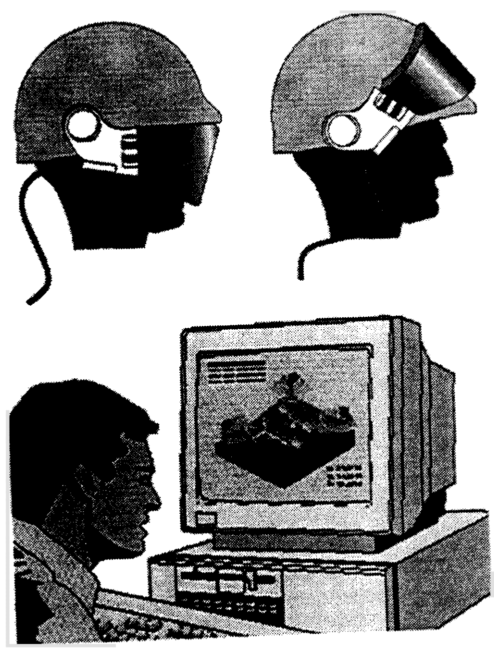
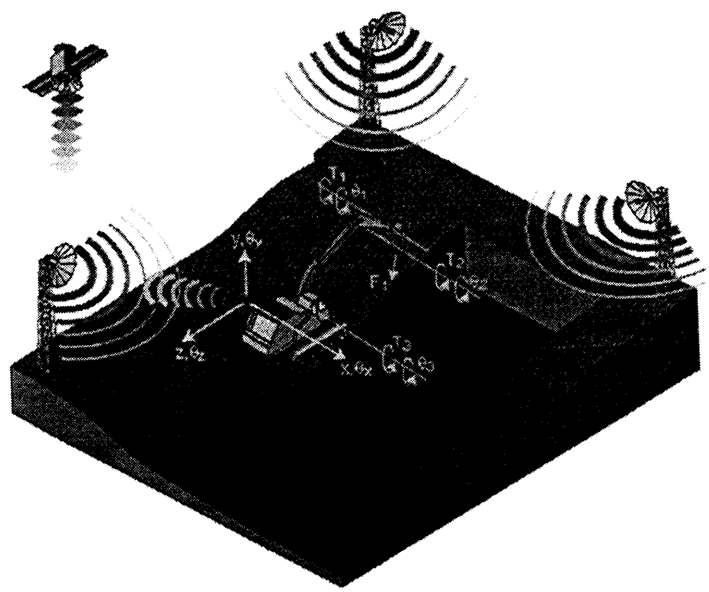
NISTIR 5856

NIST Construction Automation Program
Report No. 2

Proceedings of the NIST Construction Automation Workshop, March 30-31,1995





Building and Fire Research Laboratory
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NIST

United States Department of Commerce
Technology Administration
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William C. Stone, Ed.

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PREFACE

In the manufacturing sector vast increases in efficiency and productivity have been achieved in the past 20 years through automation. In order to reap similar benefits in the construction, repair, and retrofit industries, which account for nearly 13% of GDP in the United States, means must be established by which the status of a complex job-site may be assessed instantaneously through automated, advanced metrology systems; by which machinery can be operated in both partially and fully autonomous capacities; and in which data flows seamlessly from architectural inception through job site implementation. During the next 20 years these topics are expected to form one of the highest priority research areas in the civil engineering arena.

In the fall of 1994 a research initiative at NIST was developed in construction automation, in alignment with needs projected by the Subcommittee on Construction and Building, Civilian Industrial Technology Committee, of the National Science and Technology Council. This carried the highest levels of support from NIST management as one of six new areas of fundamental investigation for Fiscal Year 1996. In preparation for this work, then estimated to be funded at $6M/year, an industry-government workshop was held to solicit feed back from a representative selection of U.S. construction companies as to the efficacy and utility of the proposed research. Topics on the agenda included 1) sensors for Real-time metrology; 2) wide band telemetry and data acquisition; 3) virtual site simulation and object representation standards; 4) person-in-the-loop systems, including head-up displays and tele-operations; and 5) construction robotics.

The workshop was held at the NIST, Gaithersburg, Maryland campus on March 30 and 31st, 1995. The format consisted of a series of keynote lectures from NIST and industry on Thursday, March 30th, followed by a round robin discussion on Friday March 31st. For the Thursday lectures, questions are set in italic style while the speaker's response is in normal text. In each case, the names of the discussion participants are listed at the start of each exchange. A similar switching of text style is employed for the round robin discussions to more clearly delineate each speaker's comments.

Bill Stone
NIST, Gaithersburg
May 1996

ABSTRACT

A two-day workshop on Construction Automation was hosted at NIST during March 30-31,1995. Research programs actively underway at NIST in this area include the development of sensing systems, hardware, and software algorithms for advanced real-time construction site metrology; wide band telemetry and data acquisition [the ability to track many sensors at once through wireless communications]; virtual site simulation and object representation standards [development of robust virtual reality models for construction site objects and machines]; person-in-loop systems [including head-up displays, virtual simulators, tele-operations workstations, and portable database interrogators]; and semi-autonomous machine operations. These topics, and the need for database and machine interfacing standards, were discussed by workshop participants representing industry, government, and academe. Specific invited presentations included laser distancing, non-line-of-sight and kinematic GPS metrology, automated data exchange standards, real-time kinematic modeling, military helmet-mounted displays, virtual reality displays, construction robotics, automated excavation, virtual site representation, and automated building construction.

KEYWORDS: automated building construction, automated excavation, construction automation, construction robotics, data exchange standards, helmet-mounted displays, laser metrology, non-line-of-sight metrology, telemetry, virtual reality displays, wireless communication.

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1.14 Group Discussion: Day 1

Eric Lundberg, SPSI, Inc.: I would like to follow up on what Ken Reinschmidt said: I kind of see that NIST has really established themselves in the manufacturing industry. Industry is a credible source for high technology and improved methods and I think by what I see around all the walls in this room is a tribute to that, and the recognition that industry is able to provide solutions.

I don't think that construction industry has the equivalent of that — there is no leader in the industry that can provide the funding and the organizational expertise to get the people together to attack problems that we see in construction. And I think that one of the overall goals of NIST may be to try to establish themselves as that leader in the construction industry.

To do that, I just put a couple of things together. I think a number of people mentioned the fact that in the ATP funding that comes out, there is not really anything focused towards construction and maybe one way to establish that is to actually grant money specifically towards construction for groups in construction to compete against one another instead of against other manufacturing technologies that might be more attractive because of their higher tech appeal. Maybe my second point would be to also look a little bit closer to implementation as opposed to some of the far off technologies — getting to the point made by Clay Claassen of Bechtel —and looking at how you actually implement technology and actually promoting high technology in the construction industry and high tech construction techniques.

I think another issue with construction is that there is really nowhere to turn when somebody in construction has a problem and needs a solution, and one way NIST could establish themselves as a leader for construction is to become basically a database of solutions for the construction industry; recognizing and investigating technologies that could be applied to construction and certainly their vast knowledge of manufacturing and the techniques available in manufacturing could be a large part of that database and be recognized as a source that people can come to and ask questions when they have problems. I think one of the questions was: "would you be interested in participating in a CRDA?," and of course we would. I think that it is certain that a small company like us has to be very cost sensitive and time sensitive, but we're fully in support of participating in a cooperative research arrangement as we have with CERF — they established a very successful arrangement in which we were fortunate enough to participate.

Carl Magnel (CERF): I am only going to make one recommendation and make one point. I would think it would be advantageous to link construction automation as effectively as possible with construction goals. I think that that initiative is gaining momentum — in fact Dick and I will be together tomorrow morning to push this along. And of course Kent mentioned construction goals as well. But you have got to think of something different. It's a difficult industry benchmark and a difficult industry to note progress in and you have to take and leverage everything that you can to get construction automation out there in the forefront and make it.

