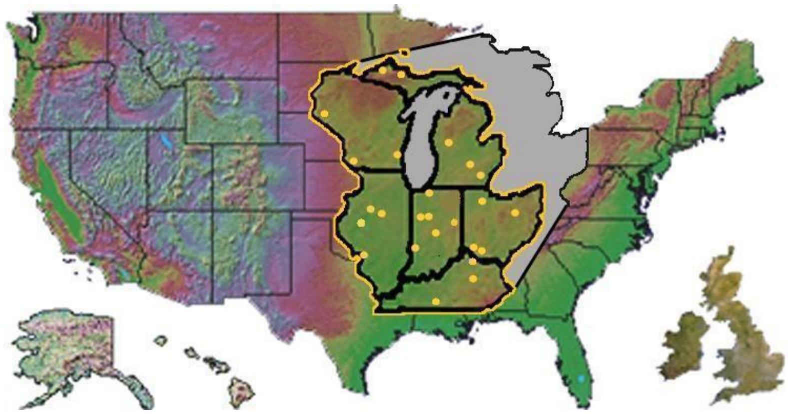

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- Dr. Euysup Shim — Illinois State University
- Dr. Pranshoo Solanki — Illinois State University
- Dr. Anne Werner — Southern Illinois University Edwardsville

The Cash-flow Simulation Game: Introduction

Euysup Shim, Ph.D.
Illinois State University
Normal, Illinois

Seongchan Kim, Ph.D.
Western Illinois University
Macomb, Illinois

To keep sufficient cash for construction projects is one of the crucial factors to contractors and cash-flows for construction projects is one topic taught in construction management programs. However, contractor's cash-flow is determined by many factors such as owner's retainage and progress payment procedure. Thus, forecasting cash-flows in construction projects is not easy and many students in the author's institution were observed to have difficulty in forecasting cash-flows. A simulation and role-play based game was developed to help construction management students understand impacts of several cash-flow related factors on cash-flows and determine maximum amount of cash to be borrowed (or invested). This paper presents needs, development and features of the game. The game was tested in a pilot study and the responses from students indicate that the game helps students understand cash-flows for construction projects and forecast cash-flows.

Key Words: Construction finance, Simulation game, Cash-flow for construction projects, Forecasting

Introduction

Construction industry has very high bankruptcy rate of 20.37% due to insufficient cash (SIO 2011) and it is critical that contractors keep sufficient amount of cash for construction projects. Therefore, contractors need to forecast cash-flows for construction projects in advance and to make sure sufficient funds are available during construction phase. Also, the forecasting can help project owner make financial arrangements (Mincks and Johnston 2011).

Accordingly, cash-flows for construction projects is one of the topics taught in Construction Management programs (CM programs, hereafter) in the United States and students are required to learn how to forecast project cash-flows (ACCE 2011). The typical method to teach cash-flow forecasting for construction projects is using spreadsheet software such as the Microsoft Excel (Peterson, 2009, Halpin and Senior 2009) and students calculate all the numbers required on a spreadsheet.

Cash-flows to general contractor in a construction project are determined by many factors such as owner's retainage, delay in owner's payment, retained money by the general contractor, and so on. And all the impacts of these factors should be accounted for forecasting cash-flows. Due to the multiple factors and their impacts, the students in the author's institution have had difficult time when they are requested to forecast cash-flows for construction projects by using Excel spreadsheet.

Thus, a simulation based game was developed to help students understand the topic in Construction Finance and Accounting course. The game was played as a pilot study.

This paper describes the simulation game and findings from the pilot study. Also, it discusses expected benefits of the game and future study.

Game-based Learning

Game-based learning is one of instructional approach to encourage students' active participation (Rafiq and Easterbrook 2005) and the approach is an increasingly universal tool in higher education (Johnson 2009). The benefits of using game-based learning were identified by many researchers and teachers (for example, Kumar and Lightner 2007): encouragement of active learning, collaboration and interactivity.

This kind of active learning is also recommended in construction management education. Stein and Gotts (2001) found that 67% of the construction management students in their program preferred hands-on learning and Carns and Plugge (2010) concluded that construction students have a tendency to be visual and hands-on learners based on analysis of previous research.

Several games were developed and used for teaching construction management courses including LEAPCON game (Sacks and Goldin 2007) and Parade game (Tommelein et al. 1999). While both the LEAPCON game and the Parade game are to teach LEAN Construction principles, the LEAPCON game is more about batching production and buffer. And the Parade game is focused on impacts of variability in work-flows on overall project performance. These games enabled to simulate real-world processes of construction process in simple and entertaining format and participating students can get hand-on experience by taking a roll of a construction participant such as specialty contractor. Furthermore, the LEAPCON game reflects cash-flows regarding different management policies. The games enabled students to understand interactions among multiple factors in the simulation effectively.

While many instructors or researchers recommend game-based learning approach for construction management education, no tool or game is developed to help student learn cash-flow and its projects for construction projects.

Teaching Cash-flows for Construction Projects: Requirements

Cash flows in construction projects is one of the most crucial factor in contractor's successful business (SIO 2011) and cash-flows are determined by many factors between two perspectives: cash-inflow in contractor's pocket and cash-outflow from contractor. While cash-flows in construction projects are affected by these factors, the American Council for Construction Education (ACCE) requires total 1 semester credit to cover Construction Accounting and Finance for accreditation. Table 1 shows the detailed topics. The required topics include only broad topics regarding cash-flows in construction projects: forecasting cash flow requirements and payment processes.

Table 1
Minimum requirement by ACCE

Construction Accounting and Finance	Required
- Cost Accounting and Industry Formats	1 semester (1.5 quarter) hour(s0
- Fixed and Variable Costs: insurance, bonding, marketing, general and administrative expenses	
- Bidding and Procurement Practices	
- Record and Report Practices	
- Capital Equipment, Depreciation, and Expensing	
- Forecasting Costs, Cash Flow Requirements	
- Payment Processes and Time Value of Money	

Teaching Cash-flows for Construction Projects: at the Author's Institution

While the ACCE specifies its requirements regarding cash-flows broadly, teaching construction cash-flow and its forecasting requires more detailed topics.

As for cash-inflows to (general) contractors, project owners typically hold some portion of amounts requested until a point in time (such as substantial completion) to motivate the contractor to cooperate in completing the project in a timely and professional manner. Another factor to be accounted for cash-inflow is delay in receiving cash. Due to time required in billing procedures, contractors are typically paid one month later than when they bill project owners. These two factors causes deficit of cash to contractors, *cash trap* (Jackson 1999), in which contractors have to use their own cash or borrow cash. Furthermore, schedule of values which is a base to determine monthly progress amount affects amount of billing and cash-inflow. For example, if owner is based on a front-end loaded schedule of values for determination of progress payments, inflow of cash into contractor's pocket can be improved.

Cash-outflow from contractors must account for 1) conditions of payment to trades (labor cost, material cost, and subcontract cost), and 2) contractor's retainage. While contractors are required to make frequent payments for labor cost (i.e., weekly or biweekly), contractors may delay payments to material suppliers and/or subcontractors until the contractor receives money from project owner. This type of payment means that financial burden is transferred from the general contractor to trades (*trade financing*, Peterson 2009). Furthermore, general contractors may hold some portion of money billed by supplier or subcontractors.

