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CONSTRUCTION SCHEDULING FACTORS, EMPHASES, IMPEDIMENTS AND PROBLEMS AS SEEN BY CONSTRUCTION EXPERTS

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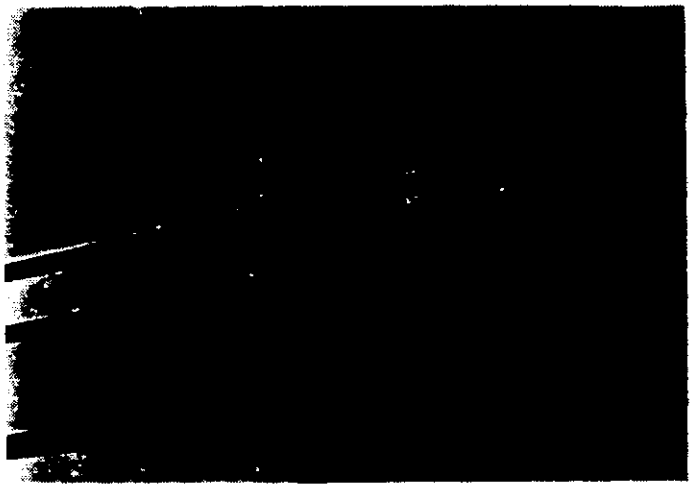

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School of Building Construction
University of Florida
1989

Construction Scheduling

Factors, Emphases, Impediments and Problems

As Seen By

Construction Experts

by

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Too many people have contributed to the creation of this report to name them all, but some must be singled out for their special efforts.

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Finally, but by no means least, a great deal of thanks must be given to the approximately one hundred construction contractor executives who participated in the study. They gave their time and expertise anonymously to produce the data base from which the report was written.

Acknowledgements are usually for people who have done work in the past, but here it is hoped that others will give of their time in the future to read and learn from these findings and then apply that learning to their work to improve the effectiveness and efficiency of the construction industry.

PROLOGUE I

IF

If you can keep your head when all about you
  Are losing theirs and blaming it on you,
If you can trust yourself when all men doubt you,
  But make allowance for their doubting too;
If you can wait and not be tired by waiting,
  Or being lied about, don't deal in lies,
Or being hated, don't give way to hating,
  And yet don't look too good, nor talk too wise:

If you can dream-and not make dreams your master;
  If you can think-and not make thoughts your aim;
If you can meet with Triumph and Disaster
  And treat those two impostors just the same;
If you can bear to hear the truth you've spoken
  Twisted by knaves to make a trap for fools,
Or watch the things you gave your life to, broken,
  And stoop and build 'em up with worn-out tools:

If you can make one heap of all your winnings
  And risk it on one turn of pitch-and-toss,
And lose, and start again at your beginnings
  And never breathe a word about your loss;
If you can force your heart and nerve and sinew
  To serve your turn long after they are gone,
And so hold on when there is nothing in you
  Except the Will which says to them: "Hold on!"

If you can talk with crowds and keep your virtue,
  Or walk with Kings-nor lose the common touch,

If neither foes nor loving friends can hurt you,
  If all men count with you, but none too much;
If you can fill the unforgiving minute
  With sixty seconds' worth of distance run,
Yours is the Earth and everything that's in it,
  And-which is more-you'll be a Man, my son!

Rudyard Kipling
from Rewards and Fairies
pub. Charles Scribner's Sons
New York, 1911

PROLOGUE II

Just as Kipling's poem IF challenges you
To be the best of human beings
So it is hoped,
This report challenges you
To do the best in construction scheduling.

If you can include in your thinking all the scheduling factors, arrange the appropriate emphases for particular buildings, eliminate or at least, minimise the problems and impediments to controlling construction work in the underlying actual construction process, and schedule all of these in a valid permutation for each particular situation of a future construction process, then you should have a very good construction schedule. This research report provides you with these ingredients from expert construction executives, now it is up to each reader to try to utilize this expertise in his future construction scheduling work.

This report presents a distillation of the consensus from a large number of construction experts on scheduling of construction. General contractor strategists, schedulers and controllers of construction processes and subcontractor schedulers and controllers of construction work all contributed their expertise to what are the factors, ingredients, impediments and problems to be resolved and handled in and by construction scheduling.

By absorbing this distilled expertise of top quality construction executives, each of us can improve our performance

in scheduling and controlling construction work to the benefit of the whole construction industry.

George S. Birrell
Gainesville, Florida
July, 1988

EXECUTIVE SUMMARY

Construction Scheduling
Factors, Emphases, Impediments and Problems
As Seen By
Construction Experts

by
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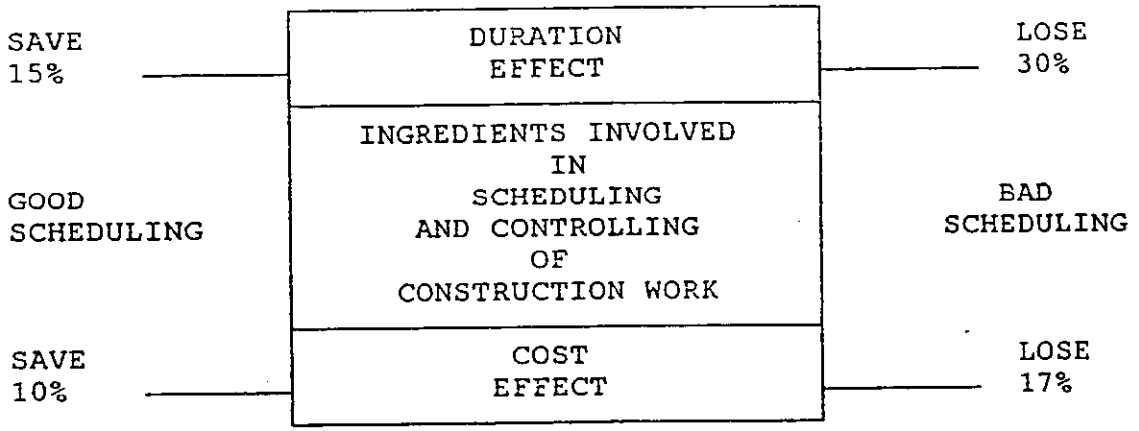
Introduction. This research report provides expert information which can improve the quality of scheduling of construction work by presenting high quality construction expertise necessary to create high quality construction schedules. It is not directed at any particular technique for scheduling such as those described in many books.
Scope of Payoff. The payoffs from considering and using the contents of this report in construction scheduling are shown by the diagram below.



Because these "save" and "lose" percentages on good and bad scheduling came from top quality construction executives, the difference between them can be seen as the minimum ranges for the extent of improvements in duration and costs of construction work which can be achieved by improving the quality of construction scheduling.
Use of the Results. The contents of the whole report can be used as a stimulating framework of thinking for schedulers of future construction processes as each sets about his work on a particular project or strives to improve the general quality of his scheduling work. Even the average construction contractor executive should be able to learn from the results of this study which came from top scheduling and control experts in the construction industry. Also, general contractors can use information in the report which is derived from subcontractors to better understand their objectives and problems in and from scheduling and vice versa.
Overview. A schedule for a building to be constructed should be a

carefully thought out guide providing the best way to carry out that subsequent actual construction process.

The positive factors and emphases to help induce high quality construction schedules include forty-five factors as well as an array of ingredients of emphases that should be considered in scheduling for any building construction process. Each factor is listed, described and presented in groups of Most Important, of Medium Importance, and of Lesser Important factors, based on the degree of their use by the top quality construction executives of general contractors involved in the study. Emphases which should be expressed in construction schedules are variables caused by different types, heights and material quality of buildings as well as their surrounding neighborhood and the potential repeatability of work processes in the construction process.

Various inhibitors tend to negatively affect resource flows and allocations, as well as work durations and times etc. of work in the actual construction process. Problems appear to be derived from different objectives of participants in the construction process and from lack of enough communications among these participants. These inhibitors and problems in the actual construction process should be considered by the scheduler so that their effect can be minimized by careful i.e., better scheduling of a future construction process.

The report also briefly discusses strengths and weaknesses of construction scheduling computer software packages used by contractors.

Sources of Information. The contents of the report were distilled from the responses from approximately one hundred top quality construction experts in both general and subcontractor organizations who are responsible for scheduling future construction work and controlling ongoing construction work. Each construction company from whom an expert was drawn, is based in one of three urban areas of northern Florida and was randomly selected from lists from their trade associations and peers. The factors, their duration and cost effects, and the various ingredients of the emphases to be expressed in schedules came from expert general contractors. The inhibitors and problems were derived from both general contractors and subcontractors' experts involved in both scheduling and controlling of construction processes.

Potential Users of the Report. Anybody interested in learning the perceptions of top quality construction executives in general contractor and subcontractor organizations on scheduling and control of construction work can use this report for their general education in the subject.

Anybody about to schedule a future construction process can provide himself with valuable expert guidance information and questions that should be considered. If such ingredients are appropriate for that particular construction process, they should be included in its preconstruction schedule from which its construction will be controlled.

Copies of the Report. Copies of the report can be obtained from the Executive Secretary of the Florida Building Construction Industry Advisory Committee, c/o School of Building Construction, University of Florida, Gainesville, Florida, 32611, which provided funding for this research project.

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INTRODUCTION

Background and Objectives Of The Study

A construction schedule is to be the best guide by which the subsequent actual construction process should be controlled to occur given the type, location and surrounding circumstances, etc. under which it will be built. The arrangement within the schedule of its ingredients and their combination into the best guide for a future construction depend upon construction factors and emphases derived from the various features of the situation of that future construction process and what is needed to be controlled to maximize the effectiveness and efficiency of the actual construction process.

This report presents factors, ingredients, emphases and impediments and problems of construction work to be faced in scheduling and controlling construction work with or without whatever schedules are used by construction executives in their work.

This report presents the distilled expertise of many top quality construction experts on factors to be thought about while scheduling construction work. As an analogy, this report is a pair of spectacles to be looked through by a person scheduling a future construction process to raise the quality of that construction schedule.

The whole research report is written to provide this distilled expertise to a potential scheduler. The data is drawn from office and site staff of both general contractors and

subcontractors who schedule and control construction work. These overlapping types of data sources were blended to present the factors and emphases which should be in construction schedules and the impediments and problems in actual construction processes which should be eliminated or minimised by good construction scheduling.

By following the distilled expertise of construction executives presented in this report, the reader can produce a construction schedule of greater potential for construction effectiveness and efficiency than he could before reading the report.

As stated above, the findings from which the report was written, came from experts in both general contractors and subcontractors. It is usually the general contractors' responsibility to think out and create the preconstruction schedule and then control the overall actual construction process by it. Thus, the majority of general contractors input is towards creating the schedule. Virtually all the work in the construction process is carried out by subcontractors under the management of the general contractor, thus, the majority of input from the subcontractors tends to deal with issues of controlling actual construction work which should be expressed in the preconstruction schedule and with the differences and their causes between the control of the overall construction process by the general contractor and the control by each subcontractor of

flows of construction resources carrying out the actual construction process.

All factors stated in this report are either as stated directly by construction executives or by an expression of the common meaning of groups of factors stated by them. If there appears to be any repetition or conflict among the factors or sub factors under different headings, that is because such patterns of repetition and conflicts exist in the responses of these top quality construction executives.

Fifty senior executives of general contractors were interviewed. Twenty of these were site based managers or superintendents who are responsible for day to day on site control of ongoing construction work with or without schedules. Thirty were office based senior executives who are responsible for the strategy of construction processes and project managers and schedulers who have more direct construction supervisory and scheduling duties. Initially, the same interview was tested with executives from sub contractors but was aborted as they approach scheduling from a different, less global but very important context within the construction process. A questionnaire designed specifically for subcontractors scheduling and control was created, tested and applied to thirty-two subcontractor executives in the electrical and mechanical trades as representing all subcontractors trades. Again, both office and site executives were interviewed to achieve an appropriate balance to scheduling and control of construction by

subcontractors. These arrays of construction experts were sought to cover the executives involved in scheduling and control of construction work to give an appropriate mix to the scheduling expertise sample which forms the results from which this report was created.

These construction executives, office and site based, of high quality construction contractors were drawn from three major urban areas of Florida which can be considered as representative of most normal construction activity in the whole state and even of construction in the whole nation. The contractor companies from whom these executives were drawn were selected by trade associations as being those which constitute the top quality member contractor organisations of these trade associations. The names of these high quality contractors were then listed randomly and initially contacted for interviewing in that random sequence.

In this way, the contents of this report on scheduling of construction work can provide excellent advice to anyone interested in how top quality construction experts think about making and using schedules in construction work.

The report concentrates on the features of construction processes which should be of major concern in creating very good construction schedules so that there will be a minimum of problems in the subsequent actual construction process for all participants and that such construction processes will be comparatively easy to control from the schedule so created.

This report does not examine or consider the mechanistic scheduling techniques which can be read in many books. Rather it presents the thinking of these construction experts on what should be thought about during the creation of good construction schedules.

How To Use The Report

There are at least three major uses of this report: (a) general educational reading, (b) as a guide to better scheduling future construction processes for specific types of buildings, and (c) bringing to general contractors and subcontractors better understanding of the objectives and needs of the other from scheduling and controlling construction work.

(a) General Educational Reading

The whole report can be read from beginning to end to increase the readers knowledge for better management of construction in general and scheduling construction work in particular. It presents expert factors, emphases, and potential problems and impediments to be thought about in scheduling and controlling of construction work.

(b) A Guide to Better Scheduling The Future Construction Of A Specific Building

The report can be used as guide to scheduling the construction of a specific building. Firstly, establish the nature of the building against the parameters of variability (the various sections of the report dealing with emphases in

scheduling). Secondly, create the schedule for the construction of the specific building having regard to the most, medium, and lesser important factors biased by the various emphases from the nature of the building. Thirdly, evaluate and modify the schedule to minimise the impediments to the most efficient use of the construction resources required in that construction process as stated in the sections of report dealing with control of construction work by general and sub contractors. Fourthly, blend the whole schedule for presentation to and use by constructors and, if desired, to be used on an available computer software package with the strengths and without the weaknesses cited by the construction executives.

(c) Differences In The Scheduling Needs And Objectives Of General And Subcontractors

The majority of the actual construction process is carried out by the work forces of many subcontractors. Each subcontractor controls his work forces according to his objectives of entrepreneurial efficiency and the interests of the whole construction process within which he is working. That whole actual construction process is controlled by the general contractor according to what he has thought out as his best pre construction schedule. The general contractor will have created his overall schedule (of whatever quality) before the actual construction process begins.

The objectives and approaches of the general and subcontractor in their separate scheduling and controlling

activities are interactively related yet each may have difficulty in perceiving, far less understanding, the others objectives and needs in the topics of scheduling and controlling construction work because each is too busy doing his own work. This report can allow each to cross that frontier and learn what is of concern to the other. Equipped with that knowledge, each can better participate in producing a better actual construction process and its control and scheduling in the future.

IMPORTANCE OF SCHEDULING IN CONSTRUCTION

Scheduling and Construction Durations

Scheduling and Construction Costs

Scheduling and Construction Productivity

The Minimum Window of Opportunity From Better Scheduling

Importance of Scheduling In Construction

The payoff from good or bad scheduling of construction work will show in its effects on the durations and costs of the actual construction process. The quality of scheduling affects the level of productivity achieved on a construction site and thus affects the durations and costs of a construction process.

The general contracting executives interviewed for this segment of the report were from top quality firms in the construction industry. From them, it was found that considerable time and cost benefits could flow from better than normal scheduling of construction. Also, if poorer than normal scheduling occurred then cost losses and duration overruns would also occur. The consensus from these construction executives was that both savings and losses from the quality of scheduling could be of significant sizes.

Scheduling and Construction Durations

These construction executives stated that if the normal construction schedule used by their top quality companies was replaced with the best schedule for construction work, that the construction duration would be reduced by about 15% from their normal duration. If that normal schedule was replaced with the worst schedule, then construction durations would increase by about 30% over the normal durations.

EFFECT ON CONSTRUCTION DURATION FROM	MEAN / AVERAGE	MODE	RANGE
Change From Normal Schedule To Best Schedule	15.3%	10%	0=100%
Change From Normal Schedule To Worst Schedule	29.5%	10%	0-100%

Scheduling and Construction Costs

These general contracting construction executives stated that if the normal construction schedule used by their top quality companies were replaced with the best schedule for construction work, then the cost of such a construction process would be reduced by about 10% from their normal cost. If that normal schedule was replaced by the worst schedule, then construction costs would increase by about 17% over their normal costs.

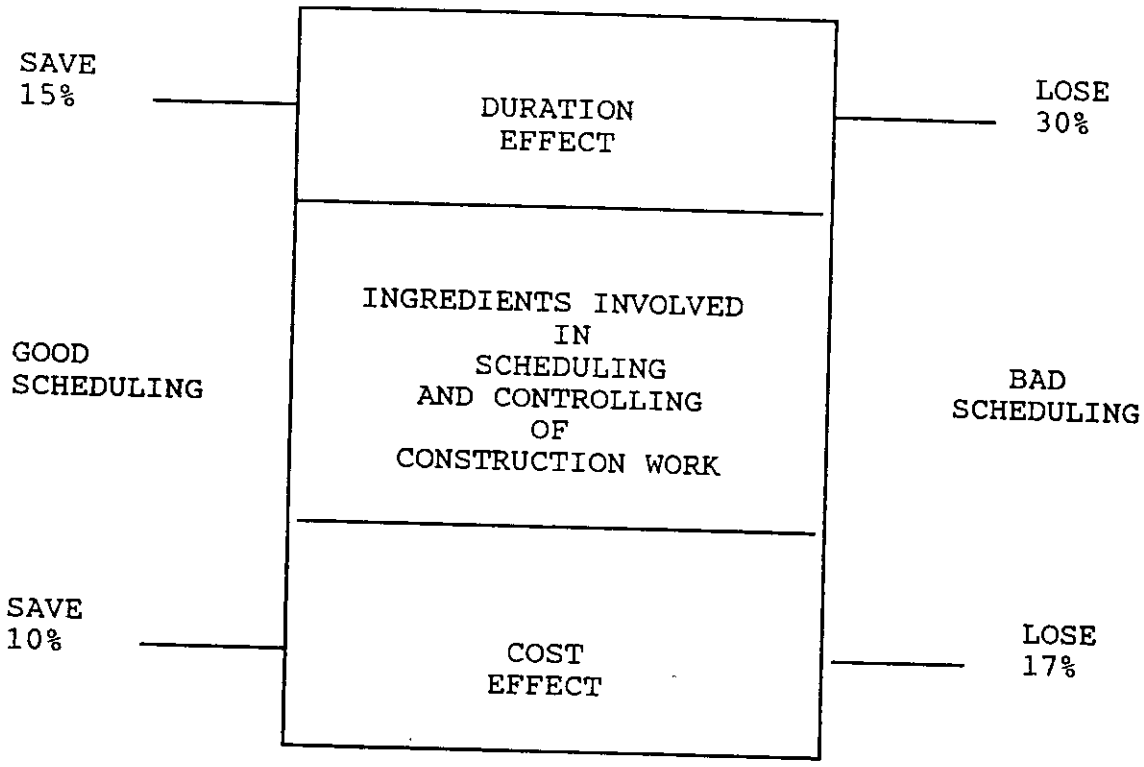
EFFECT ON CONSTRUCTION COST FROM	MEAN/ AVERAGE	MODE	RANGE
Change from Normal Schedule To Best Schedule	10.3%	10%	0-100%
Change from Normal Schedule To Worst Schedule	17.0%	10.%	0-100%

Scheduling and Construction Productivity

While inquiries to general contractors construction executives on the relationship between scheduling and productivity were directed at the ingredients etc. of scheduling

described in the body of this report, 96% of these top quality executives did state that better scheduling of construction improves construction productivity on site.

The Minimum Window of Opportunity From Better Scheduling



It should be remembered that all construction executives, office and site staff, interviewed in this research project came from construction companies in major urban areas of Florida that were recommended by their peers and trade associations as being top quality construction organisations in their construction industry. Hence, their initial normal construction schedules from which they consider duration and cost effects and construction productivity are probably of a quality greater than that of the average contractor organisation. Yet, their view of the effect of differences in quality of scheduling on their construction durations and costs is as described above. Because the normal scheduling of the average contractor is probably of less quality than the normal schedule of these top quality contractors, the beneficial effects of improving the average contractors scheduling could well be greater than the improvements of 15% of duration and 10% of costs stated above for top quality contractors.

The potential to be derived from better scheduling to improve the construction duration, cost and productivity results is already stated above. Now, how to achieve that potential is described in the remainder of this report by stating what ingredients of construction processes etc. should be included and emphasized in construction schedules and which control problems should be dissolved or minimised by management thinking during the preconstruction scheduling process.

THE MANAGEMENT OF CONSTRUCTION FACTORS TO BE CONSIDERED IN CREATING AND USING A CONSTRUCTION SCHEDULE

How The Relative Importance of the Scheduling Factors Was Established

The Most Important Factors

Optimum Completion Date

Lead Time for Material Delivery

Type of Construction (Materials and Methods)

Critical Items

Work or Material by Others

Previous Experience of the Contractor

Complexity of the Project

Previous Experience of the Scheduler

Subcontractor Input

Contract, Drawings and Specs

Restraining Items (Work or Material)

Expected Productivity

Size of the Project

Communication With Others

Conditions Which Affect Productivity

The Medium Important Factors

Availability of Materials

Anticipated Problems

Owners Requirements

Flexibility of the Schedule

Availability of Workers

Balance Between Manpower Loading and Equipment Capacity

Scheduling Experience of the Superintendent

Ease of Updating

Maintenance of a Consistent Workforce

The Estimate

Weather

Availability of High Skilled Workers

Availability of Construction Equipment

Placement of Equipment on the Site

Interference From Utilities

Optimum Movement of Crews During Construction

Location

Traffic Patterns Around the Site

Contractors Company Image

Job Safety

The Lesser Important Factors

Cleanliness of the Workplace

Scheduling Experience of the A/E

Scheduling Experience of the Owner

Possible Claims and Lawsuits

Type of Neighborhood

Specific Billing Requirements

Cash Flow

Craft Jurisdiction

Prevailing Winds

THE MANAGEMENT OF CONSTRUCTION FACTORS TO BE CONSIDERED IN CREATING AND USING A CONSTRUCTION SCHEDULE

From an earlier pilot study on construction scheduling, forty-five factors were found from interviewing senior construction executives. These were the factors considered by that group of executives as being worthy of consideration by the scheduler in creating a construction schedule and by the construction controller in controlling construction work with a schedule. Hence, to provide a very good construction schedule, it is worthwhile for the scheduler to consider these factors.

The validity on this set of factors was reinforced because when every interviewee was asked to subsequently state any additional factors, there were comparatively few and only scattered responses and quite a number of those suggested were other ways of stating a factor already in the presented list.

How The Relative Importance Of The Scheduling Factors Was Established

In the research process from which these results were drawn, forty-five factors were presented individually to each general contractor construction executive interviewed. Each interviewee was asked if he used that factor Always, Most Times, Sometimes, or Never in his scheduling work or use of construction schedules during construction work. The responses from all interviewees were collated and for each factor, the percentage of responses to each of Always, Most times, Sometimes, and Never was calculated.

Now, both Always and Never are rather extreme terms, but, for each factor, by summing the percentage of responses for each factor for Always and Most Times provides a single percentage value for each factor as to its importance across all factors.

For example, the factor "Expected Productivity" scored 60% for Always, 22% for Most Times, 10% for Sometimes and 8% for Never. Thus (for it) the sum of Always plus Most Times was 82%. This calculation was repeated for each of the forty-five factors.

This single list of percentages was then examined and found that there were twelve factors rated greater than 80%, fifteen factors rated greater than 75%, nineteen factors rated greater than 66%, and thirty-five factors rated equal to or greater than 50%. That thirty-five out of a total of forty-five factors rated greater than 50% for use to the extent of Always plus Most Times expresses a validity to the whole set of factors.

Based on the above analysis, it was concluded that fifteen factors which were rated at greater than 75% on the sum of responses to Always and Most Times, should be considered as Most Important Factors in scheduling and controlling construction work. Those twenty-one factors whose Always plus Most Times rating was between 75% and 50% inclusive should be considered as being of medium importance. Those nine factors whose Always plus Most Times rating was below 50% should be considered as factors of lesser importance.

In preparing the above sequence of importance of factors, if

two had the same summed value, the one with the greater Always value was placed first in the list of factors.

The descriptions of these factors was drawn from the meaning of the factor, careful consideration of all of the responses to all the other questions put to the interviewees and from basic construction scheduling information.

This section of the report will present and describe these factors in the following parts:

(i) the most important factors

(ii) the medium important factors

(iii) the lesser important factors

The Most Important Factors

The following factors were found to be most important for creating and using schedules for construction. They are listed in sequence from the factors with the highest score stated first with the remainder in descending order.

Optimum Completion Date Finding and establishing the date which represents the optimum completion of the construction process given all the forces at play is of major importance in the process of scheduling and its use to control the actual construction. Some of these forces are the various possible logical formats of the construction process, the realistic availability and cost of construction resources etc and the nature of the building and its location. Put another way, the expected completion date should be arrived at after thinking

about the construction input factors and their interactions rather than as a global guess without carefully thinking about their interplay for this project. The optimum completion date is then realistically achievable in a construction sense, even though it may be set up to be slightly biased towards optimism to motivate participants.

This same factor should also play on each of the individual work activities in the schedule. Having a known optimum realistic completion date for each work activity sets or influences the realistic start date for following activities. This is related to the major concept that the schedule is to guide the actual construction process to completion and not simply to get construction started. From such dates and durations, the flow of resources to the work can be better planned so that the work on each activity has greater probability to take place when it is planned to take place. In turn, this increases the probability that the whole of the actual construction process will be as close as possible to the planned process and hence, there will be only a minimum need to revise and rearrange the construction schedule, delivery schedules, and managerial activities of all participants during the actual construction process. Thus, the whole actual construction process takes place with both effectiveness and efficiency in a rational manner which minimizes the need for constant managerial revisions from perturbations on the construction process and the input flows of resources to the construction process.

Lead Time For Material Delivery By having a sensible construction process thought out and expressed in a carefully prepared schedule, the date by which each work task should begin and, hence, by which specific materials have to be on site is known. This enables all parties involved in their delivery to work to that result in a rational way rather than by guessing and hoping, etc... The validity of the scheduled delivery date for materials is a major factor in minimizing the too late or too early delivery of all materials to the site, each of which would increase costs and risks to the participants in the construction process. If materials are late in their delivery, the construction process is held up.

The schedule should consider the required lead time for delivery of major materials, especially those such as large pieces of equipment, as input to scheduling the construction work of those materials and those which require that equipment to be in place. Their impact on the schedule is such that their requisite construction work will be placed at a realistic calendar time in the schedule, given the delivery lead time required. The scheduler can start from time "now" and add the duration of the delivery time to establish the earliest date on which the work can begin on site, regardless of its interaction with other work. Better than this, the scheduler can create the schedule and fix in calendar time when the material has to be on site and then move back from that date by the delivery etc duration to begin the required delivery process. He may have to

interpolate between these two to finalize the schedule and notify those involved in construction and delivery of the required work start date. By doing this, the potential for the whole construction process to be delayed by non deliveries is greatly reduced. To ignore this factor in scheduling has a high probability of the actual construction process being very different from the planned schedule and thus the plan is a poor guide for the actual construction and may have to be changed during construction which, in turn, affects many participants work causing increased costs and durations to accommodate these changes.

It is fundamental to seek out and use realistic durations of lead times for material deliveries as input to the production of a valid realistic construction schedule. The origin of doing that is to know when the material is needed on site and its realistic delivery duration.

Type Of Construction (Materials and Methods) By having to create a construction schedule prior to the construction process, a search of contract documents has to be made to establish the nature of all the materials and methods required. This greatly reduces the chance that some materials will not be noticed as being required until their construction should begin on site. By having to create a schedule prior to the construction process, potential bottlenecks in the construction process - logic and construction methodology can be explored as to alternate

construction sequences and the optimum one chosen for the preconstruction schedule.

The "Having to create a good schedule" forces careful thinking about the construction process prior to its start on site and, hence the best schedule simplifies the subsequent management of the actual construction. The schedule should express the chosen construction methods and sequences of work having regard to the nature of the materials in the designed building, their nature, and quantity etc in various locations in the building and what work patterns or sequences among them would create the most efficient construction process. As a result of this search, thinking and evaluating, there is a higher probability that the schedule will be more effective as the best way to carry out the construction process than without such thinking.

Critical Items By creating a schedule prior to construction which included duration calculations through a realistic construction logic schedule, exposes which activities in the whole construction process are critical to the achievement of the planned completion date of the overall process.