I would also mention that one thing that we are a somewhat invisible sector — we don't get noted up on the Hill. It is only in the last couple of years that this administration, for example, has made the construction sector more visible by making it visible in the Department of Commerce and elsewhere, and certainly in OSTP. But what we forget sometimes is how important we are to the nation as a whole. We are about **13%** of CDP and the only other sector that surpasses that is health care. So we're a big component and the impact we have, or don't have, is enormous.

We are in a situation now where infrastructure renewal is really critical. How are we going to do it? We're not going to do it unless we're able to put the picture in place that the construction sector has some significant roles that they need to achieve and that there are vehicles for doing that, including construction automation, so I would really recommend that.

From CERF's perspective, Eric mentioned consortia effort that we had with SPSI. And I would tell you that we are very much interested in doing that — leveraging industry' the federal sector, to do things that no one could do by themselves.

Mike Sims, NASA: I just want to briefly describe the channel that we have in **NASA** for taking robotics technology and transferring it into the world. And I want to do that for two reasons. One of which is to invite you to consider proposing or looking at it as a way to get involved, and secondly as a way to bring it up as a possibility for a relationship with NIST because we've been exploring one with NSF.

We have a robotics engineering consortium that is located at Carnegie Mellon University and it is really our way of trying to get all government robotics work to funnel into the private sector. There are three projects we have that are currently on going. One is with Ford-New Holland, where (in 1996) we are aiming for a demonstration of autonomously harvesting 100 acres of corn, beginning in an arbitrary spot and not having particular information about the terrain in the field. You will know it's corn but you will not know the structure of the rows, for example. That is to be determined by the vehicle, before it commences the harvesting. That is a joint program between Ford-New Holland and this consortium. The second project that is going on right now is a project with Boeing to look at automating tracking of their fuselages through their assembly plant. The intention is to track and to control the moving of these vehicles through the plant.

The third project is one with Armstrong Floor and this has to do with the laying of tiles. The first milestone, the first objective of that plan, is to lay the tiles in the middle of the floor. It turns out that in certain applications the automatic laying of tiles looks like economically a very good thing to do. And in a later stage we're going **look** at laying of comer tiles. The program is set up so that any project that comes **in** is a **2-3** years program. Its set up as a joint program — in general the contract can be negotiated — but it is typically **in** terms of **50-50** funding between the private sector and the government.

An in-kind demonstration of that contribution is fine. These projects are in the realm of 1-3 million total project costs. We started last year with several million dollars. From that million we have had corporate contributions into the consortium of $8.5 million so far. That includes sizable contributions for example, from SGI and Deneb. We are interested in relationships with NSF and NIST.

We put **in** one million and our plan is to fund 2-3 projects at roughly a million dollars each, projects being **2-3** years. So our plan from **NASA** is on the order 2-3 million dollars per year. Dave Lavery at NASA HQ is probably the best contact if you would like further information on this program.

I should point out that these cooperative research agreements are between **NASA** and the Robotics Engineering Consortium (REC) and then REC establishes an agreement between REC and the commercial vendor — so in fact there is not going to be **an** issue of going out to the competition.

NSF involvement to date **has** been under discussion. Some of these technologies they are interested in. Some are ones that they have been funding for along time. They are interested in seeing those get incorporated into the real world and into industry. It has become so that one of the browny points you get **in** the national government is from actually taking your technology and getting it out for use in the world.

Milt Gore, DuPont: I would like to build on the suggestion that Eric had concerning a consortium, a technology exchange mechanism, or clearing house. Well I guess my vision is that you have owners, firms, academia, suppliers — suppliers could provide steel pipe or software, whatever — and these folks bring to the table the latest, greatest technology and maybe NIST is the clearing house. And NIST makes sure it is the latest greatest technology, and they keep the database on the solutions of every implentation. I think one of the things that we don't do a very good job of in construction is documenting our successes around implementation. We do a fair job on **a** lot of things we do and a real good job on a few things, but we really don't toot our own horn, if you will. We don't keep score and I think that is something NIST could help us do. The more you do that, the more you are going to drive the use of the technology.

I **think** the national construction goals initiative will fulfill some of that by adding benchmarks to make things visible, plus set things off in the right direction. If you got the right mix of funds. Its real difficult from my perspective for an owner to be totally credible and the NC firm to be totally credible — not if they stand alone. But if you can document a success, all of a sudden you get some credibility.

Carl Magnel (CERF): One of the challenges is to put together exactly what you are talking about. One of the things that National Construction Goals says is that in trying to implement that it is quite clear that it is probably going to have to be sector oriented. You are going to have to have residential, industrial, commercial, public works sectors because they are not the same.

Clay Claassen, Bechtel: I'd like to add a comment to the goals approach and the issue of the clearinghouse for technology and making it available to industry. One of the key elements if these concepts are going work is, number one, to actually do some benchmarking and that means in dollars And also set up methods to identify savings that have been achieved with various new technologies, so that you can get some actual cost-to-benefit analysis and ratios. That's the kind of thing that gets some attention in the construction industry, both with the engineering/construct companies and the owners. What can I save?

2.0 Day 2: Round Robin Discussion

Chuck Schaidle, Caterpillar: I'd like to comment on the questions that were raised yesterday afternoon. Did we want to recommend papers or did we want hardware or software? Caterpiller is interested clearly not in papers ... lately we haven't been documenting our own work well enough. Regarding hardware and software developments, let me say a couple of keys things. We need to address major things. There are a whole lot of little fringe items that have to be solved. Hit the major ones. We are interested in major items. This equates to commercializing. Our interest is in earth moving but we recognize there are other peoples' interests in building construction. I say this for CAT machines but its really earth moving machines I'm talking about. We recognize ourselves that the systems we're developing will need to be used on everyone's machine. We can't isolate our machine. A system that will succeed in being a system will have to involve everyone else.

I put these as priorities, but they are more a sequence as I see going through this. If you think about a multi-year NIST program or anyone's program, and our own multi-year program walks in this sequence. Operator information is critical to any form of automation. In this, you can include position metrology technologies, because that is the basis upon which all these others are going to be built. The first step, therefore, is to provide that information to the machine operator, to the foreman, to the manager etc., and then use that information to start helping the operator to control the machine. We call those "skill-enhanced" controls. These may be doing things that the operator is unaware of, or things which take away some of the more tedious functions from the operator, such as raising and lowering the blade constantly. ***An*** operator on a bulldozer, by the way, raises and lowers a blade on the average of once a second. So that is the kind of thing I am referring to as tedious work.

The next step beyond that is semi-automous, and in that category I would put robotics, and then, as you move on, there are autonomous machines and systems. It has always seemed to us that we build in that sequence, and that there are clearly commercial applications all along this.

When we look at the kind of projects we would like to get involved in, we want those to be very well defined and we want them fast moving. It turns out that if it is not fast moving the benefit we get from participation and any funds that others bring to the party simply get washed out in the time. Time is money **and** if we're spending more time at something, we would rather spend more money and go faster. And then I say with leaders, and I don't mean that to be exclusive of anyone, but what I really think that it is challenge to all of us to pick out what we are really good at, and focus on what you and your companies are really good at, and bring that to the party. Because that is a real big job and you're not going to have time to play in several fields and play catch up with the leaders. So pick what you're really good at, and bring that to the party.

Some of the specifics, as I see it , are GPS technology improvement. We would be interested in RISC chips in the receivers. These would certainly speed the GPS calculations up and it will bring the cost down. The market for GPS is going to be high and there is going to be enough demand out there to be able to afford RISC chips. What we need are affordable, high accuracy., multi-channel real-time chips. New algorithms need to be developed. If there is an algorithm in the commercial domain and it competes well with the ones that are in private domain then people will use those. Some potential partners in this field include Motorola — where they are doing some research in RISC chips. I know several of the GPS people who are developing their own RISC chips as well.