Cash-flow for a construction project is to be forecasted based on cash-inflow and cash-out flow mentioned above. The maximum amount of cash to be borrowed (or invested) is of the most interest to contractors, because contractors should secure enough funds from their own pocket or by borrowing from financial institutions (Peterson 2009). Since contractors cannot defer payments for labor cost until receiving money from project owner like other trade costs (*trade financing*), they need to use their own cash (or borrowed cash) to pay for labor cost. This affects the maximum amount of cash (or limit of line of credits) for financing. Figure 1 shows the factors related with cash-flows and their influence on either cash-inflow or cash-outflow.

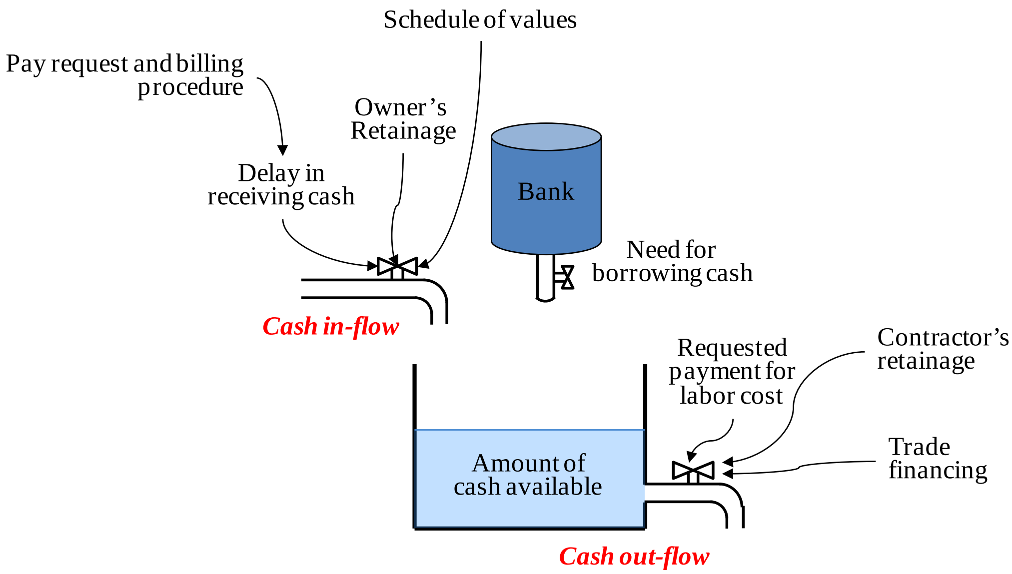

Figure 1: Influence diagram for cash flows to contractors

In the construction finance and accounting class at the author's institution, the above topics are learned and discussed with the time shown in Table 2. (Notice that 1 class meeting time in the course is 75 minutes*.)

Table 2
Topics and assigned time at the author's institution

No.	Topic	Assigned time
1	Billing procedures (including owner's retainage)	a half of one class meeting time*
2	Cash trap	1 class meeting time*
3	Schedule of values	1 class meeting time*
4	Payment request	1 class meeting time*
5	Forecasting cash-flow	1 class meeting time*

The topics related with cash-flows and required for forecasting cash-flow in Table 2 (No. 1 – No. 4) are studied and discussed along with in-class example and homework assignment in the course. Then, the last topic, forecasting cash-flow is studied and practiced on an Excel spreadsheet which is based on an example from Peterson (2009) as shown in Figure 2. Also, similar format is used for homework assignment. However, based on the author's observation, many students could not finish the homework assignment successfully. It is possible that it was due to unfamiliarity to the format in one hand or the terms in the format. However, many students seemed to be unable to integrate the prerequisite topics (from no. 1 to no. 4). Especially students were observed to have difficulty to determine the maximum amount of cash to be borrowed (or invested), which is of the most interest to contractors.

Retention	10.0%
Markup %	15.0%

Cost Loaded Schedule

Month	0	1	2	3	4	5	6	7
Materials	0	30,400	57,300	80,500	29,200	27,800	15,400	-
Labor	0	34,900	48,900	73,100	34,000	26,200	11,300	-
Subcontractor	0	54,700	123,800	136,400	106,800	66,000	43,300	-
Others (Utility Cost)	0	100	100	100	100	100	100	-
Total Costs	0	120,100	230,100	290,100	170,100	120,100	70,100	0

Projected Cash Flow

Month	0	1	2	3	4	5	6	7
Bill to Owner								
RECEIPTS								
Cumulative receipt								
PAYMENTS								
Materials								
Labor								
Subcontractor								
Others								
Total Payments								
Cumulative payment								
CASH FLOW ANALYSIS								
Cash Flow Before Receipt								
Total Cash Before Receipt								
Cash Flow at Month's End								
Total Cash at Month's End								
Maximum Amount of Cash Invested by the Company								

Figure 2: In-class practice worksheet for forecasting cash-flows

The Cash-flow Simulation Game

A game is developed to help students in the Construction Finance and Accounting course. The game simulates the cash-flows and movement of materials and services among construction project participants: project owner, general contractor, laborer, material supplier, subcontractor and banker. Furthermore, this game can incorporate different policies in schedule of values and payment to trades that students can learn the impacts of different policies on cash-flows.

This game is based on the following assumptions:

- The project owner holds 10% of each billing amount until the completion of project.
- The project owner makes payment to the general contractor one month after billing request.
- The general contractor holds 10% of all material cost and subcontract cost until the end of project.
- The general contractor is required to pay for labor cost weekly.

In addition to the assumptions, impacts of different policies regarding contractor's payment to trades (material cost and subcontract cost) and schedule of values on cash-flows can be compared in multiple rounds by selecting different policies:

- Payment to trades: 1) payment before receiving money from project owner
  2) payment only after receiving money from project owner (trade financing)
- Schedule of values: 1) schedule of values based on planned work amount each month
  2) front-end loaded schedule of values

The players whose role is laborer, supplier, or subcontractor are to roll dice to determine amount of work completed or amount of materials supplied in each session which represents week. Then, they need to move the same amount of stones as the number determined from dice shown in Figure 3 to the (general) contractor to represent furnished/completed works. The general contractor needs to give poker chips which represent cash to laborer every week. At the end of the fourth session (or fourth week), the general contractor is to bill the owner based on 1) amount he spent in the last four weeks [Schedule of values - option #1] or 2) amount which was already determined by the instructor [Schedule of values – option #2]. And after the next four sessions (one month after billing), the owner is to give the contractor with poker chips (representing cash): the payment amount (number of the poker chips) is the billing amount less the owner's retainage. And the contractor is to make payments (giving poker chips) to both material supplier and subcontractor depending on payment policies. The contractor is to record amount of poker chips he keeps at the end of each session.

Figure 3: Materials needed for the cash-flow simulation game

While this game is very simple, the features of the game are:

1) Simple and easy to follow: this game is developed to simply simulate the cash-flows and furnishing of service/materials in construction projects and number of works completed and services performed in each session are small for easier calculation.
2) Minimized calculation: by using poker chips (representing cash) and stones (representing service or work completed), the players don't need to calculate in every step. Instead, they can count number of poker chips or stones they keep.
3) Easy identification of maximum amount of cash to be borrowed (or invested)
   The general contractor is to keep a record about amount of poker chips in every session in the plot shown in Figure 4 and is able to determine the maximum amount of cash to be borrowed from the plot he prepares.
4) Uncertainty in construction progress: amount of work (or service) completed (or provided) and amount of materials supplied in each session are randomly determined by rolling a die. Impacts of

the uncertainty in work progress on cash-flows such as longer duration of financing and accordingly more interest cost can be discussed.

