CONSTRUCTIONAL STEELWORK: A STRATEGY FOR CHANGE BY 2005

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Abstract
The construction industry is facing increasing pressure to make a concerted effort to undertake substantial improvements in productivity and cost performance without compromising standards of quality and individuality. To achieve this goal, it will be necessary for designers, suppliers, contractors and clients to work together to adopt a cohesive strategy for continuing business improvement and change. The pan-European CIMsteel project is focused onto the overall improvement of the design and delivery of structural steelwork for both light and heavy structures through the integration of the design and manufacturing processes. The conclusion of the first stage was that the cost of steel frame construction must be reduced by 15% in real terms for it to remain competitive.

An improvement target such as this is only relevant in the broadest sense to be used to point the direction of change. As yet the industry has not got a robust and reliable method of assembling and publishing data on which individual project performance can be set. The data on which the target cost reduction are based do have a consistency and are based on a wide range of sources which give a certain degree of confidence in the figure. Individual project organisations will have to make their own judgement of where they are in terms of improvement, but unless they set big targets for improvement then the industry will become uncompetitive. This raises the issue of who determines the industry's competitiveness. At the moment clients and external project participants set the agenda. In the future the industry must wrest the initiative and this is the potential power within the CIMsteel project. Not only can advanced IT be used to help the industry performance it can also be used to control the interface with the project and so enable the industry to maximise its production and competitive capability.

This paper is based upon stage two of the Wider Industry Challenge package of the CIMsteel project and principally discusses the implications of using benchmarks to set an agenda for sustainable change in the competitive position of the industry. An improvement methodology is given from which strategies for change are derived: a mechanism for sustainable performance improvement is postulated. Finally, the key issues which the constructional steelwork industry must address are highlighted.

Keywords: constructional steelwork, process improvement, benchmarking

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BACKGROUND

Overview

The benchmarks arising from the first stage of the study are shown in figure 1 and the issues arising from them are:

1. The cost of the total steel frame must reduce in real terms by 14.5% - as soon as possible.
2. The erection rate of steel structures must increase by 25% in the next ten years.
3. The lead time for constructional steelwork must be reduced by a third and the factory output double.

Table 1 Summary of benchmarks.

Benchmark	Current Measured	Target
CIMsteel erection rate	1 600 m^2/week	2 000 m^2/week
CIMsteel manufacture	40/week	80 tonne/week
CIMsteel cost	£79 per m^2	£69 per m^2

Some of the major clients in the industry are already setting their expectations at these lower levels in the form of anti-inflationary construction costs, i.e. the difference being met by performance increases. Moreover, a representative proportion of this cost reduction must come from the constructional steelwork sector if it is to remain competitive.

Table 2 CIMsteel future target cost structure for the model office building.

Cost Type	£ per m^2 floor area
Structural elements	32.50
Erection	3.50
Floor assembly	25.00
Fire protection	8.00
	Total £69.00 per m^2
Assumptions:	
Frame weight	45 Kg per m^2
Cost delivered and erected	800 £/tonne

These targets must also be set in the context of the other issues that clients are also seeking. They are requiring better value for money, i.e.. steel construction has to provide flexibility of shape, profile and building space. Client's require long span construction which, at the same time, also gives reduced building height. Flexibility usually requires customisation and a consequent reduction in repetition, thus reducing the possibility of optimising the manufacturing process.

The consequence is that the steel frame industry and particularly the fabricators are in a very competitive market. The market is also increasing its rate of change. This study therefore addresses, in detail, the implications of trying to respond to these targets in the context of project delivery. It also reviews the wider commercial and organisational issues before dealing with the specific issues of where the CIMsteel project can contribute.

Methodology

An approach developed from Japanese methods of performance improvement has been employed. Typically, these techniques are used to analyse and improve manufacturing industry's processes. In order to achieve improvement, the process must first be understood. Therefore, the initial step was to create a multi-discipline working group consisting of all contributors to the process. Three meetings of the group were held. The first analysed the total project process into its sub-elements and then listed all of the inputs that have to be considered. This was then mapped and the results presented as an Ishikawa (fish bone) diagram. The diagram was circulated amongst the team after which revisions, modifications, after-thoughts and corrections made. The global targets were then interpreted into meaningful operational measures or sub-targets using a five storey building as a model as described below. The subtargets were shown at the end of each branch of the Ishikawa diagram. This helped to inform the discussion because it focused the participants into areas where they had their own rules of thumb of current performance and so they were able to gauge the level of change that was required. At the second meeting each sub-target was discussed in turn to determine if there were any barriers to their achievement. The strength of the group was the multi-discipline approach to the issues. It was inevitable that both of these stages triggered considerable discussion and many solutions as well as problems were put forward. A table was produced for each of the sets of barriers. The third stage was to review the barriers and assemble, from all the inputs, a strategy to overcome the barriers. Finally, an action plan for performance improvement has been formulated.