GPS augmentation: by itself GPS is not going to work everywhere. It will not work in the urban canyons, nor in the western canyons, and sometimes it won't work where you have a high multi-path environment. So anything we can do to augment that — maybe lasers, accelerometers, or gyros — needs to be explored. Some non-GPS location techniques: from our interest we have to get large — a thousand meters. Sure, there are some 100 m sites that our machines work on and I think the SPSI technology is one of the ones that will work there. But really, unless we can interchange between systems our machines move too fast and generally work larger areas. So I think a 1000 meter range — covering a one by one kilometer service area — is really what is needed. Some of the ways for doing that include pseudolites, lasers, and RF. We are very interested in a project in which we take an XYZ that is coming out of a system like that and plug it into the information system that I showed you the other day.

Bill Stone, NIST: If you were working on a kilometer grid, what would be your required accuracy?

For most of what we do you are going to need plus or minus six inches **(152** mm) of X,Y, and Z to plus or minus a few centimeters. Ideally, you would like to have plus or minus **2** centimeters. Particularly in the Z-direction. It is unfortunate that GPS doesn't work well in the Z-direction (vertical). **A** lot of applications could get by with 6 inches but if you're setting an accuracy target (for new technology systems), set it at **2** centimeters. **A** large western mine that will go down a thousand feet would see control of evaluation to within 6 inches at every bench that they go down. The whole mine plans are based on ***6*** inches maximum deviation from the control elevations.

It is typical now to require grade control on a parking lot to one inch drop across the parking lot. If you get any more than that, the water forms puddles, ice builds in the winter up or the water runs off too fast and washes ditches. If you start getting into paving you're going to have to get down into the centimeter range.

Bill Stone, NIST: *There was a letter that was passed out yesterday which was sent by G a y Sippel of Allegheny Excavating in Pittsburgh. This is around a 50 person construction company which mostly does excavation work, although they also develop office complexes. They use all CAT equipment. His big concern is "how do I get rid of the lasers and inclinometers on the blade and still get that one inch over grade." Even in rough conditions. This seems to be a ubiquitous question in the excavation business.*

Chuck Schaidle, Caterpillar: Onboard display technologies: we need to improve the LCD's in terms of getting cost down, illumination levels up, range of illumination up, cooling requirements down. We'll investigate heads-up displays. I don't know what the acceptance of our operators will be, but many operators have to wear a helmet on those machines anyway. It's an OSHA or MSHAR (Mining Safety Health Administration Regulation). Adding another half pound of weight to those helmets might be acceptable. It needs to be explored from an ergonomics stand point.

Bill Stone, NIST: *When you say operators presently use helmets, are you talking about regular construction hats?*

Chuck Schaidle, Caterpillar: Yes.

Ken Goodwin, NIST: *Those displays are going to just get lighter and lighter. I've seen displays that are just on the back of a computer chip.*

Ron Levandowski, Honeywell: *There's some major re-design in the helmet here. Right now, these helmets are resonably inexpensive. They're not cheap. And they are well balanced. When you add something to it, it puts the user off-balance a bit and it will increase the cost. It may be silly to just say well, let's just add this display to our existing helmets. Rather, let's look at a design that incorporates this display in a new type of helmet. With the state-of-the-art in surface mount technology that is coming out now you can almost inlay that equipment right on the inside of the shell.*

Chuck Schaidle, Caterpillar: I'm not convinced, from CAT's point of view, that the operator will prefer to have it up there on his helmet, as opposed to an easy to see location somewhwere in the cab.

Any applicable software for managing the data onboard, off board, single machine or multiple machines, or whether it's the management software, the monitoring diagnostics software, the plans, any of that, and the software that drives the information displays. Those are projects that we would be interested in participating in.

Another area that is in need of research involves pushing the capabilities of wireless data networks in a multi-machine environment. Often times, this will involve large obstructions in between and with some very high data rates, and with high demand that the data be accurate.

Bob King, CSM: *I think that there is a link here in terms of looking at architectures for large volumes of data and v e y high rates.*

They all sort of tie together in looking at a software operating system that maybe you can use to support parallel processors, rather than just a single RISC chip. I think there is a whole system that is necessary to handle these extremely large volumes of data and extremely high data rates. Especially when we get to the time of video data rates.

Chuck Schaidle, Caterpillar: Along those lines, two of the systems like the one I showed you yesterday was running with a separate computer doing the GPS calculations and another computer doing the information system. We have multi-tasked those two computers and we've also had all that done on one. At any given time, there is no preference but our preference over the long term tends to be to keep these things separate so that the individual technologies and individual component suppliers can move at their own pace.

So what in fact we have been encouraging GPS suppliers to do is to put their computer back in their signal conditioning box — give us an XYZ and time and we'll take care of it from there. Sure you could do it with one chip but then every time the GPS supplier changes its chip you have to change your system. The same thing applies to the software. Yes you can tie your display software to your data management software but I think somewhere down the road you're going to want to do that. At this point all these things are moving too fast developing too fast. Our approach is to keep it simple.

Bob King, CSM: *My point was not to tie them all together into one machine but rather that it would be a good thing for NIST to do in support of this activity is to become that information center on the lowest cost parallel multi-processor machines and information on how operatoring systems can effectively utilize those multi-processor machines dealing with this data. One multi-processor machine might be a GPS technology; another multi-processor machine might be for management of data for the whole site. I wasn't inferring that everything go to one central computer.*

Chuck Schaidle, Caterpillar: I think what your saying is for NIST to look at what is out there in the computational and storage areas and to say, "how could we adapt that to construction." The NIST group that is involved with construction automation should not try to drive processor technology. We're kidding ourselves — we are not that big — to drive processor technology.

Bob King, CSM: *We're talking about having an information database here at NIST or NIST being the source of information for improved construction techniques. This is one part of that piece of information that NIST could be gathering that would serve this activity.*

Chuck Schaidle, Caterpillar: One thought that we have been wrestling with is when you do work down here in this software and database, you need to think about that being compatible with whatever processor and whatever operating system environment **you're going** to be working in. You can't afford to be rewriting and setting new standards every time Motorola or Intel comes out with a new chip. We see RISC (Reduced Instruction Set Chip) as being key to all this. RISC is a chip that is cut to run spe cific calculations. It is not very flexible, but very fast.

Jim Albus, *NIST: One of the things we've been looking at in the manufacturing area for is what is the information that is needed to move from one module to another? What you are saying here is that you'd like to have a GPS module that just gives you XYZ and my guess is that there are a bunch of other kinds of modules like that that you would like to just have the data that that thing is supposed to produce and what you'd like to be able to say is, "I need that data to a certain accuracy. Now you tell me how accurate you are giving it to me. You give me some parameters that characterize the data, including undertainties, and somebody decides on how fast you'd like that data. Either you tell them how fast you want it or they tell you how fast they can give it to you. So you want the data, you want to have some way of specifying how fast its going to come, how precise it is, something that characterizes the data. That's the kind of information you want to into that box or get out of that box. You don't care what's in that box. That's the GPS guys' business what he puts in there. You don't care as long as it works.*

We're interested in thinking about that data exchange. That has been our thrust for a number of years. We try to figure out what the functional modules are and then worry about the exchange, that's the way IGES works — we don't care what's in the CAD system as long as your data is in standard format. When the data moves from one place to another it has to be in a standard format. I think we would be very interested in working with you and listening to your ideas, and maybe you could organize with some standard committee to look at the issue of what are the interfaces, the message protocols, the formats, what is the information content. It's sort of like the application layer of the ISO standard. That then gives you the plug-and-play system capability. Okay well say that I got 35 companies that make GPS systems. If somebody else comes up with a better one I would like to be able to pull the one out that I got out, put their in, and expect it to run.