Prior to such calculations, creating a logical construction schedule and examining it for improvements prior to its finalization as "the schedule" can expose where there may be bottlenecks in the work process. A major example of this could be finding numerous trades working in and around a particular

location on the site at the same time. The scheduler should then revise the logic of that initial schedule to dissolve such bottlenecks while maintaining the logic of the overall strategy of the construction work. If such critical construction complexities cannot be eliminated from the initial schedule by preconstruction revisions they can be flagged as construction critical items for the attention of the controller of the actual construction along with those which are critical due to their effect on the duration of the whole construction process.

These "time critical" and "construction critical" activities are those to which on site management should pay special attention. If these critical item exist in the schedule, they should be highlighted in the schedule to be used to guide and control the actual construction process.

Work or Material by Others The extent and nature of the work of others has to be sought out by the scheduler, by his construction knowledge, from whatever source is needed. Establishing required work or materials by others is another major input to scheduling very similar in effect upon the schedule to establishing the realistic lead durations for material deliveries.

By having to create a construction schedule for the whole construction process rather than only for his own work, the scheduler benefits the actual construction process because there may be work going on at the site by people other than those involved in the specific contract under which the contractor is

working. The owner may be doing work himself as required phased work to complement the contractors ongoing activities. The utility companies may be working to their own timetable rather than to the building's construction schedule. There may be an array of prime contractors each with his own schedule on the same site.

For each participant, knowing where and when your work interacts and fits into the whole construction process is of major importance to all the contractors and all these work flows should be expressed on the one schedule and reviewed for efficiency by some managerial role in scheduling. Thus, the schedule should include the work required of others in the whole required construction process rather than be only of the work of one contractor.

Previous Experience of The Contractor The extent and nature of the work of others has to be sought out by the scheduler from whatever source and guided by his construction knowledge. Work or materials by others is very similar in effect on the schedule by creating the construction schedule after having established the realistic lead durations for material deliveries. The type of construction work a contractor has previously carried out in relations to the work of the future project to be scheduled and controlled, is important input to the scheduling process. The current ability of the contractor in the techniques and uses of

such schedules is also important input to the scheduling and its uses in construction control.

The schedule for a construction process is a focal point for communications among participants of the construction process hence the previous experiences of each participant in construction work and in the techniques of scheduling is very important to facilitate communication between that contractor and the other participants. Hence the written expression of the schedule to the contractor should consider how to best communicate that schedule information to the contractor so that its use can be maximized.

To carry out the above, the scheduler has to find out the work experience, the level of knowledge of scheduling techniques and the willingness to develop his own forward looking attitudes of all the important participants to the construction process and use that information as an ingredient of his scheduling work. Alternatively, he may schedule the work in his own way but must consider the constituents of this factor as major ingredients in how he communicates the schedule to the various people who will construct the building using his schedule.

Complexity of the Project The more complex is the project to be built, the greater the potential benefit from the scheduling of its construction. The scheduling process can reduce the complexity of the construction process by careful construction thinking and facilitate the communication of the work of each

participant to him. By each participant being advised of the "what" and "when" of his work activities, he can better optimize the use of his work resources.

Scheduling can transform a potentially complex construction process into one which can be managed as a normal construction process. Complexity versus simplicity imply the relationship between (i) the volume and intricacy of information to be considered and (ii) the capacity of a human mind to simultaneously carry and think about all that information and the interactions between the parts of it. If information in the form of a schedule is written down in a diagram and words, then careful thinking and schedule modification can take place on each part of the schedule to improve its construction realism and effectiveness and efficiency. Complex written schedules can be communicated more easily than non written schedules. The output of any schedule can be produced as lists of work activities, each with its start and finish dates. Each party to the construction process can minimize his down time on an actual complex construction process by knowing how, where and when his work is to take place.

For that change from complexity to relative simplicity requires careful revisions of the initial schedule. This should take place over a series of iterations, each of which improves the quality of the schedule as a construction process. This is premised on the concept that our first thoughts on a topic or process are not necessarily our best and that, by reviewing and

revising the initial schedule, we can improve what we have written down as our original thoughts.

Previous experience of the scheduler As in all walks of life, there are construction schedulers of varying capabilities and experience levels. To create a construction schedule for any project requires both construction knowledge and scheduling knowledge. The scheduler selected for a project should have or seek out knowledge and information particular to that type of project as well as of the available array of scheduling techniques. Furthermore, the scheduler should be willing to seek out and use input from other construction executives in his organization and from sub contractors for the project and even from material and equipment suppliers.

It seems wise that for a project schedule to be most effective, "the scheduler" should be a team comprising the office based project manager responsible for the on site construction and the site superintendent who will control the work on site. They should take input from subcontractors, but remain the author and controller of the schedule for the whole construction process. While the project manager may create it and the site super critique it or vice versa, it is important that each sees himself as an author of the project construction schedule. That just one of them makes up the schedule and the other does not participate in its creation but merely accepts it, is not good enough.

How they schedule the construction work will be dependant on their past experience of scheduling, be it vague and general, or detailed and specific, or worthwhile or disastrous. To create the greatest benefit for the contractor organization, it would be wise to provide scheduling education so that scheduling expertise can more fully harness the construction knowledge needed in the scheduling of construction and its control on site.

Sub contractor input While the general contractor is responsible for the management of the whole construction process, the majority of the work is usually carried out by subcontractors. Hence, it is very important in the creation of the construction schedule that input is sought and obtained from subcontractors and used in the scheduling process. It is the work of and interaction between the work of the various subcontractors that requires most scheduling by the general contractor. Furthermore, construction processes tend to have the greatest number and variety of resource flows of men and material when the greatest number of subcontractors are simultaneously working on the site. Thus it follows that the greatest benefits from a schedule can flow from having such multi resource and complex phases of the construction process scheduled as well as possible. To achieve such high quality of schedule, it is very advantageous to seek input from subcontractors regarding their work at all stages of construction but especially for their work while many subcontractors are on site.

At the very least each major subcontractor of that future building should provide input to the scheduling regarding best sequences of their own work, their work sequences around the site, durations for phases of their work, and for work activities, and information on lead times for deliveries of major components, etc.of their work. Then the schedules of the general contractor has good information from which to schedule the whole construction process.

The general contractor need not exactly follow the input from all the subcontractors because part of scheduling is to proved solutions to conflicts among the desires and needs of all subcontractors and between the needs of the whole construction process and its details to create the best schedule for the whole actual construction process.

Contract Documents It is essential in the creation of the construction schedule that the conditions of the contract, especially the modifications to typical general conditions and supplementary conditions, the drawings and the specifications are searched for important matters as input to the scheduling process. The construction schedule, which is a major force in controlling the actual construction work, should reflect all aspects of the contract under which the work is to be carried out. At a minimum, there should be no conflict between the schedule and the other contract/documents.

Fixed project durations, by the project owner, and his desired sequencing of work etc., must be adhered to in the schedule. To do so may require increasing or decreasing the resources applied to different pieces of work in the construction process, and thus, the logic and durations of the schedule should reflect these boundary conditions set for the construction forces by the project owner.

It would be advisable that the estimate for the construction process is also used as documentary input to the schedule. As the estimator should already have thoroughly read all the above contract documents, this could be a quick way of establishing this aspect of input to the schedule. It would also bring to the scheduling process the thoughts of the estimator.

Over and above the input from the estimator, the scheduler should be familiar with all aspects of the contract, the drawings and the specification before developing the schedule. It may be that the general drawings for the building are the only ones of advantage as input to the scheduling strategy and process because the schedule should comprise the details but not necessarily have its strategy dictated by the details. Prior to finalization of the schedule, it should be checked that the details can be fitted into the schedule at the appropriate points for their construction work.

Restraining Items (Work or Material) The schedule is the guide to and controller as to how the actual construction process will

be carried out. That construction process is in a time (and, hopefully, on site sub location) sequence of work around the site. Work scheduled later in the sequence may not be able to begin, because an earlier piece of work is not completed or has not taken place. Within the normal construction process, there are tasks and occurrences which, by themselves, may not be a major piece of work, but which, by their nature or location, form a restraint on the start of a single or a series of numerous subsequent pieces of work. Such restraints can be either absolute or cost increasing. Absolute restraints are those that stop subsequent work i.e. column has to be built before a beam can be placed on it. Cost increasing restraints mean that the subsequent work can go on but will consume greater resources or duration for their execution. Items such as provision of temporary power or water, or the enclosure of the building skin, hold up the start of subsequently scheduled work. Also, the unavailability of specific materials at specific points in time when they have been scheduled for inclusion into the project may also restrain subsequent work. The schedule should identify such restraining items of work in the schedule so that those managing the actual construction process can have these items shown as being of critical importance for subsequent work starting even though in themselves such items of work may not be costly or time consuming.

Expected Productivity Construction work takes place over time thus there is a very close relationship between the duration of a piece of work in a construction process and the productivity achieved by its work crew on that site under the conditions of work and management to be expected there. Thus, establishing the local productivity of work crews on each trade's work tasks is very important to establishing the planned duration of such work tasks given their quantities of work. Clearly, the more realistic the durations are for the work tasks in the construction schedule, the higher the probability that actual work will occur closer to the scheduled durations and thus the whole schedule will be more valid as a construction control instrument. It follows that the fewer the differences in times and durations between the schedule and the actual construction process, the greater the validity of the schedule as a guide to the times, deliveries and resource needs etc. of work activities later in the schedule.

This greater certainty that the schedule is valid creates confidence and positive motivation in managers and workers and so the construction process is more productive and has a higher probability that work will occur when scheduled and finished when it should. It is probable that there is a strong relationship between having valid productivity as input to scheduling and the seeking of input from subcontractors for scheduling. It is up to the scheduler to seek and include consideration of valid forecasts of expected productivity in the schedule.

Size of the Project Size of the project affects scheduling because of the potential conflict of strategy and detail in the schedule. As another constituent of settling that conflict, it must be remembered that the schedule has to be communicated to the participants in the construction process.

If it is a small project then the required logic choices for that construction process could be expressed on one schedule for ease of comprehension by all participants.

If it is a large project then the understanding of the whole construction process in the schedule may be lost in the sea of required logic decisions and details if these are all on one schedule. The schedule for such a large project may have to be developed as an hierarchy of interrelated schedules so that each provides a balance between (i) overall comprehension of the whole construction process and (ii) the required level of detail and logic interactions between required construction tasks for the schedule to be an effective guide to the participants in the actual construction process. The former i.e. overall integration of all work activities to an wholistic efficient strategy is required to give the schedule effectiveness when the actual construction process follows this schedule. The latter is required for the schedule to be the preconstruction expression of the best detailed interaction among the required construction work activities. Both of these aspects of the schedule are required to exist as a basis for valid communication to by all

participants of the actual construction process and their understanding of what and when is their part of that process.

Communication With Others The construction schedule is the expected best way to construct a particular building as seen by the scheduler given the whole situation of the project and with input from others participants in the construction process. Thus, it is the best tool by which to control the actual construction process.

However, that actual construction process is carried out by many people and each will require information from the schedule to guide his work and each may require information in formats etc. different from that of other participants. Therefore, the information in the schedule has to be communicated to each participant in a format and content understandable and useful by each of them to guide his work. Also, the information each needs from the schedule may not be best presented in the format in which the schedule has been produced.

The final preconstruction schedule should be seen as the hub of a communication system to and from and among a variety of people, all of whom are doing different things in and for the actual construction process. There is an array different sub trades involved and in each there can be numerous work crews working on different types of work in different locations of the project. There are other people in each trade involved in expediting deliveries of materials to these various work crews

and others involved with cash flows to and from contractors and others managing inspections and safety procedures etc. The work of all of them is influenced by and influences the actual construction process which follows and is derived from the schedule.

It should not necessarily be up to each participant in the construction process to find the information from the schedule that each needs. The iterative creation and finalization of the preconstruction schedule should be seen as the beginning of the potential to communicate the required information to all participants in the written or diagram format most suitable for use in their specific work in the actual construction process. It is up to the scheduler from the final preconstruction schedule, to provide each with his needed information in the most suitable manner for his work. It is the responsibility of the scheduler to properly communicate the information in the schedule to each participant in the construction process so that each can do his work efficiently and effectively in the context of the whole construction process.

Conditions Which Affect Productivity An earlier major factor Expected Productivity discussed the productivity in the construction process itself from the resources used by the contractors on site. That "Expected Productivity" factor had a somewhat on site labor and equipment quantitative context whereas

this factor seeks out the broad situational variables that can modify the levels of that expected productivity.

The scheduler should search the local marketplace for factors that may exist or change in the future during construction duration of the project being scheduled that might invalidate the original productivity figures used to create the construction schedule durations.

The future demand for construction work for the local construction industry in relation to its size is a global feature of this factor.

Other features of this factor could be sought in relation to the various types of resources required by construction contractors. Most fickle of these is labor productivity. Whether the project is to be built with union or non union labor, big city labor or rural labor and the degree of availability of that type of construction labor in that location etc can affect the level of productivity achievable on that site over the expected construction duration. Furthermore, this search on labor productivity may have to be segmented by trades as demand on each trade will vary independently over time. Also, the capability of management of the contractor to motivate that particular type of local construction worker as a human being could be a major condition affecting worker productivity. The other major type of productive resources is construction equipment and machines. The availability and productive use of construction heavy equipment in a particular locality under the

particular construction site conditions can vary considerably from that in other situations. This resource can be dependant on weather conditions, supply of spare parts, nature of the project, capability of the driver of the equipment, etc...

Seeking out as many "what ifs" regarding these major construction resources and potential changes in their level of productivity on this building to be scheduled can increase the realism of at least the durations of work tasks in the schedule which also has impact on the preferred logic of the schedule.

The Medium Important Factors

The following factors were found to be of medium importance in the answers of the top quality construction experts who form the source of the information on which this report is produced. Specifically, these are the factors which scored between 75% and 50% ratings on the sum of Always and Most Times used by all the general contractor executives. These factors are listed in descending order of their score.

Availability of Materials For a piece of work to be carried out, the required materials must be at the hand of the worker who will carry out the work. The variety of materials needed for a construction project is large, their quantities vary, their work locations on site are many, their sources off site are many and the sub processes of their procurement are numerous and involve many people. All of the above have to be linked together into a workable management system to deliver these materials to the work at each work location.

Ensuring that these material flows are available for the workers is a major task of managing construction.

The scheduler who will be crystallizing the start date of each work task in the schedule should establish probability of availability of major materials, especially those which are unique for the project (i.e. not common materials like bricks or 2 x 4's as input to the scheduling process). The manufacture and delivery durations of such materials and their preceding

paper work processes should be evaluated by the scheduler to establish realistic dates of delivery to the site of the needed materials.

It is probable that for unique and major pieces of equipment, their delivery durations should control the start date of their installation and the construction process logic should reflect this. For more common materials, it is probably better to schedule their delivery to meet the desired logic of the overall construction process than allow their delivery to dictate to the construction schedule. However, care must still be taken to allow for realistic durations for the delivery of all materials.

Overall, the scheduler must consider in making his construction schedule, that it matches the reality of the marketplace for the delivery of materials. The construction schedule should not be created without gathering and considering such input information.

Anticipated Problems The scheduling process forces the scheduler to look ahead at the future construction process. By carrying out a thorough search of all appropriate input information and creating the most effective and efficient and simple overall construction sequence as the preconstruction schedule, the scheduler is forced to think about, anticipate and solve problems which might occur in the actual construction process.

He should review and revise draft initial schedules to eliminate complicated interactions among required resources and too much simultaneous work in the same geographic location on the site. He should seek to realistically sequence all the work required to be done in a way that minimizes the interactive frictions that reduce efficiency of construction of each resource flow.

After solving all of these problems, he should express their solutions in the final preconstruction schedule so that none of these potential problems show in the schedule. The actual construction process which follows such a final preconstruction schedule will be more efficient than one which has not dissolved out these anticipated problems.

Owners Requirements There may be owners requirements regarding the construction process which are specifically stated in the contract documents or may be stated verbally in a preconstruction meeting or may be implied from the input information. These contractual requirements are major inputs to the schedule and should be met in the schedule. They can be seen as contractual boundary conditions within which the schedule should be created.

If a contract requirement is onerous to the contractor or separately a benefit can be provided to the owner from a modification to one of his requirements of the schedule, the contractor should discuss it with the owner and seek his agreement for the modification. It should be the owners decision

if a discussed requirement remains or is modified in the schedule and contract.

The scheduler should seek out these requirements from the contract documents and discussions with the owner. Then they should be incorporated into the schedule or explained to the project owner if they create an inefficiency to the construction process without an accompanying greater benefit to the project owners interests.

Flexibility of the Schedule The schedule is thought out as the best process by which the actual construction process should be carried out. Thus control of the actual construction process should be directed at making the actual construction process occur according to the scheduled process. If that does not occur, the actual construction process will be less good than it could have been.

The final preconstruction schedule is the "route map" to be followed by the actual construction process. However, when monitoring the similarity between the schedule and the actual construction process takes place regularly during construction, differences between them will be exposed. To reconcile such differences, the actual construction process could add resources or change its sequence for it to return to the same "route" as stated by the schedule. However, after some such monitoring occasions, there may be the need to change parts of the remainder of the schedule to bring the actual process and the schedule back

in harmony within the overall objective of the schedule and within the shortest duration in the future.

Under these circumstances, it is very useful if the original preconstruction schedule has flexibility in the sense that the whole schedule is comprised of somewhat self-sufficient logical sub parts of the overall preconstruction schedule. This should not be confused with sub schedules of activities of single participants in the scheduled construction process. If the preconstruction schedule has been structured and built from these sub schedules for segments of the work or time phases of the work, then say, while one logic sub schedule or module is changed to accomplish the above objective, all the other sub schedules or modules remain as originally scheduled. This allows solving the short run problem with a minimum disturbance to the whole schedule because the preconstruction schedule has logical flexibility. The managerial processes of the non affected participants remain as in the construction schedule. This is very meaningful because some of these managerial processes, such as ordering materials etc., may already have take place or will need to take place simultaneously with the solving of the short run inconsistency between the schedule and actual construction but remain valid for the effectiveness of the whole future construction process.

The scheduler has to structure the schedule in the most appropriate modules or sub schedules to create this flexibility potential. To quite an extent this will be derived from the

nature of the project itself and the skill of the scheduler to modularise the schedule.

Availability of Workers To create a construction schedule which is realistic and has a very good chance of actually being carried out there must be workers to carry out the work required of each trade from those available in the local construction industry. This requires the scheduler to know,or at least, check out the local availability of construction labor in each trade and the members being utilized on the other local projects. The schedule should be of work tasks with durations based on consideration of the availability of the required construction workers.

During, or prior to, scheduling construction work, project site controllers should be asked to tell or discuss the numbers of workers required to keep each subcontract trade working at a speed compatible with the desired overall speed of the work on the schedule. During actual construction, the site controller should regularly check that the target number of workers is being met. (If these numbers are collected regularly from each project, then a data base can be created as a company internal source of worker numbers as input to scheduling.) The results of this factor can be better applied to scheduling by blending resource histograms derived from previous construction schedules with the numbers of workers available in the local marketplace. Again, these considerations should occur in the evolutionary iterations of scheduling between the first draft schedule and the

final preconstruction schedule so that problems therein have been eliminated prior to the creation of the preconstruction schedule.

Balance between manpower loading and equipment capacity As both (i) manpower and (ii) construction process equipment such as cranes, hoists, on site transport etc. are the two main types of productive resources it follows that the work volume of each on site should be complementary. That either is waiting on the other creates redundancy costs without adding to the end product. The scheduler should address this issue in creating the schedule by firstly developing charts of resource loading per week from his draft schedule for all types of resources. Then, he should examine them in relation to the proposed capacity of each type of resource to be put on site. Probably then is also the time to settle the issue of which types of construction equipment should be put on the site so that the construction process and its numbers of workers is neither inhibited by the proposed capacity of the equipment nor will it be standing redundant for considerable durations. Also involved in this factor may be whether it is better to put two or more smaller pieces of equipment on site with about the same capacity of one larger piece of equipment. To do so gives both resource flexibility on the site location and reduces probability of total construction stoppage by breakdown of the only support piece of equipment on site.

Another aspect of this factor is the duration for which major pieces of equipment are needed on the site. These are expensive as well as productive resources so that by revising the schedule so that these pieces of equipment are on site for the shortest calendar duration can reduce the costs of construction without affecting deleteriously the construction duration. However, this may require simultaneity of work that requires the services of such equipment but which, in turn, may overload the labor force or management or create too close interactions among such work which leads to slow downs and increases in durations of actual work thus causing actual construction to drift away from the schedule. All these aspects of the schedule have to be traded off and brought into balance in the evolution of the schedule to create the best blended guide for the whole actual construction process.

Scheduling Experience of the Superintendent Clearly, the level of knowledge and experience of the site super on the technologies of scheduling can enhance or inhibit the benefits flowing from construction scheduling.

In order to be able to properly control the actual construction process from the schedule created, he has to be able to understand that schedule. If he only has a slight knowledge of the subject, the construction control plan may be tailored to his knowledge level of scheduling, even though that would not fully utilize scheduling potential. In that case, he should be

provided with education and training on scheduling technology and construction scheduling i.e. the blending of scheduling and construction knowledge so that the site super does not inhibit the benefits flowing from the use of a carefully created and wisely realistic construction schedule which has been put together as the best way to carry out the actual construction process for a project.

As the site super, along with the office based project manager, should be the major authors in creating the construction schedule, it is wise that the site super be appropriately knowledgeable in the technologies of scheduling. Without such knowledge it will be a much poorer schedule than could be if he had that knowledge. Also, site super may not fully participate in creating the schedule because of his lack of knowledge of the subject. This, less than full participation, will result in less commitment from him to carry out the actual work according to the schedule even if he understood what it said.

It appears that simply tailoring the construction schedule to minimal knowledge of scheduling by the site super partially defeats the fundamental purpose of scheduling.

It may be that some improvement could be made in construction performance by improving the communication of the schedule to such a site super. However the site super should be an integral part of the authorship of a schedule for a project of which he will control the construction. If his lack of scheduling knowledge causes his input to scheduling to be

precluded, then his psychological commitment to trying to work to the schedule is greatly impaired and thus the actual construction process has a higher probability of being less efficient than it could have been. Also, the schedule which guides the actual construction would be less good than if the site superintendent was an author of the schedule.

Ease of Updating The creation and evolution of the schedule can be one sub process, the transforming of it to the best basis from which to communicate with and among construction people is another sub process and the actual control of construction by the schedule is a further sub process.

As a major activity in controlling construction processes, the progress of the actual construction process must be regularly monitored against the scheduled expected progress to specific dates. Then all differences between scheduled and actual should be established prior to managerial decisions on what should be done about their differences. This post monitoring process may require updating of the schedule i.e. the adjustment of the remainder of the schedule to be a construction process to meet the original project objectives but with a schedule of changed logic and/or changed resources and supplies for the remainder of the construction process.

This updating process can be inhibited or facilitated by the format and nature of the schedule set up as the original final preconstruction schedule by which to control the actual

construction. The format of the schedule should make it easy to update the schedule. The most appropriate schedule format to ease updating as well as understanding of the schedule by construction people of less than complete scheduling knowledge, is a time framed bar chart of network activities which also shows the construction logic interactions between all tasks. This appears to be the most appropriate format of a schedule from which to control actual construction work. However, to originally create and develop that construction valid schedule includes network logic diagrams, activity durations, network calculations, consideration of resource histograms, calendar timing and iterative evolutions to improve it from origin, or first draft, to be ready, and of a quality to be presented in the above time framed logic bar chart from which to control the actual construction process.

Maintenance of a Consistent Workforce Most contractors prefer to put workers on site whose number builds towards a work force of optimum size and then keep it at that level for as long as possible before running it down sharply towards the end of construction. They do not want to move men on and off site during their construction and they want to keep everyone fully employed while on site.

The construction schedule should be created recognizing that most contractors see this as the optimum way in which to carry out their work. If the schedule does not allow the above to

occur there is a high probability that subcontractors will put a smaller than optimum overall work force on site and take longer calendar time to do their work to create their desire of a consistently productive and thus more easily managed work force. Alternatively, they will put a work force on the site of required numbers of men over a series of short durations when, and if, such men are available from other projects. In both cases, the construction schedule can say one thing and the subcontractors will operate differently.

The scheduler should understand this real productivity maximizing issue and realize that it is the resources of the sub contractors that he is scheduling and that the site super does not have absolute control over them but must manage them through their employer. Thus the schedule should include the appropriate balance between the needs of the construction process as a whole and the work continuity and productivity/cost needs of its major participants by arranging for realistic sizes of consistent work forces. In turn, this influences the logic of the schedule and the durations of activities in the schedule. By not recognizing this issue there is high probability of major differences between the schedule and the natural construction process.

By the schedule recognizing this factor and the real world forces behind it which cause contractors to allocate their resources to a construction process in this way means that the final preconstruction schedule will be more realistic and thus

better as the datum by which to control the actual construction process.

The Estimate The estimate, its productivity figures and its underlying construction premises, can and should be a major input to the creation of the construction schedule. The estimate for the construction process is a carefully created forecast of the expected cost of the construction process. Construction costs are derived from the consumption of numbers of costed resources over durations of time on each construction activity/work item in the estimate. The schedule presents the same information as the estimate but in the format of time framed logic sequence of the construction process showing the various construction activities and with each activity showing its duration and calendar timing. Thus it can be seen that the schedule to a large extent, could be derived from the information in the estimate by reformatting that information from cost to time.

At the very least, the information in the estimate should be carefully consulted as input to the schedule and the estimator may be called upon to join the office based project manager and the site super as a major author of the schedule. He made choices of construction processes and expected overall process of construction as part of creating the estimate and he is working for the same organization as the scheduler, office based project manager and site superintendent for the project so it is sensible that his input be considered in creating the schedule.

weather seasons of this factor, the scheduler can find how to minimize the added increment of cost to achieve the specified completion date.

Availability of High Skilled Workers Just as a construction process activity can be on the time critical path or be a logically crucial piece of work for the start of many other tasks so the availability of appropriate high skilled workers can be a crucial or critical constraint on carrying out certain work. The more expensive or time critical or logic crucial a task, the more willing a contractor will be to have it carried out by high skilled workers to ensure that it is done correctly both technically and according to the schedule. Thus each sub contractor has not only to have enough workers to meet the scheduled speed of his work but also requires enough high skilled workers to preclude holding up the actual construction process from non execution of work which requires highly skilled workers.

It follows from the above that both the scheduler and the on site controller should seek out information on the availability of high skilled workers in each trade in the project locality and firstly schedule the work accordingly and secondly ensure that the appropriate subcontractors have such skilled workers on site when they are required by the schedule.

This factor may cause the logic of the schedule to be adjusted to enable the same small group of high skilled workers in each trade to work continuously over the duration of the

schedule or sub parts of it rather than have the schedule cause delays in other work because all work by a high skilled group is schedule to occur somewhat simultaneously.

Intended Use of the Building The intended use of the building has implications as input to the scheduling and should be derived from the contract documents. This factor is usually directed at setting the level of complexity or simplicity of the construction process which has a direct bearing on the nature of the schedule. The schedule should try to present the actual construction process as simply as possible thus dissolving its inherent complexity before the constructors have to do their work. Clearly a first step in that process is establishing the inherent level of complexity of construction which usually comes from the intended use of the building e.g. a hospital is much more complex than a retirement home although both are in the medical types of building.

The intended use of the building and the level of inherent complexity may also affect which scheduling technique would be best used.

The importance of the intended use and the effect on human life therein will affect the stringency of inspections and the level of care that must be taken in the construction process. Both of these affect the logic of the construction schedule, the array of tasks required in the schedule, and the durations required on most work activities to be carried out either

carefully or simply or quickly. These different durations on different projects for what appears to be the same activity can seriously perturb the overall schedule for a particular project if the intended use of the building is not allowed to influence the chosen durations.

Availability of Construction Equipment Construction equipment can be considerably more productive than human labor thus its use can dramatically affect the durations of activities in a construction process. The use of construction equipment on site is dependent on its availability in that project locality.

Usually most types of construction equipment can be found for rent for any project location but that introduces the issue of rental or ownership cost of the equipment which may cause the choice of equipment to be of one size rather than another size of the same type of equipment. The choice of equipment for a particular project may be influenced by what is owned but currently unused equipment in the general contractors yard. Again, the choice of equipment should be made from what is available and the schedule logic and activity durations should be based on construction process productivity given the choice of equipment to be put on the site.

Which type and size of equipment will be used in the actual construction process should be input to the scheduling process and once the schedule is created the equipment choices should not be changed without changing the schedule. This has implications

for the scheduler in that he has to find out and know what equipment is available and what would be the most appropriate to use on this project. Once the construction strategy has been set based on the use of particular choices, then the durations of work activities and the whole schedule can be more realistically set.