Mapping the inputs and setting sub-targets

A full construction programme had been developed by the team members utilising the current measured benchmark data collated in the first part of the CIMsteel Wider Industry Challenge project. At present, best practice steel frame construction achieves a rate of 1600 m^2 per week. However, this construction rate does not include any floor assembly or fire protection. A one hour fire protection rating for the sprayed beams in such a building would be undertaken at a rate of 40 m^2 per day per man and the boarding of the columns will be undertaken intermittently during the finishing stage, which is not on the critical path. Simultaneously, the ground floor would be constructed at a rate of 1200 m^2 per week and the floor assembly for such a building would have a production rate of 1600 m^2 per week. This, it was felt, presented constructional steelwork in a fair and reasonable light. The test project programme for the typical office building is shown below (see figure 3).

There has been an assumption that all elements of the inputs would make an equal contribution to the reduction in cost. This makes a large assumption that the basic price of steel will fall in real terms. Already there has been a 6% price increase in 1996. Steel is a world traded product and whilst there are possibilities of using imported steel differences in quality are at present limiting its use. If the price of steel were to remain constant then the whole of the real cost reduction must fall on the fabrication and assembly process. To expect this sector of the industry to reduce its costs in real terms by 30% is therefore at the Latham target level and this is significant. As studies for the Latham report have shown a target of 30% cost reduction is only achievable by organisations at the leading edge of any industry in the world. This world class performance whilst strived for by many is only achieved by a few. But this is the implication for the steel industry if it intends to take these targets seriously and there is no support from British Steel in its pricing of the basic product.

Place Order Start on Site Frame with Floor Completed Frame

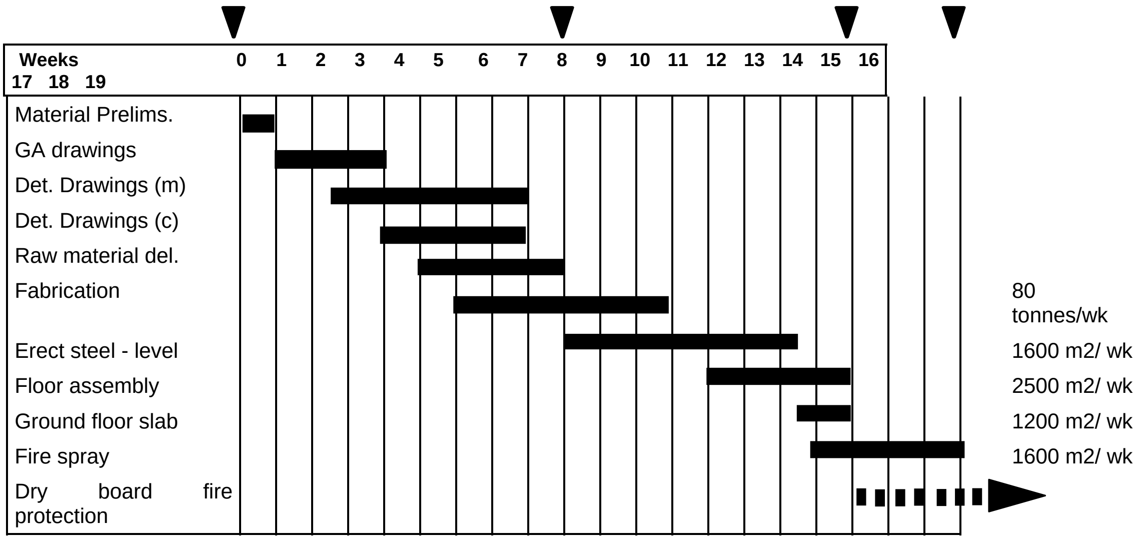

Figure 1 Typical 10,000 m^2 Office Building Project Programme based on CIMsteel current measured best practice benchmarks.