Chuck Schaidle, Caterpillar: It goes way beyond GPS. I would like to take the survey data that comes off of anyone's survey system, whether it's GPS-based, total-station based, or a fly-over digitized map. It gets complicated pretty fast. I think what Ernie was showing yesterday is a start. It is a layered environment. Another question we are often asked is how accurate does this have to be, what is the minimum cell size. The minimum cell size depends on what the application is. It wouldn't be too bad if you say for mining it's one thing and for parking lot construction it's another. But then it gets down to what machine you're using, because some of these machines are working to much less exacting standards and are getting data every meter. Then it get down to how fast the machine is running; that's when you start getting into information display. If you only have data every 10 meters, the question is, "what do you display to the operator when he's between those data points."

It is not acceptable for him to be shown one piece of data and then immediately jump up to something else. So either you have to interpolate between those — and you hate to do that if you have good data. If for some reason now you come along and you take that dozer that went over there and its got survey data all the way along there, you do not want to throw out 9 points and save 1. So it gets into the problem of making a gross-accuracy database compatible with a very detailed base. And you can exchange data between a gross database and a detailed database.

***Jim Albus, NIST:** You know we **run** into that at a completely different scale in the inspection of machined parts. Now were talking about a thousandth of an inch resolution or 1/10,000th of an inch resolution. When you machine it, you've got to size it. Often, when you inspected it you just touch it in a few spots and make inferences as to what is between those spots. In fact, one of the projects that we are working on right now involves collecting data using optical sensors and stylus probes, and passive probes that fry over the surface. All that technology is being developed for things like turbine blades, but you could quickly apply it to things like improving the accuracy of a grading maneuver. It's just three orders of magnitude difference in scale.*

Chuck Schaidle, Caterpillar: Another analogy is finite element analysis for structures — you can have a gross grid until you come to a weld joint (where you have high stresses) and you want a detailed analysis of that area. Then you go out and test it, and it breaks somewhere else. Now you have to go in and do a detailed analysis of that new area. Our machine, the dozer, when it leaves the office it drives to the site where it's going to work, with the same database that it uses to do the work, but with a totally different data intensity. You have to do that. The highway map — the road out to that site may be ten years old, but you've got a digital map, you can't afford to go back and redo that.

***Jim Albus, NIST:** There are also some interesting applications now with military unmanned ground vehicles where you in fact want to drive without an operator, and be able to give the vehicle a command and have it come back by itself — using inertial or **GPS** data that you recorded on the way out. **You** don't want any radio transmission after a certain time. Lots of potential leveraging of this technology.*

Chuck Schaidle, Caterpillar: I am not sure that any of us in this room are good data managers. You need to be looking at the AutoCADs etc.

***Kent Reed, NIST:** We're better than you think we are (laughter).*

Bob King, CSM: Chuck, I think this concept applies — we've been using positioning data as an example and of course at a construction site we would be earth moving, building, whatever. There are a lot of other kinds of data, and they all have the same need. For example, when we do the system help assessment with multiple sensors on a machine ... you mentioned 65 or a hundred, however many sensors we have on the machine, we don't save every data point. We collect data at a very high rate, but we are continuously testing these data points and if we see a linear situation - a straight line — developing, then we just have a equation with that line. Only when it doesn't fit the straight line, we run a good test, do we save a point. And so what you are saying is that there are some instances were you just need gross data. And other instances where you need higher frequency data. That applies not only to positioning, but also applies to ten different types of data on the compression cycle. It just not just positioning data that you should be considering.

Bill Stone, NIST: *You gave us some number there: plus or minus 6 inches in one case, plus or minus 2 centimeters in another. Perhaps this is something that Milt (Gore) can answer better. When you are talking about putting up buildings and other types of major projects, what is the accuracy that is really needed if you wanted to know that something was put in place properly?*

Milt Gore, DuPont: I haven't been involved in too many building projects other than blast resistant control houses on federal government projects but generally we're looking for single story buildings we need to be better than quarter inch.

John Schlecht, Ironworking Institute: *Structural steels fabricate plus or minus an eighth.*

Jim Albus, NISE What is the limiting factor or tolerance there? How good could you do it?

John Schlecht, Ironworking Institute: *The limiting factor is the bow and the sweep in the hot rolled shapes. Every thing really is fudging back from the mill tolerance.*

Bill Stone, NIST: We have talked about a good many things here in the last two days. Earth moving seems to be one of the obvious candidates for automation — one that people always tend to think about. But there is another facet to this that relates to what Milt Gore at DuPont was saying yesterday, where they are looking at on-the-ground prefab segments and lifting these "value-added" units up and assembling fewer, more complex macro components. That concept applies to a lot of things, not just in the petrochemical industry. The idea would be that if you prefabricate something it would be nice to do automated "docking," as the guys at NASA would say, and have it automatically assembled. You can connect that prefabricated component to a crane and bring it in and have it automatically recognize where it has to go. The reason that I say this brings me back to the question: "if we are autonomously contolling a crane to bring in a wide flange steel section that is going to be bolted in place, what kind of accuracy would have to be maintained such that a guy could go up and slap the bolts in and then go ahead and take over?"

Clay Claassen, Bechtel: *We are talking about two different things. One is fabrication tolerance and the other is erection tolerance. And the answer on erection tolerances is, "what is the demand of the envelope you are working in." For example, any elevator building has exactly what you are talking about. That is, a module inside the structure that has to operate within a certain tolerance. But I think normally, and I'm not positive on this, but I think then you're talking about halving that tolerance down to about a sixteenth of an inch. But of course that is over a distance. You keep coming back to the plus or minus sixteenth as you go in vertical envelope — which is called plumbing, or a plumbing-up operation.*

I think it's hard to come with a standard for structures. It depends on what the structure's requirements are. I think back on a project we had few years ago down at the Kennedy Space Center. We were building a large *launch complex structure where it was a moveable launch complex structure about 30 stories high and it was on huge railcar wheels. And on the front of it was a door that would swing open. The door is a 150 feet tall and about 75 wide and weighed about 125 tons and we had as far as positioning for installing door, we had to check the steel at different parts at different times during the day. Depending on the thermal effect of the* ***sun*** *on that structure, even cloudy days versus sunny days, we had to perform those measurements to see how the structure reacted to thermal expansion/contraction before we determined how that door will fit. It all depends the kind of application you're talking about.*

Milt Gore, DuPont: Those requirements — that building envelope requirement — is a standard architectural consideration in your specifications for the curtain wall, the elevators, and that is one of things that you do in the plumbing. You have to allow for the time of day and the temperature.

Bob King, CSM: *To add to that, in the high wall mining application that I mentioned yesterday — of course we don't have* ***GPS*** *underground and we commonly use a sensor called a ring-laser gyro ,and in that application we been able to achieve about 1 inch over 2000 feet. And that is necessary to keep the pillars of rock between those two high wall entries straight so that you don't leave too much material in one and cut out the material in the other and end up with a collapse. DuPont has an underground coal mining subsidiary called Consolidation Coal Company that uses a mining method called Long Wall mining, where they start at one end of a long block of coal and just take a slice all the way along that block of coal, and it might be a 1000 feet long. So that they obtain an even slice every time, usually each slice is about* ***42*** *inches thick, they have a laser alignment system that keeps them over that 1000 feet within an inch of precision.*

Clay Claassen, Bechtel: The important thing as far as positioning is having the capability of collecting positioning data from a variety of sources and, depending on the information you are trying to collect, making that available at the construction site in a common format. That positioning data has to be able to be collected and recognized on a real-time basis. You have to be able to integrate positioning data from whatever source it's coming from into a common program so that you can represent what you are trying to describe. It has to be translated in a manner where it becomes visual to the people that are going to be using the data. It can't be in abstract form, it has to be displayed in a manner that is understandable and can be related to what an individual is trying to accomplish. So, you have to have a lot of flexibility in a system that is **going** to either satisfy earth moving operations, steel erection operations, equipment installation operations etc.