Prior to and during construction it follows that the equipment built into the strategy of the construction process should be used. If that is not done, the actual construction will be different from the scheduled construction process with the obvious undesired problems occurring during construction for all participants to the process.

Placement of Equipment on the Site The location on the construction site where construction equipment is to be placed can increase or reduce travel distances of materials and labor as they move to and fro across the site in relation to their various specific work locations. These distances of travel affect durations and productivity of the workers as well as the cost and durations moving materials to the workers. Problems in these movements may create delays in the actual construction process thus causing differences between it and the construction schedule.

For the schedule to be a representation of the best actual construction process it follows that the placement of equipment on site should be an input to the scheduling process. Also, the

actual placement of equipment on site should not differ radically from their planned placement without revising the schedule.

The scheduler should find out and create with the site super what these placements will be prior to finalizing the schedule.

The placements need not be an absolute prerequisite to scheduling as the two are interactive. Thus it may be appropriate on some projects to develop an initial best construction process schedule, then consider the best placement of equipment on site and then revise the draft schedule accordingly. It should also be remembered that there are more than this one flow of inputs into the scheduling process and the relative importance of each flow may vary from project to project but be fairly fixed for each project.

This factor is also dynamic in that during the construction process it may be beneficial to overall construction productivity to change the placements of equipment as the locus of construction activity moves across the site. If such changes are of benefit to the efficiency of the construction process then such changes of equipment placement should be shown on the schedule and the effect of the changes in their location on the productivity and durations of activities should be built into those aspects of the schedule.

Interference From Utilities This factor can be considered in two ways, (a) the location of existing utilities on site and (b) the

work of utility companies in doing work on site related to the contractors construction process.

The location and runs of all utilities on site should be found and fixed on the construction site prior to beginning construction. This establishing of utility runs should be input to the scheduling of the construction process and thus this search should be made before the beginning of scheduling rather than only before actual construction. Usually, location problems occur with those utilities which are underground and not known. The impact of these may only be on the excavation trade but a delay in excavation usually delays all work of other work trades which compresses them into a shorter time window which increases the probability of more complex or simply closer time interactions between all the other trades which can reduce productivity. Also, management work on deliveries etc for later work is put into confusion by this type of delay of the whole process.

If new utilities have to be provided on the site or existing ones modified then the local utility companies might well be working on the construction site during the construction process. Their work should be shown on the schedule even though they are not contractually part of the project. To schedule the utility companies work requires the scheduler or his company to interact with the utility company to establish when their work can be carried out and if possible, induce that work to take place at a calendar time compatible with the construction process. There

are at least two aspects of that compatibility, (a) the utility companies work is carried out during the most appropriate phase of construction work and (b) it is completed by the point in time that the utility is needed to function on site so that its non completion will hold up many other subsequent pieces of construction work. Temporary power or water or sewer services could be examples of these.

If the utility company appears to be operating in a non cooperative way with the contractor in these matters of fixing work times, the contractor may want to bring the project owner into the situation as he may have more leverage on the utility company than the contractor. At least by involving the owner regarding the utility work being put into the schedule, he is aware that if there is non performance by the utility company, that there will be an impact on the remainder of the construction process which may be costly in time and money to the project owner as well as to the contractor.

Optimum Movement of Crews During Construction The amount, distance, and variety of movement of each work crew of all subcontractors on the site can increase or decrease the durations of work, worker productivity and costs of construction. If workers have to move themselves and their tools and materials almost randomly across the site from day to day, it will take longer to build the whole project with a given set of workers than if the crews moved from one work location to an adjacent one

to another adjacent work location. Thus, in setting up the schedule for the best actual construction process, the scheduler should carefully arrange the flow of work locations as a series of adjacent locations so that there is a minimum of travel time from one work location to the next and the next etc for all work crews.

This factor can be seen as a major strategic construction factor to be introduced as a repetitive controlling pattern of sequences of all construction activities in the schedule. It involves seeing the sets of similar work tasks as best taking place in a series of geographic locations on site. Then each series of similar work tasks is woven together as the whole construction schedule. That weaving requires combining each of the above series of work tasks and locating with groups of similar work types usually from rough work to finish work across all trades throughout the whole project. It also involves considering the flow of materials etc. to the site and on the site so that they and the above schedule can be meshed together. These strategic considerations should be considered and established prior to the development of the detailed scheduling of individual construction activities.

Location of the project can be seen in two ways (a) the relationship of the whole site to its surroundings and (b) the location of the building on the site to the nature and layout of the site.

The scheduler should obtain and use the information on the surroundings to the site and their relationship with the site as input to scheduling. These factors of the location should be considered as potential accelerators or decelerators to the construction process and as input to the most appropriate strategic logic to guide the details of the schedule representing the best actual construction process.The establishing of what is the nature of the surroundings to the site can affect the numbers of on site temporary activities required and the logic and duration and manner in which on site construction activities can or should be carried out as a strategic flow around the site.

The location of the building on the site affects the size and layout of the remaining space on the site and which may vary upwards from zero depending on the building and its location. The placing of on site temporary services and stores should be thought out in conjunction with the creating of the construction schedule. These matters have considerable impact on the strategic logic of the construction process and the durations required to move resources across the site and do the work. Hence these matters have considerable impact on the durations of required construction activities.

Traffic Patterns Around the Site Traffic patterns around the site can be considered to include the permanent traffic on highways etc around the site and the temporary roads etc made on site to move materials and equipment across the site.

These factors affect the durations and facility of moving materials and resources etc to the work place on site. It may be that because of considerable public traffic around the site that deliveries can only be carried out within specified time windows during the 24 hour day. If this is so, then the construction schedule should reflect the batched use of on site equipment to handle deliveries during the unloading phases rather than assuming that the equipment will be used steadily throughout the working day to support normal construction activities. All of this impacts on durations of activities in the construction process and to a lesser extent, the logic of the schedule and should be considered in both creating and following the schedule.

Temporary traffic patterns on the site also affect the durations of construction activities and this should be recognized in setting up the schedule. These temporary traffic patters should be integrated with the placing of construction equipment on the site and both should be seen as input to scheduling of construction work. The scheduler can also interactively integrate (a) temporary traffic patterns required for placement of major equipment in the building with (b) the construction process as represented by the schedule rather than one dominating the other (although dominating by either may be appropriate in specific situations).

Contractors Company Image This factor can be seen more of benefit to the general marketing of the contractors services

rather than how it benefits the efficient execution of construction by following the schedule for each project.

The idea is that if the contractor uses valid scheduling techniques that he can generate more business and maybe more repeat business for his company. To generate repeat business due to his scheduling abilities would require not only that he uses such scheduling but that he produces benefits for others from that scheduling. Such benefits could be for owners by his regularly completing projects on time or it could be for subcontractors by the general contractors good scheduling and control of actual work by the schedule causing subs not to have to chop and change their work sequences which makes their forces more productive and his profits greater. Under such expectations of future scheduling, subcontractors will bid lower to such general contractors thus making them more competitive thus increasing the profits of the general contractor due to the reality of their reputations as good schedulers and good general contractors.

Unless the reality of good scheduling and control exists it may not be beneficial for a contractor to present himself in his marketing as such because such a difference between reality and marketing image will tend to reduce his potential for more work in the market place rather than enhance it. Under this circumstance, he will have to spend more resources continuously looking for project owners for whom he has not worked before, but who believe his marketing presentation on his scheduling ability

and who do not cross check his marketing claims with other project owners for whom he has built projects.

Job Safety Job safety is required of a construction process and hence, the schedule should include for the required safety features in both the logic of the process and the activity durations needed for safe construction work. It may be that erecting and moving safety barriers etc should be shown on the schedule as activities just as one would consider the movement of form work as part of the explicit schedule. A major influence on the schedule from job safety is that the duration of each activity should reflect the duration needed to carry out that work safely. In the rush to set activity durations or shorten the overall project duration, it could be that work safety may not be considered as fully as it should.

The draft schedule should be examined for different work activities that are going on simultaneously to examine the safety impact of each on the workers on the other activities so that the final preconstruction schedule includes the required safety separations between activities by time or distance.

All of these consideration should be built into the final preconstruction schedule rather than leave them to chance occurrences or changing the schedule during construction on the site. If they are not on the schedule, but have to be done on the actual construction process it is probably that the durations of placing the safety features will cause the actual construction

process to be "slower" that the "incomplete" schedule. This poorer than need be schedule from which the actual construction will be guided and controlled will cause considerable updating and revisions in all managerial work related to the project. All of these potential losses can be minimized by carefully including their solutions in the final preconstruction schedule.

During the evolution from initial schedule to final preconstruction schedule, the safety aspects of work occurring simultaneously can be evaluated by using a time framed printout of the evolving schedule. Subsequent to this evaluation, the unsafe simultaneous work activities can be repositioned to safer times in the schedule.

The Lesser Important Factors

The following factors were found to be of lesser importance than the others in the answers of the top quality construction experts who formed the source of the information on which this report is produced. Specifically, these are the factors which scored below 50% ratings on the sum of Always plus Most Times used by all the contractor executives on their responses. these factors are listed in descending order of their score.

Cleanliness of the Workplace The degree of cleanliness of the workplaces and on site generally, can have an influence on the speed of construction. If workplaces are not tidy or materials waiting to be incorporated into the building stacked up on the site, it is more difficult to move and manoeuvre resources across the site and hence more time will be required for that work. This, in turn, increases the durations required for the actual construction process thus the expected tidiness of the site should be factored into durations in the schedule.

If there is an abnormal amount of wasted materials lying on site, there may be delays in actual construction due to later non availability of the required quantity of these materials when needed because they have already been "accidentally" destroyed.

The scheduler should take these issues into consideration and they require an evaluation of the contractors approaches to their materials and work as it might affect the cleanliness of the workplace. Also, activities in removing waste might or might

not be needed in the schedule and on site temporary services layout depending on the strategy to be adopted for waste.

Scheduling Experience of the A/E If the A/E is to be involved in the management of the construction process then his knowledge and experience in scheduling should be considered as input to the preconstruction scheduling. More importantly, his scheduling experience will affect how he operates during the controlling of the actual constructing process by the schedule. The impact of the scheduling knowledge level of the A/E will probably have its greatest impact on the interface between the owner and contractor during monitoring of the actual construction progress compared to the scheduled progress. Therefore, the scheduler should establish the scheduling knowledge level of the A/E as input as to setting up the regular monitoring and update processes.

It may also be valid to include in the schedule the shop drawing, samples and submitted activities of the A/E dependant on his expected behavior in these important tasks. This tends to be tangential to firstly establishing his knowledge of scheduling to facilitate how to communicate with him regarding construction progress but it is important to the speed of actual construction, and hence, also important to its scheduling.

At the very least, the A/E's experience and knowledge of scheduling would have to be known so that communication to and from him regarding the construction scheduling and control

matters could be provided at or above the desired level of clarity.

Scheduling Experience of the Owner The project owners level of knowledge and experience in scheduling technology is somewhat separate from his knowledge of construction processes. It would be wise for the scheduler to find what is the project owners level of knowledge of these two matters as input to the scheduling process. As with the scheduling experience of the A/E, these aspects of owners' knowledge may be more important in setting up the construction monitoring and schedule updating processes than as input to the scheduling process. However, the manner and efficiency of monitoring actual construction is considerably influenced by the quality of the final preconstruction schedule.

It also follows that the project owners experience in scheduling can be balanced out by carefully formatting the communication of schedule information to and from him by the contractors scheduler/controller.

Probably the level of knowledge of the owner in scheduling would impact the contractor mostly in the degree to which the owner could be set up for claims and extras by the contractor. The less the owner (and the A/E) understands about scheduling, the greater potential for the contractor to arrange the schedule to be used to show cause for the actual construction progress to be delayed by the owner and A/E and vice versa. Of course, if that occurred, the owner may utilize the services of someone

knowledgeable in scheduling to redress the above imbalance between the parties. Also, the ethical standards of the contractor would become exposed should he choose to operate that way.

Possible Claims and Lawsuits The schedule is the datum to which the actual construction process should be built unless there are changes in the required work due to change orders. The issue of a change order changes the contract between the owner and the contractor, including the schedule, if appropriate.

Delays can be caused in the affairs of the general contractor or his subcontractors and their suppliers - all of which are the responsibility of the general contractor to handle and correct at his own expense. Other delays to the work of the contractors may be caused by the actions of the owner or his architect/engineer. Shop drawings may be handled slowly or decisions may be made slowly during construction which will slow or hold up the construction process or its preceding managerial activities. If the cause of a delay is the responsibility of the owner or his agent, then its effect on the schedule and the costs of construction may generate a claim by the contractor. If such claims include consideration of time then the scope of the claim will be the difference between the planned schedule and the actual process of construction caused by the reason for the claim.

If the contractor is of a contentious nature or the contractor considers the owner to be of a contentious nature, then the contractors' setting up of the initial schedule may contain consideration of potential for delays and claims to be raised during the actual construction process. Such consideration by the contractor during creating the preconstruction schedule will be to increase the potential for later claims by the contractor against the owner by skewing the schedule to overly fast construction which is dependant on faster than normal inputs from the owner and his advisors. This can be seen as somewhat unscrupulous or as a defensive approach by the creator of the schedule. There can be a tendency among some contractors to create two schedules to this end. One of them can be a construction schedule which is the best realistic plan for the actual construction process to be followed. The other schedule is one which acts as the interface between the contractor and the project owner. That schedule will be the one by which to evaluate future claims and make up interim progress payments.

At one extreme, this double schedule approach by some contractors is often expressed by providing a preconstruction schedule to the owner and A/E that is comparatively too vague to be used to control the construction process. In turn, during construction, careful records are kept of the actual construction process and if extras are to be sought by the contractor late in the construction process he will then retroactively create a planned schedule from his actual work process record to maximize

the validity and size of the claim by maximizing the difference between his actual construction process recorded and the newly and subsequently created hypothesis of what the initial plan was intended to be.

While all of the above can become pernicious and draws attention away from creating, prior to construction, the best schedule by which to carry out the actual construction process, it does appear to exist but is poor practice by a minority of contractors.

Type of Neighborhood The type of neighborhood around the site can affect the array of on site temporary services provided and their costs to the project.

Protection of the site from vandals, location of on site temporary services and storage facilities etc are influenced by what lies outside the site. More fundamentally, factors such as the height of surrounding buildings, the volume of traffic on adjacent streets and the location of utility services etc all affect the construction process and its required resources. The choice of what type of cranes is influenced by the height of surrounding buildings and may limit the capacity to move materials across the site. Similarly being able to or not able to unload trucks on adjacent roads can affect the speed of construction and the congestion on the site surrounding the building, again affecting logic of the schedule and durations of activities in the schedule. These site services, in turn, affect

the sequence that is the best construction process and the durations of the activities in the schedule.

The scheduler should consider the characteristics of the neighborhood and their effects on the construction process as input to scheduling the construction process and these factors may lead to the generation of a number of alternative schedules each with variables in the resources (e.g. types of cranes etc) used and examine all to seek out the best schedule.

Specific Billing Requirements The conditions of contract normally specify how and when interim progress payments will be calculated and made. Supplementary conditions of contract may require a specific sequence of major parts of the building (or the buildings forming the project).

Both of these aspects of the contract can affect the content, sequence and timing of work activities to constitute the construction schedule. These aspects of the contract will certainly affect the contractors cash flows - outgoings and incomings which are also derived from the sequence of the construction schedule. Hence, there is interaction between the billing requirements and the construction schedule on a fundamental aspect of running a construction company i.e. project cash flows. This negative or positive cash flow on each project has to be capable of being handled by the finances of the contractor, he has to set up the construction schedule to provide the work sequence to provide a cash flow that can be handled.

Hence, the scheduler should consider this matter as input to scheduling the construction process.

Cash Flow From a logically prepared construction schedule of identifiable independent activities with each activity having attached to it a calendar duration, its cost and its price, it is possible to create cost cash flow per unit of calendar time and a price/income cash flow per unit of calendar time for the whole construction process. Clearly by doing the above, the difference between the outgoing cash flow and incoming cash flow can be established per unit of calendar time.

All of this cash flow information can be very beneficial to the constructor and scheduler as they consider the financial ramifications the construction process. Usually, as a result of showing these cash flows, the initial construction schedule from which they were derived may be revised and modified logically or in time sequence but not usually in the allocation of resources to each activity on the schedule. The objective of these modifications of the initial schedule is to create a more beneficial balance for the contractor between his outgoing cash flow i.e. costs and the incoming cash flow i.e. interim payments from the project owner. This has to be achieved by the scheduler while he still schedules the underlying construction process within the expected overall duration etc. as efficiently as possible.

These cash flow considerations should take place in the iterative revisions of the schedule between its original creation

and its evolution to become the final preconstruction schedule which will be followed by the actual construction process in which the cash flows will occur.

Craft Work Assignments The work assignment distinction between construction crafts will be more prevalent and important in union labor locations than in non union locations, but it is important even in the latter for simplicity of management of the construction process.

Generally, each specific work activity in a construction schedule should be allocated to a specific subcontractor on the project and to a specific craft or trade in the project locality. The scheduler should ensure that his allocation of work activities to a particular subcontract falls within the work scopes which will be or have been bid and contracted by subcontractors and care should be taken regarding this prior to letting a subcontract and creating the construction schedule.

The contract work scope of a subcontractor should be expressed as a list of work tasks and the work tasks of all subcontractors on the project should be the universe of work tasks from which the schedule is created.

In union situations poor allocations of work tasks to trades and their subcontractors could lead to jurisdictional disputes. Union jurisdictions help to define subcontract scopes and which work tasks are carried out by which sub trades in a locality. In

turn such local industry specificity assists the construction scheduler.

In non union locations, which trade does what work will require more attention by the general contractor and thus the choice of subcontractors work scopes are more in the hands of the general contractor. Hence, it is more important in this situation that the purchasing agent of the general contractor and the scheduler utilize their relative freedom of choice carefully. They should coordinate making their choices for allocation of tasks to subcontractors prior to creating the contract packages and buying out the work and a smoother construction process can be scheduled and achieved. This greater potential for choice implies an early consideration of work tasks for scheduling as input to the procurement process.

Prevailing Winds The direction of prevailing winds across the site may affect where to place temporary services that create a lot of dust so that it has minimum effect on the workers. Of course, benefitting the workers on site may cause hardship for the neighbor to the site on whose property the dust will blow.

Another aspect of considering prevailing winds may be the location of storage of materials which require to be hoisted by crane towards the building. By placing such stores downwind from the building causes their hoisting across the site to be into the wind towards the building thus assisting the control of these

materials in the air and minimizing the potential to damage the building and the materials from a collision.

The location of these temporary services may affect the sequence of construction work and the duration of activities therein and thus this factor can influence the logical generic sequence of construction which is set by the schedule. Hence, the prevailing wind direction should be considered as an input to scheduling.

SCHEDULING EMPHASIS FROM DIFFERENT TYPES OF BUILDINGS

(a) Office Buildings, Shell Only

(b) Office Buildings, Shell Plus Finishes

(c) Apartment Buildings

(d) Schools

(e) Factories

(f) Hospitals

(g) Housing Subdivisions

Scheduling Emphasis From Different Types of Buildings

Different types of buildings require somewhat different emphasis in their construction processes for each to maximize construction efficiency. Hence, the construction schedule for each type of building should emphasize the construction process features meaningful to that type of building.

The construction executives were asked to state what features of the construction process should be emphasized in the construction schedule to facilitate construction efficiency in different types of building. The building types so presented were (a) office buildings, shell only, (b) office buildings, shell plus finishes, (c) apartment buildings, (d) schools, (e) factories, (f) hospitals and (g) housing subdivisions. The scheduling emphasis for other types of buildings could be derived from interpolation from the above array.

It should be realized that these emphasized factors for scheduling of different types of buildings should be considered in combination with those stated for buildings of different natures. For example, a hospital can be high rise or low rise and it could be in a city center or rural or suburban situation. For a particular hospital project, the scheduler should blend the factors stated in each of three categories of variables e.g. the hospital factors, with the high rise factors with the city center factors. That combination creates the conceptual framework from which to express the details of that specific building in a

construction schedule for use to guide and control the actual construction process in the most efficient manner.

The factors or groups of factors which should be emphasized in the schedule for particular types of buildings as stated by the construction executives will now be presented.

(a) Office Buildings, Shell Only

The factors for shell only office buildings fall into two major groups: those dealing with the expediting of the construction process and those parts of the building which required most attention to speed construction of the whole building.

In the construction process the coordination of the work of all subcontractors and their work crews is important and should be scheduled to maintain continuous flows of work for all work crews.

Fast construction is desired with minimum buffer time gaps between the work of each work crew in each work zone of the building.

Greater managerial effort should be expended in expediting work which is crucial or critical work for the whole process and such work should be clearly identified in the schedule.

The early provision of utilities, either permanent or temporary and the availability and careful management of vertical transportation of materials and men facilitate the continuous flow logic of such a schedule for a high speed work process.

The schedule for the shell office building should receive input from the owner regarding what the expected tenant finishes will be and when that separate broad wave of work will be required to begin and finish in each segment of the building. This aspect of scheduling the shell work establishes the most appropriate flow of construction activity around the building and should be established before actual construction work of the shell begins.

The availability and delivery flow of materials to the site is important input to the construction scheduling especially that of special and major pieces of electrical and mechanical equipment.

In this type of building, a small point but one which may cause difficulties and thus should be considered by the constructor is the activity required and the probability of obtaining a local government certificate of completion for shell only construction because shell only is not a complete building.

The skin or shell of the building along with the structural frame are of major importance as these constitute the majority of the work to be carried out. Drying in the building by completing the external wall finishes and roof should also be expedited by its early, but realistic, position on the schedule.

Any special foundations for particular subsurface conditions are important as is the completion of the elevator work. The latter can facilitate the construction of the building by placing less need on temporary hoists and cranes.

The early completion of the site work to give the finished appearance to tenants which assists renting, is also of importance to scheduling this type of building. This work may have to proceed simultaneously with and in some conflict with the construction of the shell building to achieve that objective.

All of these features should be thought about and emphasized as input to creating the construction schedule for this type of building.

(b) Office Buildings - Shell Plus Finishes

A major input to scheduling this type of construction is to establish what will be the nature and scope of the tenant finishes broad wave of work in each part of the building. If these are known prior to starting the schedule for the shell work then a whole preconstruction schedule can be produced.

The more likely situation is that these tenant finishes will not be known at that time and scheduling such work should be expressed in two major waves of work (i) the shell and (ii) the finishes. Then the scheduler has to schedule when the finishes information will be available and what might well be its design and use a probabilistic approach to scheduling that work. The probable finishes work should be used as input to selecting the best strategy of construction for the whole project. Furthermore, the timing and duration of design of finishes and its contracting etc should be work items on the construction schedule of the shell and whole building. Whether each tenant

will be designing, contracting and construction their own finishes or whether all such work will be handled by the project owner are inputs which have major impact on what the schedule for construction will be.

Fundamentally, the shell work has to be scheduled, the finishes work has to be scheduled and their interactions have to be coordinated by scheduling. This can be done as two separate waves or schedules or they can be treated as one construction schedule with a small time buffer between their work activities in the schedule. The objective is to finish the whole building as soon as possible therefore the shell work should tend to facilitate the starting of finishes work as early in the schedule as possible.

The desired level of quality in the finished building will have impacts on the durations of work activities and the amount of temporary protection work required for it while the remainder of construction continues. These in turn require enquiries on the availability of materials and skilled workers to carry out that work. All of these are inputs to the schedule.

The logic of the schedule should facilitate fast construction by all work crews. This requires the scheduler to consider cycle times, work sequences around the building and paralleling the work of required finishes and their rough ins in different locations of the building. In turn, this implies the potential of seeing the building finishes as being in a series of

geographic locations and scheduling each as simultaneous work in all the locations in the whole building.

Clearly, to enable finishes to start as early in the construction process as possible the shell work should be expedited and the schedule should reflect this. Shaping the schedule to achieve early dry in of the building envelope is very important here. To a large extent this requires all work required for the envelope i.e. external walls and roof and their structural requirements to be carried out very quickly with a minimum of holdups. This requires considerable management effort in ensuring the flow of resources to the site to maximize the work speed.

The scheduler should establish the size and capability of the management to be put on the project to establish the most realistic achievable speed for construction and use that information as input to scheduling.

The scheduler should also check on the local availability etc of materials and workforce required to support that desired speed of construction.

Other features considered of importance as requiring emphasis in scheduling on this type of building are the internal finishes etc and that core areas of bathrooms and elevator shafts tend to be geographic location work bottlenecks in the construction process. Hence these geographic locations should be more carefully scheduled than others, to minimize frictions between work crews.

Work involved in providing temporary utilities and services for the construction process, should be included in the schedule if they are desired to expedite the construction process.

(c) Apartment Buildings

Construction of apartment buildings and their scheduling tend to aim at high speed construction. The schedule has to carefully sequence the work of the various work crews of different sub contractors, carefully sequence the work flow around the building and have all work crews of a resource size and capability working for a duration in each work zone compatible with the work cycle required of all work crews.

The schedule should also be derived from the sequence and dates upon which each major segment of the building is to be completed and handed over for selling or renting rather than simply construct the building as a process within itself which has to be changed later because such information on required completions was not sought prior to scheduling.

The schedule should be trying to balance (i) continuity of flow of work of all work crews, (ii) maximizing the use of workers learning curve, (iii) maintaining stable sized work crews, (iv) minimizing friction between work crews, (v) maximizing repetition etc., with the object of achieving speedy completion of the whole construction process and each geographic zone scheduled within the whole.

Less obvious but relevant features of the schedule for this type of building are to coordinate and schedule the work of mechanical and electrical work crews prior to scheduling the work of framing crews of other trades.

There can be considerable differences in durations of carrying out the same construction work after tenants are occupying some apartments compared to doing so before tenants enter the building. Thus, durations of work activities should reflect this matter in the schedule. The logic of most construction work activities, especially site work sequences, will be affected by this factor.

The overall size and layout, or position, of the building on the site have considerable influence on the construction schedule as does the nature and placing of access to the site from surrounding streets.

The desired quality in the buildings can affect durations of their work activities. Positioning all the required municipal permits and inspections etc by local government agencies should be considered as work activities and included in the schedule as work activities. Also to be shown as work activities with realistic durations is work to be carried out on public highways etc for utility hookups etc.

The scheduler should check out the availability of workers to carry out the type and quality of work required and allow these factors to influence the duration of construction activities from that so that the schedule is realistic and

achievable. The availability of materials and the quantity of their flow to the site which is capable of being handled, should also be considered as input shaping the realism of the schedule.

The major physical parts of an apartment building which should have major emphasis in the schedule are the processes of completing the frame or structure, enclosing the envelope to enable all finishes work to proceed and the site development work before, simultaneous with and after the building work.

The construction of the frame is a precedent to carrying out the finishing of the envelope, which is a precedent to the work of the large array of finishes work crews which finishes the construction.

The site development work around and under the building has to be done before the building but the site development work away from the building may be done simultaneous with the building work. If the building can be seen as a set of geographic sub-projects then all of the work could be scheduled by using multiple crews, each on the same type of work and so maximize the parallelism in the schedule to achieve minimum calendar duration of construction.

The apartment building construction may have to enable fast early work on model apartments to be carried out to completion while the rest of the project is being constructed normally. The models could be treated as a separate work package from the main work or carried out by the same sub contractors within their overall work. Whichever approach is decided upon, its work

activities should be expressed in the overall construction schedule. The work activities required by the maintaining of access to the models etc by the public should also be thought out and expressed in the schedule.

(d) Schools

Factors to be considered in scheduling school construction are in two major groups - factors dealing with (i) the process of construction and (ii) the parts of the building requiring most attention.

The overall strategy and a major boundary of a school construction process is set by the school calendar year. The construction must be finished by a calendar date to enable the school to function at the beginning of the school year or term. As the actual construction must achieve this objective the schedule should guide the constructors to that goal by creating the construction schedule to meet that deadline into the schedule.

A major feature in the construction process that should be recognized as work activities in the schedule are the various inspections and approvals for parts of the building by school authorities. Also it appears to be wise to include in the schedule all the government paper work processes regarding the construction process of schools. While these are not direct construction work activities they are required activities for the future construction work activities to start.

There needs to be concern for the availability and productivity of the labor force on construction work of the comparatively simple nature required in schools. Both the numbers of workers and their productivity affect the durations of work activities and so should be part of the input to scheduling. Similarly the availability and delivery processes for materials, especially those for food services, mechanical and electrical equipment etc. and other specialist equipment with long lead times should be sought out and realistically appraised for their durations as input to the setting up of the logic of the schedule in relations to calendar time. Access to the site for such materials and equipment should also be checked for potential inhibitions to the speed and logic of their inclusion in the construction process.

The logic of the construction schedule for schools is usually directed by the type of building design for such buildings. School designs tend to be of a low rise type with load bearing walls with mechanical equipment on its roof.