STRATEGIES FOR CHANGE

Raw material costs

The raw material costs form a significant part of the total cost, approximately 50%. Therefore, the input cost of the steel must be reduced. There are two strategies: the cost of manufactured steel must be reduced by £110 per tonne (assuming a price of £760 per tonne) or the total weight of steel must be reduced to achieve the equivalent cost reduction. The alternative is a joint strategy between the steel suppliers and the fabricators. In practice this means a whole industry strategy must be developed.

Table 3 Barriers to material cost reduction.

Barrier to be removed	Strategy to overcome barrier
Cost of raw material too high	Use less steel
Use British standards of quality material only	Reduce trend of raw material manufacturers to understate grade of steel
	Use imported cold rolled steels

Cost of raw steel

This is dependent upon the material suppliers and the quality of supply. British Steel products are of a high and consistent quality. Cheaper imported steels are still to the same British Standards, but do not exceed them in the same way that British Steel tends to do. Designers could downgrade their designs if using steel from British Steel, thus reducing the cost. This requires that the design criteria are sensitive to the detailed characteristics of the steel rather than setting a blanket specification which allows import penetration at the expense of UK steel (there is a hidden cost to the British economy of higher import penetration).

Weight reduction

The total weight of the frame could be reduced to compensate for the rising cost of the raw steel. A weight saving of 36% would be required for total compensation from the raw steel component. Clearly this would have to be achieved through rationalisation of the design of the frame or other design related processes.

Design

Table 4 The barriers to cost reduction through design.

Barrier to be removed	Strategy to overcome barrier
Non-optimat gad dimensions	Rationalise grid dimensions to 7.5m x 7.5m for bays involving cars, and 6.0m x 6.0m for an office fit-out grid
Non-optimat design of connections - too many	Maximise the repetitive use of simple moment connections and minimise the use of moment connections
Non-standard design of frames and connections common	Specifications that are realistic for the required building function
Too high specification demanded	High strength materials to reduce column sizes Design floors for 2.5 + 1 KN/m^2
Documentation to control tolerances at interfaces impractical and too detailed	Use European standards of working &: assembly conditions
Low gross:net ratio of floor space	Culture of cost appreciation needs radical change
Over-design of floors - imposed loading	Weight:cost attitude needs to be changed
Limited flexibility to change British Standard recommendations	Change building regulations
Progressive collapse regulations too stringent	Use Eurocodes
Poor thermal boundary layer properties	Allow an overall/integrating designer to control tight interfaces
Out-turn costs always equal to bid cost + 10%	Design with this in mind from the start Standardise design of structural members and connections to maximise repetition, simplicity and commonalty of the parts set
Non-continuous frame designs	Increase continuity of members in frame design

Conceptual design stage

A number of issues within the conceptual design stage are critical to the reduction of costs. The most common point, and given the various initiatives within the industry the most topical, was the use of standardised structural members and connections to maximise repetition, simplicity and commonalty of the parts set. Similarly, the use of moment connections should be minimised and the use of simple connections maximised. The essential thing is to work within the competencies of the manufacturing process. If there is too much change from one project to the next then this is highly disruptive of the process thus reducing it efficiency. Equally the manufacturers must be developing an improving capability and offering it to the designers otherwise the product will become a constraining factor in the design.

Alternatively, the design of the frame should be such that the continuity of the members is maximised and the size of the columns is minimised by the use of high strength materials. Apart from the down-sizing of columns, the net usable floor area can be increased. user specifications need to be challenged; best practice floor design is currently considered to be 2.5+1 KN/m^2 floor loading but Institutional specifications still set levels in excess of this for 'safety'.

In office it is common for the structural grid to facilitates the ease of car parking on the lower levels which is not suitable for office lay-out on the other levels and viceverse. Often, the interfaces with other building elements are considered as an afterthought. For example, if a floor is designed to have high thermal boundary properties then it is likely to have a significant and positive impact upon the services.

Standards, specifications and tolerances

There is a wide variability in standards, specifications and tolerances from one structural design practice to another. This appears to be based upon personal preferences and experience. The National Steel Specification is a widely used standard, but is often only the baseline from which individual project specifications are developed. Moreover, the practice of setting standards tighter that the British Standard is commonplace, ultimately resulting in a sub-optimal production process. There is still a need for a fundamental change of culture away from the power of individual engineers to the adoption and implementation of industry developed standards and practice. This requires either a change in the UK building regulations or a transfer to the use of Eurocodes or the embodiment of the standards into the industry's IT systems.