Bill Stone, NIST: *If I read you correctly,* ***you*** *are suggesting that there ought to be a standard digital format* ***for*** *metrology sensor output, such that it* ***can*** *be recognized by any standard package as to the rate, the accuracy, the repeatibility and things like that* ***for*** *that type of sensor, so that any program then could get data and say, "Oh this is a low grade sensor, it is going to update every second." Then maybe whoever is using that can set a flag which says that you can't do that for this application, it's not accurate enough.*

Then you have a suite of technologies. Then, f you had a job where you said you have to control to 1/16 of an inch ***over*** *a 20 story* building *and click on GPS, the system is going to say, "sorry, not accurate enough to achieve that tolerance." You have go down and figure out what other technologies you have available to you.*

Clay Claassen, Bechtel: I want to clear up one thing. We may be skating off on very thin ice here. These tolerances you are talking about, in steel construction, at some point along a beam or a girder or something like that your tolerance may be, because of bow and sweep and shape, **you** may be off by half to three quarters of an inch. You come back to your tolerance at the connection in the plumbing operation. In other words, you are never going to have a grid along a member where you are always within that 1/16 limitation. I think maybe there was a little misinterpretation there. The thing that controls the tolerance is the actual rolled shape, which is to a fairly big tolerance.

Bill Stone, NIST I guess there are two things. In my mind I don't think steel erection is going to get the stage in the near future where it is done automatically. There are going to be people up there who are going to be making the connections and the placement as the components are brought in.

Ken Goodwin, NIST: *Not necessarily. That's exactly what Lehigh has been working on at ATLSS. You need +/- 1/4 inch to place those. Its a wedge shaped connection which gives you larger tolerencesfor the initial mating maneuver. If* **you** *go to different type of construction like that, when you go to an assembly now you are doing this plumbing and you are doing a lot of adjusting. If you could go to a self-aligning and self-plumbing system — something like the Lehigh connectors — it would pull things into compliance.*

Clay Claassen, Bechtel: As far as commercial building construction, you are working to a larger tolerance with concrete than you are in steel. So you are always going to be controlled by a broader tolerance, where your footings, walls, and all that other stuff goes, and interface -- where one material frames to another. So it is always a process, in laymen's terms, you are always getting out to a point **and** pulling back to what your tolerance might be **and** then that's what they call in steel "plumbing it up." When you have a bay in place then you pull it back to within your required tolerance.

Ed Pendelton, SPSI: *I would like to summarize some of the things that* ***I've*** *heard here.* **As** *far as what NIST can do, I think you should think about what you do best.* ***And*** *what of those things I would say is setting standards. I picked off a few of the areas mentioned on the information sheet we got before we came here, including virtual site simulation and object representation. We talked a lot about positioning information which is certainly an interest of mine, and of SPSI, but there are a lot of other elements out there to keep track of. We know this will be criticalfor a fragmented industy where you have a lots of different kinds of folks trying to talk to each other. You need to have those standards so that* ***we*** *all can speak a common language.*

A *second area I see is lessons from manufacturing automation, because I think there is a* *lot to be learned from this that is applicable to the construction industry. And I'll give you some counter examples with **our** technology (SPSI) we're not just looking at construction, but going into manufacturing. We are finding a lot of interest in manufacturing **for our** technology. So maybe here is a case where construction can teach manufacturing something — we'd certainly like to think so.*

*I think there is a lot we can learn from NIST with regards to their experience with manufacturing automation. In terms of data communication, this is another area mentioned ... wide band telemetry and data acquisition. If **you** look at all the presentations we saw yesterday and the job sites of the future, if you could visualize what the EMF signal would look like it would look like a ball of fire with things going everywhere. So I think that is going to be a real **key** problem and I know that is one of the problems we are always constantly working with. With our system, we don't have any problem getting information at the user site, wherever he has that instrument. But getting it relayed back to a station on site to be used at a CAD station is a problem.*

*With regards to question #2, whether we would be interested in CRDAs, I have to take Eric, who is the technology guy **for SPSI** and I am the marketing **guy** so I come down a half of notch, I say CRDA maybe, but it depends on the application **for us** and then I sort of slipped this in this morning after Bill said "grants," and I say probably. So being **a** small company, we're always interested in what we might be able to do to partner **up** with folks and to further develop not only **our** technology **but** others as well where we can help.*

Jim Albus, NIST: You should be aware that under a CRDA, the companies that we deal under CRDA can own the patents that come out of the research. If we give you a grant, we own the patents.

Ed Pendelton, SPSI: *We have come up with a very innovative technology, but we're faced with coming up with an equally innovative means of marketing the technology to the construction industry. So I think that its key that whatever NIST does here in terms of furthering certain technologies, to really keep in touch with the customers here. Sometimes that is a very difficult thing to determine in construction. There are a number of customers. It could be owners, architects, engineers, and designers, any number of **folks**. So that's what makes marketing to construction a difficult task. It's not always clear exactly who your customers are going to be. Other than that, I would like to say anything that will promote **new** and emerging technologies, as Clay mentioned yesterday, of course we are very interested in because we think that we have very exciting technology and will be used quite a bit not only in construction but in other industries, and we are certainly looking forward to working with NIST now that we have an office in Reston.*

Bill Stone, NIST: Do you have any comments, Mike (Sims), about data communications. We talked about this a little bit yesterday but the idea is, if you have hundreds of Dantes (CMU autonomous robot tested in August, 1994 on Mt. Spurr, Alaska) out there, you said 50% of your time on a mission was spent setting up the communications links. What do you foresee as the bedlam (or lack thereof) in trying to implement that on a construction site?

Mike Sims, NASA: *Our systems are not traditional for evey site. We are in the realm where we go and perform a week long field test or possibly up to several months, but it's really a different setting each time. My first guess for implementing this technology at construction sites would be to go out and try standard commercial packages, such as radio ethernet — set yourself up in an environment that has a protocol for communication and see if that meets your needs. If it does, great. You can then easily get multiple machines communicating with each other locally via radio ethernet.*

I don't have any direct answers to how you would deal with the problem of having a hundred Dantes out there, tying to get images back. The first thing I would do is I would say, I would be real careful of taking something like that to be a requirement, because it's sort of looking and projecting what might occur. I would rather try to take actual situation paths and see what the requirements are on those and see what that volume of data coming back really looks like.

Chuck Schaidle, Caterpillar: I'd make a comment on that. The need is more immediate than that. We have more than one customer that's operating in excess of 50 machines that wants to equip those systems that I showed you yesterday on each of one those machines. That customer wants each of those machines inputing and extracting data from a common database that is also tied to their engineering planning system and is also tied to their management system to calculate things as fundamental as productivity on a daily basis.

Mike Sims, NASA: *Those bandwidths could be vey small. If you give the machines at some point initially their own databases and they only communicate back and forth critical pieces of that data. The required bandwidths can be dramatically reduced. It may not yet be an issue. If you were telling me that you had to get real-time video back on all 50 of those machines I would start to worry about how we were going to do that.*

Let me follow up on a comment — if go to the point of defining standards or protocols of communications among various data sets we have in construction, I think it's useful to be careful about what kind of data that is and where standards may or may not be useful, and what those standards might be. What I mean by that is, take an example of the image data, two dimensional image data. There are dozens of formats that image data is written in. In fact those dozens of formats are fairly well known, and if you go to a reasonable environment you could take any of those dozen formats and put them into your system. So from the point of view of most of most of those, it doesn't matter, usually. So in terms of the data that I am getting back, which looks like an image, for which the format is not terribly important, but what I don't know about is that there is not an agreement. There is an agreement on how to communicate a certain type of data — it's this XY data form. But there's not an agreement on what that data means.