Areas of comparatively complex construction such as auditoria and gymnasia should be more carefully and fully scheduled to minimize friction among work crews of different subcontractors in those areas while also providing work continuity over the whole construction process for all such work crews.

The construction of the structural frame appears to be of major concern in expediting school buildings and the most complex parts of the building appear to be the mechanical (HVAC) and electrical systems including their integration and the installation of major pieces of equipment which tend to be placed on the roof. Thus, the scheduler should provide the appropriate detail in the schedule to create and guide and coordinate these types of work.

To a lesser extent the roofers work, internal millwork and specialty items on the interior of the building and suggested as requiring attention by the scheduler because they are potential bottlenecks or holdups to the remainder of the construction process.

Perhaps as schools tend to be low rise buildings with the above required emphases, the schedule should guide each of these various types of work as waves of work moving through the same sequence of zones in the building. That sequence of zones should be chosen having consideration of the location of site access relative to the position of the building and the desired sequence of completion for handover of each geographic work zone to the project owner.

(e) Factories

Scheduling of factory construction can be seen as providing an envelope for an array of production machines or processes. Usually such machines require support equipment and power

supplies and most of these items are unique and for all of them considerable lead time is usually required for their shop drawings, manufacture, and deliveries. The construction of the envelope and its schedule might well be arranged around and after the creation of the procurement schedule for these pieces of equipment which might not even be in the scope of work under the contract for construction. At the very least, the construction should be scheduled after receiving considerable input from the machinery procurement schedule. The processes of handling these machines and moving them across the site should also be included in the construction schedule.

It is of major concern that the construction schedule be arranged in phases to match the desired sequence of commissioning of the factory processes and machines by their manufacturers and their acceptance by the project owner's operating staff. All of these phases should be set up by the calendar dates of their starts and finishes and these dates should be expressed in the construction schedule as boundaries for the construction work required within that phase.

The access to the site and on site potential to provide enough space for fabrication of machinery and their support equipment (in or not in the construction contract) should be considered by the scheduler as he prepares the logic of the construction schedule and the duration of its work activities.

The structural framework of the factory is important for the schedule due to it usually having to be complete before the array

of machines can be put into place. Delays in the work for structural framework can create havoc to the site due to double handling and /or temporary on site storage of the machines delivered and risks of them being damaged on site. Thus, realism in the schedule for the structural work in relation to machine deliveries is desireable. Roofing and floor slabs may also be types of work which should be considered in the same manner as the structural work.

Large and very complicated electrical and mechanical services might be required for the factory machinery and may include sophisticated control devices etc. Work activities of this nature has to be scheduled carefully and their logical interactions and adequate durations for installation and for their combined testing and commissioning has to be carefully scheduled to prevent domino effects in later construction work.

The scheduler should establish whether the workers in the existing factory of the project owner are unionised or not unionised and what health and safety regulations cover the work in the finished factory. These subfactors can dictate what will be expected in the construction process or, at least what problems might arise if the construction process provides different coverage from those conditions which will exist in the completed operating factory. All of these factors should be established as input to the schedule and are especially important if the construction work is altering an existing factory. In this situation, all of the above factors have to be considered

plus the scheduling of the ongoing factory work, its downtime for construction, along with the newly constructed parts.

The modification of an existing factory would required the actual construction process to be more strictly controlled and hence, it would be advantageous to have a more detailed, high quality schedule. This can aided by the schedule adhering to carefully chosen phases of scheduled construction. This also puts a greater emphasis on the need for realism and accuracy in the logic and durations. The schedule for altering an existing factory should also have appropriate flexibility to handle required work which is unknown until existing parts of the factory have been torn out.

(f) Hospitals

Hospitals are usually extremely complex buildings and their construction process requires considerably more control of detail than other construction processes so that their schedules should be more detailed than for constructing other buildings.

Due to the life or death effect on humans in hospitals, there are extremely stringent inspections required of construction work by hospital authorities. This implies that to facilitate construction work, these inspections should be work activities in the construction schedule and they should be placed logically in the construction process and have appropriate durations for their execution. In addition to inspection by hospital authorities, the constructor most likely will be wise to

carry out a greater volume of quality control work by his own forces than in other buildings and these activities should also be parts of the schedule.

The schedule may also benefit from having some slack in logic and durations, or at least some flexibility, to handle the effect of changes in hospital regulations against which the construction work is inspected.

The process of procuring complex machinery and equipment for installation in the hospital along with their shop drawings and delivery and storage etc prior to installation is very important to facilitate construction of hospitals. These pieces of equipment tend to be very specialized and require very long lead times. Thus, establishing their realistic time requirements and dates of delivery to site are very important inputs to creating a realistic schedule of construction. Due to the specialized nature of these pieces of equipment, the duration of their installation testing and commissioning may be much longer than needed to simply couple up some pipes. This installation etc. work should be allocated realistic durations in the schedule. It may well be that each of these pieces of equipment require connections from a number of service delivery systems which affects the logic of the construction schedule by further increasing the installation complexity. These complications require far greater coordination of services subsystems work, each of which may be constructed by a different sub contractor or even work specialty within the same sub-contract. All of the

above needs to achieve the required coordination should be expressed in the schedule.

The most complex parts of a hospital project are its internal services, their rough ins and the finishes to each user space. Each user space may have a number of very complicated flows of services e.g. electricity, a variety of gases and medical liquids, sophisticated air conditioning and a considerable amount of control systems to integrate all of these to provide the required support to the interactive medical team which will use that user space in the hospital.

While each of these services and the parts of the building which support these rough ins are complicated, their construction integration is also important. This further compounds the construction process because they all have to be focussed into comparatively small geographic spaces such as individual rooms or to a number of locations within one large room in the hospital.

The construction work activities for these internal services are greatly helped by the existence of permanent or even temporary power on site. Some of the finishes work also requires the existence of humidity etc control. Hence, the earlier these major services can be functional on site i.e. by being scheduled early in the construction process, the more time is available for these complicated interactive finishes activities.

From the above it is clear that careful coordination of work crews and individual worker specialists is required in the construction schedule so that the actual construction process can

overcome this critical mass of complexity with a semblance of efficiency for each crew. Hence, the schedule has a more vital and central role to play in this type of construction for efficiency of all construction participants than in other types of buildings. The complexity of the services and finishes of each user space, the comparative lack of repetition from room to room and the wide array of needed construction resources require that the schedule be valid in its logic and realistic in its activity durations.

Once such a high quality schedule is created, it is the focal source from which all the work and management activities should be derived.

There can be considerable losses to the whole process and all participants by any one type of construction resources operating to its own efficiency and advantage by constructing without consideration of others and the schedule. This implies that the central role of this valid preconstruction schedule should be backed up with strong construction control management to have the actual construction process meet the requirements of the schedule by insisting on fixed scheduled deadlines being met by all participants. Put simply the actual construction resources should be directed to achieve the scheduled process more thoroughly on hospitals than on other types of construction because the costs of disturbing the prescheduled complicated actual schedule are very much greater than on other construction projects.

There is also good sense in the construction schedule being an interactive agglomeration of (i) the basic construction sequences of work activities of each work crew of each subcontractor, (ii) inspections, (iii) the procurement and delivery schedule for all major materials and equipment, (iv) a schedule of on site movements of construction process equipment and, (v) movement across the site and to the site of materials and equipment to be installed along with, (vi) required movement of construction support equipment and activities on the site and, (vii) the inspection schedule of finished user spaces including components and equipment which, in effect, is the schedule of handover of these spaces to the owner.

This whole agglomerated functional schedule should also be capable of being broken into parts for each construction sub contract package and by each geographic work zone in the hospital.

A schedule such as above should also try to maximize the use of the strategy of moving all the required construction work crews through these geographic zones of the building in the same sequence. Abberations from this strategy will have to be tolerated in creating the schedule to meet the realistic constraints of calculated delivery dates from long lead times of special pieces of equipment. Alternatively, it may be worth paying premia for deliveries to meet the overall strategy of the best construction process schedule depending on the prevailing specific circumstances of each project.

The parts of the building that require most attention in the schedule for hospitals are the multiple services to the user areas along with their rough ins.

The rough ins of the fabric finishes which have to be integrated to the services finishes and the provision of hospital quality surface finishes all have to be expressed in the schedule.

The early provision of (i) power and (ii) completion of the building envelope facilitate the start of the complex finishes and (iii) the potential to close off rooms that have been inspected as complete should all be ingredients of a schedule which facilitates construction work which is as fast as possible given the nature of hospital buildings.

If the hospital construction work is altering an existing hospital as it continues to operate (which is fairly normal) then all of the above demands of the schedule are further compounded by having to schedule the construction work within the boundaries set by the interface between the ongoing hospital activities and the construction work. This is usually done by creating work packages of and for the additional and alteration construction work in contiguous geographic zones of the future hospital. Such work packages should contain all construction work of all trades within each work package. The sequence and/or simultaneity of these separate work packages has to be scheduled to match the ongoing hospital activities and each may or may not be under a separate contract for construction.

The scheduling of hospital construction requires an wholistic approach rather than only scheduling the work in the construction contract or contracts. The construction work should be integrated into the whole hospital creation process rather than be an isolated entity standing alone and it is the whole hospital creating process that should be scheduled.

(g) Housing Subdivisions

The complexity of the construction process of a housing subdivision comes less from the doing of the construction work of each house and more from trying to schedule continuity of work for each type of construction resource over a series of individual houses in the sub division. This comes from each type of construction work crew having a different work load from other work crews in each house and also from the sequence of houses to be built probably requiring construction resources to jump around the site to meet demands of the buyers in the marketplace. Under these fixed and random disruptive circumstances, it is difficult to schedule a sequence of work and to find a cycle time that is efficient for all resource types.

This situation suggests that careful scheduling could provide considerable benefits to the construction process rather than merely accepting the inherent inefficiency. To do this, the schedule should encompass construction of all houses in the subdivision as one process rather than seeing it as adding together the construction schedule of individual houses. An

ingredient of such scheduling should be the consideration of how many houses it is desired will be under construction at any one point in time. That number of houses should be derived from the size of the realistically stable work force in that location. To balance all of these forces requires realistic consideration of the numbers and productivity of the available workers of each required subcontractor that can be found in the project locality. These factors should be considered as input to scheduling of housing subdivisions.

Major boundary conditions to the construction schedule are the marketplace driven nature of the housing business. This creates volatility and perturbations of a balanced construction process.

The requirements of local municipal etc. housing construction regulations, zoning and environmental hearings and requirements, etc., permitting processes and inspection etc. are all more specific activities along with appropriate durations which should be expressed in the construction schedule.

The effect of the volatile marketplace of house buyers on the scheduling of the construction work should be handled by setting up an optimum speed and logic flow of construction of the subdivision given the best evaluation of the expected degree of normality of demand. Then the control of actual construction should have the minimum amount of minor oscillations of incompatibility between the marketplace induced changes and the actual construction process. If there is a major change (rather

than minor changes) in volatility of demand - up or down - upon the normalized scheduled construction process then the remainder of the schedule should be redrafted as a total schedule under the new prevailing circumstances.

Site work, placing of utilities on site and other infrastructure work, are the types of work which require major emphasis in the schedule because their unique nature, dependence on site conditions and that they usually need to be done prior to the construction of the houses, means that they should be scheduled for fast construction to minimize the overall construction duration. Some site work surface finishes may need to be done out of the most efficient sequences to enable model houses to be ready for the public early in the construction process.

The combination of the site work and house construction parts of the schedule may best be achieved by breaking the housing subdivision into geographic subparts and having a strategic optimum sequence of construction within which each of geographic subparts.

SCHEDULING EMPHASIS FROM REPEATABILITY OF WORK PROCESSES IN THE BUILDING

Buildings With Many Repetitive Work Processes

(a) Learning Curve

(b) Work Cycle

(c) Sequence or Flow of Work Resources

(d) Resources Available

(e) Inspection of Work

Buildings With Few Repetitive Work Processes

(a) Diverse Array of Work Activities

(b) Duration and Efficiency of Each Work Activity

(c) Information Flows for Management

(d) Availability of Workers with A Broad Array of Trade Skills

(e) Availability, Delivery and Lead Times of Materials

(f) Construction Control Process

Scheduling Emphasis From Repeatability of Work Processes in the Building

By the design of the building there can be varying degrees of repeatability of work processes in the building. If there are features or components which are repeated many times in the design then there can be a highly repetitive, but still complex construction process. If there are very few repeated design features then the construction process will be made up from an array of diverse types of work activities. Also, there can be building designs which cause construction processes to have a mixture of the above two constituents.

Furthermore, and often not considered, the more astute and observant is the scheduler or construction controller of this phenomenon of repetitive potential, the more opportunity there is for seeing repetitive patterns of work in the design of a building that overtly appears to have only a few repetitive features.

Underlying the concern for perceiving scheduling in these ways is the maximizing of the learning curve in sequences of work tasks which are repetitive and maximizing the quality of logical interactions in construction processes which tend to have little repetition.

As scheduling of the construction process intends to lay down the best actual construction process to be followed for each building then that schedule should reflect and harness the realities of the degree of repetition in the building to be built.

The features of scheduling, schedules and their uses in controlling construction which are seen as important and appropriate for building of many repetitive features and few repetitive features will now be presented. Schedules etc. for buildings between these extremes should interpolate from both of these divergent sub sets of results to match to the degree of repetitive features in each building.

Buildings with Many Repetitive Work Processes

The major input factors to construction scheduling for buildings of this nature are (a) the learning curve, (b) work cycles, (c) sequence or flow of work resources (d) availability of resources and (e) inspections of work.

Maximizing the use of the learning curve for as many work crews of as many subcontractor trades as possible will minimize the cost of the construction process. To achieve that across the whole construction process requires integration of the work cycles and flows of all such work crews. This is usually coordinated by setting up the work cycle for all of them which will be repeated in many one work locations in the building.

To enable the work cycle of one work location in the building to be compatible with the same work cycle in each of the series of work locations in the building requires that a set of sequential work locations be identified throughout the building, all of which have approximately the same volume of work for all work crews.

The availability of materials and men are again factors to be quantified as input to the schedule because they affect speed of work crews and hence, the durations of work activities. As high speed of construction is likely as well as desired from this approach, the time of inspections should be scheduled so as to maximize the potential that they will occur when needed while minimizing their potential to hold up the state of subsequently scheduled work.

(a) The Learning Curve. If a work crew can carry out the same piece of work (in a sequence of locations) in a continuous series then the duration of each piece of work in the series can be and tends to be reduced over the series of work activities as the resource learns to improve the execution of that type or piece of work.

If a building has many repetitive features in its design then its construction process can include many series, each of similar pieces of work in that construction process. By the scheduler presenting these many series of similar work activities for each work crew in the construction schedule enables the benefits of the learning curve to be achieved in the actual construction process by each work crews, as that actual construction process is controlled by that schedule.

(b) Work Cycle. This cycle comprises two aspects (i) sequence and (ii) duration.

Consider one work location from the middle of the anticipated series of work locations in the building in which each of the array of required construction work activities is required. Then all these required work activities have to be formed into a list in the most appropriate construction sequence by which they can be carried out. This sequence then becomes the sequence of work by all work crews in all work locations in the building with repetitive features. After that has been established, the scheduler establishes the most common duration for each of these work crews to do its work in that location. The duration becomes fixed as the work duration for all work crews in that and all work locations.

Then the resource allocation is established for each work crew of each subcontractor to carry out that amount of work in that duration. By this approach to calculating the ingredients of the construction process maximizes the potential that all work crews can move at the same (common fastest) speed while each derives the benefit of the learning curve, which minimizes construction costs and maximizes harmony in the construction process which, in turn, minimizes costs of management of the construction process.

(c) Sequence or Flow of Work Resources. The above scheduling work regarding work cycle of each work crew and its speed of work and resources required how to mesh with the overall strategic flow of work around the building. This is established by the

scheduler analysing the building into work zones or locations each of which has about the same amount of work required in it for all work crews. This similar intensity of work from zone to zone should not be confused with similar square footage of floor area in each zone. It is work volume that is the concern of harmonizing construction, not end product building volume or area.

Once the building has been analyzed to these work locations the scheduler then has to prepare the sequence of the work zones or locations through which will pass all of the work crews on the sequence and speed established under the work cycle factor described above.

This sequence of work zones/locations is the best flow sequence of all work around the building having regard to the flow of work towards the ingress accesses to the site surrounding the building. This direction of flow should minimize the traffic of workers and materials through already finished parts of the building.

Finally, once this sequence of all work resources through the building has been established, it and all the decisions reached under the factor on work cycle have to be combined and expressed as the schedule which represents the best actual construction process for that type of building.

(d) Resources Available. The scheduler has to establish if there are enough workers available to do the work at the speed

scheduled from the locality of the building and from the subcontractors. This can be a revision of the schedule already created or an input to the resource allocation aspect of the above scheduling factor of the work cycle. The revision of the schedule produced from the confluence of (i) the factors of work cycle and zone sequencing and (ii) the level of resource availability need only affect the speed of work and hence only work activity durations may need to be adjusted and the logic of the initial schedule remains.

Materials must also be (i) available in the locality and (ii) capable of flowing to and across the site to match the desired speed of construction. Again the scheduler has to establish the status of these matters as input to creating the schedule so that the reality of the construction situation will be represented in the schedule. Only when that reality is in the schedule can the actual construction process occur with minimum perturbation from the schedule. Nonetheless, the schedule should have a slight bias towards optimism as a motivating target feature for actual construction.

(e) Inspections of work. Buildings whose construction schedule presents the comparatively high speed construction potential from repetitive features in the buildings design creates the potential that any required process that could inhibit, slow or stop any part of that construction process could disturb that comparatively finely tuned whole construction process. It

appears that inspections by municipal or regulatory agencies or even approvals by the project owner could create such disturbances if they do not occur when it is most appropriate for them to occur. Hence, it would be advisable for the schedule to include these inspections and any other activity which could have a similar effect on construction. Thus, early notice can be given to the inspectors or whomever as to when their activity is scheduled to occur in calendar time. Here the objective is to remove or reduce the potential of disturbance to the continuous flow of all construction activities because such disturbance will require much more managerial effort to correct them than would be needed on construction work which is scheduled with the less interactivity dependence.

Buildings With Few Repetitive Work Processes

The major component of schedules for construction of buildings which have few repetitive features is that emphasis should be placed on the logical and sequencing interactions among their ingredient work activities. This is mainly because such buildings have (a) a diverse array of work activities which have to be scheduled as one wholistic construction process. Other factors of lesser importance are (b) the durations and efficiency of each work activity, (c) the information flows for management, (d) availability of workers with flexible trade skills, (e) availability, delivery and required lead time of materials and

(f) that control of actual construction requires careful preconstruction thinking and actions.

(a) Diverse Array of Work Activities. Few rcpetitive activities means that there will be a diverse and varied array of work activities to be included in the construction schedule. Thus the scheduler should carefully think out and present the best sequence of work and logical interactions between the work activities from all required subcontract trades for the building.

Underlying careful thinking by the scheduler is important on locations in the building where (i) inter trade conflicts between work crews could occur and (ii) where and when specialty items or required different or abnormal items should best be built into the scheduled work process. The construction sequence in time and work flow process around the building should be carefully considered as the overall strategy of the scheduled construction process then the above more specific details should be built into the schedule.

The construction schedule for a building such as this most likely will require more detailed work activities and thus be more complex in its logic than a building with a mix of repetitive and non repetitive features. It follows that the higher the quality of the logic of the schedule, the greater will be the minimization of the problems of actual construction on building like this. Therefore, it is the logic of the schedule

for a non repetitive building on which the scheduler should primarily concentrate his thinking.

(b) Duration and Efficiency of Each Work Activity. Because of the logical complexity of the actual construction work and the low potential for benefitting from the learning curve of workers doing the same work again and again, it is probable that durations for each work activity in the schedule will be longer for each work on this type of building than on other types of buildings. Paying attention to this subfactor will provide more realism to the schedule as a construction control tool.

On a building with few repetitive features it may also be wise to allow in the schedule some down time between work crews of different trades doing their sequential work in the same work locations in the building. It may be wise to express such down time as duration buffers between such work crews in such locations in the construction process. The alternative will be to risk friction in many locations between many work crews which creates a deterioration in productivity of all work crews thus jeopardizing the whole construction process. Alternatively, this duration buffer may be expressed as an increment of increased duration for each work activity of each trade in the whole schedule. To do that risks that incremental buffer duration being used to do work rather than be a buffer but that is less

deleterious than having the whole schedule being unrealistic and a poor guide the actual construction process.

(c) Information Flows for Management. Again, because of the diverse nature and greater volume of the work activities involved in the construction process of this type of building, there is a high probability of a greater volume of required preconstruction information to be processed. Shop drawings, normal detailed drawings and inspections etc. will be required in greater numbers than in buildings with less variety in their design. Any of these information processes moving more slowly than stated or implied in the schedule could disturb the flow of actual work from the format in the schedule. Therefore, in preparing the schedule, these required information activities or flows and their realistic durations should be closely investigated and established as input to creating the schedule. The most important of these should be stated in the schedule if they are considered to be of major importance to controlling the actual construction process to follow the schedule. However, to include some of these processes in the schedule and exclude others may cause those excluded to be ignored or not pushed and they may hold up the actual construction process.

(d) Availability of Workers with A Broad Array of Trade Skills.

For a building of few repetitive features, the schedulers as well as generally checking on the quantitative availability of required workers in the project locality should also examine the availability of workers who have a broad array of skills within their trade. This type of worker can be put on a building such as this and work successfully at a wide variety of work activities in his trade. Put another way, because of the lack of repetition in the work on this type of building, there is little potential to use individual work crews which compose different but narrow skilled specialists. This aspect of constructing buildings of this nature should be recognized in the schedule logic as well as the durations of work activities.

A building with few repetitive features will tend to require or benefit from workers of a high quality of skills as well as variety of skills for economic efficiency of its construction process. This relatively high skill aspect of work availability should also be established and considered by the scheduler in his prescheduling enquiries.

This worker skill level and availability factor has impact on and interaction with the previous factor on durations of each work activity in the construction schedule. It may also interact with the major factor of the most appropriate logical sequence of the construction process being scheduled because if there are only a limited number of high quality workers available, their work should be scheduled to employ them as continuously as possible.

(e) Availability, Delivery and Lead Times of Materials. Again, as in scheduling of most types of building construction, the local availability of materials and the potential volume of that flow to the site should be considered as input to the scheduling. This type of building with considerable variety of features will require a wide array of different materials, each tending to be in a somewhat smaller quantity than for other types of buildings. Therefore, there is greater potential that any one of them being slowly delivered or simply overlooked could cause a delay in this more logically interactive schedule required for this type of building.

This has implications for managerial control of these material flows and increased risks from missing materials causing construction holdups. Existence or non-existence of an on site storage space for such a variety of materials could be another source of a bottleneck causing the same problem in the construction process - and this it should be clarified before being taken as input to the scheduling process.

A potential for simplification of the actual construction process of building of diverse types of features, work and materials and hence simplification of its schedule may be by consideration of the prefabrication option. Such an approach could be carried out off site or on site and may only need to be for crucial parts of the building which, if built in place, may cause complex groups of interactive work tasks in the schedule. This consideration should be carried out prior to and as input to

the scheduling of the construction process because it affects both the logic and the durations of work activities.

(f) Construction Control Process. Because of the comparative complexity of the construction process for a building of many different features, its managerial control will require more care and probably greater quantity of staff than for another building.

The work activities within the work scopes of each subcontractor trade will occur in a more complicated interactive construction process than normal and hence control management has to pay more attention to work at a more detailed level on such a construction process to maintain expected, realistic progress for all subcontractors as well as the whole construction process.

Given the above, a carefully prepared for and carried out preconstruction meeting of all subcontractors would be a vital aspect of starting the construction process on the right approach for all participants, especially for the contractor who will control the actual work. Prior to such a meeting each subcontractor should have been sought out for input to the scheduling priorities of his trade on that building and then the whole scheduled construction process balanced between these various and possible conflicting inputs.

The existence of such a carefully prepared schedule which is realistic in logic and duration for that particular building process can be a major asset in holding the number of required

resources in construction control management to a normal level during actual construction even though the volume of detail by which to control the actual construction process is greater than normal.

SCHEDULING EMPHASIS FROM HEIGHT OF BUILDING

High Rise Construction

(a) Cycle Time and Process for Each Floor

(b) Vertical Movement of Materials

(c) Cross Site Flow of Materials, etc.

(d) Enclosure of the Building Envelope

(e) Structural Framework

(f) Foundation Work

(g) Installation of Big Pieces of Mechanical and Electrical Equipment

(h) Installation of Elevators

Low Rise Construction

(a) Maximizing Continuous Harmonious Work Flows With Minimum Interferences

(b) Layout of Site Support Services for Construction

(c) Availability of Required Materials

(d) Enclosure of the Building Envelope

(e) Structural Framework

(f) Foundations Work

(g) Installation of Big Pieces of Mechanical Equipment

(h) Installation of Elevators

Scheduling Emphasis from Height of Building

In regard to height of the building, the two extremes of high rise and low rise building construction were presented to all the construction executives and their responses were sought on the features of each which should be emphasized in their construction schedules. With these features in mind, the scheduler would be better equipped to produce a schedule which would more clearly represent the solutions to the difficulties in the actual construction process of that type of project.

In the high rise building construction there is an emphasis on continuity and harmony of flow of work for all construction resources i.e. work crews. This requires a careful blending of all features of the construction resources as to their number, work speed, direction of flow etc and to the continuity of availability of all materials being supplied to the required work places. The early enclosure of the building envelopes is a factor of concern in this type of construction process.

In low rise construction the emphasis for efficient construction is to have a schedule which presents the best logical interactions among the many required detailed, diverse work activities. These individual work activities should have been derived from the building and its site to provide flexibility potentials in setting up an array of work sequences from which to choose the best. The time of enclosure of the building envelope and the complexity of site development work

also have important effects on choosing the best construction sequence for this type of building.

High Rise Construction

The major factors to be emphasized for the high rise construction process and its scheduling are (a) cycle time and process for each floor, (b) vertical movement of materials (c) flows of resources across the site etc and the temporary services required to assist that flow.

The features of the building itself cited as of major importance to the progress of construction and hence scheduling were (d) when the building envelope would be closed in and how fast that would be achieved, (e) work on the structural frame work of the building and (f) its foundation work. To a lesser extent, (g) installation of big pieces of mechanical and electrical equipment and (h) installation of elevators and were seen as other important matters in the schedule.

(a) cycle time and process for each floor. There will be many floors each with various work tasks within framework, rough work and finishes work to be carried out. It expedites both (i) the work on all floors and (ii) scheduling of that work if a process for construction one typical floor is carefully thought out as a cycle and its overall duration established for construction of that one typical floor given the array of tasks it requires from all trades. That cycle time then is the duration from the start

of the first specific trade on a floor to the finish of the last trades work on that floor and it includes all work activities by all trades involved in that cycle of work.

For application to construction work and its scheduling, that scheduling can be generally broken into three major sequences of cycles or waves, each of which operates as above. These waves of work are (i) the structural framework cycle and (ii) the rough work cycle and (iii) the finishes work cycle. Overall these form three sequential phases of the construction process but are overlapped in calendar time in the schedule and work process and each wave comprises work activities from most construction trades.

The structural wave is easiest to understand and control because it is usually the responsibility of the one subcontractor doing the structural framework. In this wave, if either the scheduled and actual performance is slower than need be there will tend to be a delay of the whole of the remainder of the construction process.

The other two waves are more important for the schedule and its work as they involve the simultaneous work of all the other trades involved in the finishes (i.e. non structural framework) of the building. In the latter pair of waves, if one subcontractor is slower that the rest then the whole construction process is slowed down.

The scheduler should exercise very careful and thorough thinking regarding the cycle, and each wave, stated above as

input into his construction schedules for high rise building construction, In fact, only upon completion of his analysis of the project and creation of the cyclic process and waves etc., should he begin to create the more normal schedule from which the actual construction process will be controlled.

(b) Vertical Movement of Materials The vertical movement of materials for all trades by a permutation of hoists, cranes, temporary elevators or construction use of permanent elevators is very important for the realization of the scheduled flow of work. If this aspect of high rise construction is not planned, scheduled and controlled to be compatible to the construction schedule, then such a construction schedule has a high probability of failure. The scheduling of vertical movement of materials should be done either before the construction schedule is created as a major input to the construction scheduling or the scheduling of vertical movement of materials should be done after the construction schedule has been created so that the materials required for the construction as designated by the schedule will be at each work location prior to when its incorporation into the end product is required by the schedule.

While it is probable that this issue for the structural work cycle is built into that cycle process, it is also probable that the scheduling of vertical movement of materials for rough work and finishes work of all the trades involved is left without much

formal scheduling yet it is the aspect of construction work with the greatest potential to cause breakdowns in actual work process.