Column stiffening

The use of additional column stiffening should be avoided in order to optimise both the fabrication processes and the site erection. Additional complexity of fabrication is added at the joints reducing further the possibility of using automated production. The additional items will also increase the number of unique items thus increasing the complexity of the scheduling and delivery process.

Cost culture

What is clear is that as a generality the designers of constructional steelwork and their cost advisers often do not appreciate the complex relationship between; complexity, the weight of the frame and the resultant cost. Whilst it is acknowledged that increasing the weight of the frame will require more tonnes of steel at a certain rate per tonne, the productivity and time dependent advantages of a simple frame design in terms of the fabrication and erection processes nearly always far outweigh the implicit additional weight costs. On the other hand, the constructional steelwork industry does not have an open culture for the reasonable cost appreciation of the products that they produce. It is immensely difficult from a specifier's point of view to actually ascertain what products are more expensive and why, as they may be of the same weight.

Flooring assembly

Table 5 Barriers to floor assembly cost reduction.

Barrier be removed	Strategy to overcome barrier
Too much secondary steelwork	Optimise spans to accommodate latest deck design to reduce secondary steelwork
	Use special beam sections for composite floors
	Secondary beams omitted by use of arched deck
Propping of beams common	Avoid propping beams by the use of pre-bent beams. Promote simplicity of design
	Don't heap concrete during construction
Too many studs	Minimise studs - primary beams only
	Use of screws or rivets
	Investigate alternative composite designs & actions
	Omit fixing of deck

Secondary steelwork

The cost of the floor assembly was a significant barrier to the cost reduction of steel frames as it accounts for 35.4% of the cost for the finished frame of the typical building. The design of the floor assembly, particularly the level of secondary steelwork is a major issue. Three potential solutions are presented. Firstly, optimise the design of the flooring system in order to minimise the necessary number of secondary beams. A number of contemporary flooring systems are only optimal when combined with specific floor spans. It would, therefore, seem logical to design the frame with this factor in mind, ultimately reducing the level of secondary steelwork. Secondly, is the use of beam sections specially designed for use with composite floors. These would enable a more efficient erection process than would otherwise be the case. Finally, is the omission of secondary beams altogether through the use of pre-cambered deck system. In this case the productivity is likely to be optimised and frame weight reduced. However, the cost of a pre-cambered beam system versus the cost of a more conventional secondary beam arrangement, after taking into account of any time dependent variables, needs to be examined on each project.

Construction methodology

During the construction process, it is essential not to heap concrete, creating the need for the propping of beams. Propping has a detrimental effect on the productivity of the construction process whilst only adding to the final finished frame cost. Propping can be avoided through the utilisation of pre-cambered beams. Also if pumping of concrete were to be mandatory with a flowing concrete mix then dumping and heaping causing localised problems would not apply.

Fixing technique

The conventional methods of fixing a pre-formed metal deck to the beams of the frame is questioned. Firstly, it is sensible to minimise the number of studs required, particularly if they need only be used for joining the deck to the primary beams of the structure. Secondly, is the possibility of a more radical redesign of the composite structure and all relevant actions. If this work was to be successful, then the irradiation of any fixing of the deck unit to the frame could become a reality.

Erection

Table 6 Identification of the barriers to erection performance.

Barrier to be removed	Strategy to overcome barrier
Tolerance too tight for the lining and levelling of frame	Use broader tolerances when not absolutely essential
Site programme not facilitating erection process	Correct information at appropriate stages
Poor materials handling on site	Use bundling of steel packages on site
Poor access to plant on site	Improved access to plant on site
Concrete curing too slow	Use high strength concrete to improve curing time vs. strength and turnaround
Inappropriate sequential handover timing	Appropriate handover timing
Unnecessary power float finish	Only use power float when absolutely necessary
Excessive use of materials and 'over-construction' common building	Minimise the use of materials and do not 'over

Site management

The site programme is rarely considered early enough to the ease the erection process. It is essential that site programmes are realistic and represent a realistic appraisal of the construction duration which is implicit within the design. Moreover, the erection team should have all the relevant information at the earliest possible opportunity so that they can plan their work properly. Similarly, the programmes are commonly based upon inappropriate sequential handover timings, the implications of which need to be mutually understood by all members of the project team.