So there's not an agreement on, for example, protocols as to whether this image represents a square centimeter or a square kilometer ... you just don't know that. Sometimes it is embedded in the headers, sometimes its not, but there is no protocol about it, there is no standard. In fact there are no standards about what that image data is. You can embed all kinds of data inside that particular image format and we do it on a regular basis, *and really then it's not an image at all. So when you gather up this piece of data you don't know what language it's speaking in. So, that is an issue about who actually knows the content of the data.*

Traditionally in programming, we do that by making notes in the source code. So the programmer has it in his head and then they embed the content information in this coded form and the code passes back and forth this string of vey compacted data. But it has no infomation about what's in it.

As you get closer to object-oriented ways of dealing with information you tend to ty to start putting some of that information into the data itself. My point is that there is a distinction between the actual format in which you are transmitting data — which allows you to communicate among various elements. In fact I would suggest that the way image data does it is very different, in that very powerful compression processing is involved to effectively transmit that kind of data. There is a whole other suite d image data that is useless to do. You don't know enough about it to use that data.

On the other side, what is the language of communications? If you want take a data set at XYZ location you can do that. What is the systems of units you are talking about? Is there a common language we can agree upon enough to say that this piece of data is, for example, topography. Or this piece of data represents coloration. I don't know what the right parameters are. Is there enough commonality that you you know where to go to find more vocabulay then say, "this is what that data is." There is this fundamental issue of whether to embed that information in the data or not to embed it.

In recent information work, it is not embedded in data for several reasons. One is because it is less efficient to transmit the code than the data. If you put more information in it it becomes less efficient to transmit. Sometimes that is significant and sometimes it's not. Another reason it's not often done is that it's hard to do. It takes more work to create data sets which have information in them than it does to create data sets that don't.

So ,image data we use all the time contains virtually no information even though we could put a header into it in various formats. But typically there is none there simply because it is to much trouble to bother with and there is also the problem that once you've decided what this is, is it really more work or less work if somebody else could use that?

The idea of transmitting data from, in the sense of that the data in and of itself knows enough about what it's doing that the data in a sense becomes self-readable, The data can be transmitted in a format that's useful. It is an extremely powerful idea at certain levels of abstraction, but as the world is right now I don't know about the future. As the world is right now there are certain levels of abstraction in which I am specific enough that putting more information in actually slows down post-processing.

Bill Stone, NIST **That would be in something like updating a full screen video frame whereby the header would take up refresh *time?***

Mike Sims, NASA: *I am not worried about that per se.. For example, when we go on a mission and we come back with thousands of images — lots of data space. We also take those images and process those images in lots of ways. As it is right now, we don't keep* *track of the history of those process changes. We always keep a raw set, but we don't keep careful track of the history of those process changes to that data, except in our heads. That might be extremely useful. But the overhead to getting it done right now doesn't justify our time. People are, in fact, very good at keeping track of such changes. So as of right now that additional piece of information — "this is place XYZ" — with lots of header stuff would be useful, but we cannot include the entire history of how that data has been processed.*

Bob King, CSM: I'd like to get back to what was said yesterday about automatically creating the as-built drawings for a site. This is very closely tied to that activity, and I think a lot of the ways we can reduce the data volume, like you said "not send stereo images with all the information in them everywhere,", is simply to have models and a sort of a pose of each model, a position and orientation of each model. And as that pose changes, that's what we transmit: the item which identifies each object and its new pose, rather than trying to transmit complete video images.

Bill Stone, NIST: *I think in the case of when you're talking about position or orientation, particularly in terms of a vehicle, I think you're right — you can have packetized information that has a binary byte that identifies the type of machine and then it might be two bytes if you want to cover all types of known construction machinery, but probably not more than that. So you would have an encoded packet. And there would be another packet for XYZ and yet another for theta-x, theta-y, and theta-z. And there might be a few others to cover other general articulations. I don't know how much that would end up being, but it would certainly be more on the order of several tens of bytes at most, as opposed to a megabyte per frame at 30 hertz for video. It would be for these smaller packets that data exchange standards might prove useful.*

Bob King, CSM: Somewhere you have a knowledge base of all these models.

Bill Stone, NIST: *Exactly. So that way somebody like Chuck (Schaidle, CAT) over there — if they have a very complex piece of equipment that has just come out, maybe it has ten degrees of articulation that they want to know about, they have a standard representation format to work with in describing that machine. The standards people on the other hand have to allow up to, say 20 different arculations in their standardized kinematic model. Then it's up to Caterpillar to assign what those mean. When you get down to video, that's a whole different ball game. We have to ask questions like, "where would you need video and what would it be useful for?" I'm not convinced that real-time video is required in most practical situations. It is in the case of teleoperation. For that situation you need it. But not for 99.9% of the average construction sites in the U.S.*

Kent Reed, NIST Let me remind you of my comments yesterday morning about digital standards. I think you'll find that from now until the end of time you will have a lot of different standards. You certainly need to think about an architecture. It may be the same syntax that we use in every layer of the architecture but the meaning in each case will be quite different, depending on how much information is passed and how fast and who really needs to know about it. I would really be nervous about any standardization effort that starts off saying, "how many bytes do we have to work with?" I think that's the wrong end of the telescope.

Bob King, CSM: *A lot of earth moving operations require this positioning data and other data to go into different types of software packages. You mentioned a couple ones — an engineering issue management system and a planning system, an inventoy system and so on. I know that Jim (Albus, NIST) has worked with Ray Harrigan at Sandia where they have or are beginning to build a standard called the GISC (Generic Intelligence System Controller) system. It's really not DOE's pervue, but because such a thing didn't exist where they could merge let's say a kinematics and dynamics modeling package with a robot controller with a real-time expert system with another piece of database software,and soforth and so on. They wanted a standard way of interfacing all these different software packages that you can buy from a large number of vendors, and that certainly is a worth while endeavor which has applications in construction as well as manufacturing.*

John Schlect, Ironworking Institute: I have both a question and a statement along those lines. Does NIST have a role in an effort combining with the American Institute of Architects, the American Society of Civil Engineers, maybe the American Institute of Steel Construction to ... I am looking at this presentation of construction bottlenecks from yesterday afternoon and it asks the same question I was trying to ask yesterday: Can structural drawings be electronically transferred to create and automate reinforcing steel fabrication and placement drawings? And then obviously the next thing would be robotic placement, for example. And then in the structural steel arena, basically the same question: can the task be automated to develop directly from the structural engineer's drawings?

You need to be concerned that downstream interfaces involve big lag times, including getting in a mill order, generating shop drawings etc. Caterpillar says there is an end product, but all those phases leading to the end goal could achieve tremendous improvements in efficiency if we had a standard for data transfer through each of those phases.

Kent Reed, NIST: *That is exactly what we are working on with STEP. We want to maintain histories of manufacturing back to the materials that went into the components. The Europeans are ten years ahead of us. We need tofocus on all the pieces, so that the end results come out better. This might suggest another workshop that is a bit morefocused than this one.*

John Schlecht, Ironworking Institute: This is the first time I've heard of STEP. But I'm new at this job.