5) Easy comparison of impacts of different policies about payment and/or schedule of values The comparison can be achieved by playing additional rounds by changing the policy.

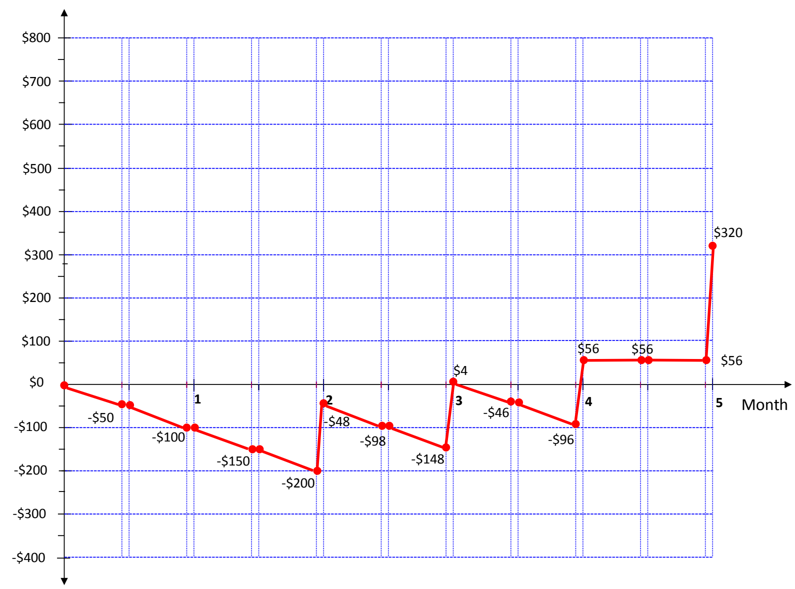

Figure 4: Game worksheet for forecasting cash-flow and expected result of one example

Pilot Study of the Game

The game was played by 21 students in the Construction Finance and Accounting course in spring 2011 as a pilot study. The teams (except one team) were composed of six students and the game play was completed only in two rounds due to limited class time (75 minutes). Figure 5 shows a picture taken during the game play.

Figure 5: Game worksheet for forecasting cash-flow and expected result of one example

The students' responses indicate that this game is helpful in learning forecasting cash-flows in construction projects. The responses include: 1) the game is fun and interesting, 2) easiness in determination of maximum amount of cash-flows, and 3) easy understanding pay-request and payment procedures. Thus, based on the students' comments it can be concluded that the students could be motivated for active learning, and they were able to forecast cash-flow amounts and to determine the maximum amount of cash to be borrowed easily.

While this pilot study was targeted to 3 rounds, only 2 rounds were completed in the 75 minute period. Thus, the impacts of using front-end loaded schedule of values on cash-flows could not be compared and discussion was performed in the next class session. The game needs to be tailored into the fixed time slot.

Conclusions and Recommendations

The Cash-flow simulation game was developed to help students understand cash-flow factors and their impacts on cash-flows and determine the maximum amount of cash to be borrowed in Construction Finance and Accounting course. Also, different policies regarding payments to trades and schedule of values can be compared with regard to impacts on cash-flows. From its pilot study, the benefits of the game were identified qualitatively as following.

1) It encourages and motivates students for active learning.
2) It helps students understand construction project cash-flows and determine maximum amount of cash to be borrowed (or invested).

However, this game should not be replacement of working on spreadsheets for forecasting cash-flows. Since contractors need to deal with large number (dollar value) and more numbers due to long duration of construction projects, they need some type of spreadsheet software. Instead, this game can help students prepared for projection of cash-flows for construction projects.

The findings from the pilot study don't provide scientific proof that this game is beneficial to students and a more efficient tool for teaching construction cash-flow forecasting. Therefore, it is intended that the benefits of this game are scientifically and quantitatively measured and proved in a future study. Also, the game is to be monitored and reviewed by industry experts for their comments.

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A Study of Construction and Instrumentation of Pavement Test Section on I-35 in Oklahoma

Pranshoo Solanki, Ph.D. and Richard Boser, Ph.D.
Illinois State University
Normal, Illinois

Musharraf Zaman, Ph.D., Kanthasamy K. Muraleetharan, Ph.D., and Marc Breidy
University of Oklahoma
Norman, Oklahoma

The instrumented pavement test section in Oklahoma was constructed from April 2008 through May 2008. The primary objectives of this instrumentation project includes two important aspects of the Mechanistic-Empirical pavement design namely, fatigue and rutting. The test section is closely monitored through array of environmental and dynamic data sensors located beneath the pavement and embedded during and after the construction. The environmental sensors include temperature probes for temperature measurements and moisture probes to measure moisture content in the base and subgrade layers. The dynamic sensors include earth pressure cells for measuring stresses, asphalt strain gauges for measuring strains, and lateral positioning sensors for measuring wheel wander. Additionally, weather station was also installed near the test section for recording weather parameters including air temperature and relative humidity among others. Environmental data are collected at every one minute interval, but only hourly averages are stored. Dynamic data is collected weekly for randomly selected 20 Class 9 vehicles. Details of the site evaluation, design, and construction of the I-35 instrumented pavement section are included in this paper. Also, preliminary traffic and performance trends in terms of falling weight deflectometer (FWD) test on the test section are presented and discussed.

Keywords: Asphalt Concrete, Subgrade, Pavement Performance, Falling Weight Deflectometer.

Introduction

The performance evaluation of a pavement can provide useful data for future design and construction. The data becomes particularly useful if such data spans over the entire life of the pavement. Several test roads have been constructed for collecting such long-term pavement performance. For example, the foremost road test sponsored by AASHTO (American Association of State Highway and Transportation Officials), which ultimately resulted in the now famous AASHO Road Test. The data gathered during this test cycle formed the basis of the AASHTO 1993 Design Guide for Pavement Structures.

A number of test road sections were monitored and instrumented to evaluate and measure the effect of materials, load, and environment on pavement design. This helped pavement engineering community to move beyond empirically-based design (e.g., AASHTO 1993 Design Guide) and analysis toward mechanistic-empirically (M-E) based procedures. According to Yoder and Witczak (1975), for any pavement design procedure to be completely rational, three elements must be considered fully: the theory used to predict the assumed failure or distress parameter, the evaluation of the materials properties applicable to the selected theory, and the determination of the relationship between the magnitude of the parameter in question to the performance level desired.

The above mentioned elements can be fully understood only by considering mechanistic pavement response (stress, strain and deflection) under moving vehicle loads and empirically relating these to observed field performance. This results in a M-E design approach which is applicable over a much wider range of material, traffic and environmental conditions (Timm et al., 2004). The new Mechanistic-Empirical Pavement Design Guide (M-EPDG) is an outcome of continued movement towards mechanistic design of pavements through NCHRP Project 1-37A (AASHTO, 2004). The overall objective of NCHRP Project 1-37A is to develop and deliver the 2002 Guide for Design of New and Rehabilitated Pavement Structures, based on mechanistic-empirical principles, accompanied by the necessary computational software, for adoption and distribution by AASHTO (Hallin et al., 2011). One of the empirical parts of the new M-EPDG is relating field performance data used to correlate to accumulate damage. This “transfer” function, as it is sometimes called relates to the theoretical computation of “damage” (which is, in turn, a function of pavement deflection, strain, or stress response) at some critical location with measured distress, completing the full mechanistic-empirical loop of the pavement design (AASHTO, 2004).