Dictatorial behavior by one trade over others using the approach that it is the "pushiest" trade that gets their work done, most efficiently should be thwarted because it is very probable that it is achieved to the detriment of other trades and the whole construction process. It may also thwart the overall construction process schedule even though the vertical movement of materials schedule has been coordinated with the overall construction schedule.

Attention to developing vertical material delivery schedules for rough and finishes materials input factors to scheduling can create considerable potential benefit for the schedule to smooth out a major bottleneck in the overall construction process.

(c) Cross Site Flow of Materials, Etc. The objective of this sub topic is to have a smooth flow of resources, mainly materials and men, from off site to (and from) their work locations in the building. It can be seen as having three major subcomponents (i) location and capacity of cranes, hoists etc.., (ii) work and store areas on the site and access to the site and (iii) numerical/quantitative availability of materials and men in the project location.

Location and capacity of cranes and hoists is closely related to the previous factor of vertical movement of materials.

These pieces of equipment are the vehicles brought to the site to create and achieve the objectives of these vertical flows. Clearly the capacity of each machine and its placement is an integral part of the durations it takes to achieve fast or slow flows of resources across the site and hence, such factors should be integrated with the creation of the construction schedule.

There must be adequate work areas on (or off) site for fabrication etc work for all trades and areas for temporary storage of materials, tools and workshops. Again, their adequate volume and size and location have a major impact on the speed of flow of resources and hence these matters should be thought out and integrated with and their results included or implied into the construction schedule.

Site access is another feature of this sub topic. Normally high rise construction takes place where land costs are high and that is usually in urban locations of heavy road traffic. The speed and numbers in which trucks can be brought onto the site to be unloaded and leave the site is vital information for the scheduler developing schedules of vertical movement of materials and hence also influences the speed of construction achievable in the actual construction process. All of these should be represented in the pre construction schedule with as realistic durations as possible under the given situation for that construction process.

Availability of materials and men in the project location must be established as input to the volume of these flows of

resources and the capacity of all of these temporary services to handle these flows. The number of men available must be established and so must the capacity of the material wholesale and transportation services in the locality. These tend to be permanently in place in the locality and the scheduler has to establish their flow handling capacity and how much of it is free to service this project being scheduled, given the volume of other projects in the locality. This somewhat permanent supply capacity to provide and handle materials and men is usually somewhat outside the control of the contractor and thus should be clearly established as input to scheduling the construction work and all of these support flows and the capacities.

(d) Enclosure of the Building Envelope. When the envelope of the building is completed is a crucial date to be established in the construction schedule for high rise construction because it is after that date that most of the many work tasks of the rough and finishes work can begin. While some rough in work can be done prior to close in most cannot because it could be damaged by weather and a controlled internal climate is desirable for some such work.

A dynamic complication feature in this factor is that the date when each floor (or group of floors) may be closed in may be different for all trades because there is no point in waiting till the whole building is closed in to start finishes work on

the lower floors. Also, in itself, this variable close in time is not necessarily valid as some work may require the whole building to be closed in whereas others may only need a single floor to be closed in for their work to be carried out there.

It should be realized that there are many work activities in finishes and their rough ins across many trades and most of them cannot begin until that closed in state has been achieved. Thus all of the above features should be input to the scheduling of roughing and finishes work.

As the date of close in is when many finishes works can begin, it signals (allowing for their lead times) the start of a build up of simultaneous deliveries to the site of large quantities of materials and men. Therefore, knowing that date in calendar time is very advantageous to managing the resource flows to the site and on the site.

This close in time signals the watershed between (i) the start of multi trade work on site with its complicated simultaneity of work on site and (ii) its precursor of one or very few trades working on the site. Thus, in the context of the overall construction schedule, it is advantage to try to minimize the duration of the precursor simple work phase so that there is as long a calendar time available for the subsequent more complicated and more resource laden roughing and finishes to be carried out as efficiently as possible.

(e) and (f) Structural framework and foundations work These types of work constitute the major work in the pre closing in phase of the building construction work process mentioned above.

The structural framework is controlled in high rise work by its cycle process and its duration which should be carefully created as to process and the duration of each piece of work on its cyclic process. As stated above, this cycle should be an input to the construction schedule.

The foundation work usually must be done before the structural work can begin. Thus it can be an early bottleneck or time delayer to the whole construction work. This potential delay problem occurs because to some extent the underground features are not fully known until excavation has been carried out and thus some redesign work may be needed which can delay the whole process.

A more inherent delay potential in the construction process is the reality that the foundation subcontractor tends to be on site by himself, with the whole construction duration to follow, and it is less easy to be highly motivated by oneself than if one is working ahead of and behind the work of other subcontractors working on the same site. A further potential disincentive to expediting work, is that there remains the majority of the construction duration when the foundations are being put in, thus there can be the tendency to be less urgent in carrying out foundation work than other work later in the construction process.

(g) Installation of Big Pieces of Mechanical and Electrical Equipment. These big pieces of mechanical and electrical equipment usually require special handling on site for their installation and their delivery is usually tied to lead times that are (i) longer than for normal construction material but also (ii) they are more controlled by the manufacturer/supplier delivery process rather than by the subcontractor. The construction schedule should position such work in time primarily by when it can realistically be delivered to the site and secondarily by when its installation has least impact on the construction process. Included in the delivery duration are the manufacture, shop drawings, approvals etc and delivery to the site.

(h) Installation of Elevators. When the permanent elevators (with permanent or temporary cabs) are installed signals when these elevators can be used to assist or carry out vertical movement of materials and thus signals when the volume of finishes work could be greatly assisted by increasing the site capacity to deliver materials to work locations and when the services of the tower cranes and hoists might be stopped as major costs as well as resources to the construction process. Clearly, the potential use of the elevators is a major force which can affect the volume of simultaneous work and thus is a major input to creating the schedule.

Low Rise Construction

On low rise buildings the emphasis in construction and hence in scheduling appears to be on the coordination of diverse, somewhat individual activities by many subcontractors in the construction process. These activities could be scheduled in many sequences because of accessibility to the building from many directions on the site. Thus, the logic of the schedule is very important for there to be an effective actual construction process. This requires considerable thought as to the best logical sequence of overall work around the building. This strategic concept also provides a major benefit in the negative by that best overall schedule precluding individual subcontractors and work crews from being free to work in whatever geographic sequence each considers to be best for itself but which would be detrimental to the whole construction process.

The schedule should present (a) maximizing continuous harmonious work flows with minimum interferences, (b) logistic layout of a site surrounding a low rise building, and (c) availability of resources. The features of the building itself which were stated most often as being of importance for scheduling were (d) when the building envelope would be closed in, (e) erection of the structural frame of the building (f) foundation work and (g) site work. To a lesser extent (h) installation of major mechanical equipment and (i) elevators installation should be considered and stated in the schedule.

(a) Maximizing continuous harmonious work flows with minimum interference. The schedule should try to maximize the continuous flow of work for each subcontractor on the site and within that provide continuity of similar work for each work crew within each subcontract on the site.

As the work of all work crews of all subcontractors usually requires to be interwoven into one construction process then there is the added constraint to the above that for each work crew to do its work in each location in the building its work should be not be impinged upon by other work crews. This requires a schedule which presents continuous flow harmony of speed and geographic flow direction of all work through the building with sufficient time spaces or buffers between sequential work crews to enable each work crew to do its own work efficiently and effectively.

As input to the construction schedule, this requires a single generic flow for all work around the low rise building which is adhered to by all work crews of all trades. This format of scheduling construction work provides the maximum potential to have simultaneous working by many work crews on the site while each work crew is in a different sub-location in the building. Such a construction schedule enables maximizing the parallelism of all work flows required for the project, which maximizes the potential for benefits from the learning curve concept while tending towards minimizing the calendar duration of the whole

construction process without the use of parallelism in the schedule.

(b) Layout of site sub part services for construction process. The layout of site services around the building should recognize the selected generic flow of all work in the building. It is probable that movement of materials will be horizontal in general nature and hence cranes etc might well be of a mobile nature and feed the construction process from an appropriate (maybe sequential) variety of delivery locations adjacent to the building. Thus access to these mobile crane delivery locations and movement between them should be available.

The other given factor in this will be the location of access to the site from surrounding roads and if there is a choice the accesses should match the above concerns. If site accesses are fixed then the site layout should be derived from (i) the above generic overall building construction flow logic and (ii) these fixed accesses to the site from surrounding roads. Thus the locations of site offices and storage areas and work fabrication locations should tend to be derived from the generic single construction process flow and its detailed construction schedule, the fixed accesses to the site, the planned delivery locations to the building and the on site travel routes between them rather than be decided prior to scheduling and treated as input to construction scheduling.

(c) Availability of required materials. The availability of materials and the capability for them to be delivered is a feature to be considered as input to scheduling of low rise construction. The scheduler should obtain information on the local availability of common materials and their potential volume and speed of delivery and then develop the construction schedule which matches that potential. He should also consider the effect of the size and number of accesses to the site and the size of on site temporary transport services as a potential constraint to the flows of these materials. All of the above is to establish a realistic assessment of volume and speed of the flow of materials to the construction process as input to scheduling that process as realistically as possible.

(d) Enclosure of the Building envelope. This is a crucial point in time because it signals when the majority of the rough ins and finishes work can begin. It should be clearly identified in the schedule. This is compounded by the above wise approach of moving the various work crews through the building zones in the same sequence. Thus the date on which the building is closed in is really a series of dates when each geographic location in the low rise building is closed in.

Subsequent to the close in date many finishes can begin but prior to that date only a limited amount of work of a structural or rough in nature can be carried out. This is an important

watershed date prior to which only few work items can be carried out, mainly in a sequential format, but after which many work items can go ahead in parallel. This factor in the schedule increases the importance of scheduling the roof work as early as possible in the construction of the whole building or for each work zone in the building. The roof work should be sequenced around the building in the same sequence as is derived for the generic schedule of finishes work.

(e) and (f) Erection of the structural frame and foundations work. Both of theses types of work should be sequenced in the schedule to match the best flow or sequence of the finishes work in the schedule rather than what might be best individually for the foundations and/or the structural frame. This expedites the whole construction process rather than having some parts of it inhibit the majority of the whole process.

Both of these types of work tend to be the only work going on at the site at that time. Thus their duration tends to preclude the starting of other multiple task work which could start earlier if foundations and the structural frame were built in a shorter duration. Thus attention should be paid to expediting such work by trying to maximize the resources applied to that work given their availability. Another approach to expedite such work is to schedule it to occur simultaneously

where possible by carefully overlapping work activities in calendar time.

(g) and (h) Installation of big pieces of mechanical equipment and elevators. These major pieces of equipment have to be built into the schedule and each piece may be coming from a different manufacturer and each may be being installed by that manufacturer or a specialist subcontractor. Clearly for the best logic flow of the whole construction process and having regard to their location in the building there will be an ideal time in the construction process to install each of these pieces of equipment. However, each piece has a purchasing, shop drawing, manufacture and delivery process etc. which is comparatively independent of the overall construction process and which tends to dictate its delivery date. The scheduler should establish the realistic durations of these lead time activities and compare when each piece could realistically be on site to be built in. The delivery schedules should be examined carefully to verify durations and these should not be appeased by allowing them longer than need be. Then the best construction schedule and the realistic delivery dates of each major piece of equipment should be expressed in calendar time in the final preconstruction schedule at the calendar date they can be realistically delivered. Any inconsistencies between these two different construction forces should be solved with a bias towards holding

the delivery schedules which are less under the control of the contractor. The scheduler should remember that the above situation is a trade off between the two forces and that minimization of cost and duration to the whole construction process is the overall objective. Control of both actual activities has to be used from now till installation of these pieces of equipment to mesh them together in reality and thus to minimize disturbance to the whole scheduled actual construction process.

SCHEDULING EMPHASIS FROM QUALITY OF MATERIALS IN THE BUILDING

Buildings Which Require High Quality Materials and Finishes

(a) Delivery Flows of Materials

(b) High Skilled Craftsmen

(c) Appropriate Overall Construction Process

(d) Availability of Materials

(e) Quality Control of Construction

Buildings Which Require Low Quality Materials and Finishes

(a) Availability of Highly Productive Individual Workers

(b) Work Speed and Coordination

(c) Flow of Materials To the Site and Their Availability

Scheduling Emphasis From Quality of Materials in the Building

The quality of materials and finishes chosen in the design for the building is a major force in the value of the building as it tries to create its desired status for its users subsequent to construction.

Some buildings have high quality derived from the intrinsic nature of materials used and this may or may not need to be but is usually coupled with high quality skilled construction work to achieve the above objective. At the other extreme some buildings only need low quality materials and finishes to satisfy their mundane function subsequent to construction. Most of such buildings will not require high quality skilled construction to satisfy their design requirements. Other buildings may have a mix of high and low quality materials and finishes included in their whole design. For any building its required quality of materials and finishes will be stated in its specifications and to a lesser extent, in its plans.

While it may not be axiomatic that high quality materials and finishes require more time for their construction, there is an array of implications for the construction process and its scheduling derived from the level of quality of the materials and finishes required in the building. These factors are stated and described below for each of (i) buildings which require high quality materials and finishes and (ii) buildings which have low quality materials and finishes required in the design. For those buildings which have a mix of high and low quality the scheduler

should interpolate from the factors of each of (i) and (ii) below in the proportions of high and low quality he finds in each particular building for which he has to create a schedule.

In regard to the quality of materials in the building to be built, the two extremes of high quality and low quality were presented to the construction executives. The factors which they said should be emphasized in scheduling buildings with high or low quality materials were analyzed and are presented below.

In buildings of high quality materials, it appears that emphasis should be placed on realistic and somewhat longer delivery durations for high quality materials being built into the schedule than for normal materials, and that high quality craftsmen are beneficial to the execution of such work. Provision of adequate durations for such work which also implies trying to move the framing work for such materials to earlier in the overall schedule and that appropriate on site construction quality control has to be considered as another component of the durations for the work activities and the whole construction duration.

In buildings of low quality materials the creation of a realistic schedule requires consideration of the availability of highly production individual workers, the logic to enable fast construction with coordination of work activities and a realistic appraisal of the availability and speed of flow potential that can be achieved for the delivery of these low quality materials.

Buildings Which Require High Quality Materials and Finishes

The major input factors to construction scheduling for buildings of this nature are (a) delivery flow of materials, (b) highly skilled craftsmen, (c) appropriate overall construction process, (d) availability of materials and (e) quality control of construction.

What the actual construction process should be as a guide for its control and management should be presented in the preconstruction schedule. To efficiently construct a building of high quality of materials and finishes requires that it include careful and proper delivery and handling of the high quality materials. That there is a preponderance of high quality materials being handled in the construction process should reflect the allocation of appropriate durations not only to the placing and protecting of the finishings that are visible in the finished building but also appropriate durations should be provided for the construction rough in work to which these high quality finishes are to be attached. Usually such rough in work is much stronger and more extensive than that for low quality finishes.

(a) Delivery Flow of Materials. The required lead time for delivery of high quality materials is a factor of importance to realistically scheduling the flow of construction work on buildings requiring high quality materials and finishes.

The higher the quality of materials called for, the lower the probability that it can be supplied off the shelf, especially from local suppliers. The effect of establishing these durations on the schedule should help to establish the calendar time setting for building each of the variety of high quality materials.

In a building of this type probably there will be a variety of different high quality materials or there may be only a few types materials of high quality required. Each of these high quality materials usually requires longer lead durations for purchasing, shop drawing and submittals, and samples as well as manufacturing than for commonly available materials of normal quality. The scheduler should try to be realistic in assessing and fixing these durations rather than consider them to be the same durations as that for off the shelf materials. The scheduler should not try to present an unachievably optimistic schedule by ignoring the extended lead times of high quality materials. The strength of these required lead times are real and will later cause compound changes from the schedule and confusion in the actual construction process of many work activities in the actual construction process if it tries to follow a schedule which ignores the realism of that strength.

The delivery of these high quality materials to the site, their storage on site and cross site movement usually requires more care than do common or cheap materials. High quality usually means and more costly materials and more easily

damageable characteristics. Also, there is the implication that to minimize construction costs the duration from manufacture to incorporation in the building and receipt of interim payment should be as short as possible. Therefore, their movement on site should be as smooth as possible i.e. minimum number of handlings. It follows from this that the closer their actual flow to realistically scheduled flow the lower is their cost to the construction process but that requires more careful and realistic scheduling of such flows.

To enable the preconstruction schedule to be as realistic as possible regarding these material lead times and cross site flows, the scheduler should seek out and use the information from suppliers and the subcontractors who will handle at least those materials of high quality which have a major impact on the flows of the whole construction process. He should also check out the effect of the proposed on site handling processes to be used on each project on its schedule. What store areas, work areas and fabrication areas are available for the flows of these materials should also be established as a constituent of creating realistic input information to scheduling.

(b) High Skilled Craftsmen. To successfully and efficiently carry out work using high quality materials and finishes in the actual construction process, it is usual that highly skilled craftsmen are required, or at least their presence is advantage

to doing such work. Looked at another way, if low skilled workmen are doing the work then there is considerable probability that the work using high quality materials may be done poorly and require to be redone. This consumes further amounts of high quality materials as well as time and can seriously disrupt the actual construction process as well as the schedule on construction tasks directly affected by the poor workmanship and on others to be built subsequently.

Thus in making the schedule which will guide the actual construction process, the scheduler should establish the availability of the number of highly skilled craftsmen needed for the building as a sub feature of availability of numbers of each required labor force. There is also the probability that low quality workers will destroy more high quality materials than would more highly skilled workers. Therefore a greater amount of high quality materials will need to be ordered and delivered to the site subsequent to their destruction during construction. As their delivery process has already been cited as a major factor of concern, there could be double jeopardy to the construction process from ignoring factor of the degree of the availability and use of highly skilled craftsmen on this type of construction work.

As a subpart of this factor, the scheduler should also establish the competence of each subcontractor to manage high quality work within his trade. Like individual humans, subcontracting companies have their specialties within their

trade. Some do high quality work and others do work of other qualities. The speed and duration of their work with high quality materials and finishes will depend on their ability to do that work. The scheduler has to establish all of this information before completing the preconstruction schedule.

(c) Appropriate Overall Construction Process. A major factor in scheduling building work using high quality materials and finishes is that the work activities have enough duration to correctly install the high quality materials and finishes. These work activities appear to take longer to install than more common materials serving the same function in the end product building. Regardless whether it is inherent in the intrinsic nature of these materials or workmen to take longer installing them or that craftsmen who are best at doing these types of work take longer, it is clear that it is seen that longer durations are needed for these work activities in the construction process and hence they are also needed in the preconstruction schedule.

A secondary aspect of this factor but also important is that high quality materials and finishes tend to require a larger amount of backup rough in or framing work than for less high quality materials and finishes. The work activities for such framing should be included in the logic of the schedule and their durations should reflect the greater volume of that work than for normal framing.

In addition, the overall strategic scheduling of the whole construction process, should try to move such framing work as early as possible in the whole schedule. This can allow the appropriate longer duration for high quality materials and finishes (which tend to be built towards the end of the whole construction process) to be built without extending the overall construction duration. Alternatively, the use of more work crews working in parallel on the same type of work may have to be put into the schedule for both framing and finishes to put their calendar time phasing within the desired overall duration of the construction process.

This factor requires the whole schedule to give overall time allowance for the work needs of high quality materials and finishes and their requisite rough framing work. The scheduler should try to schedule in parallel the earlier work which is of more normal quality and mundane execution to facilitate the work with higher quality materials.

As minor constituents of working with high quality materials it was suggested that the workers are greatly assisted by the existence of permanent power in the building. Therefore, the point in time of the start up of the permanent power and its necessary preceding work, should be scheduled prior to work requiring high quality materials.

(d) Availability of Materials. The availability of materials required for the building is, again, a factor to be considered as input to scheduling. Without such basic information as this, the schedule may not be as accurate i.e. realistic, as it could be. A discrepancy between realistic material availability and the poor schedule without such input, will only come to light during the actual construction process. This implies that if the speed and quantity of the actual flow of high quality materials to the site is less than scheduled, then a discrepancy will be created which will cause compound changes in the subsequent part of the schedule and its actual construction process.

As the schedule should present the best way of constructing the building it should include input on the realistic availability of the required materials. This is especially true when, as noted from the factors above, the high quality of materials and finishes are major costed time constituents of a particular building for which the schedule is about to be created.

(e) Quality Control of Construction. The manager of the construction process, while having adequate inspection after work has been done, should also have adequate supervision of ongoing work and even of preconstruction processes. This positive and creative approach to quality management can take place if there is a very good i.e. realistic schedule of what should be the best

actual construction process. With such a schedule those managing the construction can expedite the movement of materials and men towards the work activities that comparatively need to receive more attention. Also, such a schedule can be very helpful as input to meetings before and during construction with all participants of the construction process. To maximize the realism of such a schedule requires the acquiring and use of input information from at least all major subcontractors and suppliers for major high quality materials.

Another aspect of quality control which tends to protect the viability of the construction schedule is that temporary protection for finished pieces of work is provided as work activities in the schedule. If this is not done, considerable delays and holdups will be created from the long durations of more necessary deliveries of materials to replace those broken due to protection not being provided.

Buildings Which Require Normal Quality Materials and Finishes

The major input factors to construction scheduling for buildings of this nature are (a) availability of highly productive individual workers (b) work speed and coordination, and (c) flows of materials to the site and their availability.

In buildings of normal or low quality materials and finishes, the emphasis appears to be on maximizing speed of construction through using an adequate number of highly

productive workers and carefully creating a construction process and its schedule arranged to occur with a minimum number of logical bottlenecks. Also, the minimization of construction delays through non availability of materials is important because the construction schedule should be set up to operate at a speed and volume of work compatible with an achievable level of flow of materials to the building site.

(a) Availability of Highly Productive Individual Workers. To efficiently construct buildings which have normal or low quality materials and finishes it is considered important to use workers who are individually highly productive. That these highly productive workers exist in the various required trades in the locality of the project should be checked out by the scheduler as part of his establishing the status of numbers of available workers in the locality in each trade. The number of highly productive workers available is a major input factor to scheduling because it has a direct bearing on the durations of work activities in the construction schedule as well as the actual construction process.

(b) Work Speed and Coordination. The logic of the schedule should be set up so that fast construction by each work crew of each subcontractor can be maximized. This can be assisted by

continuous flows of work for each work crew even though the work may be of different types within the same subcontract trade.Each subcontractor should be managed so that the work durations of each work activity within his work scope is in harmony with the durations of other work activities to assist continuous flows of work for all of the work crews on the site.

If there is enough space on site for prefabrication of work activities, then careful consideration of preassembly of components etc should be carried out and included as input to the schedule.

Overall the emphasis in the schedule should be to create fast work by all resources. This can be achieved by the schedule logic maximizing parallelism of flows and minimizing potential friction between different adjacent work crews.

The work activity durations should be set for fast work but only as fast as can be achieved with the numbers and skill level of the highly productive workers available for the future construction process being scheduled.

(c) Flow of Materials to the Site and Their Availability. The real duration of delivery of materials to the site should be established as input to scheduling the work of these low quality materials and finishes.. As the work is desired to progress quickly there will tend to be a high volume of materials being handled at any point in time. Therefore, that the volume of

materials for the desired speed of the construction process is available and that the appropriate capacity of the support services on site to handle that large volume of material flow will exist on site is important input to scheduling this type of construction work.

These on site support services of this factor of scheduling are also linked to the material acquisition or purchasing process and to the submittal process for them. However, generally normal or low quality materials are usually commonly available and hence their submittal processes tend to be reasonably simple.

The availability of the required materials in the locality of the site should also be established as a subpart of this factor of input to scheduling.

SCHEDULING EMPHASIS FROM THE NEIGHBORHOOD LOCATION OF BUILDING

City Center Locations

(a) Off Site Movement and Deliveries of Materials and Access to the Site

(b) On Site Storage of Materials

(c) Security Interface Between (i) The Site and (ii) The Public and Workers

(d) Employee Parking

(e) Subsurface Conditions, Site Utilities and Early Notice to Subcontractors

Rural Locations

(a) Availability of Materials and Material Deliveries, Etc.

(b) Availability of Labor

(c) Site Security From Theft And Vandalism

(d) Availability of Utilities and Power On Site

Suburban Locations

(a) Security Fencing For Children and Against Theft and Vandalism

(b) County and Neighborhood etc. Ordinances Controlling Working Hours

(c) Site Access and Delivery of Materials

Neighborhood Location of Building

The neighborhood - city center, rural or suburban - in which the building is to be built can require different emphasis in the construction process to maximize efficiency of the construction process in that location. Each location has a different array of factors of influence to be expressed in the construction schedule of any buildings construction process in that location.

It should be noted that most of the factors in this neighborhood influencing section of the report are not directly involved in the construction process but influence the (i) flow of resources which feeds the construction process and (ii) providing inhibitions as to stop the wrongful movement of materials off the site and (iii) the movement of invalid people on to the site.

City Center Locations

The major factors to be emphasized in scheduling construction work in city center locations are (a) off site movement and deliveries of materials and access to the site, (b) on site storage of materials, (c) security interface between (i) the site and (ii) the public and workers, (d) employee parking, and (e) sub surface conditions, site utilities and early notice to subcontractors etc.

(a) Off site movement and deliveries of materials and access to the site. Both of these subfactors can be constraints on the flow of resources to the site and hence to the attainable speed of work. Therefore each has to be considered as input to realistic scheduling.

Off site deliveries of materials comprise a number of features such as the traffic flow patterns in the streets around the site and the traffic control mechanisms which exist in the neighborhood. These are augmented by establishing the potential to off load trucks in the streets adjacent to the site and at what hours that can occur. Perhaps more fundamentally, the same should be established for when during the day deliveries can be made in that part of the city center. The degree of control that exists over the delivery trucks arrivals will affect the degree to which scheduling of deliveries can be meshed with the construction process schedule and speed. This degree of realism of this information will affect the probability of the schedule being met as reality. Consultation with city traffic and police departments would be advantageous prior to scheduling such flows of materials.

Access to the site should be carefully studied and established in relation to the traffic flow pattern in surrounding streets and the location of the building on the site and the nature of the building at ground level. This factor was stated most frequently as being of importance to scheduling of construction of buildings of this type. It can be implied that

simply (i) scheduling deliveries and their arrival at the site access, (ii) scheduling movement of trucks on site, and (iii) scheduling unloading of trucks in an harmonious manner is an important ingredient of maximizing construction efficiency of buildings in city centers. This factor is closely related to subsequent movement of materials to their work places on site.

(b) On site storage of materials, work staging areas and movement of materials to work places. Usually there is little space for storage of materials outside the building line on site in a city center location. Therefore, usually storage of materials and work staging areas have to be within the building. Therefore, it is advantageous that deliveries be carefully scheduled as to their arrival at the site, unloading and movement on site, including vertically, to be moved in one continuous flow to minimize costs and breakage potential. This movement is also so that materials can be stored as close as possible to their final work place rather than cluttering ground level on a small vital area. The staging areas for materials and the work fabrication can then be dispersed around the building rather than being on the congested ground floor while considerable empty space exist in other parts of the building. Of course, this requires careful integration of (i) scheduling actual construction which creates these empty spaces with (ii) the delivery of materials which are needed for future incorporation into the building , (iii) the availability of already built

spaces adjacent to the future location of these subsequently delivered materials and (iv) the minimization of duration between delivery to site and incorporation into the building because by their delivery such materials are beginning to cost the contractor money as they are now in his possession.

The capacity of on site construction cranes and hoists and as well as permanent elevators available later for material handling should be established by the scheduler so that their capacity in volume per unit of time and in size and weight lifting are adequate to feed the work flow represented in the construction schedule. Clearly, that construction schedule should be created to be interactive with the scheduling of the above movements and perhaps the construction schedule could be seen as being derived from them rather than being created simultaneously with them.

For the future actual construction process to be realistic, potential constraints and opportunities such as above should be thoroughly checked, evaluated and quantified as input to scheduling of the actual construction process.

(c) Security interface between (i) the site and (ii) the public and workers. The scheduling of deliveries and their movement etc. to the workplace is an important factor in the speed of construction and hence in its scheduling. It follows that if material on site is lost or moved off site by whatever means that there will be a future holdup in the construction process

and that the extent of that holdup is unknown to the controllers of the construction process. Thus theft of materials on site must be kept to a minimum to minimize the risk of future unknown stoppages in the construction process. To do this may require a strong, high fence around the site and/or a more abstract security system including active worker exit security screening. These facilities should exist on site and be built into the schedule and site layout.

The safety of the public from the construction work on site or adjacent to it e.g. unloading areas, is an important factor of construction in city centers. The anti theft security fence can be of double use by keeping pedestrians off the site. Accesses to the site should have notices and even guards to maintain the same safety. If pedestrians have to pass close to the site, temporary lit walkways with roofs should be provided. Their building, maintenance and removal should be work items in the construction schedule.