Tolerances and finishes

Unrealistic, in terms of levels of accuracy ova and above rolling margins, tolerances and finishes cause considerable problems to achieve line and level on site. Extensive adjustment to achieve positions to a level of precision beyond that which the basic material can achieve is time consuming and has considerable knock on effect to subsequent operations.

Erection method

Steel erection is totally dependent upon the effective and continuous use of the crane. The three basic steps are: materials off loading, positioning and temporary fixing and finally lining and levelling. The sequence set out in the Senator House case study1 is the most effective reported so far. By dividing the building into complete work zones the three basic steps were integrated into a total responsibility for each team. They focused on delivering a complete section of the work and could not move onto the next area until the first was signed off as complete. This method achieved a consistent average of 39 pieces of steel erected per crane per day with a peak assembly rate of 110 pieces per crane per day. This level of production was achieved through a close packaging of the work into equal volumes of work and then a rigorous analysis of the restraints on the operation of the crane. Other techniques such a chandeliering, i.e. the suspension of two or three beams spaced one floor apart simultaneously thus allowing beams to be fixed each floor with only one lift of the crane, have been used to remove dependence on the crane. Japanese fabricators in their attention to detail and understanding of the production process pre-package all the bolts for a particular joint and attach it to the steel in the factory so that when it arrives on site the fixer has a ready made kit attached to the joint and can immediately start fixing. Until this practice is common or all bolts are common the fixers will still have to prepare schedules of bolts and laboriously assemble the sets on site. Japanese practice has been known since 1989, but has yet to be fully adopted (Steel Construction Institute 1989).

Logistics

Table 7 Identification of the barriers to improvements in logistics.

Barrier to be removed	Strategy to overcome barrier
Inefficient raw materials purchasing	Just-in-time ordering of raw materials for immediate fabrication Fabrication programme based upon site-led demand
Little reservation of raw materials	Crude programming for the purchase of raw materials
Sourcing timescale of raw materials very short	Build partnerships with material stockists
Long lead times required to ensure an efficient fabrication plant	Crude programming in advance for the fabrication of materials
Raw material expense high	Pressure material producers to increase added value of materials, e.g. semi-finished products

Material supply

The raw material purchasing strategy in many fabricators is inherently inefficient, as the double handling of materials is wasteful and unnecessary. Some of the more responsive fabricators are now operating a just-in-time system for the ordering of their materials. This has the effect of reducing material double handling to a minimum, whilst freeing the funds which were previously locked in non-income earning material stocks. To operate this way requires a fabrication programme based upon the site erection process. In turn, the material suppliers must deliver their raw material in the correct sequence for the fabrication process. However, the time duration during which the sourcing of raw material has to be undertaken is very short. It is necessary therefore, to build long-term partnership arrangements with material stockists and distributors in order to facilitate both a quick sourcing process and to ensure that the material is delivered just-in-time. This may in turn require a crude reservation mechanism of materials.

Lead times

Typically, the lead time from when a fabricator is given a final decision to proceed with the production of a frame, until that frame is starting to be erected on site is too long, currently being in the order of 8-10 weeks. Clients of the industry are pressing hard for this lead time to be halved. For this transition to take place, a more integrated approach by all project participants, including the client, to the process of frame construction is necessary. For example, this may involve a crude programming mechanism of materials through the fabrication shop in a similar fashion to that previously mentioned for the fabricator and the raw material suppliers.

Semi-finished materials

The cost of the raw materials in relation to the finished frame cost has already been discussed. However, increasing levels of semi-finished materials are becoming available from the material suppliers. This method of purchasing materials could be of particular advantage if a particular fabrication shop lacks a specific facility, or to assist in decreasing the duration the fabrication process. In this way, the additional value of the semi-finished product can be translated forward to the client of the fabricator.

Fire concepts

Table 8 Identification of the barriers to fire engineering.