Clay Claassen, Bechtel: *The idea is to permit raw data generated in each phase of the engineering and construction to pass through to the next. STEP is attempting to do that, in order to eliminate some of the reformating of information — essentially the same information — which sees slightly different use depending on the current phase in the process. What we need to do is eliminate the middle men. We are presently reformatting numerous times information that really hasn't changed. We generate different information for the procurement process, the field engineering process, the fabrication process.*

All of these people are just re-interpreting the same information and what we really want in the end is simply to get that information in a useable format into the hands of the people doing the work.

Kent Reed, NIST: All that reformatting is at best value added and, at worst, noise!

Ken Goodwin, NIST: *Does STEP incorporate topographic information? Does it embed information concerning where things are as well as what they are?*

Kent Reed, NIST: The structure of STEP allows for all types of information. But there are not many people working on those aspects. Furthermore, the construction industry has been slow to bring those concepts that it finds of concern to the table. In process plant design, we are able to convey information concerning shape, location, interference geometry and tolerances etc. The real question is, "what topology do you want?" Do you want to capture every phase in the construction process?

Bob McClelland, Fluor Daniel: *What we would like to see is a totally integrated information exchange system involving, by automation, transfer of design data, material/procurement information, progress status, etc. We would like to be able to do that between all disciplines involved in an engineer-construct project. Such a system would involve interfacing design systems, material control systems, project controls systems, and field supervision systems.*

We think that bar-coding and wireless transmission of data to a jobsite server is a good idea. You need to send that information to the people who are in need of receiving that information and screen it from those who don't want or need to see it. The use of pen-pad computers with radio ties to a jobsite server would eliminate a lot of paper. When you are up 60 feet and the wind is blowing and its hot the penpad is a real advance. We are using it on a project right now for redlining. As built, they come with onboard PCMCIA cards and a 250 megabyte hard disk. They can carry all the drawings they need out to the field.

It is encouraging to hear that most everyone here has the same train of thought. Let me reiterate that an important aspect is to make sure any personal digital assistant (PDA) speaks the same language (data) between different systems — whether its designed on AutoCAD, PDES, ProEngineer etc. They must be able to talk to each other.

Let me finish with just a few words about Fluor Daniel. We may be interested in a CRDA partnership, but this requires VP approval. I, as an individual engineer, would be interested. Fluor Daniel Technology (California) would likely be the tie-in point since their interest is blue sky technology. What I've seen talked about here during the last two days is of interest to the construction division.

Early in the day, someone made the statement that maybe NIST was not such a good platform to encourage the implementation of new technology in certain government contracts. Keep in mind that NIST is involved with standards and technology. I think, contrarily, that it might be possible, and useful, to write into the standards and specifications on certain government contracts the provision for the inclusion of new technologies.

Kent Reed, NIST: We have helped the Navy write specifications and have helped our own procurement division write specifications. Where we see problems is in defining what constitutes a working database; what constitutes a release database; how do you embed license stamps and seals — as in who authorized this drawing or who stamped it. The technology exists, but establishing the business authorization is hard.

Mike Sims, NASA: *There are widely used commercial software version control codes out there.*

Bob McClelland, Fluor Daniel: Here is our bottleneck we have invested a large amount of effort designing our plants in Intergraph format. We would like to issue that model direct to the field, but the drawings have to be stamped. So we are stuck — we presently have to print out a hardcopy, stamp them, scan them back in, and then we can issue them.

Kent Reed, NIST: *The real issue is how to achieve this integration. It's useless to talk about technology when business practice is the block. Bob (McClelland) talks about the potential* for *a digital P.E. stamp. So, how is tort law going to handle such things as digital notebooks, stamps, signoffs. There are no established mechanisms for dealing with this right now. What this creates is new exposure to risk. You can just imagine going out and getting a lawyer to convince a judge that you didn't assume responsibility* for *some job. What is the verification mechanism for this digital P.E. stamp?*

*Another point that was brought up is that knowing your customer is hard in the construction industry. Plant STEP is such a consortium. And yet various parts of **Fluor,*** for *example, have been approached and don't seem to be interested.*

Bob McClelland, Fluor Daniel: one part might be interested; one not. I'd suggest you contact the Technology Center, whose mission is to identify new technology and partnerships that Fluor could benefit from. Another likely group is Ken Reinschimidt's part of Stone & Webster.

Kent Reed, NIST: *a consortium **works*** for *some and not* for *others.*

Bob King, CSM: Do you have a phased approach toward getting to automated information exchange?

Kent Reed, NIST: *Yes, it's going to take several years to implementation. This was described yesterday by Dick Wright and is detailed in the BFRL report to the National Science and Technology Council. There are several initiatives that have been proposed to halve the cost or manhours of doing a particular activity. The initiative has seen different names, but overall, the idea is to integrate the various tasks so that all participants can communicate together.*

Ken Goodwin, NIST: The **ATP** program experience with the medical industry showed that what they really wanted was an integrated information system, not new technology. The next step is to develop new means for the integration of information. **ATP** grants are now being made for developing the missing technology in that area. So, in the construction analog, what are the missing technologies? I think we need to enhance communications between various systems.

This could be a step in the right direction for NIST. We need, for example, a generic means for STAAD 3D to talk to PDES. For PDES to talk to Prima Vera etc. Right now there is no field superintendent's Planning and Reporting package -- something to help them know what equipment is on site, what's available and to use the PDES model to plan activity. And there is still the issue of tagging information to components.

Bob McClelland, Fluor Daniel: *2 0 bar coding is a few years away. It may be a good idea to have one standard for eveything. 2D coding can contain the equivalent of an 8-1/2 x 11 sheet of paper in information content — but there is no national standard yet. For example, you have a pump out there. The drawings could be contained on the 2 0 bar code, as well as the build date, the operational data sheets. Furthermore, there are memoy buttons out there as well that can hold four megabytes of data (16 pages plus graphics). You can extract information from these, or rewrite to them. They have a ten year lifespan. From our point of view, it would be extremely beneficial to be able to send a PDES drawing to vendor, instead of design drawings (hardcopies), and say, "build this".*

Kent Reed, NIST I'm always shocked by how little information content is included in the uniform bar code system. If you go to the grocery store and you scan a carton of milk, you can trace back to what vendor it was and what that product cost. But if you scan the carton of milk next to it you have no way from the bar codes of knowing that both are discussing bottles of milk, or even that they are both generically discussing the same kind of grocery product. It is an incredibly backward system; so if there is a need in the construction industry to have better marking of materials, then they need to fix the two dimensional code. Here's the opportunity to try to make it smart.

Bob McClelland, Fluor Daniel: *We're working our vendors to t y to come up with a more intelligent one-dimensional bar code that supplies us more information. I am not working on that specifically myself but there is another guy that's sits a couple of offices down that does nothing but work on bar codes.*

Ernie Kent, NIST: I think if we have the right kind of information exchanged between different packages we begin to give that site superintendent the tool that we were talking about yesterday morning, which is the ability to deal with "what ifs". What if it rains tomorrow? So we have some material properties about the soil and we know, "is it OK for this dozer go ahead and work on this particular site tomorrow?',. What if this critical piece of equipment is broken down? What else could I do on this particular site.

Bob McClelland, Fluor Daniel: *What if it's going to rain. Do I have the material in the lay down yard to go and work inside tomorrow?*

Ernie Kent, NIST: Right. That's really where you want to get with this. You are not just after information exchange. You might get, in a couple years, to being able to exchange all this information. What's the real value of that? Well, the real value is so that the superintendent doesn't have to spend all his time writing all this information down and filling out reports and so **forth.** The superintendent can now talk about, "let's do this what if analysis every day and plan what we're going to do the next day.