As the M-E design approach for designing flexible pavements is in the process of evaluation by many state agencies and researchers, there is a need to assess the accuracy of the load-response model and performance prediction models under actual vehicular loading and environmental conditions, which are the core components in the M-E design process. By measuring actual field response and monitoring performance, the relationship between response and life is more directly determined. To this end, a 1000-ft. long instrumented pavement section was constructed for exploring two important aspects of M-E design; namely, the pavement performance model to predict fatigue and rutting. Details of the site evaluation, design, and construction of the I-35 instrumented pavement section are included in this paper. Also, preliminary traffic and performance trends on the test section are presented and discussed. Moreover, difficulties associated with the instruments used in the I-35 project are discussed.

Construction and Instrumentation of the Test Section

Location of the Test Section

The 1000-ft. long test section used in this study is located in McClain County, Oklahoma, on the (right) southbound lane of Interstate-35. Additionally, one preexisting Weigh-In-Motion (WIM) station near to the instrumented section was used for collecting traffic data. The WIM station is located approximately three-quarter mile down the instrumentation site of the test section on I-35 southbound lane. The thickness of the test section was deliberately designed thinner so that it fails in a relatively short period of time, and its in-service performance can be monitored over the entire life. Thus, this design resembles the concept similar to the accelerated pavement testing (APT), but it involves actual vehicular traffic and environmental conditions rather than controlled conditions used in APT.

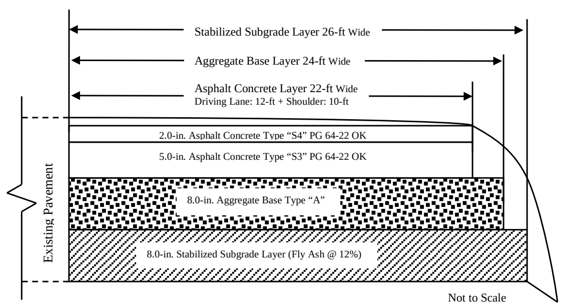

Figure 1: Sketch of Typical Section, Looking South

Layout of the Test Section

The test section consisted of five layers (Figure 1). The top layer is 2.0-in. thick; it consists of type "S4" asphalt concrete containing PG 64-22 binder. The layer below is a 5.0-in. thick asphalt concrete of type "S3." This is a recycled mix with PG 64-22 binder and 25% recycled asphalt pavement (RAP). The third layer has a thickness of 8.0-in. It consists of "Type A" aggregate base. The fourth layer is 8.0-in thick cementitiously stabilized subgrade layer; stabilized with 12% fly ash. The bottom layer is the subgrade soil. It is basically lean clay (having liquid limit at 33 and plasticity index of 15) and dark brown in color.

Instrumentation Plan

The instrumentation plan was developed by considering two important factors: (1) to place the instruments where they would be trafficked by the vehicles; and (2) to be a certain level of redundancy in each test cell in case gauges became dysfunctional during installation, construction or full operation of the facility (Timm et al., 2004). Since only the outside lane of I-35 southbound was to be removed and reconstructed, instrumentation focused on the outside wheel path of the outside lane. A total number of twelve asphalt strain gauges (CTL Model No. ASG-152) were centered on the outside wheel path. Six of these twelve were oriented longitudinally (parallel to traffic direction) and six transversely (perpendicular to traffic direction) to measure strain in longitudinal and transverse direction, respectively (Figure 2). In each group of six strain gauges, three were redundant gauges. As shown in Figure 2, the gauges were spaced at 2-ft. on centers to capture the spatial distribution of strain and provide sufficient space such that the presence of one gauge should not greatly affect another (Timm et al., 2004).

Also, a total of three earth pressure cells (EPC, Geokon Model No. 3500) were installed at the top of each pavement layer namely, subgrade, stabilized subgrade and aggregate base to measure traffic-induced normal stress at these locations. The geometric plan of the three EPC's used at the instrumentation site is shown in Figure 2. The first EPC placed on the top of natural subgrade is at the center of instrumentation array. The second EPC on stabilized subgrade was positioned 7-ft. after the center of the array, while the EPC at the top of aggregate was positioned 5-ft. before the center of the array.

Five temperature probes (Campbell Scientific Model No. 108-L) were installed to measure variations of temperature in the asphalt concrete (AC) layer at a depth of 0.0-in., 2.0-in., 3.5-in., 7.0-in. and 10.0-in. from the pavement surface. The moisture probes (ECH2O Model No. EC-5) were placed approximately 3.0-in. below the top of each layer centered between the wheel paths, as shown in Figure 2. Three lateral positioning sensors (Dynax® axle sensors Model No. AS400) were also installed on the top of the AC layer to address the wheel wander of vehicles over the test section.

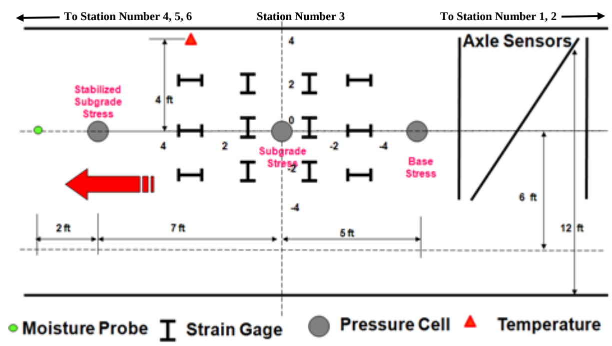

Figure 2: Dynamic Data Sensors Layout (Geometry)

Construction and Instrumentation

The chronological sequence of construction and sensor installation of instrumented section is shown in Figure 3.

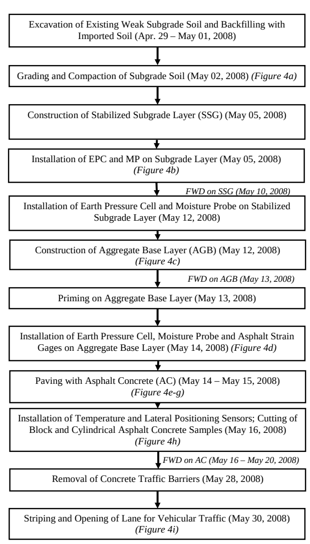

Figure 3: Flow Chart of Construction and Instrumentation Process

Broadly, the construction and instrumentation of the site was divided into four phases. The first phase consisted of grading, leveling, and compacting of the subgrade and then installation of sensors on the top of subgrade. The second phase consisted of constructing the stabilized subgrade layer (SSG) and then installation of gauges on SSG. In the third phase aggregate base layer (AGB) was constructed and sensors were installed on the top of AGB, and the last phase involved paving the road with asphalt concrete (AC). These phases are discussed in the following sections.

Figure 4: Construction and Instrumentation of Test Section

Before construction of the test section, the AC layers as well as the base layer of the existing pavement were milled. After removing these layers, the construction equipment experienced very soft subgrade soils with excessive moisture contents, in excess of 16%. Because the soft subgrade was unsuitable for construction, it was decided to remove 1- to 2-ft. of this layer and to backfill it with soil imported from the northbound lane of I-35. After backfilling, the subgrade was graded uniformly using a dozer. Following the grading operation, the surface was compacted using an Ingersoll Rand sheep-foot roller (Figure 4a). The subgrade was further smoothened by using a smooth-drum roller.