Similar walkways for workers between parking areas and their work places via their site trailers or at least designated pathways should be planned for the site and their creation, maintenance and removal as well as movement on site during the construction process should be work items in the schedule.

(d) employee parking. Most construction workers drive to work and in city center locations all day parking can be a major problem and expense for them. Hence they are less likely to want

to work on a building where the parking is poor or non existent than on one where a parking facility has been properly established to enhance working productivity in the construction process. In turn, the building with good parking will have a more stable and productive labor force. The probability of the actual labor force being maintained as required to meet work activity durations in the schedule will be greater if the scheduler has established the nature of a viable parking lot for the project prior to scheduling rather than seeing no connection between these issues or making no allowance in the schedule for such connections.

Even poor or distant parking facilities for the labor force can reduce worker motivation and have considerable effect on their productivity and speed of work and hence affect the durations of work activities in the actual construction and which should have been recognized in the preconstruction schedule.

(e) subsurface conditions, site utilities and early notice to subcontractors etc. The scheduler should establish all known information on subsurface conditions as input to scheduling. All expected soil conditions and existing utilities should be established and their work activity durations in the schedule should reflect the expected existing conditions.

Municipal regulations on when construction work or specific types of work can be carried out e.g. blasting, material unloading, etc. should be established by the scheduler and all

their required support activities should be built into the schedule.

Keeping the site clean and tidy and other necessary support work to facilitate direct and indirect construction activities should be built into the schedule as work activities. At least the duration of direct and indirect construction activities should reflect the impact of the degree of congestion expected on the site so that the scheduled flow of work can be achieved under the realistically expected site conditions.

As it is likely that many contractors will be working on such a building each should be given notice with appropriate lead time, of when he is expected to begin work, what will be his sequence of work and where his trailers etc. can be placed and where his materials can be stored and when his materials can be delivered to minimize their friction on the overall scheduled construction process.

Rural Locations

The major factors to be emphasized in schedules for buildings in rural locations are (a) availability of materials and material deliveries, etc., (b) availability of labor and their transportation to site, (c) site security for theft and vandalism including scheduling to minimize materials stored onsite and (d) availability of utilities and power on site.

(a) availability of materials and material deliveries, etc. Rural locations of buildings usually means more than normal distance between its construction site and the source of materials - wholesale or retail. This implies longer than normal lead times for material deliveries, more randomness in times of delivery to site and generally less availability of materials onsite. Even shelf life of cement or the potential of using ready mixed concrete have to be questioned as features of the construction process and hence as input to the construction schedule which will guide it.

The distances over which delivery of materials must take place is compounded by the probability of rural roads being of varying capability to carry heavy weights of deliveries, the on site availability of unloading equipment and the issue of unusual accesses to rural construction sites. All of these subfactors should be checked out and their status or solutions worked out by the scheduler so that the construction schedule reflects the reality of how best to construct that building in that location.

Another facet of this factor is that if additional material deliveries are needed suddenly to enable the actual construction process to recover from omissions in an earlier delivery, or because of theft from the site, these will usually require special deliveries rather than being serviced from a delivery truck circling a number of construction sites, such as in an urban location.

Cost per unit being delivered over long distances dictates that most deliveries have to be specific for that rural building and omissions from a regular load of a few pieces of materials, or even tools, may hold up the whole construction process. Thus, the logic of the construction schedule should be set up to maximize the potential that all work resources have a number of work activities that they could be doing at any one time. This scheduling concept of providing operational flexibility can be seen as a conceptual buffer between the above delivery constraints and the continuity of the actual construction process.

(b) availability of labor. There is greater unavailability of construction labor in rural areas compared to urban areas. Therefore, the scheduler has to establish the realistic number of craftsmen available to work on the building in each subcontract at that rural location and when they shall be needed in calendar time. This, in turn, sets the speed of the various work activities which directly affects their durations. It also affects the logic of the schedule because once a subcontractor work force is on site the schedule should guide its work to do as much as possible in a continuous flow as possible. The above features of the rural location probably would increase the problems of trying to have the subcontractor bring work forces back to the site once they have been moved off the site.

Another aspect of this factor is that augmenting the work force at a rural location from an adjacent urban construction marketplace requires travel time hence either diminishes working time (or increasing costs per time unit of actual work) which affects work activity durations. Alternatively, the prefabrication of components off site may be a potential solution to this issue. Whatever is chosen as the solution to the labor availability factor, the scheduler should use its results as input to realistic scheduling of construction in a rural location.

(c) site security from theft and vandalism. Rural sites tend to be distant from other buildings or habitats. If expensive components or even desirable materials are left stored and unprotected on such isolated sites, there is a reasonable probability that thefts will occur. It also appears that such locations are more sought out by vandals than those in densely built up urban areas. Some constructors may provide security with a temporary large fence and gates which is expensive and still assailable in out of the way rural locations. Other constructors tend to deliver to site only the amount of materials than can be fixed in place very quickly. Thus the whole already difficult combining of delivery scheduling with construction process scheduling is further compounded by using many small batches of deliveries for security purposes.

This places a heavy burden on the scheduler devising a construction logic which keeps the work of all subcontractors labor forces and the whole process flowing but being supplied by small quantities of deliveries at hopefully regular intervals by suppliers who are not fully under the control of the contractor. The alternative is to risk theft of materials from large deliveries to the rural site and the probable later unforseen delays in the construction process from suddenly finding that there is not enough materials on site to keep the labor force working according to the schedule. There is also the additional delays until replacement materials are provided under long distance and time delays from other wholesale sources which are usually in adjacent urban areas.

(d) availability of utilities and power on site. Much construction work requires machinery which requires energy to make it operate. Most construction work especially the wet trades, require water of a usable quality. Thus to create a meaningful construction process in a rural location usually requires that the site is serviced with utilities of power, water and sewage very early in the construction process. Thus, establishing when the local rural utility companies will provide each of these services can have considerable impact on the shape of the logic of the realistic construction process as well as on the speed and duration of each work activity within that schedule. Hence the scheduler should establish the time when

each type of utility service will be available at that rural construction location as input to the scheduling of the construction process.

Suburban Locations

The factors to be emphasized in the schedule for construction of buildings in suburban locations are (a) security fencing for children and against theft and vandalism (b) county and neighborhood etc. ordinances controlling working hours and (c) site access and delivery of materials.

(a) security fencing for children and against theft and vandalism. A major feature of constructing in a suburban location is that it is close to where people have their homes and usually there are always some people who are adding to, improving or altering their homes.

Usually suburbs are in proximity to and ease of movement to and from adjacent urban areas. The adjacent availability of even heaps of common construction materials as well as major pieces of equipment is often a tempting a target for potential home improvers in suburban locations. Also, suburbia is where children and teenagers play and construction sites which are near to their homes are like magnets to iron filings for such young people.

While there is the issue of keeping such people away from construction sites for their own safety, there is the other desire of precluding or minimizing the theft of materials from suburban construction sites or the vandalising of materials or work already built on site. The schedule should include the construction of a security fence and its subsequent removal if that is the chosen defence on a site against these potential perturbations to the construction process. However, probably more important is the potential effect that choice may have a slowing effect on the flow of materials to the site. Whichever solution is chosen to this potential problem should be input to the chosen logic of the construction process in the schedule and its effect on the duration of each work activity in the construction process.

Loss of materials which have to be replaced and the rebuilding of vandalised work can cause serious perturbations to the construction process. Hence, the schedule should perhaps include duration buffers to allow for such replacement work.

(b) county and neighborhood etc ordinances controlling working hours and conditions etc. Suburban locations is where many people reside and these locations tend to carry ordinances which control directly or indirectly the times when construction work can take place, the amount of noise and dust etc to be tolerated, when delivery trucks may travel these streets, which routes they must take and the maximum loads they can carry. These ordinances

may also control the permits to be obtained and environmental rules to be followed.

Each and all of these ordinances can have considerable effect on what the actual construction process will be in logic and durations of work activities and what its flows of supplies of materials and workers can be. All of these potential constraints should be considered and their status established by the scheduler as input to scheduling the logic of the construction of the building to be built in a suburban location. These various constraints also affect independently, the durations of each work activity on such a schedule as well as interactively with the logic of the whole schedule.

(c) site access and delivery of materials. The scheduler should examine the site to establish where there are potential accesses to the site from the surrounding suburban streets. These potential accesses should be qualified by their load capacity in quantity, times of use in the day, which truck routes they required and what is tolerated on them under the local regulations. These site accesses should then be considered in relation to the position of the building on the site as to which would be the most advantageous access locations to use in creating the best construction process for that building in that suburban location along with minimizing the potential of losses from the site because of that chosen access.

Delivery of materials is in two parts straddling the access to the site. One part is the off site deliveries and the other is the on site movement of materials.

Off site deliveries may be hampered by difficulty of moving trucks through suburban streets and even finding their way through residential areas. Other subfactors may be the unavailability of required materials and/or the shop drawing or submittal processes.

On site movement of materials, their storage locations and their laydown and fabrication locations have to be thought out prior to or as part of scheduling the actual construction process before work begins.

MAJOR PROBLEMS TO CONTROLLING LABOR FLOWS TO AND ON SITE

Major Impediments to Labor Flows As Seen by General Contractors

(a) Material Deliveries Including Equipment For Moving Materials

(b) Schedules Having Work Activities But Which Lack Their Work Location and Resources Required, Etc.

(c) Poor Quality Labor and Its Management

(d) Lack Of or Poor Communication

(e) Site Conditions

(f) Poor Or Changing Design Information

Protecting Work Crews From Interference From Other Work Crews As Seen By General Contractors

(a) Achieving Minimum Intercrew Interference On Site

(b) On Site Communications to Minimize Intercrew Interference

(c) Tight Field Supervision to Minimize Intercrew Interference

Problems Scheduling And Control Flows Of Labor As Seen By Subcontractors

(a) Establishing Required Labor Force Prior To Work

(b) Adjusting Labor Force During Construction Work

(c) Causes of Variance In Demand For Labor

(i) labor allocations

(ii) work of other subcontractors

(iii) deliveries of materials

(iv) incomplete information

(v) variable work supervision

(d) Variables In The Work Force

(i) positive factors

(ii) negative factors

MAJOR PROBLEMS TO CONTROLLING LABOR FLOWS TO AND ON SITE

This part of the report is in three sections. The first deals with the potential major impediments to on site labor flows and the second deals with how contractors try to protect their work crews from interference from other work crews. These two sections are from the viewpoint of general contractors.

The third section, which is from the viewpoint of subcontractors, deals with potential problems in scheduling and controlling his flows of labor on site.

As the schedule is to be the best guide for the subsequent actual construction process, it follows that in its creation, the scheduler should consider these potential impediments and problems and create a schedule which minimizes their impact on the actual construction process.

These potential impediments and problems to the flows of labor to and in the construction process come from the responses of the construction executives, schedulers and controllers interviewed in the study. They are stated in descending order of importance by their frequency of being stated by these executives.

Major Impediments to On Site Labor Flows

On site labor flows can be impeded by a number of factors. Those perceived as causing the greatest impediments to labor by the expert constructors are (a) material deliveries including moving equipment, (b) schedules having work activities which lack

their work location and resources required etc., (c) poor quality labor and its management and to a lesser extent (d) lack of or poor communications (e) considering site conditions and (f) poor or changing design information.

It should be realized that the scheduler should consider these potential impediments to the execution of construction work in creating the schedule. At the very least, they can influence the productivity and speed of construction labor working on that project and hence, affect the realism of the durations of work activities in the schedule.

(a) material deliveries including moving equipment. Simply getting the proper material delivered across the site to the labor flows work place or places was cited as the major impediment to construction labor doing its work. Poor timing of the proper material deliveries is a small constituent of this major impediment. It appears that a major cause of this impediment to construction labor is the non-existence on site of the proper haulage equipment and the lack of hoisting capacity to move the materials to the required work places in the building. Other sub parts of this impediment to construction labor are poor site access and inadequate laydown areas for materials and areas for on site fabrication work.

The objective should be to get the required materials to each work location of each scheduled work activity at the same time as or prior to the arrival of the work crew, so that workers

do not have to wait for materials. These matters and the logic and durations in the construction schedule should be interactively planned and controlled.

(b) schedules having work activities which lack their work location and resources required etc. Too many work crews being scheduled to work in each particular work location at the same time is one result of this major impediment to labor flows on site. Also, simply improper or poor scheduling of work in the whole construction process leads to overall labor inefficiency as well as pushing more labor crews into fewer work locations on site. This may be the poor way the work was scheduled or by trying to increase the volume of current work to catch up on already lost production. The poor or improper sequencing of or poor interspersing of work crews in the schedule from different subcontractors can be other ingredients in impeding the work flows of each crew.

When a poor schedule exists then site management tries to revise how the actual work should take place form the inadequate schedule. This places a heavy load on the site management which increases the risk that their control of actual work is reduced which in turn exacerbates the situation from the poor schedule and so a downward spiral begins to occur in the management of the construction. Also, a poor schedule inhibits good monitoring of actual progress which accentuates the above downward spiral which originated with the poor preconstruction schedule.

To eliminate, or, at least greatly reduce, this negative aspect of poor construction schedules, requires that the location within the building and the resource requirements of each work activity be stated in its description. By so doing, it can be clear in the schedule how many work crews of particular resource types are required to work in each location of the building at each unit of time.

(c) poor quality labor and its management. The use of labor which is not skilled enough to carry out the work required is a fundamental impediment to labor flow. This can be made worse by labor being in short supply, being inconsistent in attendance on site or being put into work crews of unusual sizes or poor balance among its skills - both of which create low productivity. These secondary subfactors can play on even adequately skilled individual workers on the site. Furthermore, the existence of these features in the labor force has a demotivating effect of workers of any skill level which reduces their productivity and can cause a domino effect through the whole work force on site. Even if subcontractors management hires and fires till a good work force is achieved, a lot of productivity loss occurs and the demotivation may still exist.

The problem of low quality management capabilities of subcontractors hired for the project is an inhibitor on labor flows in itself and by its effect on even high quality labor through mismanagement and demotivation.

All of these sub factors cause lower productivity than expected in the schedule and hence, the actual durations of work tasks are longer than the durations in the schedule. Thus, the scheduler should check out the probability of occurance of all of these sub factors as input to establishing the durations of each work task in the schedule.

(d) lack of or poor communications. A serious impediment to labor flow efficiency occurs when the general contractor fails to or poorly communicates to each subcontractor and hence, to his work crews what work he wants them to do when in time they should do it and where in the building they should do it. It is the subcontractor who should communicate his materials needs to suppliers etc and ensure that his deliveries occur when needed.

Failure in communication of what the schedule states about each work task will cause inefficient construction even though the work has been wisely scheduled. Even a poor schedule well communicated to those who do the work is a coordinating mechanism among the many people in the construction work force.

Fundamentally, the schedule should be created as the best overall construction process to be followed by the actual construction process. However, the schedule, either in total or relevant parts, must be communicated to the people managing the work forces building the project for that fundamental guidance to take place.

A marginal overload on the communication system may occur if too many trades, work crews and people are working on site simultaneously but that quantitative aspect should be easily solvable if recognized by modifying the organization of people managing the project and its required communications.

(e) site conditions. Weather and its constituents of heat and rain are cited as inhibitions of labor flows in the actual construction process and these may fundamentally affect the workers physical and mental productivity of construction output. In turn, this means the actual duration of a work task will take longer than scheduled, if the scheduler has not considered and included the expected site conditions into his calculations of durations.

Lack of drinking water and toilets etc were also cited as being similar inhibitors but while these are full inhibitors of productivity, their lack can be controlled by management.

(f) poor or changing design information. Misinterpretations of drawings, many design change orders, incomplete designs and slow responses to questions or making decisions by the building's designers were cited as inhibitors of labor flows on the construction site.

It appears that these inhibitors are somewhat out of the control of the contractor but that their input could be somewhat alleviated by careful examination of drawings prior to scheduling.

of the construction and the search results used as input to the scheduling of construction work.

By so doing, at least certain areas of the schedule could be marked as probabalistic rather than being finite and hence, the construction controller is armed with valid information from which to control that construction process.

Protecting Work Crews From Interference From Other Work Crews

When asked how contractors actually protect their crews from interference from other workcrews, the majority of experts stated factors that fell into groups related to communications among on site managers and tight field supervision but the majority of these sub factors suggested described sub factors of the nature of the preconstruction schedule.

This part of the report will be in parts dealing with (a) achieving minimum inter crew interference on site, (b) on site communications to minimize inter crew interference, and (c) tight field supervision to minimize inter crew interference.

(a) achieving minimum inter crew interference on site. When asked how contractors build into their schedules protection for their work crews from interference by other work crews, a reasonable percentage of experts said that it cannot be done by the schedule alone but that it was mostly done by careful supervision which must handle that problem on site.

For (i) good communications regarding work sequences etc among on site managers and (ii) a basis to provide tight field supervision of crews working on a construction site there must be a single originating datum source of information for both of these types of managerial activities. It should describe what all participants should be doing at each point in time and what has been scheduled to achieve harmony in the future construction work. That is a major purpose and use of the preconstruction schedule during the actual construction process.

The schedule should present what the different work crews should be doing so that each subcontractor can guide his crews from his own sub schedule and have minimum problems if he adheres to the schedule. What might have been interference among work crews say, in a particular location of the building, should have been seen by the scheduler. He should have dissolved that problem by thinking out an acceptable and workable solution and express its solution in the schedule. If the scheduler cannot wholly eliminate such problems in the scheduling process, he should note the potential remaining difficulty on the schedule as a potential logical critical part of the work process so that the on site controller is forewarned of the matter.

Actual construction is much easier to communicate to others and control if there is a clear statement of what is to be communicated and from which datum the actual construction should be controlled.

It is the scheduler who should think ahead of the construction process to solve problems in advance of actual construction. It could be seen that the higher the quality of the preconstruction schedule to show the best way of constructing that building the less on site effort will be needed to think out what to do on site. There will remain the on site tasks of communication of what (and sometimes when) to build and control detail parts of the work. However, the on site control of the construction process is difficult enough to do without also simultaneously having to establish what to do.

It is a preconstruction schedule which has been created to show how to minimize crew interferences that will be the best source of information to simultaneously achieve good on site communications and a tight field supervision regarding these matters as well as create an efficient overall construction process for all participants. High quality in these regards in the schedule can minimize, but not necessarily eliminate, interferences among work crews on the site.

(b) on site communications to minimize inter crew interference. Given that the preconstruction schedule presents the work activities in a way that minimizes the interferences between work crews then (i) that schedule has to be communicated to the on site managers - super and all foremen - who will control the individual work crews and (ii) control should be exerted to

monitor actual work crew progress against the schedule and expedite actual progress to match the desired scheduled progress.

Communication conveying the schedule to those who will manage the actual construction process is best done in preconstruction meetings. These can be among groups of subcontractors and the general contractor prior to start of construction work or as each new subcontractor is mobilising to start his work on site. The latter type can be either between only the general and the new subcontractor or the introduction of the new subcontractor to the weekly meetings of all on site managers or both of these types of meetings can be used.

Regarding desired and actual progress of construction, the schedule will be the major sources of information against which actual progress will be monitored and the data base to be occasionally modified prior to conveying such changes to all participants.

These meetings should be held about once per week depending on the size and complexity of the building and the speed of construction. Daily meetings among sub groups or all on site managers may be held as and when necessary for communication or control purposes.

Good communications require giving of clear information and feedback that it has been received and understood. It also usually requires discussion between parties so that each understands the objectives and problems of the other and that all are trying to reach the best overall solution for everyone. An

analogy for this discussion process could be a football team's huddle prior to making a play. A precursor to a successful play is that all participants know what each has to do to create harmony which creates success uninhibited construction program. This desirable better more open communication among on site managers develops greater trust among them which in turn increases the potential to achieve the desirable objective of them working together as a team.

Receiving, considering and using information on preferred sequences, work activity durations etc. from the schedule gives the on site controller information with which to discuss, consider or rebuff suggestions from other roles to change the schedule during construction which conflict with that earlier input from the same organizational source.

(c) tight field supervision to minimize inter crew interference. The basic idea behind tight field supervision is to make every effort that the actual construction process follows and occurs just as the schedule says the work shall be carried out. In other words the actual construction process will be at its most efficient when it follows the carefully created schedule which is the best thought out way of construction that building.

There should be good quality site superintendent and subcontractor foremen managing the work on site. Each should know his own trade and its generic interactions with other trades, be able and willing to communicate with others on the

site and work together as a team with these other on site managers. Their objective should be for the actual work to follow the schedule by ensuring that all required resources by type and quantity are in place prior to the start of each work activity. It is they who set up and should control the flow of resources to the site and on the site. They should monitor progress of their work crews, adjust resource allocations to keep actual construction according to the schedule and monitor progress regularly and discuss the status of the whole job openly and regularly among themselves.

From the overall pre construction schedule, they may set up temporary sub schedules for the next three weeks or one week or a couple of days against which to work achieve the objectives of the whole schedule. Then they will control their resources to achieve their sub objectives which, in turn, achieve the overall schedules objectives. These sub schedules should recognize the time and logic and construction critical features of the overall schedule and it is usually up to the site super to watch out that these matters are communicated to all on site mangers and that each recognizes them in his on site tight supervision of his work forces.

Problems Scheduling And Controlling Flows of Labor As Seen By Subcontractors

It appears that the subcontractors use the schedule at two major and two minor aspects of the construction process regarding his labor forces i.e. (a) prior to construction work and (b) during construction work and to a lesser extent, the schedule relates to (c) an array of causes of variance in demand for labor and (d) positive and negative variables in the work force.

(a) Establishing Required Labor Force Prior to Work. In this preconstruction phase the use of the schedule is to arrange the required size, flow and segmentation of the subcontractors labor force against time.

The schedule should provide the origin of such requirements to the subcontractor by enabling him to establish the number of workers he will need in each unit of time. Within such global numbers, it should also enable him to establish the number of each labor skill type the construction process will need from him. Also, he can use the schedule to establish the required numbers of highly skilled tradesmen he will need within his whole labor force. At a more sophisticated level and within the above, it would be advantageous for the schedule to show him how many men he will require simultaneously but in different work zones of the building.

The schedule should indicate which work activities to be carried out by the subcontractor have time and logical importance

to the whole construction process and which work activities have importance only to his own progress. The former will require more managerial attention but the latter gives the subcontractor the opportunity to adjust the timing of such work to level out any variances that may exist in his overall work force.

It should be borne in mind that the subcontractor's desired labor profile/histogram will begin with a small starting force which builds up rapidly to the desired size of the overall work force. Once the overall desired number of workers are on site the subcontractor wishes to have all of them fully employed for as long as possible until the ending phase of his work when there should be a rapid decline to zero. When the overall schedule requires the subcontractor to operate with a labor force profile/histogram different from the above desired one the subcontractor will tend to follow what is best for his efficient operations. This usually implies that he will not operate his work force in numbers and work locations dictated by the schedule. The result of this is that the schedule tends not to be followed and thus each subcontractor begins to impinge on the work of other subcontractors which tends to cause more friction on the work and labor flows of all subcontractors.

From the above, it follows that the schedule should be cast in such a way to enable each subcontractor to create a labor profile/histogram for his work that generally tends to follow the above desired profile/histogram.

(b) Adjusting Labor Force during Construction Work. The control of labor flows during construction by subcontractors tends to focus on each of the time intervals between the points in time when progress monitoring takes place.

The subcontractor will consider the work demands on his labor force subsequent to monitoring actual progress against the schedule at a point in time and equipped with the schedule for that next time interval of the future construction process. Such a schedule will be either as it was in the preconstruction schedule or as it was plus how it has been adjusted subsequent to this last monitoring of progress. He will base his decisions on controlling his labor force on the labor demands from these work needs and the actual labor force he has on site at that time. That labor force may or may not be as per the preconstruction labor profile/histogram for his work in the next time interval.

In this situation the subcontractor is trying to most efficiently man the work he has to do in that next time interval but more importantly to him, is to ensure that the whole work force is fully employed. He will also be taking a view on the demands for his labor in the subsequent remainder of the construction process from the nature of that construction process up to the present point in time. If, in the past, progress has been slow or late in starting, he will probably already be running his labor force at a level lower than in the preconstruction labor histogram to match actual labor demand. Furthermore, in such a state he knows demands on his forces will

be pushed to increase during the future remaining work he has to do to finish his work in the whole project by the planned finish date.

In situations such as the above which are comparatively normal for subcontractors, some of them will deliberately underman their work compared to the above optimum histogram from the schedule. At least this will be done early in the construction process until reasonable certainty has been achieved on the speed being set by the general contractor for the whole construction process. Their objective here is that once a labor force is on site it has to be paid for it whether or not it is working. Therefore undermanning will minimize the risk of unproductive labor force on site. The overall total work has to be done but later in the construction process the labor force can be increased to meet its demands.

The above strategy is almost wholly based on entrepreneurial view of minimizing loss of productivity today. That this strategy might well be in the minds of every subcontractor on the site does not bode well for the actual construction process being close to the scheduled progress in the preconstruction schedule until the general contractor's managerial strategy and day to day approach to expediting work is known by the subcontractors. This, in turn, can be and usually is compounded by the general contractor creating an over optimistic preconstruction schedule to counter this expected behavior of the subcontractors. The gap between these two forces is a major grey area in construction

scheduling which (i) reduces the validity of the preconstruction schedule as a guide to actual construction and (ii) exacerbates all problems which arise when the actual construction process is divergent or diverging from the preconstruction schedule.

To close that gap on a particular schedule and construction process attention should be directed towards construction realism in logic and durations and labor demands in that construction schedule. This realism will engender trust between the two parties which can strengthen their relationship which in turn leads to more productive construction.

(c) Causes of Variance in Demand For Labor. An array of individual factors was gathered which influenced variance in demand for labor during construction. The major grouping of these factors deals with labor allocations and others include the schedule not being followed, delayed deliveries, lack of information and nature of supervision.

(c)(i) labor allocations. The subcontractor has to know from the general or by his own analysis of the schedule what skill types and numbers of men he needs at each time phase per period of his work. To try to ensure achieving full productivity, the subcontractor may try to underman his work generally and use overtime in short durations to balance the underproduction by the smaller work force prior to a progress monitoring point in time.

The subcontractor will be looking for delays in starting his work which, in turn, affects those who follow him and may be caused by those subcontractors who precede him. Another cause of variance in labor flow is that the schedule may have work activities which do not require full time work by the required skills and the subcontractor will tend to batch these work activities to provide full time work for these skilled men in defiance of the schedule but leading to fuller output per man on the site. In turn this may cause perturbation to the durations of the work activities in the schedule which then impinges on other work of this subcontractor and the work of all other subcontractors on site which then causes reverberations throughout the whole construction process.

Above all else it should be realized that the schedule deals with the construction process of one building but the subcontractors overall objective is optimising the output of his whole work force across all of the buildings he is working on simultaneously. If he has to, a subcontractor will move labor from building project to building project to achieve his overall objective. Conflicting with this objective is a general contractors overall schedule for construction of each individual building. Furthermore, some general contractors desire that their will be workers from all subcontractors on site over the whole construction process to facilitate the general contractors management opportunity to change actual work process from the schedule on a short term basis due to unforseen circumstances on

site. Clearly, such managerial flexibility for the general contractor causes problems and costs for each subcontractor achieving his objective of labor efficiency.

(c)(ii) work of other subcontractors. Another cause of variance in demand on labor flow of a subcontractor is the work of other subcontractors. Some of them will be working behind their schedule in time and others may be working in zones of the building which are later in their time schedule. There may be valid reasons for these workings out of their scheduled sequence etc such as lack of resources, they can't work where they should because of others etc. However, for each subcontractor the incomplete and uncompleted or out of sequence of work by others disturbs the schedule for his work and his labor force. This can lead to inefficiency in his productivity which leads him to try to redress the imbalance by operating more independently of the schedule which further reduces coordination of the whole construction process by the schedule.

(c)(iii) deliveries of materials. Deliveries of materials to the site which arrive later than required to meet the construction schedule or whose arrival is a random occurrence can cause variances in the demand for labor. This is especially severe once the labor force is on site because the lack of materials delivered leaves the site management of the subcontractor with few options other than putting men to work on

work activities from the future remainder of the schedule which, in turn. can disrupt many other work activities on site as well as cause discontinuity within the work of that subcontractor.

(c)(iv) incomplete information. Compared to the above causes of variance in demand for labor are the factors of incomplete information and variable work supervision.

Incomplete information comprise poor and incomplete design drawings, delays in creating revised designs and change orders which are being contemplated but not yet decided. In these situations, it is the uncertainty which causes variance in needs for labor. Also their effect on procurement and deliveries of material originally in the designed building as well as for materials being contemplated in the design changes causes uncertainty in planning future labor flows along with its work etc.