Bob McClelland, Fluor Daniel: *We are currently using the PDES (Plant Design System) model. We have it implemented on an Intergraph system. It is capable of containing a great amount of data including material delivery, orders, purchase orders, specifics in size and dimensions and weight of certain things. So, it's got the space in its tables to give any object on a screen-specific entity and that's what we'd like to do is give those items specific entity information so that the superintendent down in thefield can click on that piece of equipment and pull up reams of data.*

Bill Stone, NIST: At this point, our time is up. I would like to thank each of you, and the organizations you represent, for taking the time to participate in the past two days' discussions. We will look forward to your continued advice as we move towards implementation of our initiative in construction automation here at NIST.

Appendix A: Workshop Participants

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Appendix B: Letters from Industry

Gary A. Sippel
Allegheny Excavating

I am the president of Allegheny Excavating Inc., a commercial site development contracting company in Pittsburgh, Pennsylvania. Our primary work is site development for shopping centers, retirement villages, and housing plans.

In my 17 years of business, I have seen the industry move from transits and levels to the present use of EDMs and grade lasers. These instruments depend upon a direct line of site which presents a problem at times.

We begin our bidding process by reviewing a blue print drawing of, for example, a 60 acre heavily wooded site. Suppose the drawings show building locations on this site for a shopping center. Under this building is a 45 to 50 foot cut with 600,000 cubic yards of earth and rock to be moved.

In order to accurately determine the amount of rock excavation by core drilling, we would have to locate building corners in the middle of a dense forest. This procedure requires partial clearing and surveying to get an accurate location on the building and surrounding areas to be graded. This process can get very costly.

It is very important that we establish control points for our test boring and locate them on the prints. Then we log these points into our earth works program, so we can determine an accurate quantity of rock strata.

As we start construction, we search for limits of work. We always used an engineer to establish property lines and limits through over-grown areas, peaks, and Valleys. Because the site is not table top, this requires major control sets by an engineer, all of which cost money.

Once the site is cleared and we move on to top and bottom of slope, the most critical locations are fill slope (which could be 200 to 300 feet long) or a cut slope (which may be 100 to 150 feet long). Due to these lengths, locations and elevations cannot be off. If they were inaccurate, once you reach the top of a fill and you have a road or building, you cannot go back and add **a** sliver of fill or cut a sliver on a cut slope.

As earth moving continues on the site, some times we are asked to provide two building pads totally remote from each other, with a major mountain in-between them. Once again we have to have our engineers set up control and shoot each pad separately. This is so that once the first pads are done, the general contractor can begin constructing the first two buildings while we are moving the earth between them.

As the project enters its final stages, we bring the site from a rough woods to within a tenth of grade. We use our grade lasers in combination with blade controlled sensors on our scrapers, dozers, and graders to cut and fill to meet final sub-grade. The need to know elevation, and location is necessary in order to complete this operation.

The laser equipment is good on a **2** or **3** acre building pad or a 10 acre parking lot, provided that the grade does not change. Once there is deviation and grade change, the instrument has to be set up again at a different location and different percent of grade.

In general, the laser equipment is good because it is accurate, cost effective, and efficient. The problem is in order for us to use our laser effectively, we must be provided with location and elevation control from **an** engineer. This takes a lot of engineering backup and control to establish. I have always thought that there has to be a better way to control elevation with location.

Relating our need with a company in our complex which sells tractor trailer locators. This system uses a satellite to determine where a truck is and if it is in transit. The only problem is that this degree of accuracy is far too wide for construction use.

As a contractor, **our** needs are by use of an aerial beaming device such as a satellite or sound device. **A** contractor could use the design engineer's layout on computer and input field reference points, such as property corners, into the computer. This would enable us to take a sensor and or a laptop computer to certain areas of the site to establish the limits of clearing, boring holes, top and bottom of slopes, building comers and pad elevations or certain areas in the parking lot or roadway and define an exact location and elevation using our inhouse instruments.

From start to finish on a site there is a "need to know." Everywhere we improve the site, we need to know the location and elevation. By producing a system that does not depend on direct line of sight for elevation and location, would help revolutionize the construction industry. This would allow us to be considerably more productive and efficient.

Appendix B: Letters from Industry

David Seagren
Charles Pankow Builders, Ltd.

Design- Builder's Perspective

Construction Bottlenecks:

Primary

.Information

As a design-build contractor, the development of architectural and structural documents has the greatest impact on our bottom line. We are ready to commence construction with just the foundation contract documents completed, but usually have to wait. This is the number one source of delay to a project. Can any automation be applied to the architectural and engineering firms in developing design information?

• Information Transfer

Architectural, structural, and MEP document information transfer in expediting the subcontractor shop drawing development and approval process is critical to achieving greater efficiency. For example, can structural drawings be electronically transferred to create and automate reinforcing steel fabrication and placement drawings for precast and cast-in-place construction? Currently these shop drawings may take from 2 to 7 days to draft, depending on complexity, and the specifications usually require an additional *2* to 3 weeks for the structural engineer's approval. Contractors are forced to either proceed without approval or build this time lag into their schedule. For a fast-track project this lag is unacceptable. **A** significant technology to improve this process a number of years ago was the FAX machine. Another example of a significant bottleneck is the structural steel shop drawings. These may take 6 to 8 weeks to develop and 3 weeks for approval. From the time of subcontract to the steel hitting the jobsite can be 5 to 6 months. Can this task be automated so that shop drawings can be directly extracted from the structural engineer's drawings?

Both of the above examples relate to costs associated with the owner's revenue stream, the cost of financing the project, and the contractor's general conditions. Compressing the schedule for document development and transfer will significantly impact the cost of the project from our perspective.

Beneficial Items:

Minor Software Needs

Performance-based Design Software:

Design tool for performance requirements to be selected by owners (lenders or insurers). Drift (lateral building sway under lateral loading) based?

Code Requirement Software (non-structural)

Input basic initial parameters for conceptual design

3D Contractor Planning Software

Site planning, structural erection, material & manpower movement and hoisting locations. Fast and easy input with basic structural elements and equipment preloaded in library. Can this be linked to create rough schedules?

Minor Field Applications

Automate Rebar Cage Fabrication:

Develop portable flexible manufacturing systems to fabricate, onsite, column and beam reinforcing rod cages.

Automate Concrete Placement:

Allow placing boom or pump to place concrete at desired rate and location based on input.

Safety Tag

Develop a worker safety tag which transmits a proximity beacon to receivers on all moving construction equipment to notify the machinery operator through an audible tone of a pending collision. This would prevent accidents caused by lack of visibility and complacency. This type of accident is all too common and costly in our industry

Compression Strength of Fresh Concrete:

Develop a low-cost and accurate instrument that would prevent placement of poor quality material. Most projects will encounter the problem of a low-strength load and the costly ramifications. CPBL applications would include slip-forming construction methods where a low-strength load will halt construction. Similarly, an instrument is needed to accurately measure the water content of concrete transported in ready-mix trucks.

Portable Dust Collector:

Remodel / Build over projects (e.g. shopping mall rennovations) create conditions where contractors must protect store fronts and tenant and anchor merchandise from dust. Drywall dust is the primary culprit.

Water Intrusion Detector:

All buildings leak. Tracing the source of moisture can be an expensive operation as well as a source of ill-will with the owner.

A Note on Most Expensive On-Site Tasks:

The cost of a particular task is highly dependent upon the type of construction and the structural design. The exact same structure at different locations can have significantly different costs associated with different tasks, e.g. setting foundations, and placement and removal of shoring for cast-in-place type construction. Generally speaking, it is important to recognize that labor has the greatest single impact on construction cost.

Highest Safety and Financial Risks:

Fall Protection for employees. Public Safety. Existing structures: protect from damage or settlement.

Recommended NIST Involvement:

- Fund and conduct research where the fragmented construction industry lacks the necessary funding and willingness of owners to pay for it. NIST must keep industry involved during all phases of the research to ensure applicability.

- Technology Transfer: Provide means and methods to introduce new technology and overcome cost barriers.