The stabilized subgrade layer was constructed on the top of the compacted natural subgrade layer. As mentioned earlier, Class C fly ash (CFA) was used as the stabilizing agent. The CFA was hauled from Red Rock, located about 130 miles from the site. The CFA was spreaded using a motor grader. A pulver mixer was used to mix the soil with the CFA (12%). According to the contractor, mixing of soil with CFA after installation of EPC and moisture probe could cause a breakage or rupture of these instruments and cables by the teeth of the pulver mixer. Therefore, it was decided to install the EPC and the moisture probe on the top of the natural subgrade layer after mixing the subgrade soil with CFA. After compaction (May 5, 2008), the compacted soil-CFA mix was allowed to cure for few days so as to allow chemical reactions (Solanki et al., 2009). After curing and drying of the stabilized subgrade layer, one set of EPC and MP were installed on the top of the stabilized subgrade layer (Figure 4b).

The aggregates were hauled from Dolese plant in Davis, Oklahoma. The aggregates were spreaded using a Caterpillar D6R dozer on the separator fabric (Figure 4c). A nuclear density gauge was used to measure in-situ density at identified stations on the compacted aggregate base layer. The compacted aggregate base layer was coated with prime coat. The prime coat was allowed to cure for one day before installing the strain gauges on the top of the aggregate base layer. With the guidance of NCAT professionals, 12 asphalt strain gauges were installed in the corresponding locations on the aggregate base layer (Figure 4d and e). Then, EPC and moisture probe were installed on the top of the aggregate base layer following the same procedure for installation on the top of the natural subgrade layer and the stabilized subgrade layer.

Paving took place after construction and instrumentation of the pavement up to the aggregate base layer. The first lift of type S3 HMA was laid first on the north end of the instrumentation site. Paving was performed with a paver manufactured by Caterpillar® (Figure 4f). After the mix was laid, a vibratory roller was used for compaction (Figure 4g). A pattern of two heavy vibratory modes and one pass with static mode (no vibration) was followed to achieve the desired density. After proper compaction of the first lift with vibratory roller, tack coat was applied; then the second lift of type S3 HMA took place. After that, surface course of type S4 HMA was laid on the asphalt mix and compacted to an approximate thickness of 2.0-in.

After paving work was completed, five temperature probes were bundled together and installed in the pavement by cutting a core and trench line on the top of type S4 HMA layer. Installation of axle sensors took place after installation of temperature probes. First, a concrete saw was used to cut three slots in the pavement approximately 1.5-in. wide by 1.5-in. deep in cross-section. Then, a leaf blower was used to dry out the slots and remove the debris from the slots. After drying, the axle sensors, supplied by IRD (International Road Dynamics), were laid down in the slots and a mixture of epoxy and sand was placed in the slots to attach the sensors to the pavement (Figure 4h). All the sensors were then attached to the Data Acquisition System installed in the cabinet near the test section. A total of six HMA cores were extracted from the test section to measure the amount of air voids in the test section. It was found that the test section was having approximately 8% to 10% air voids. After cleaning the surface of the newly constructed test section, it was white paint line striped (Figure 4i) and opened to traffic on May 30, 2008.

Test Stations

A total of six stations, namely, Station 1, 2, 3, 4, 5, and 6, were selected randomly for monitoring the pavement performance on the test section. These stations were marked along the outside wheel path and located at approximately 100-ft. intervals. Specifically, Station 1, 2, 3, 4, 5 and 6 were located at approximately 144-ft., 235-ft., 319-ft., 540-ft., 738-ft., and 900-ft., respectively, from the north end of the test section. Only Station 3 located on the top of subgrade EPC lied within the instrumentation array (Figure 2). Other stations (1, 2, 4, 5, and 6) were outside the instrumentation array. Road straps were laid down on the pavement surface at all the stations during the first field test on August 21, 2008. The pavement performance was monitored by conducting falling weight deflectometer (FWD), rut depth measurements and crack mapping on Stations 1 through 6. Only FWD measurements will be discussed in this paper.

Data Acquisition and Processing

On I-35 instrumented section, two distinct networks were used to acquire data from different sensors. The first network was used for capturing dynamic response data from axle sensors, ASG's and EPC's at a high sampling frequency of 2000 Hz. This was achieved by using a 14-bit resolution data acquisition system manufactured by DATAQ (Model No. DI 785-32). The second network was used for capturing environmental data from temperature sensors, moisture probes and the weather station at a relatively slow sampling rate of once per minute and stored as hourly summaries (maximum, minimum and average). To collect and store data at slow sampling rate, a data acquisition system from Campbell Scientific, Inc. (Model No. CR 10-X) was selected. The weekly high sampling frequency data collection cycle consisted of capturing data of 20 Class 9 vehicles having one steering and two tandem axles. During weekly data collection cycle, a video camera was set on both instrumentation and WIM sites. The movies captured from both instrumentation and WIM sites helped identify and collect the axle load of Class 9 vehicles which were used for capturing high sampling rate data on the instrumentation site. A commercial software, DADiSP, was used to process the high sampling frequency data. Each steering and tandem axle was processed for all the Class 9 vehicle data collected during the weekly data collection cycle.

The WIM site is instrumented with two inductive loops and two piezoelectric sensors, both having a length of 12-ft. The sensors detect the presence of a vehicle and record the axle count, axle weight, axle spacing, vehicle class, vehicle length, speed and ESAL. The data are recorded using a 2 MB onboard automated electronic counter, called ADR 3000 installed in a road cabinet on the side of the WIM sensors. Traffic files are recorded on a daily basis, and downloaded using a modem dial-up connection. For each day, two files are created, each ending with a different extension (.bin and .pvr). However, both files are needed to generate the traffic data. A user-friendly software, TOPS (Traffic Operations Processing Software), was used for reading and analyzing the traffic data files recorded by the WIM station. The TOPS program opens the appropriate raw WIM files, and allows multi-file processing, previewing, and editing of reports. It is also capable of generating a suite of daily, weekly and monthly reports. Unlike other experiments, such as NCAT Test Track (Timm et al., 2004), the I-35 test section was subjected to actual vehicular traffic. This gives a better simulation of development of distresses (e.g., fatigue cracking, rutting) than occurring on an open-access facility.

FWD Testing

A Dynatest model 8000 series (8002-057) type FWD was used in this study. The testing pattern was designed for a series of six stations located at approximately 100-ft. intervals along the outer wheel path. For conducting tests on the top of AC layer, a plate of 11.8 in. diameter was used with seven deflection sensors spaced at 8, 12, 24, 36, 48, and 72 in. from the center, as recommended by the ASTM D 4694 test method. The deflection sensors had an accuracy of 0.04 mils. The loading pattern included three seating drops plus one load drop from different heights in progressive order. The loading pattern included four different loads (6, 9, 12 and 15 kips) for testing on the top of asphalt concrete layer. For this investigation, the FWD data was collected periodically covering a wide range of temperatures. Specifically, FWD data was collected from May 16, 2008, through May 20, 2008, at different times of day before opening the test section to actual traffic. Also, after morning lane closures FWD data was collected on August 21 and December 3 of 2008, May 19 and October 28 of 2009, February 16, May 18, August 11, and November 22 of 2010, and February 14, and June 07 of 2011.