Barrier to be removed	**Strategy to overcome barrier**
Fire protection increases on-site duration	Remove from the critical path by using alternative materials Remove the process from site by using, for example, intumescent paints Fire engineer rather than fire protect

The issue of fire protection and fire engineering raised much discussion, with each of the participants having their own favourite solution to a particular problem. Principally, the question was whether or not fire protection was on the critical path. The answer being, it depends on the type of fire protection used. This can be simplified into three alternative solutions. Firstly, remove the fire protection process from the critical path by using alternative materials for the protection. For example, the use of dry board encasement when applied during the fit-out stage of a project would enable a shorter time duration until any follow-on trades could begin. Secondly, remove the process from site by using, for example, intumescent paints. Such paints can be applied to the frame at the end of the fabrication process by the fabricator. Thus, when assembling the parts set on site, only minor touch-up fire protection as a result of the erection process need be undertaken. Finally, is the possibility of fire engineering rather than fire protecting the frame. In this case, the cost of extra weight of the frame would be offset against the cost of the fire protection. This third option may prove to be the most effective, particularly if the frame design was undertaken within the simpler, but possibly slightly heavier, frame design culture. However, the overall cost of protecting the frame against fire cannot be allowed to rise.

A PROCUREMENT FRAMEWORK FOR MAXIMUM CONTRIBUTION BY THE SPECIALISTS

An integral part of the initial discussions which led to the development of the Ishikawa diagram of the process were the issues of design, procurement and management. It was decided to deal with these issues separately as the procurement framework obviously impacts upon the process, but the needs of the process must be identified first. In this way the issues are not confused. The procurement framework must aid process improvement and not put barriers in the way.

An alternative approach to the conventional architect/engineer designed structure is developed which includes the specialist frame contractor in the design process (see Table 8) This approach can be adopted in contracts such as: JCT with contractors design, design and build, management contracting and construction management. The key is the recognition of the production and process optimisation skills of the frame contractors and the need to restructure the roles and scope of the design team to maximise the input from the contractors.

