projects were not schedule driven, most were scheduled as though they were.
- Project controls are inadequate, especially the failure to conduct comprehensive physical progressing in the field.
- The amount of construction supervision provided is often not optimal.
- The use of travellers appears to be problematic.
- Contractors are too often selected without technical competence to do the particular project being the primary criterion.

- Contractors are failing to involve craft labour in the planning of construction tasks.

If these practices were improved to average, our evidence suggests the UK's labour productivity would close the gap on its global competitors. If these practices were consistently improved to best practice, our evidence suggests the UK would be superior in engineering construction labour productivity.

All of this is, of course, much easier to say than do. Owners may well have lost some of the competencies required to make these improvements, particularly around scheduling and control. The point, however, is that owners and contractors have the keys to superior engineering construction labour productivity in their own hands. Only they can turn the key.

# ANNEX

As part of IPA's Assessment of labour productivity in the UK engineering construction industry, we evaluated a number of possible hypotheses. Some hypotheses were suggested by BERR and others are based on IPA's experience and previous research.

This annex is provided as a supplement to our formal report and is intended to itemize the different hypotheses tested and to give a brief description of our conclusions. The intent is to give a brief summary of all the hypotheses considered and tested, even though many were not supported by the data or not testable using our database.

We have broken down the list of hypotheses into 4 categories: workforce characteristics, project management, knowledge transfer, and contracting.

**Workforce Characteristics**

1. **A workforce with an older age profile will lead to lower productivity.**

   IPA tested the impact of the number of years of experience of core team members on the labour cost index and engineering construction productivity. We found no relationship to exist for either metric.

2. **A higher proportion of foreign workers on a project (i.e. from a country other than the one the project is being built in) will increase productivity.**

   Within the text of the report, we discuss findings pertaining to the use of travellers. The IPA database does not however capture the country of origin. Therefore, we cannot make any conclusions regarding the use of foreign workers. We did test for relationships between engineering construction labour productivity and projects that experienced language or culture related problems during the project execution. These tests were not significant.

3. **Unionized workforces are no more and no less productive than non-unionized outside of the USA.**

   There is no statistical difference between union and non-unionized workforce engineering construction labour productivity outside of the USA. There is also little variability in the percentage of non-unionized workforce outside the USA.

4. **The technical qualifications of UK workers are lower than those in other countries.**

   IPA tested the skill level of craft labour realised on a project, as perceived by the owner at a projects completion. IPA found no statistical difference in UK craft labour compared to the USA and Continental Europe. Furthermore, we found no relationship to engineering construction productivity.

5. **Productivity is greater if the workforce is incentivised by team productivity bonuses than if they are not.**

   IPA tested the relationship of incentives paid to the contractor and incentives paid directly to the craft labour. The use of incentives did not result in improved engineering construction productivity, whether applied to the contractor or directly to the craft labour.

6. **Productivity is greater if the workforce is incentivised by individual productivity bonuses than if they are not.**

   Refer to hypothesis 5 above.

7. **Productivity is greater if the workforce is incentivised by team productivity bonuses than if they are incentivised by individual productivity bonuses.**

   Refer to hypothesis 5 above.

**Project Management**

8. **There a significant difference between the productivity of different contractors working on UK projects.**

   IPA tested this hypothesis and found no significant difference between contractors engineering construction productivity performance.

9. **Fewer design changes mean higher productivity.**

   IPA tested this hypothesis and found there to be a strong correlation between overall project controls and the labour cost index and engineering construction productivity. However, there was no statistical difference between the number of design changes and engineering construction productivity.

10. **UK projects have more design changes than projects elsewhere.**

    IPA tested this hypothesis and found that the frequency of design changes experienced by UK projects is comparable to other locations included in this study.

11. **Projects with a better health and safety record (fewer accidents) experience higher productivity and profitability.**

    IPA tested this hypothesis and found no statistical relationship.

12. **UK projects have a better health and safety record than those elsewhere (fewer accidents, injuries, fatalities).**

    All countries included in this study have comparable safety records.

13. **Projects that are completed on time and on budget have more sophisticated management systems and more highly experienced/trained top management in: the owner/client, the managing contractor, sub-contractors.**

    IPA tested this hypothesis and found no statistical relationship.

14. **Involving the contractors or potential contractors at the start of the project leads to fewer delays, rework and disputes between contractors and clients.**

    IPA tested this hypothesis and found no statistical relationship.

15. **Companies investing strongly in innovation experience higher productivity on UK projects.**

    IPA tested this hypothesis and found no statistical relationship.

16. **Greater use of off-site manufacturing (or modularisation) on a project leads to higher productivity.**

    As discussed in the report, modular projects were excluded from this study. Projects containing high levels of modularisation, do not contain adequate cost splits to develop labour cost and engineering construction productivity indices. This is because modular project costs are wrapped into a lump sum package cost that includes labour, materials and overhead costs.

17. **Larger/more complex projects have a decreased likelihood of coming in on time and on budget.**

    IPA tested this hypothesis and found no statistical relationship.

18. **The weather has more impact on the productivity of UK projects than in other European countries.**

    Weather impacts were tested in a previous IPA study.[37] Given the time restraints and additional research required, we were unable to update these findings for the purpose of this study. The primary findings of the previous study concluded that high winds and extreme heat have the greatest impact on engineering construction productivity. We suspect the relationships would still hold.

**Knowledge Transfer**

19. **Knowledge transfer between similar sites improves productivity.**

    IPA tested the use of internally captured lessons learned between sites prior to project execution and found no statistical relationship with engineering construction productivity.

20. **There is less knowledge transfer between sites/ projects in UK than in other countries.**

    IPA tested this hypothesis and found the use of internally captured lessons learned between sites for UK projects comparable to other countries included in the study.

**Contracting**

21. **Projects with strong elements of alliancing (open book, continuous information sharing) are more likely to complete on time and on budget.**

    IPA tested this hypothesis and found no statistical relationship.

22. **Projects where a single contractor completes the work or a number of contractors form a partnership to complete the work are more likely to come in on time and to budget than those where a managing contractor subcontracts work packages.**

    IPA tested this hypothesis and found no statistical relationship.

23. **A managing contractor and subcontractor arrangement is more common for UK projects than non-UK ones.**

    IPA tested this hypothesis and found there is no difference in the percent of projects using managing contractors in the UK compared to other countries included in the study.

**Other hypotheses considered but unable to test due to absence of data**

24. **On UK projects, contractors employing significant amounts of foreign labour will experience higher productivity than those employing mostly UK workers.**
25. **A workforce where workers are multi-skilled is more productive than a workforce where workers are not multi-skilled.**
26. **A workforce permanently employed by the contractor they work for is more productive than one that is not.**
27. **The workforces on UK projects are less likely to be multi-skilled than on non-UK projects.**

[37] E. Merrow, K. Sonnhalter, and K.A. Brown, *Understanding Construction Labor Productivity in High Wage Countries,* IBC, March, 2002

**28. National or local regulations have no particular impacts on productivity.**