The modulus values from FWD data were back-calculated using MODULUS 6.0 software (Liu and Scullion, 2001). Several techniques, as mentioned in Von Quintus et al. (1994), were used for analyzing and interpreting the FWD data. The first approach involves the validation of the deflection data obtained from sensors. This procedure involved investigating the deflection basins and verifying that they were sensible. The depth of each layer was specified on the basis of measured thicknesses from the extracted cores (Solanki et al., 2009). In addition, several trial sections with different depths of bedrock were analyzed. The modulus values of each layer and absolute error were examined carefully for all the six stations. The back-calculated modulus values for aggregate base, stabilized subgrade and natural subgrade layer were compared with the range of resilient modulus (M_r) values obtained from laboratory testing on the corresponding field collected material in accordance with AASHTO T 307 test method (Solanki et al., 2009). The deflection basins providing back-calculated modulus values outside the range of adjusted laboratory M_r values were discarded. An adjustment factor of 1.43, 0.62 and 0.75 was used for aggregate base, stabilized subgrade and natural subgrade layers, respectively (AASHTO, 2004). The depth of bedrock giving sensible M_r values and lowest absolute error was selected.

Data Analysis and Discussion

Traffic Data

The analyses presented herein summarize three-year of traffic data, collected from June 1, 2008 through May 31, 2011 (1 Year: June 01 – May 31). The data between these two dates are not entirely continuous; some days were lost due to technical problems with the WIM station. Also note that the instrumented section was first opened to traffic on May 31, 2008, but was not included in the study for simplicity. Also, traffic data included are only for trucks with two or more axles (Class 4 through 13), in accordance with the Federal Highway Administration (FHWA) grouping system. Motorcycles, cars and SUVs (Class 1 through 3) are excluded from the analysis because, first, these types of vehicles are not detectable by the WIM station, and second, their load impacts on the pavement are insignificant when compared to trucks.

Table 1: ***Traffic Volume Statistics***

Time Period	Lane 1	Lane 2	Total	Difference
Year 1 (June 01, 2008 – May 31, 2009)	1,170,870	263,609	1,434,479	--
Year 2 (June 01, 2009 – May 31, 2010)	1,156,246	248,544	1,404,791	-1.0%
Year 3 (June 01, 2010 – May 31, 2011)	1,187,837	282,139	1,469,976	2.3%
Total 3 Years (June 01, 2008 – May 31, 2011)	3,514,954	794,292	4,309,245	
Percentage	81.6%	18.4%	100%	

A summary of annual traffic volume passing through Lane 1 (outside or slow lane) and Lane 2 (inner or fast lane) is presented in Table 1. Also, the difference in total traffic volume between two consecutive years is presented in Table 1. It is evident from Table 1 that 81.6% of total traffic volume drives on Lane 1; only 18.4% of total traffic volume drives on Lane 2. Higher volume of traffic in Lane 1 (slow lane) is expected due to state traffic law practice which enforces truck (Class 4 through 13) drivers to drive on the slow lane. In terms of total traffic per year, Year 2 (June 01, 2009 – May 31, 2010) had the lowest traffic volume, with a difference of -1.0% from the previous year. This drop in vehicle volume is believed to be connected to the economic recession that started in late 2008. However, Year 3 showed an increase in traffic volume of about +2.3%. Overall, in three consecutive years more than 4.3 million vehicles passed on the section.

FWD Data

As noted earlier, modulus values were back-calculated from FWD data using MODULUS 6.0 software. Also, mid-depth (approximately 3.5 in.) pavement temperature values were calculated from data generated by the temperature sensors installed on the shoulder of the instrumented site. The variation of back-calculated asphalt concrete modulus values were then plotted with temperature, as shown in Figure 5.

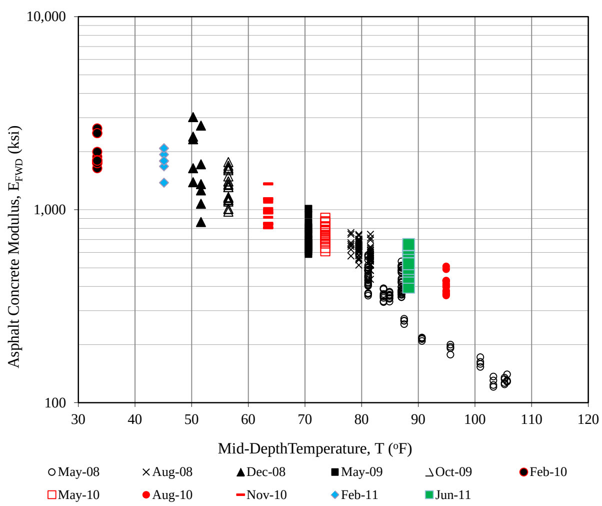

Figure 5: Variation of HMA Stiffness with Mid-Depth Temperature (Last Data: June 07, 2011)

In general, it is evident from Figure 5 that the back-calculated modulus values increases with decrease in temperature, as expected. At low temperature modulus values back-calculated from FWD shows higher variation as compared to modulus values back-calculated at higher temperature. For example, at a low temperature of 50°F the average back-calculated modulus value is approximately 1,792 ksi with a 40% coefficient of variation. On the other hand, at higher temperature of approximately 105°F the average back-calculated modulus value and coefficient of variation is approximately 131 ksi and 4%, respectively. It is also clear from Figure 5 that the modulus values back-calculated from FWD data collected before opening the lane for traffic is lower than the modulus values at corresponding temperature collected after opening the lane for traffic. For example, the average modulus value collected at a temperature of approximately 95°F is 191 and 412 ksi before opening the lane for traffic (May, 2008) and after opening the lane for traffic on August 11, 2010. Since the test section had relatively high initial air voids (approximately 8% to 10%) in the AC layers, it is expected that compaction of AC layer took initially by compaction due to traffic and thus increased modulus values.

Difficulties Encountered During Instrumentation and Field Measurements

Several difficulties were encountered regarding instrumentation and field measurements. (1) As noted earlier, three moisture probes installed in the test section on top of the aggregate base layer, stabilized subgrade layer and natural subgrade layer. Unfortunately, all of the moisture probes stopped working during the first winter and were not able to collect any volumetric water content data. (2) Three Dynax® axle sensors were very prone to rupture. For example, these sensors had to be replaced on August 21, 2008, just approximately three months after the test section was opened to the traffic. These sensors were again replaced on October 28, 2009. From these observations, one could conclude that this type of axle sensors may not be suitable for a very high volume road. (3) During November, 2008, three temperature probes started reporting unrealistic temperature data of the test section. After noticing this problem, all the five temperature probes were replaced on December 3, 2008.

Summary and Conclusions

The I-35 research project in the Oklahoma is currently conducted with the primary objective of monitoring the performance of the test section under actual environmental and loading conditions. A database containing dynamic, environmental, traffic and pavement performance data is currently under development from which two important aspects of the Mechanistic-Empirical design namely, fatigue and rut transfer functions will be derived. Preliminary results showed that a total of 4.3 million vehicles passed over the I-35 section from June 01, 2008 through May 31, 2011. Out of this 3.5 million (81.6%) were driven on Lane 1 (slow lane). This translates into annual average daily truck traffic (AADTT) of 3,210 trucks per day on Lane 1. The traffic volume distribution between the two lanes can be explained by the tendency of truck drivers to feel more comfortable while driving on slow lane in accordance with state traffic law. The modulus values back-calculated from FWD data showed sensitivity towards temperature; back-calculated modulus values decreased with an increase in temperature. Further, the back-calculated modulus value from FWD showed more variability at low temperature (50^{o}F) as compared to high temperature (105^{o}F). This raises question on the validity and pavement performance evaluated by FWD at low temperature. Further, higher variation at low temperature could be partially attributed to relatively smaller deflections (< 0.50 mil) at low temperature. The FWD data collected at different times of year showed the influence of traffic on back-calculated modulus values. The difficulties and experiences learned from I-35 instrumentation project indicate that the type of axle, moisture and temperature sensors used are not suitable for high volume roads.