(c)(v) variable work supervision. Variable work supervision at the level of the general contractor site superintendent may cause variances in labor flow for a subcontractor. In the control process, if the site superintendent makes major changes in actual work logic or timing of work activities from that stated in the schedule which gave labor allocations to a subcontractor then there will likely be major variances on the demands on the subcontractors labor force. Perturbations of this nature are usually used by subcontractors at least a signals on how the

construction will be run by that site superintendent. Generally, the subcontractors response will be to reduce his work force to below that demanded by the original construction schedule and note all such changes in work to be done as potential future claims for extra payment.

(d) Variables in the Work Force Itself. There appear to be two general sets of variables in the work forces of subcontractors i.e. positives and negatives. The positives tend to express that the subcontractor has no great problems with this work force if he operates in a particular way whereas the negative factors are those problems which seem to have a lowering impact on productivity.

(d)(i) Positive Factors. By treating workers humanly and getting to know them as people over a period of time will create mutual respect between the parties and ease the interface between them when a work push or change is needed or negotiations occur on an issue of mutual concern. The contractor should try to build up a work force of rounded competent workers and employ people with seniority in their trades. He should try to have such workers employed all year round and set up his work loads accordingly. (This may be more appropriate for non union situations than for a unionised work force). Perhaps variances in the work load overtime can be handled by workers hired for short durations, or putting full time workers on overtime for

short periods. It follows that operating in this manner might cause the subcontractor to try to carry out his work on various projects in sequence rather than in parallel. In turn, this affects how he approaches his work on each building regarding how closely he will follow its schedule. However, these matters should be considered by whomever is creating the schedule for each building process.

It was also suggested that by trying to have materials ready on site or at the work place prior to workers moving to that work location is a way of improving the attitude of the workers and thus raise their productivity.

(d)(ii) Negative Factors. Specific causes of low productivity from individual workers and from work crews etc appear to range from drug and alcohol problems, sickness, personal problems to worker apathy. Beyond these specific negative factors was general absenteeism and labor not showing up for work or men just needing a day off. These negative factors may be extended to encompass that workers appear to actually work only about sixty percent of the time they are on site. It may be that such a level of productivity is not wholly due to only the above negative factors but also is created by inefficient management. A general lack of training in their trade was also cited as a problem in keeping an on site labor force working full time.

Overall these negative factors or ingredients in the work force of a subcontractor show that there can be a considerable

amount of uncertainty as to the number of workers on site on any day and that human work capabilities as well as skill capabilities available on site from day to day will vary considerably. Such uncertainty, as to what his work force will be from day to day, shows that the meeting of an agreed and construction realistic schedule of work by a subcontractor can be closer to a probabalistic nature than a certainty. The above underlines the validity for a subcontractor to try to maximize the above positive factors in a subcontractors labor force as being those which can give him a better potential to meet the realistic construction schedule he previously agreed with the general contractor for that building.

MAJOR PROBLEMS TO CONTROLLING MATERIAL FLOWS TO AND ON SITE

Major Impediments to Construction Material Flows On Site As Seen By The General Contractor

(a) equipment availability

(b) space availability

(c) site conditions

(d) manpower availability

(e) coordination of material flows

(f) procurement process

Major Problems in Material Flows From On Site Storage As Seen By General Contractors

(a) lack of space

(b) flow of logistics of storage

(c) security

(d) weatherproofing

(e) location of storage

Major Problems In Controlling Flows Of His Materials As Seen By Subcontractors

(a) false delivery dates

(b) improper deliveries

MAJOR PROBLEMS TO CONTROLLING MATERIAL FLOWS TO AND ON SITE

The preconstruction schedule should present the best actual construction process to be followed. The preceding scheduling process should include consideration of these material flows and at least they should be implied in the final preconstruction schedule even though they may not be stated as work activities.

This section of the report is arranged in three parts. The first two parts describe the views of the general contractors experts on this topic and the third part is from the viewpoint of the subcontractor.

Major Impediments To Construction Material Flows On Site As Seen By General Contractors

All of these impediments and problems can, at least, affect the duration of work activities in the construction process itself and may well have implications for choosing one logic over another for the schedule because they have an effect on the times by which these materials could be built into the building.

This part of the report is presented under the headings of (a) equipment availability, (b) space availability, (c) site conditions, (d) manpower availability, (e) coordination of material flows and (f) procurement process.

(a) equipment availability. The unavailability of proper equipment to handle cross site movement of materials was cited as the impediment most often encountered by material flows. This can be seen as any of the proper equipment simply not being on

the site or on site for too short a duration etc. or inadequate numbers of pieces of appropriate equipment or simply inappropriate equipment being put on site. All of these can impede material flows which affects the speed of construction as well as the risks of breakages etc.

Alternatively, the proper equipment might be on site but its use is poorly managed. This can be by deliveries of different materials by different subcontractors arriving randomly at the site, resulting in inefficient use of the equipment or it could be that the location of the equipment on the site creates inefficiency. Also, if contolling such equipment usage for material deliveries is left to the laborer driving the hoist then it is highly probable that the overall delivery processes will not flow according to the schedule. Hence, neither will the whole construction process flow according to the schedule even though it has been carefully thought out to be the best way to construct that building.

Within equipment availability there is a clear priority to consider equipment for handling vertical movement of materials because that is seen as a major potential impediment to construction. Here is usually a crucial point or location on site where the various material flows converge and have a maximum potential of interference for each other. Each subcontractor desires the speediest and cheapest delivery of his materials over the others. Hence, if the general contractor does not wisely control such material movements the whole construction process

can be in jeopardy. To most easily and wisely control such flows requires good scheduling and expediting of the material flows for the whole construction process. That schedule for vertical movement should be derived from the desired best construction schedule, hence, this potential impediment should be dissolved by careful thinking in the creation of the construction schedule.

(b) space availability. The availability of space on the ground on site for staging areas or laydown areas for materials as they move to their work places of temporary on site storage areas is a potential impediment to the flow of materials across the site. Their existence or non existence may affect the speed of the flow of materials and these areas should be sought out and considered as input to the scheduling, especially in establishing work durations. Storage areas should be as close as possible to the final work location or locations in the building. This also induces or is derived from the benefit of moving materials directly from off site to these store locations close to their work locations in one movement. Staging areas and laydown areas are necessary where fabrication of work can take place in locations which enable work efficiency and safety and minimum friction on the material flows.

There is need for clear access to the building for materials. This may include leaving temporary openings and their protection at various points in the building skin either vertically or horizontally at ground level. This also requires

space for the handling of materials immediately around the building and especially around the locations of vertical material movement.

Temporary roads and their upkeep on site are another aspect of space needs for the material flows. Even the lack of upkeep of temporary roads and hardstands can cause delays or slowdowns in deliveries which in turn, can slow or stop the actual construction process which then diverges from the schedule. This feature is especially important if highway vehicles are to move across the site to expedite deliveries.

(c) site conditions The movement of materials across the site are affected by both underfoot conditions and weather. Underfoot conditions are related to maintaining the temporary roads, hardstands and storage areas on site so that materials can be moved in and out under all expected weather conditions.

The expected seasonal weather conditions should be considered as a potential impediment to the material flow which in turn, affects the speed of construction. The objective should be to maintain a flow of materials to the work places required for the speed of the construction schedule by either increasing deliveries in good weather or ensuring availability on site of support services to expedite deliveries in weather which can slow deliveries.

(d) manpower availability. To move materials across a construction site requires support manpower to run and maintain the hoists, elevators, cranes and trucks and stores etc.. Also, the maintenance of on site roads and hardstands requires workers. The non-availability of required numbers of men to do all of the above can seriously impede the flow of materials which can impede construction and hence, change durations in the actual construction process from the scheduled progress.

Numbers of such men is often kept at or below minimum because such workers are seen as not directly construction the building and therefore are perceived as unproductive overhead. However, it is these somewhat few workers that keep the whole supply of material flowing to maintain the direct work flowing at its scheduled speed.

(e) coordination of material flows. There are many flows of individual materials from a variety of subcontractors moving across the site at any point in time and any one of them could interfere with the other. The lack of carefully considered logistics of which materials are moved when and by whom and from where to where on site is a major factor in slowing down the speed of all material flows and the whole construction process. It is beneficial, if not necessary, to ensure that such confusion itself does not impede the flow of all materials.

The coordination of delivery traffic on site should be scheduled to minimize conflict and delays among vehicles and

between the loads and on site equipment capacity. Randomness of deliveries and deliverers who adopt the attitude that they have to be handled before anyone else whether or not it is wise to do so for the benefit of the whole construction process will cause considerable friction on the scheduled construction and cause overall losses in time and money.

Such impediments to material flows can have considerable impact on the speed of actual construction and the expected degree of such friction on material flows should be built into the pre construction schedule.

(f) procurement process. Before any material can be delivered to the site it has to be purchased, ordered, shop drawings or submittals have to be handled, manufacturing may have to take place and delivery to site carried out. All of these off site procurement processes have probabalistic durations which can affect the arrival of material at the site. To minimize that probability, the controllers in each subcontractor and in the general contractors coordination processes,have to schedule such processes. Regarding the material movement on site, the objective should be that materials arrive on site when expected and prior to their need on construction. By controlling the off site flow of materials, the task of handling the flow of materials on site is brought closer to what was scheduled which, in turn, enables the actual construction process to flow closer to its scheduled process.

Failure to carry out the above work in creating the schedule causes dates upon which materials should be delivered to be probabalistic. Failure to monitor and control these processes can put the whole actual construction process in jeopardy of being radically different from the scheduled process.

The scheduler should examine the contract documents to establish the various major materials, especially those of a unique nature, which will involve time probabilities in their procurement. Once identified, their durations for procurement should be studied and their most likely durations scheduled and their delivery dates correlated with the start date of their installation in the scheduled construction process.

Major Problems In Material Flows From On Site Storage As Seen By General Contractors

On site storage of materials is a sub process of the whole material flow from off site to the various work places in the building. On site storage can compound the whole delivery of material process and or impede the speed of construction by its status on a construction site. It can also facilitate the construction process when handled to that objective.

Major factors of on site storage which can be seen as potential impediments to construction work are described below.

(a) lack of space. This was the most often cited impediment factor regarding on site material storage. Often space outside

the building but on site is very limited and only parts of it can be used for storage. This pushes the scheduler to establish storage spaces within the partly completed building which can be turned to advantage by placing stores as close as possible to the future work locations. However, care must be taken that stores near work locations can create friction on the actual construction work by the stored material causing impediments to the flow of other workers and their materials in the building.

A sub part of this factor is that lack of on site space may cause poor access to and from storage areas and or poor layout of stores which causes further delays in movement of materials, all of which can impede the actual construction process. Hence, the scheduler has to think out these potentials as he sets the durations and speed and acceptable complexity of the preconstruction schedule.

(b) flow logistics of storage. The lack of appropriate amount, area, location etc of required storage areas can severely impede the flows of materials.

The objective should be to have adequate inventory of materials on site to maintain the scheduled flow of construction work. This can be achieved by a continuous flow of materials from off site to the work places but that is ideal and if there is a disruption in that flow to the site the construction work stops. This type of stoppage would not occur if there is an adequate supply of materials stored on site as a buffer to

potential construction work stoppages. These are emergency stores and their contents tend to be placed there early in construction and used towards the end of construction, if not used to cover an emergency.

Overcrowded stores, poorly laid out stores, relationship of storage spaces to on site material handling equipment should be considered as potential sub-impediments to the best logistical flow of materials to and from such stores.

(c) security. On site stores are targets for theft by people coming on to the site looking for things or by workers already on site. Therefore store security is a major concern in on site storage to best ensure that when an item is required to be built into the building that it can be drawn from the store. Security reduces access to stores by workers, may require accounting procedures and that only certain workers can withdraw items through that security screen. These matters can impede construction but they also have a counterbalancing feature in that they increase the probability that an item will be in the on site store when needed, if it was delivered to the site.

(d) weatherproofing. Stores without weatherproofing features can keep items safe from theft but they may not be usable in the construction process if they are weather damaged. Clearly such a type of store creates an impediment to the on site material flows or to the construction process. Perhaps stores should be classed

as weatherproof and non weatherproofed and items allocated to them according to their needs.

(e) location of storage. The placing of a store on site should be a tradeoff between security of the items being kept ready for construction against the minimizing of the cost of their movement on site. The best location for security may be in an out of the way location but that increases the potential double or triple handling and long distances of movement to and from the store to the work locations. Furthermore, poorly located stores can create impediments to the labor and material flows on site. However, it appears that the closer the store is to the building being built and its various work places appears to create the least impediment provided there is adequate space to have all stores located by that principle.

Another potential impediment feature of the location of storage is its relationship to the location of on site material handling equipment and the capacity and reach of that equipment. All stores should be reachable by trucks and those holding heavy or awkward items should be within an area reachable by the cranes that are on the site.

Major Problems in Controlling Flows of His Materials As Seen By Subcontractors

The major problems of material flows to the construction process are with special pieces of equipment or components which are unique from the array of components readily available in the marketplace. Put another way, it is comparatively easy to arrange delivery of common materials through different local wholesalers or suppliers but these special pieces of equipment or materials tend to be from a sole source or at least, once the purchase contract has been let, their delivery etc will be through one supply channel.

There can be a logical construction process scheduled in which there are times when such pieces of materials are best built into the building. However, the duration of ordering, procuring, manufacture and delivery, etc tends to be derived from the (i) requisite parts of the supply channel of each material rather than from (ii) the duration from time of preconstruction scheduling to the points in time in the schedule when such pieces of material should be optimally built into the building. Hence the schedule should reflect the realistic points in time at which the deliveries of these special pieces of material can be built in, as derived from their delivery duration.

Presuming that the above two forces have been made compatible in the final preconstruction schedule there appears to remain two major groups of causes which result in a holdup of actual construction because such pieces of material are not on

site when needed for construction. These two groups of causes are (a) false delivery dates and (b) improper deliveries.

It should be borne in mind that the general contractor usually makes up the preconstruction schedule and the subcontractor may or may not be the provider of material delivery dates to the general contractor for that preconstruction schedule. In turn, the general contractor may or may not use them in making up his schedule. Also the actual delivery process may be in the hands of a sub subcontractor or a trucking company or a material wholesaler or a manufacturer and also involves paperwork interaction among most of the above roles plus the architect for shop drawings and submittals.

Interestingly, these shop drawings and submittal papers etc. were hardly cited as a problem by subcontractors with deliveries; whereas, during actual construction their focus of concern was on the delivery of the physical object to be built into the building.

(a) false delivery dates. The major causes of false delivery dates being stated by subcontractors is that they have been given false delivery dates by suppliers of these materials. Suppliers may be local wholesalers, delivery companies, manufacturers representatives or manufacturers themselves or a combination of any of the above.

Other causes of false information on delivery dates of material to the site can extend from the supplier not knowing his

stock of materials and presuming that it is there, and that the longer the lead time for a type of component the higher the probability of inaccuracy in the forecast of a delivery date for its arrival on site.

False delivery dates lead to an invalid and unrealistic schedule from which to control the actual construction process.

(b) improper deliveries. Deliveries were seen as improper under an array of characteristics. The proper material arriving at the site later than expected was seen as improper delivery but was probably at the least injurious end of such an array. The wrong item might be delivered to the site, the material or component might be delivered in parts and only some parts reach the site. In other instances, the correct component reaches the site but is damaged so that it would be futile to build it into the building. Some deliveries may be correct but an inadequate quantity is delivered so that only some of the on site work can take place and the remainder must wait thus perturbing the remainder of the schedule. Truck or freight lines may make mistakes in their shipping processes which cause delays in delivery beyond the expected delivery date. The material or component may be delivered to the site on time and undamaged etc but the contractors receiving processes are weak and the subcontractor may not know that it has arrived on site or where it is stored on site thus it is considered not to be there.

Clearly, improper deliveries can inhibit the progress of the actual construction process. If the preconstruction schedule was valid and realistic, then these improper deliveries increase the gap between the actual construction process and the schedule from which it is being guided. If it was a poor schedule to begin with, then the gap between it and the actual construction process will be wider and more probabalistic than it was before the improper deliveries.

MAJOR PROBLEMS IN CONTROLLING CONSTRUCTION WORK ON SITE AS SEEN BY THE SUBCONTRACTORS

Factors Which Cause A Negative Impact On Construction Work

(a) Poor Supervision

(b) Poor Performance of Work

(c) Work Performed Out of Scheduled Sequence

(d) Incomplete Work in Work Zones

(e) Lack of Respect or Concern For the Work of Others

Interferences With Construction Work and Its Management

(a) Inadequate Physical Spaces In the Design

(b) Interference From Sequencing of Subcontractors In a Work Space

(c) Interference From Too Many Work Crews Simultaneously In A Single Work Zone

Major Problems From Having To Change Work Durations and Dates During Construction

(a) Changes in Manpower Allocations

(b) Changes in Material Deliveries

(c) Problems in Subsequent Labor Productivity

Major Problems In Controlling Construction Work On Site As Seen By Subcontractors

This section of the report deals with the subcontractors view of managing his work under the management (and schedule if there is one) of the general contractor.

Here are the issues, problems, impediments etc. to the work of a subcontractor that a good schedule should try to eliminate before construction work begins.

This section of the report is in three sections. One deals with management problems, the second deals with interferences to the work and management of the subcontractor and the third deals with problems faced by the subcontractor from having to change his work from the schedule during the construction process.

It should be understood that the problems faced by subcontractors dealing with their labor flows and material flows during construction as related to scheduling, appear in the sections of the report dealing with these flows.

Factors Which Cause A Negative Impact on Construction Work

There appears to be five groupings of factors which comprise the majority of negative impacts on the work of a subcontractor. These are, in descending value, (a) poor supervision, (b) poor performance of work, (c) work performed out of scheduled sequence, (d) incomplete work in work zones and (e) lack of respect or concern for work of others. Within the above, the single most mentioned factor was that a piece of work by a preceding trade work crew was not completed prior to a work crew

of this subcontractor having to start their work in a geographic zone of the building.

It is clear that the degree of control exerted over the actual construction process is the common feature from all the above groupings. That thrust may come from poor control of actual work against a good construction schedule or poor control may be caused by a poor or non existent schedule. However, in creating a schedule for a future construction process, it should be formatted to minimize the potential of these negative factors during actual construction upon the work of the subcontractors.

(a) poor supervision. The general contractor provides supervision and management of the whole construction process and the array of chosen subcontractors. The overall construction process should coordinate the individual work activities of the work crews of each subcontractor into streams of work. Each piece of work should have a designated realistic duration.

Poor supervision of the actual construction process appears to be derived from either poor control on site or poor logic in the construction schedule from which the control originates or both. It can also occur in the situation of workers controlling their work and interactions with others rather than being controlled in a coordinated manner, by the site superintendent. Furthermore, every change that is made to the construction contract, should be in writing and that every change order should reach all parties on the site affected by that change. It

appears important that such changes should be incorporated in the construction schedule.

Poor supervision can also include poor relations between subcontractor staff and the generals site superintendent and with the staff of other subcontractors on site. Lack of clear and adequate communications appear to be the core of this part of poor supervision. To achieve good supervision calls for full and proper verbal and written communications with all parties on site along with consideration for the different objectives of different participants. Reference to the schedule should be an important aspect of all communications regarding the construction process.

(b) poor performance of work. Work done which contains mistakes, is not according to the design, is simply of a quality that is not up to specification etc. or in carrying it out it abuses or destroys part of the work of others, all lead to the need for rework and hold up of incoming following work crews which then can create a deleterious domino effect through the whole construction process.

This factor points up the issues of provision of what quality of work is required on each work activity as input to these work activities and the concurrent, or immediately following, inspection of quality of work being done. By so doing, there is a higher probability that when a work activity is finished the next work crew can begin their work fully without

interference from subsequent rework by the poorly performing preceding work crew.

(c) work performed out of scheduled sequence. A carefully prepared construction schedule should present the flow of work of each work crew around the building by time and location. Control of the actual work should ensure that all work crews follow that sequence. Care should be taken that work crews are not allowed to pick their own work flow around the building to the detriment of the overall construction process.

Work being executed out of sequence can be by a work crew simply falling behind in time or not starting their work on time so that they are constantly behind their schedule. Maybe a holdup in material delivery for whatever cause will push a crew to do a different piece of work out of sequence because they can't do the scheduled work at that time. It may be that the schedule directs too many workers of different crews into one work location at one time thus causing all of them to be delayed. Some of these work crews may move to another part of the building so that they can utilize their time productively. However, this causes perturbations to the whole construction process due to that work being done out of schedule sequence.

The result of all of the above is that the whole construction process becomes more random than scheduled because the work to be done has to occur upon the work already in place. This randomness causes inefficiencies in the execution of that

subsequent work as well as the deleterious work in place having been executed out of the most efficient sequence of work from that type of work on this building.

(d) incomplete work in work zones. A work crew may be unable to complete its work in a work location for a number of reasons. These may be from lack of materials or unavailability of particularly skilled labor or some tradesmen have been moved to do work on another location on site etc. It may be poor control by the subcontractor of his labor force allowing them to do as much work quickly in as many locations as possible without finishing out any one work location. The subcontractor may operate this way to maximize an interim payment, or utilize a work crew learning curve to the detriment of the whole construction process. It may be that the work crew has completely finished its work in a location but has left waste and debris etc. lying around. If the following work crew wants to start its own work it has to clear away that debris or have it moved by someone else. All of such delays impact on the progress of the whole construction process. The result remains that the work to be done by a particular work crew in a particular work location is not completed before it moves on to its next work location.

That incomplete work means that the work of the following work crew in that location will be at least hampered in its execution or it cannot begin until the earlier work is complete, thus causing inefficiencies in the whole construction process.

(e) lack of respect or concern for the work of others. When work crews of subcontractors work under the premise that their work is more important than all other work on site, or they do not consider the work processes of other work crews, there is high potential that they will damage the previous work put in place by others and that they will carry out their own work with maximum ease to themselves. This approach will create rework by preceding work crews and may increase the amount of work by subsequent crews which have to unnecessarily work around the work already put in place.

This lack of concern for the work preceding and following the work being carried out can build up a considerable volume of unnecessary work which slows the whole construction process. It also builds frustration into the work of many participants in the construction process which can cause breakdowns in vital on site communications, reduce cooperation among participants and induce some participants to strike back at whomever causes the unnecessary extensions to their work. All such activities slow the actual construction process, increase its costs and create unnecessary divergences from even a very good construction schedule.

Interferences With Construction Work and Its Management

Interference with a subcontractors work can be seen as comprising factors which inhibit his work from flowing freely or

in as straightforward a way as possible. The common thread from all the responses to what are typical interference to the work of a subcontractor deal with three different types of spaces. These are (a) physical spaces in the designed building within which the work of the single subcontractor has to be carried out, (b) interferences to a subcontractors work in a designated work space caused by the work of the other subcontractors chosen to precede each specific subcontractor and (c) interferences caused by too many work crews scheduled to be working simultaneously in the same work space.

The first of the above types of spaces has to be faced but the second and third types are the result of the schedule or non scheduling by the general contractor. The type of interference caused by too many work crews working in a work zone was clearly the most frequently cited type of interference to their work stated by subcontractors and meeting the buildings design was the least frequently cited interference.

Much less frequently cited interferences were, lack of coordination between specialist drawings, improper measurements on drawings and that changes in the work of one subcontractor were not mentioned to other subcontractors.

(a) Inadequate Physical Spaces In The Design. The building is usually designed as an end product to be used by its users and efficiency of construction is rightly a secondary feature of most designs. While small spaces in such designs cause interference

with the efficiency of construction work, they can be seen as an acceptable part of the price paid by the project owner. Nonetheless, designs were criticised to the effect that space available for workmen to construct the building could be too small for optimum execution of that work. For example, equipment rooms could be too small for optimum work given that the contained major pieces of equipment put in place by different trades. Sometimes the work to be carried out by different trades were unnecessarily located too close to each other for efficient construction by each trade. Awkward access routes for pieces of equipment or materials to final designed locations was another sub factor seen as inhibiting construction work of a subcontractor.

(b) Interferences From Sequencing of Subcontractors in a Workspace. The general contractor may schedule the work of subcontractors in the wisest sequence in each work zone of the building or he may not do so. He may provide such a sketchy work sequence to subcontractors that it is unclear which subcontractor puts his work in place before another subcontractor. If the general chooses a poor sequence for various subcontractors work in a series of work zones of a particular building, then the subcontractors who follow may have their work processes more inhibited than they would have then if the sequencing of all work crews of all subcontractors was sequenced differently. Clearly, more careful thought should be given to this matter prior to

finalizing the overall preconstruction schedule. This careful pattern should be derived from the design of the building but it should also be borne in mind that the same sequence of work activities across work crews of all trades should be repeated in all geographic zones in the building for schedule simplicity. A clear example of this situation is the work of a number of subcontractors in the ceiling space of an office building. Here there are pipes, ducts, conduits, hangers, supports etc of numerous subcontractors and all have to do their work in that ceiling space. Given the design of that space of the building, there can be an array of sequences of subcontractors work crews in a mixed sequence from most to least efficient construction processes. If the general contractor makes an unwise choice in the sequences of all of these work crews it follows that the work of virtually all of these work crews throughout all work zones in the building will have to be carried out with less efficiency than could be with a wise choice of such sequencing.

If there is no clear indication from the general contractor in his schedule as to which subcontractor should precede and which should follow each other in a sequence, a more serious type of interference may be induced. Without that guidance as to work crew sequence, it is up to the subcontractors to do their work as best as they can. This tends to lead to anarchy among them and the subcontractor who gets there first, and does his work, in the empty space has the least inhibited workplace, he is the "firstest with the mostest". The subcontractors who follow such

an anarchist have to work around the work already there and if that causes them more work, they just have to do it in that less efficient way. This inefficiency can reverberate through the whole array of work crews of all subcontractors in the construction process to which can be added the deleterious effects of antagonism, low morale and little cooperation among subcontractors. Some subsequent work crews may then choose to jump their work out of sequence to empty spaces in the building to regain their own efficiency. This causes the other factor of inefficiency of working randomly and inefficiently spreading through the whole construction process.

The above may also occur if the general contractor has stated his sequence but if that sequence is not being followed by the subcontractors. The on site control staff of the general contractor should make sure that his chosen sequence of subcontractor work crews is being followed. Thus it could be a failing in either of (i) scheduling or (ii) control of actual construction against the schedule that leads to the above important type of interferences with the work of each subcontractor on site.

(c) Interference From Too Many Work Crews Simultaneously In A Single Work Zone. This was cited by subcontractors as the most common factor causing interference to their on going work on site. If too many tradesmen or work crews of subcontractors are working in one work zone in the building then the work of all of

them will be inhibited. If this occurs it will have been caused by (i) poor or casual scheduling of the coordination of work of subcontractors on site, usually by the general contractor or (ii) poor control of on site work allowing this to happen or (iii) accelerating of on site work to try to catch up time lost on earlier delays or slow work.

More sophisticated causes of such poor scheduling related to this issue can be derived from a number of sources. Probably the most likely will be the lack of consideration of separate geographic locations as work zones in the construction schedule. Without such an initial analysis of the building, it is very probable that this interference factor will occur in the actual construction process. Alternatively, allowing different work crews of different subcontractors to progress at different speeds through a fixed series of work zones due to their different numbers of productive resources will also lead to too many work crews being together in the same geographic work zone at the same point in time. Failure to start work crews at their scheduled time may cause this problem to exist. It might also be that the relative timing of the movements of work crews is not in harmony, or the inspections of work completed does not allow subsequent work crews to begin or continue when they are scheduled to work that causes the build up of more than optimum numbers of work crews in particular work locations. It may also be that the initial construction schedule did have the above suggested features to keep work crews apart but that schedule was not

subsequently examined for interaction among the above sub factors which allowed the simultaneity of different work crews in single locations of the building prior to finalization of the preconstruction schedule by the general contractor.

Of course, the schedule which was created and is being used, may be simply a poor schedule by which to construct that building rather than examine it for the above more sophisticated parameters of high quality scheduling of construction work.

Major Problems From Having To Change Work Durations and Dates During Construction

The major problems for a subcontractor in changing his work activity durations and their dates during the construction process deal with the need for (a) changes in manpower allocations, (b) changes in material deliveries and (c) problems in subsequent worker productivity.

The major approach used by subcontractors to minimize the surprise of such changes is by knowing what is going on in that construction process among all participants and in your own work and work force and all interactions that may affect your work.

The subcontractor should be watching progress on a construction process before he moves his forces on to the site as well as when he is working there. He should also verify the work he has to do on site and try to have the most realistic information possible on his work from the general contractor and his own men and also from his suppliers. The confluence of these

information flows should give him the forward looking approach necessary to anticipate potential changes in his work rather than the subcontractor be surprised by a change of duration or calendar time for a piece of his work when it is announced by the general contractor or arise in discussion in a weekly job coordination meeting, He may also equip his site staff with a list of work activities that can be done almost at any time in the construction process as time fillers to absorb some changes he has to make while wishing to leave his work force intact on site.