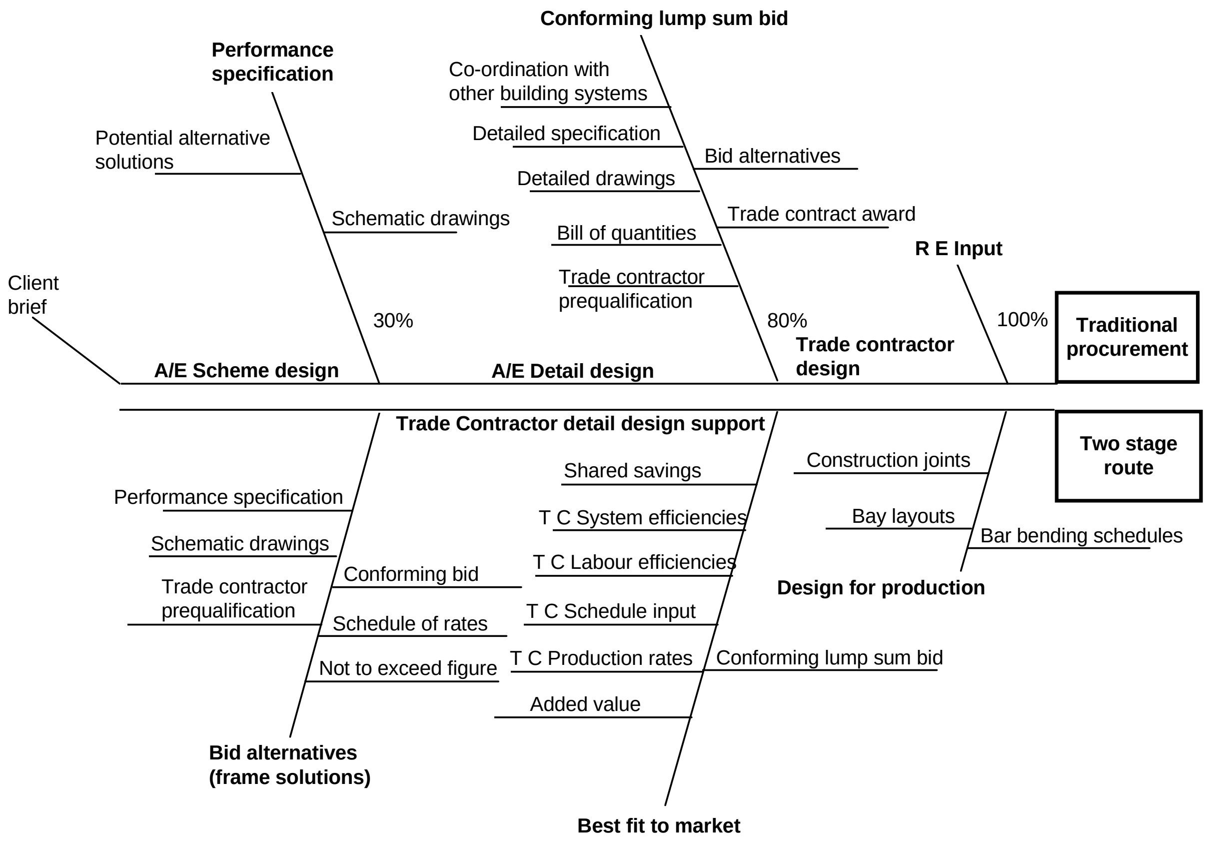

Figure 2 Ishikawa style diagram for a two stage procurement option.

The two stage approach advocates that the input of the specialist is sought at the scheme design stage. The input can be on the basis of a conforming bid which gives a not-to-exceed price or a payment for design consultancy. The object is to maximise the design for production skills of the specialist. The specialist is expected to optimise the design at the detailed level having of course proposed the most efficient concept design. This optimisation requires a trade-off between all of the resource inputs not just the material v strength trade-off. In return for this freedom to contribute the specialist must ensure that they don't just turn to a contract detailing engineer to produce a conventional design with little advantage. If the specialists are given this certainty over their work then they must start to develop their skills for the new market.

IMPROVEMENT ACTION PLAN

Table 9 Identification of actions for improvement action plan.

Barrier to be removed	**Action**
Raw material cost	Build long-term partnership arrangements with key suppliers and operate JIT delivery systems
	Integrate the project team to utilise specialist trade contractor knowledge
Design of structural frame and flooring assembly	Adopt CIMsteel - Design for Construction guidelines
Cost culture	Optimise using new product technology and components
	Produce a detailed open database of individual component costs and complexity of use and benchmarks
Standards, specifications & tolerances	Promote simple frame design rather than least weight
Communication of information	Evaluate existing specifications and promote the use of a specification geared towards an efficient production process
Protection against fire concept	Improve information communication links through the use of advanced technology
Lead-time before erection	Adopt SCI recommendations on best practice
	Halve the lead time through the use of advanced technology and improved communication of information to integrate project participants

The production of steel framed structures is both a technologically advanced and complex process involving a wide variety of project participants at all levels. The main recommendations of this paper are:

1. Promote a change in design culture from that of least weight equals least cost to that of simple design leads to least cost when considering alternative solutions. This must initially be imposed upon the structural design community, but will ultimately filter through to designers through education.
2. Actively encourage the participation of the steel frame fabricators earlier in the design stages to reap the benefits of their production knowledge and product technology. Adopt the recommendations of the best practice design manual produced by the CIMsteel - Design for Construction team and of the SCI with respect to fire protection and fire engineering.

3. A sophisticated cost model should be created. In this way, designers and engineers can differentiate the implications of even minor variations and additions to an optimal process oriented approach, and thereby understand the true cost of the complexity that they are adding through customised components. A default model would cost the most economic and productive construction design at the benchmark construction rate.
4. The National Steel Specification embodied into the future IT systems specification which, when applied to the majority of steel framed structures, will enable the industry to consistently deliver benchmark performance.
5. Targets for benchmark performance should be produced.

CONCLUSIONS

The UK will continue to build customised solutions for the foreseeable future. To optimise for reduced cost and construction time will, therefore require designers to have an ability to perform several optimisations simultaneously:

- steel weight v fire engineering
- steel weight v efficient manufacturing
- steel weight v efficient site assembly
- simple connections v minimal weight

OVERALL COST V MINIMAL STEEL WEIGHT

These optimisations will change as more detail is developed during the design process. An effective evaluation will keep pace with the detail design and report any significant change beyond an initially agreed boundary. The initial boundary setting must be from big targets set to achieve the industry level improvement benchmarks.

This study has revealed that there are many barriers to the constructional steelwork industry being able to deliver a competitive and efficient product and process. The requirements to enable step increases in productivity are given as an action plan. When considered altogether, they form the basis of a strategy for sustainable performance improvement.

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