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A Case Study in Application of Green Building Strategies using Building Information Modeling into a Construction Education

Seongchan Kim, Ph.D.
Western Illinois University
Macomb, Illinois

Euysup Shim, Ph.D.
Illinois State University
Normal, Illinois

"Going Green" is a phrase that is becoming more and more common in our world. Since buildings play a major role in annual fuel and energy consumption, as well as greenhouse gas emissions, the "Going Green" of the building sector is crucial for ecologically sustainable development. Building Information Modeling (BIM, hereafter) enables the Architecture, Engineering, and Construction (AEC) industry to achieve interoperability and data integration among the different components of building systems. This paper presents the integration of BIM and green design measures such as: 1) passive design, 2) building envelope selection, 3) improvement of efficiency through plumbing fixtures, and 4) power use and generation through improving electrical efficiency of fixtures and controls into an undergraduate construction management course. The result was very positive, which enabled students to be introduced to the integration of BIM and sustainability in design decisions.

Keywords: Green Building, Building Information Modeling (BIM), Autodesk Revit, Green Building Studio

Introduction

BIM is a relatively new technology for construction visualization and contributes to the understanding of construction projects since BIM combines graphical information such as 2-D and 3-D drawings with non-graphical information including specifications, cost data, and schedules. In addition, BIM models can be extended to evaluate and improve sustainability of building designs through minimizing energy waste and enhancing efficiency of the active building system. For example, amount of lighting, power, heating, cooling, water supply, and waste can be manipulated to minimize the demand for external resources (Elvin 2007).

BIM also helps with design and evaluating green design measures by exploring: 1) passive design, 2) building envelope, 3) water use and collection, 4) power use and generation, and 5) daylighting (Autodesk 2011).

Using construction visualization tools within a construction management curriculum can improve students' ability to read plans, develop an estimate, and comprehend the construction process more comprehensively (Gier 2008). Post (2006) states that BIM allows users to visualize the construction projects by creating 3D, 4D and 5D models that show every little detail.

This paper describes how software tools can be used to construct a BIM model and apply green design strategies to BIM model. It also discusses students' response to the project.

BIM Software Tools

There are a number of BIM-based software commonly used throughout the industry including; Autodesk Revit Architecture (Revit), ArchiCAD, Bentley, and SolidWorks. The Freedom Towers project, which is one of the most important construction projects in the United States, produces construction documents using Revit Architecture. Disney World and GSA (US General Services Administration) have used Revit Architecture to complete and manage some of their projects and reported it as a successful tool (Woo 2007). In order to develop a building model and evaluate the sustainability of the building for this project, several software tools were utilized including Autodesk Revit Architecture (Figure 1), Green Building Studio (Figure 2), and green building Extensible Markup Language (gbXML, hereafter) Schema.

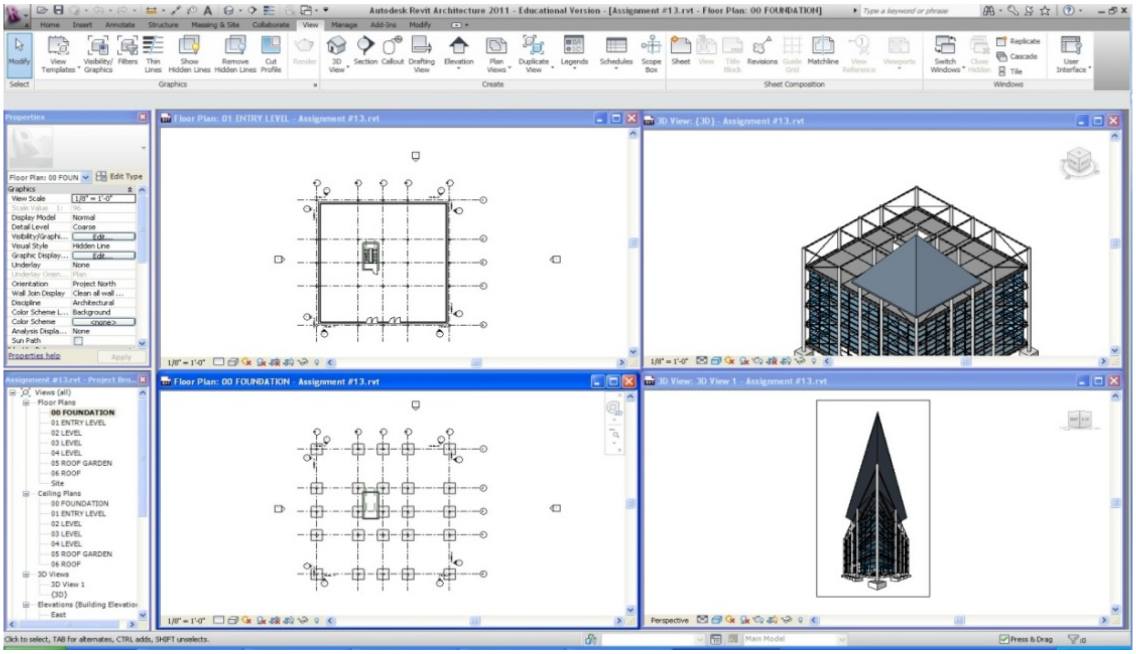


Figure 1. Building Modeling by Revit Architecture.

Green Building Studio is a web-based service which enables to assess: 1) energy and carbon results, 2) water usage data, 3) photovoltaic potential, 4) daylighting results, and 5) design alternatives. This software was used to evaluate the environmental impact of building design and design alternatives. The results of energy savings are shown in monetary terms that reflect the local costs of utilities (Figure 2).