(a) changes in manpower allocations. By carefully considering the simultaneity of work activities in his work schedule, the subcontractor should have created for himself some flexibility in moving his labor force across an array of types of work activities and work locations on site at any point in time. While best productivity is usually achieved by focussing on one type of work over a short period of time to benefit from the learning curve, his primary objective is to keep all of his workers working all the time. So the subcontractor will move men away from work that is held up to others that can be done.

The finding of appropriately skilled men for the needs of the project usually means that once the work crews are on site he wishes to keep them there till the end of their work. The schedule should give him the labor histogram he requires of his trade. Now, when the scheduled durations as calendar times of

work activities changes, the labor histogram will change unless the subcontractor has created the above flexibility to be harnessed under this condition. With that flexibility the subcontractor may have to scramble to keep his work force fulling employed. He always has the alternative of moving men off site and trying to bring more men on to the site later but both of these create additional costs to his company.

Other alternatives are to consider or use overtime and or more than one shift to handle the extra work load caused by acceleration. It should be noted that these approaches are usually only beneficial to productivity when used in short bursts rather than being used continually.

The subcontractors overall objective is to maintain full workload for his full work force on site over their duration on site. The schedule should try to provide satisfaction to that objective for each subcontractor on site.

(b) changes in material deliveries. If the duration, or more likely, the calendar time of a work activity changes there will likely be interaction with the delivery dates for materials for such activities.

When the move is to an earlier calendar date than scheduled, the delivery problem is one of speeding up the logic of the delivery process. This may be very difficult to do given the reality of the delivery durations which are not wholly under the control of the subcontractor.

When the move in time of the work activity is towards a later calendar date, there are the alternatives of changing the delivery process to a later date or leaving the deliveries as originally scheduled and paying for the materials at the originally expected point in time but having to pay the demurrage for a longer duration and the added risk of damage from storage on site.

In all of the above changes, there are the money and time costs of making the changes and also the increased probabilities of mistakes in rescheduling such work and deliveries while mainly trying to control the actual construction process. It may be worthwhile to pay extra to have the deliveries when they are needed so as to not hamper the on site construction work. Alternatively, a subcontractor could use a warehouse approach for his material deliveries to all sites.

The additional costs of arranging and making the deliveries at a differently scheduled time may be able to be negotiated as an extra to be paid by the general contractor or the project owner should they be the cause of the change. Overall, it may be better to pay the money costs and maintain as much of the original schedule to minimize the continuity of the domino effect of such changes on the remainder of the overall construction process and the remaining work of each subcontractor.

(c) problems in subsequent labor productivity. Even if such changes in durations or their calendar dates are made, there is

always the completion date for the whole project which tends not to change.

Given that there are delays which cause later calendar timing for some work activities and that the completion date remains valid then there will be work acceleration in the later stages of the work of the subcontractor. This implies more work to be done in a shorter calendar time which, at very least, means a more complicated management load on the subcontractors site staff which, in turn, increases the risks of mistakes and more confusion.

Construction work tends to have a momentum over the construction process or at least, each major phase of it. When changes in duration or calendar timing occur during actual construction, that momentum is usually affected in a negative way. Such changes usually break up the harmony of the common momentum which can easily slip to a more random process which is less easy to control and manage. Thus, these changes tend to have a serious deleterious effect on the productivity of the whole construction process which causes longer durations for work activities which extend the domino effect over a larger part of the construction process.

The changes also have an effect on workers because they then tend to be moved from work activity or work location to another in an seemingly random manner. This changeability in the process reduces worker productivity and may even lead to inducing apathy in their morale which further decreases productivity.

There is obviously the cost issue of changes in the construction process and, at the very least, the subcontractor should put such matters in writing to the general contractor if no change order has been issued. It may be that the written statement is the basis for a subsequent claim but it should be put in writing as soon as possible after the time change is presented to the subcontractor.

An alternative to the above change order and claim approach to obtaining costs is to negotiate a time extension for the work with the general contractor.

A possible construction solution to the above is to try to schedule for an array of work crews to work in parallel on the same type of work rather than working in sequence in the schedule. This will execute more work in the same calendar time. However, it implies a different strategy of work in the schedule and may require the view that a building is made up of a set of sub projects all being built simultaneously in parallel. To change from a sequentialist strategy to a parallel strategy during actual construction will affect the whole construction process and could have a traumatic effect on all the subcontractors, especially if some agree to the strategic change while others do not agree to it. Such strategic changes may require subcontractors to place more work crews on site and require greater management forces. Also, under parallelism, there is less benefit from the shorter and more numerous learning curves for each work crew.

COMPARISONS BETWEEN GENERAL CONTRACTORS SCHEDULES AND SUBCONTRACTORS SCHEDULES AS SEEN BY SUBCONTRACTORS

Major Factors Brought Out By Comparison of General Contractors Preconstruction Schedule and Subcontractors Work Control Schedule

(a) Start and Finish Dates of Subcontractors Work

(b) Material and Labor Availability

(c) Manpower Loading

(d) Work Phasing

(e) Schedule Logic

(f) Durations of Work Activities

Factors In The Subcontractors Preconstruction Schedule Which Are Most and Least Likely To Be Changed By The General Contractor

(a) Schedule Factors Most Likely to Change

(b) Schedule Factors Least Likely to Change

Realism of Durations In The General Contractors Final Preconstruction Schedule As Seen By Subcontractors

Comparison Between General Contractors Schedules and Subcontractors Schedules As Seen By Subcontractors

This part of the report provides the views of subcontractors on the nature etc. of general contractor's schedules under which they work during the actual construction process. The three sections of this part deal with firstly, a comparison between the general contractors final preconstruction schedule and the work schedule of a subcontractor, secondly, the factors which are most and least likely to change from the subcontractors preconstruction schedule because of input from the general contractor, and thirdly, the views of subcontractors on the realism of durations in general contractors final preconstruction schedule.

Major Factors Brought Out By Comparison of General Contractor's Preconstruction Schedule and the Subcontractors Work Control Schedule

The general contractors final preconstruction schedule is the schedule by which he proposes to guide the actual construction process. It may have been created solely by the general contractor or it may have received input from some or all of the subcontractors to be involved in the future construction process.

The subcontractors work control schedule is the schedule by which he will attempt to control the work of his own work force during the future construction process. It may be derived from the general contractors final preconstruction schedule or it may

be derived from the subcontractors preconstruction schedule or his earlier cost estimate or his input to the general contractors final preconstruction schedule.

Both the general contractors final preconstruction schedule and the subcontractors work schedule can vary considerably across the ranges of objectiveness to subjectiveness, computer produced to unwritten, sophisticated and careful construction thinking to merely doing the next construction work task that is seen as best to do next, etc..

It was apparent from the responses of subcontractors that once the preconstruction schedule is agreed between the general contractor and the subcontractor it is very clear that virtually all subcontractors then make up their own work schedule by which to control their own work.

The major factors which were brought out by this comparison appear to group around the following headings: (a) start and finish dates of subcontractors work, (b) material and labor availability, (c) manpower loading, (d) work phasing, (e) schedule logic and (f) durations of work activities.

(a) Start and Finish Dates of Subcontractors Work. The start and finish dates of the whole work of the subcontractor are seen as always being used to control the work of the subcontractor. This sense of similarity may be derived from the contractual aspects of the relationships between the parties or it may be that the subcontractor at a very high level allocates his

attention from building project to building project based on these dates. This concern may also filter down to cause him to try to hold to start and finish dates of major phases of his work within each construction process. Thus such milestones are a major feature that should be expressed in the agreed schedule to enable this managerial concept of subcontractors to flourish to the benefit of the whole construction process.

(b) Material and Labor Availability. The subcontractors tend to see the prearranged dates of delivery of materials and labor to that site as being more fixed than is the work activities of the general contractors preconstruction schedule. This applies to and from major pieces of equipment more than common materials and labor and so they tend to schedule their work between these major deliveries which tend to be seen as fixed milestones in calendar time to which the scheduled construction process is secondary. Nonetheless, economic batching of deliveries of common materials and periods of time of availability of different types of labor skills also set a rhythm to the work of the subcontractor seeking efficiency in his efforts. Thus, the construction schedule should recognize these realistic dates of delivery if it is desired that the schedule remain viable as a meaningful guide by which to control the actual construction process.

(c) Manpower Loading. There is an intimate relationship between work activity scheduled durations and required

productivity both quantitatively and qualitatively. Primarily the subcontractor is interested in maximizing the productivity of his total work force and only secondarily in meeting the scheduled durations of work activities in the general contractors schedule. Therefore, a subcontractor will allow the actual durations of the construction work to change from the agreed schedule either overtly or by merely carrying out his actual construction work to his major objective even by infringing on the work time/space of work crews of other subcontractors preceding and following his work crews.

It follows from the above that to minimize the differences between the agreed preconstruction schedule and the subcontractors work control schedule, that the agreed preconstruction schedule prepared by the general contractor should try to schedule by logic and durations that each subcontractor will have work to do for the approximately the same total work force over the majority of the duration of his stay on the site.

(d) Work Phasing. The subcontractor tends to see his work, maybe even unconsciously, as types of work activities under each of (i) roughing and (ii) equipment and (iii) finishing within each major category of his work in his trade. Prior to scheduling each specific building, and maybe even in his estimate, there should be a set of categories of parts of the end

all other subcontractors which is being scheduled under similar constraints. It should also be borne in mind that work flows of individual work crews from different subcontractors tend to have to work adjacent to and intermingled with each other in time and space as all of them move together in an interwoven pattern through the predominating aspects of roughing, equipment and finishes work in the overall construction process.

The above work phases and their boundary conditions tend to set the overall logic of the construction process and their durations tend to fix the start and finish dates, of work phases and the whole construction schedule.

Of course, a general contractors final preconstruction schedule which expressed all of the above for each subcontractor in the whole construction process in the context of an integrated schedule and optimized for durations labor consumption and cost, would be tending towards the ultimate schedule by which to guide the actual construction.

As a consideration of bar charts and CPM diagrams the following observations were made by subcontractors staff. Bar charts were seen as being simple and easy for field staff to understand but were not detailed enough expressions of the future construction process from which to control work. Also it was felt that small businesses understood bar charts and that they could be used for durations only i.e. they did not display the underlying construction logic. On the other hand it was felt that CPM diagrams were too complicated for most situations and or

subcontractors. It was felt that CPM diagrams were expressed with too much detail. It should be realized that the normal CPM schedule is at a level of a summary of a construction process and does not approach the level of detail discussed above as the level of detail thinking of some subcontractors. Again this could be from the conflict between the desired characteristics of the schedule for its use, the scheduling knowledge and capabilities of the subcontractor user and the relative complexity/simplicity required to be a useful guide for the future construction process.

This brings out a deeper feature of construction scheduling that a somewhat simple presentation of the schedule is needed for use and communication by and among users but that complex interactive and conflicting matters have to be thought out and resolved in the preconstruction scheduling process for the output schedule to be a valid preconstruction schedule to be followed by all participants. It may be that neither bar charts nor CPM diagrams are fully capable of expressing the above suggested optimum type of schedule for subcontractors control of the complexities of his work.

(e) Logic. The logic of these two schedules tends to be the same in overall work sequence and each follows that of the agreed preconstruction schedule.

Where different, the subcontractor may tend to emphasize the phase by phase nature of his work within each work activity. For

example, the work activity in the overall schedule may be "Place piping" but the subcontractor sees it as "Place hangers", "Place piping", "Connect piping" being work for different work crews or the same work crew in different calendar times. This means that he will desire to tend to focus each work crew on the same type of work and move them through the building and then change emphasis of their work efforts to the next wave or type of work within his work scope and repeat the same sequence through all the geographic zones of the building.

The work control schedule of the subcontractor will comprise a breakdown of the schedule to more detailed work activities than in the agreed preconstruction schedule. This can be seen as the difference of level of detail as one moves down the hierarchical construction team which requires more detail to enable the lower echelons to properly control their work within the context of the whole managerial hierarchy on the project. Where required a subcontractor will modify the logic of the schedule for his work to accommodate realism of the interactions among those details in the construction process. It is likely that this more detailed scheduling is done mentally rather than being put on paper with all the risks that are so entailed. Depending on the expression of the general contractor's overall schedule, it may appear that the subcontractor is working (as above) to a different logic than the general contractor but such differences tend to be caused by the summary nature of the general contractors (and sometimes, the

subcontractors) overall schedule as compared to the most efficient use of construction labor by the subcontractor.

(f) Durations of Work Activities. While the overall logic of the schedule tends to remain approximately as agreed, the durations of the work activities desired by and thought appropriate by the subcontractor may be different for his work. The subcontractor will tend to modify slack time on his schedule by reducing the peaks and filling the troughs of demands on his on site labor force. Thus, scheduled durations of some work activities may tend to change but durations of phases of work within which such work activities may remain as scheduled. The man hour volume for the subcontractors work will tend to stay as scheduled and its minimization is the subcontractors major objective.

Factors In The Subcontractors Preconstruction Schedule Which Are Most and Least Likely To Be Changed By the General Contractor

The subcontractors preconstruction schedule is whatever schedule he has prepared prior to negotiating or discussing his work schedule with the general contractor. It could be simply his cost estimate for that construction process or it could be a time schedule of how he proposes to do his work or it could be the information he has prepared for the general contractor as input to his preconstruction schedule, etc.

Subcontractors provided these factors which are most and least likely to be changed, in response to the question of which factors in your original schedule are most and least likely to be changed by the general contractor.

Changes made to that subcontractors preconstruction schedule by the general contractor will tend to come from the need for (i) an overall optimum coordinated schedule for the whole construction process and that (ii) work flows for all subcontractors have to be blended into that overall coordinated schedule.

While the general contractor will change factors in the subcontractors initial schedule or provide his own schedule for the whole construction process which is different from that of the subcontractor, it should be recognized that the subcontractor has input to make to whether or not such changes should be made. That input can be in the preconstruction negotiations or even in the post bid negotiations between the general contractor and each subcontractor. The subcontractor can choose to be strong or weak in negotiating various items in the schedule. Hence it should be seen that these factors are most and least likely to be changed as a result of input from both the general and subcontractor and their interactions in the schedule negotiating process and influenced by the nature and timing and their perceptions and objectives in these negotiation processes. Most likely each party will have a somewhat different objective in these negotiations. The general contractor is looking to smooth or

optimize the overall single construction process and each subcontractor is looking to smooth or optimize his own work process within the overall construction process incorporating the work of all subcontractors. If these negotiations are post bid rather than preconstruction, the parties will have different perceptions on their objectives by that difference in circumstances of the negotiations.

(a) Schedule Factors Most Likely to Change. In general, the factors of the subcontractors initial schedule which are most likely to be changed by the general contractor deal with time in the sense of durations and when work activities should start and finish.

It appears that underlying the changes in duration of work tasks and phases, there is the attempt to move work activities towards the beginning of the construction process that allow other work activities to begin sooner. There is also the desire by the general contractor to have work activities scheduled with a duration that tends to be minimum rather than tending towards optimum. This tendency towards minimum durations for work activities seems to occur regardless of its probability of realization in the actual construction process. This implies that general contractors tend to agree with subcontractors that their work is in an appropriate sequence and that is reasonable for the subcontractor given the nature of the building but that

the general contractor wishes to rush the execution of that logical construction process.

The subcontractors perceived that start dates, finish dates and durations of work activities and phases of their work are most likely to change from their initial schedule. This has considerable negative implications for (a) level manpower loading over the whole construction process and for (b) the compatibility of (i) realistic delivery dates from material suppliers with (ii) the dates of beginning work activities in the actual construction process.

The effect of duration on timing changes on the subcontractors manpower loading might cause him productivity problems if the result is not compatible with a steady number of workers on the site for as long and as continuous as possible. While the changes in durations and time may be required to allow for appropriate interactions between work crews of different subcontractors the schedule should still allow a reasonably steady total work load at each point in time for the whole workforce of each subcontractor.

The implications of time changes from the subcontractors original schedule may affect the interaction between delivery dates of materials and when the schedule requires these materials to be built into the building. This is more a problem with special equipment and materials rather than with common materials. The date of delivery of special materials and equipment tends to be controlled by the procurement and delivery

processes rather than the construction process thus the delivery date may be somewhat rigid from these external factors. However, for the subsequent construction work to flow as scheduled, these pieces of equipment should be built into the building at a time to mesh with the whole construction process. Now, if the subcontractor has carefully established the delivery dates and they require a long duration for delivery etc, then changes by the general contractor of schedule durations and their work activity start times will be deleterious to the actual construction process if it speeds up the construction process. If the subcontractor can find valid flexibility in the delivery dates to change them to suit the changed schedule, then there should be little difficulty from the changing of the schedule times requested by the general contractor. However, if such changes in start dates/delivery dates are numerous or the delivery durations cannot be changed but the schedule is changed, then serious gaps will arise between the preconstruction schedule and the reality of the actual construction process, thus greatly reducing the benefits which can flow from having a realistic construction schedule.

These matters raise questions about the reality of the delivery dates initially stated as being valid by subcontractors as part of the foundation as to why their initial schedule has the durations it has. The general contractor may be wise to check that validity prior to and as part of his decisions to change schedule work activity durations from those in the

subcontractors initial schedule. These are very important issues to be considered in creating and modifying a construction schedule and they indirectly affect many work activities of many subcontractors.

(b) Schedule Factors Least Likely to Change. Two factors stand out as being least likely to change from the subcontractors initial schedule to the general contractors schedule. These are the manpower loading required for the subcontractors work and the delivery dates of major pieces of equipment and materials.

The subcontractors manpower requirements are derived from his cost estimate and are the number of man hours of work required to construct his trade in that building. The subcontractor would like to be able to put a set of workmen on the site and have them all fully employed for their duration on the site. He will put a set of workmen on the site to match the requirements of the schedule for his work but he wishes the manpower loading to be a reasonable number and composition of skills for that building. The subcontractor does not want an overall work schedule which places a fluctuating demand for the number of men he has to put on the site. If that happens, the subcontractor will adjust his total workforce to be at a level of full employment given the schedule and when more men are needed he will work overtime or just be behind schedule and late to

complete his work. Such is the strength of this issue in the minds of subcontractors.

The delivery dates of major and special pieces of equipment tend to be fixed by their procurement, manufacture and delivery processes. At one extreme, if they can't be on site by a particular date, they can't be built into the building. While the control of deliveries may be in the hands of suppliers etc. it tends to be the subcontractor who is responsible for the procurement and delivery process in relation to the construction schedule. Because of the importance of these items in the end product, the risk of damage to them if stored on site and their usually long procurement lead times, they tend to be, or should be, strong enough elements to have the overall construction schedule to some extent molded around them.

Where delivery dates and the best construction process can be joined together there is the best construction schedule. The general contractor's scheduler should be careful that stated delivery dates from subcontractors are valid and are not being used to provide more calendar time for the work of each subcontractor.

Two other factors with minimum likelihood to change are the start time for the subcontractors work and the expected payment schedule.

It seems that the date of entry to the site by a subcontractor tends not to change from the original schedule. However as that date is dictated by the logical interaction of

work tasks in the whole construction process which is controlled by the general contractor and probably may be first expressed in the post bid negotiations by the general contractor (when the subcontractor does not yet have the subcontract) it appears that this matter is under the controls of the general contractor. However, the general contractor should be wary of its acceptance at this juncture by a subcontractor who may acquiesce with the general's desired trade start date in order to close the deal to win the subcontract.

The small likelihood of change of the payment schedule to the subcontractor as a result of schedule changing activities of the general contractor points up the separation of money control and time control of the actual construction process. The dollar amount of price for a work activity is the same whether that work activity is done in one week or ten weeks and the interim payment will be calculated by percentage of completion of the whole work activity. The time control of each work activity of the subcontractor would be based on the duration for each work activity in the final preconstruction schedule, be it one week or ten weeks.

Realism of Durations in the General Contractors Final Preconstruction Schedule As Seen By Subcontractors

In general, about two-thirds of subcontractors staff considered that general contractors do put realistic durations on construction work activities in their final preconstruction schedules for the work of subcontractors. The remaining one-third of the subcontractors think otherwise.

When the general contractors final schedule contains durations which the subcontractor considers to be non realistic, he tends to follow one of two main avenues of action. Either he brings these improper durations to the notice of the general contractor or he overtly accepts them but may not adhere to the schedule for his actual construction process.

The majority of subcontractor staff bring the durations which they see as non realistic to the notice of the general contractor. They may simply tell him or they may put their request in writing. Such notice may be couched as a request or a complaint. They may try to persuade and convince the general contractor to change these durations. They may supply what they consider to be the realistic durations for such work activities. These statements may be supported by an explanation of the impacts on the actual construction process if these durations are not changed to be a more realistic duration in the mind of the subcontractor.

Some subcontractors see such matters as a continuous battle with the general contractors and may or may not try to meet

wholly or partly the scheduled durations. Such discussions may take place before construction begins or may take place at the first on site job meeting by which time the subcontractor has started work.

The alternative response by a subcontractor to durations they see as unrealistic is to allocate workers to the job as they think it should be manned and then during construction tell the general contractor that they will not be able to achieve his finishing dates by requiring longer durations for the work activities.

They may also work overtime to try to keep the unrealistic calendar durations as valid. This may be done if they have put some costs of overtime in their original estimate and bid. Alternatively, when faced within unrealistic durations from the general contractors schedule, the subcontractor may stop work and state that he needs more payment for working in an inefficient manner which requires accelerated work to meet the unrealistic durations. The subcontractor may also have to utilize more than normal management time to put pressure on his suppliers and wholesalers to change their delivery lead times affected by these durations he sees as unrealistic.

Clearly the incompatibility of the minds of the general and even a few subcontractors on any one building project regarding the validity of durations can increase the probabalistic nature of the whole schedule. In turn, this greatly reduces the effectiveness or potential of the schedule to best guide the

actual construction process to the most efficient execution. Whereas, if these scheduling issues were resolved realistically, then the schedule would be the best guide to the actual construction process which could be executed efficiently by all participants and meet its overall commitments to the project owner.

The subcontractors staff suggested two major and one minor approach to improving the delinquent durations in the general contractors final construction schedule. The two major ones were that the general contractor's schedulers have a better knowledge of the underlying work of subcontractors than he has and that more input on durations be sought from subcontractors prior to scheduling their work by the general contractor. The minor suggestion to this end is better quality control of the actual construction process which will minimize rework which can compound the construction process.

It is felt by subcontractor staff that general contractors knowledge and experience of the work of subcontractors is not deep enough to select proper durations for all work of the subcontractors. They feel the general contractors staff could be better educated in the work of subcontractors. While this may or may not be so there is the interpretation that if the general contractor has that deeper knowledge of each trade that the overall forces of the whole construction process may still be sufficiently strong to perceive that a duration of a detailed work activity is still a detail in the whole process and that it

is valid that the whole process has a power at least as great as the sum of the details.

The greater input from subcontractors regarding durations spans from (i) each subcontractor developing his own schedule by his own staff and giving that to the general prior to him scheduling the whole process to (ii) the subcontractor and the general spending time discussing the generals final schedule and the appropriateness of the durations of the scheduled work for that subcontractor.

Some subcontractors feel that input information they provide or are requested to proved to the general is not used by him as fully as he could use it in scheduling. It would seem that there is potential for greater communication between a subcontractor and the general contractor before the latter makes up his schedule than is done at present. For the general to make the effort to so communicate and interact with the subcontractors would build better rapport between them and the actual construction process could benefit from at least the better psychological climate so created between them.

The minor point of better control of the actual construction process would require more capable supervision by the general contractor's staff, more honesty between the parties and the need that a written schedule exists as a datum of coordination and communication between the general and the subcontractor.

CONSIDERATION OF COMPUTER SOFTWARE PACKAGES FOR SCHEDULING BY GENERAL CONTRACTORS

(a) Amount and Manner of Use of Scheduling Software

(b) Scheduling Strengths of the Software Package Used

(c) Scheduling Weakness of the Software Package Used

Consideration of Computer Software Packages for Scheduling By General Contractors

This part of the report describes the state of use of computer software packages for scheduling and monitoring construction work by general contractor executives.

The responses were somewhat sketchy and may not fall fully under the topic of the underlying factors of construction to be expressed in construction schedules. However, the questions were put because the state of use of a computer software package for scheduling is reasonable and relevant to the overall topic of this report.

The responses will be grouped under the headings of (a) amount and manner of use of scheduling software, (b) scheduling strengths of the software package used and (c) scheduling weaknesses of the software package used.

It should be realized that there were many different scheduling software packages being used by different construction executives from which their observations were drawn. These descriptions of the responses are directed at pointing up the beneficial and detrimental features of such packages as seen by construction executives who use them.

(a) amount and manner of use of scheduling software. While about 40% of the construction experts say they always use a computer software package for their construction scheduling and control work, about the same percentage say they never use a

software package for scheduling work. The remaining approximately 20% of the construction executives use a software package either on most or some of their projects. Looked at in summary, it appears that about half the executives normally use a software package for scheduling while the other half do not.

Of those who use a software package for scheduling, virtually all of them do so by their own choice rather than just because it is called for in the contract. A variety of software packages are used of which only a very small number are of the in house or custom created type. The majority of construction executives use commercially available scheduling software packages and there is no clear preference to one particular commercial package over the others available. The scheduling software package is a tool to do a job.

The construction schedule created by the software package is usually housed in the office or on the site but at the same location as the project manager. Site staff have access to the construction schedule produced by the software package, regardless of where the package is located. When the project manager is not located on site, some on site staff have the ability to try "what if" proposed changes to the schedule but the majority of site staff do not have that potential.

(b) scheduling strengths of the software package used. That a package is easy to use is seen as a major strength by construction executives. Ease of use means that the user can

concentrate on the construction scheduling and control rather than having to have considerable computer knowledge prior to or during his work in scheduling and monitoring construction work. Flexibility and ease in making changes to the schedule during creating the schedule or in updating its status subsequent to monitoring are other major ingredients of ease of use of the software package. Other ingredients of ease of use are the ease of learning its features and that the schedule and the software package can be used at the construction site.

It is seen as a strength of a package that the construction data input for the schedule has to be marshalled into a particular format. This requirement of the package induces a discipline on the scheduler that might not be there if the software package was not being used.

Once the initial schedule has been created, it is seen as a strength of the package that there is the flexibility to easily change durations of work tasks and, change or relocate work tasks in the schedule logic as it is being iteratively improved prior to crystallisation as the final preconstruction schedule.

Usually the computer based schedule is created jointly by the office based project manager and the site superintendent. During construction, the schedule and the package usually are located with the project manager, but the schedule itself can be referred to by the on site staff for their ongoing daily management of construction work. If changes are to be made to the schedule or changes are contemplated, they will take place

under the project manager probably with discussion input from the site staff. Informal schedule changes to the schedule can be made on site with the subcontractors but such changes occur within the context of schedule in the computer.

If after monitoring the status of actual construction against the schedule the remainder of the schedule is to be updated or modified, then it has to be input to the schedule via the package. Ease of carrying out this updating process is seen as a strength in a package.

Other individual features seen as strengths of packages are that the package can easily identify work activities which are time critical, that the earliest start and latest starts etc. of each work activity can be calculated and output, that resource analysis can be done, scheduling can be coordinated with accounting and estimating, and that a variety of required output reports can be produced directly from the package.

It appears that the major feature of strength seen in a package is that the preconstruction schedule and post monitoring schedule, can be both produced as time scaled schedules of work activities showing their logical interactions in the construction process. This format is especially useful as a communications tool because on site people can simply place a vertical line on the schedule to establish where actual progress should be by a given date or what work should be beginning or ending on a given date. Also, on such an output format it is relatively easy to

plot durations from the present to a future point in time such as the beginning of a future work activity.

A more elaborate strength mentioned was the ability to summarise the schedule and produce it without the burden of large amounts of detail. The complement was also considered a strength i.e. the ability to derive detail subschedules from an overall schedule.

A few executives stated that another strength was the ability of the software package to provide legible printouts and other good documentation from the input data. That a professional look is given to reports is seen as a minor strength.

(c) scheduling weaknesses of the software package used. The most common response to stating weaknesses of the software package used grouped around that none had so far been found in the various packages being used.

Equally numerous individual weaknesses stated were that use of the software package required human capability to use a computer of any type, that it took time to learn the contents and procedures of the package and that the software package was not user friendly.

Lesser weaknesses were that site people do not like them and don't understand them and that subcontractors may be afraid of them and would have to adjust their work to schedules based on

something coming from a machine or process they didn't understand or like.

There was also an array of individual weaknesses features such as high cost of the software packages, that it was difficult to revise or update the schedule, that weekends and holidays could not be built into the calendar and that there may be a maximum number of work activities allowed in the schedule for it to be handled by the package.