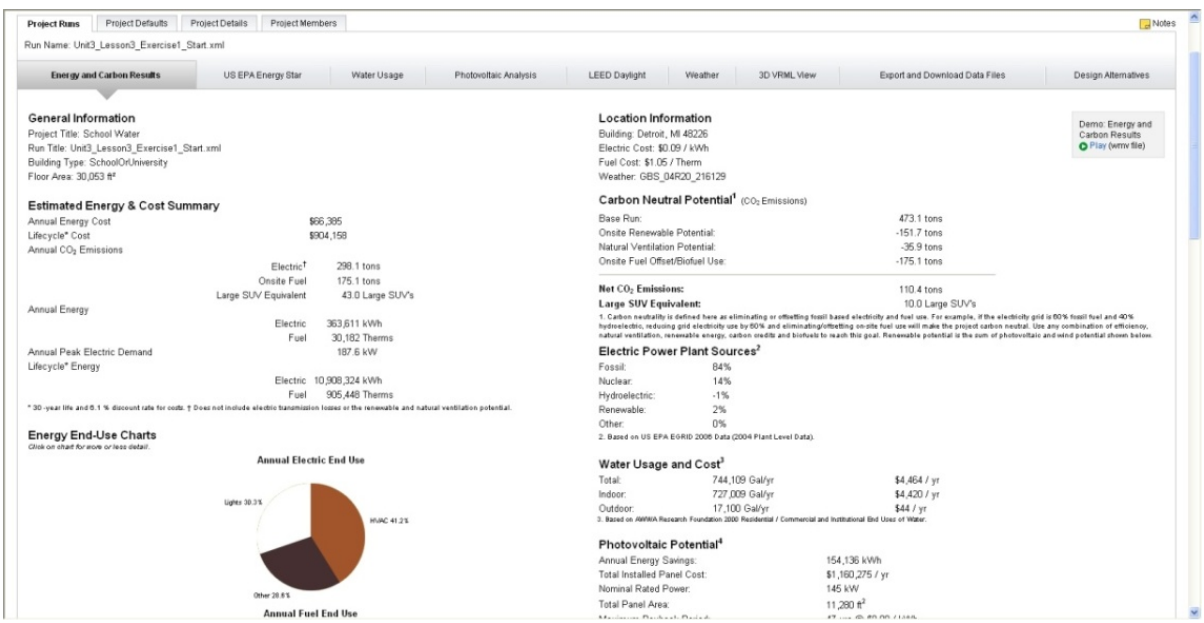


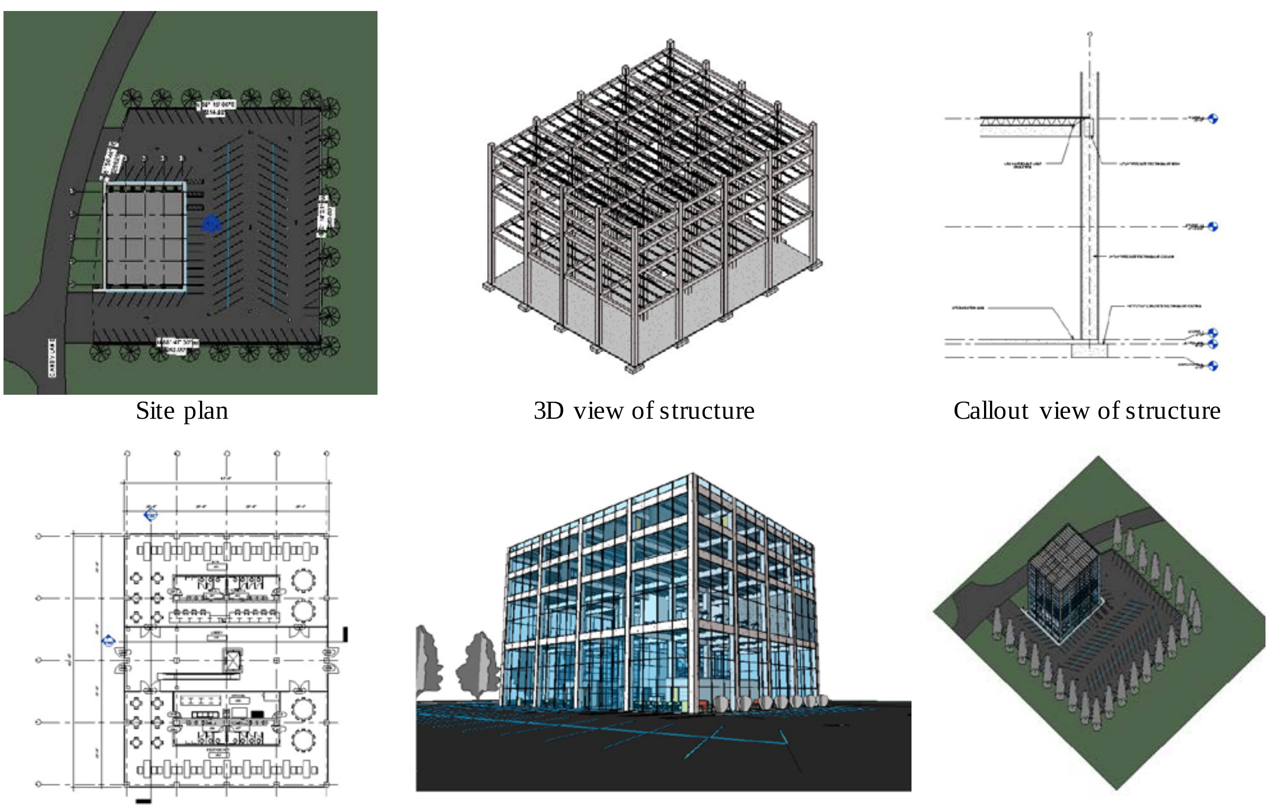
Figure 2. The Sample of Results of Green Building Studio.

The gbXML Schema was used to transfer essential information contained within a Revit Architecture model to Green Building Studio. This information includes items such as building geometry, walls, windows, and room areas, but excludes superfluous items such as furniture, stairs, and appliances. This format allows for a consistent way to share information between Autodesk Revit products and other software tools that adopt the schema. Therefore, after modeling the initial design, BIM model was saved as gbXML files in order to transfer the data into Green Building Studio.

The Case Study: Implementing Green Design Measures to BIM

This course was open to construction management students who had already taken an introductory AutoCAD course, and twenty undergraduate students registered for this class. The software used for this class was the 2010 version of Autodesk Revit Architecture and Green Building Studio. The software tools were available for students to download for free, and they were also available in the computer labs on campus. Basic software tutorials were presented in the lecture to help students understand functions of Revit Architecture during the first few weeks of a semester. These tutorials included different building structures, construction method, construction material, architectural features, and ways to model them using Revit Architecture. After tutorial sessions, green design strategies were discussed with a student who was enrolled in “In-Course-Honors” option. Students who are enrolled in “In-Course-Honors” option need to perform extra project with a faculty for in-depth investigation of a subject matter and professional development during the semester. If students meet the expectation, students will receive a commendation upon graduation. Then, the student started identifying which green design strategies can be utilized by given BIM tools as the student started his own project. According to Autodesk (2011), there are a number of strategies including manipulations of : 1) passive design such as building orientation, building mass and shape, and architectural features (window placement, roof overhangs, and shading features), 2) building envelope such as thermal properties of building materials, thermal transfer and thermal comfort, 3) water use and collection such as estimating the water demand baseline, improving efficiency through plumbing fixtures, 4) power use and generation such as improving electrical efficiency through fixtures and controls, and 5) daylighting provided through architectural features in the building model. Figure 3 shows samples of screen shots of the final project.

Initial design was developed using Revit Architecture. The project guideline was provided for an initial design. For example, the project should have been kept within the range of 8,000 sq.ft per floor, number of stories less than five, and building system should have been a steel structure. After building up the structure, walls, widows, roofs and other architectural features had to be installed to the initial model.



Site plan — 3D view of structure — Callout view of structure

Floor plan — 3D view — Site 3D view

Figure 3. Example of Final Project.

Then, the developed initial model was converted to gbXML format to transfer a BIM model into Green Building Studio. Using Green Building Studio, efficiency of different green strategies such as variations in features, materials and system were evaluated and results were analyzed by the student. After the analysis, the best combination of strategies was implemented to the final model. Finally, the student compared how much energy could be saved by implementing various green strategies in monetary terms using the local costs of utilities. Figure 4 shows the process of analyzing the green building strategies by the student.

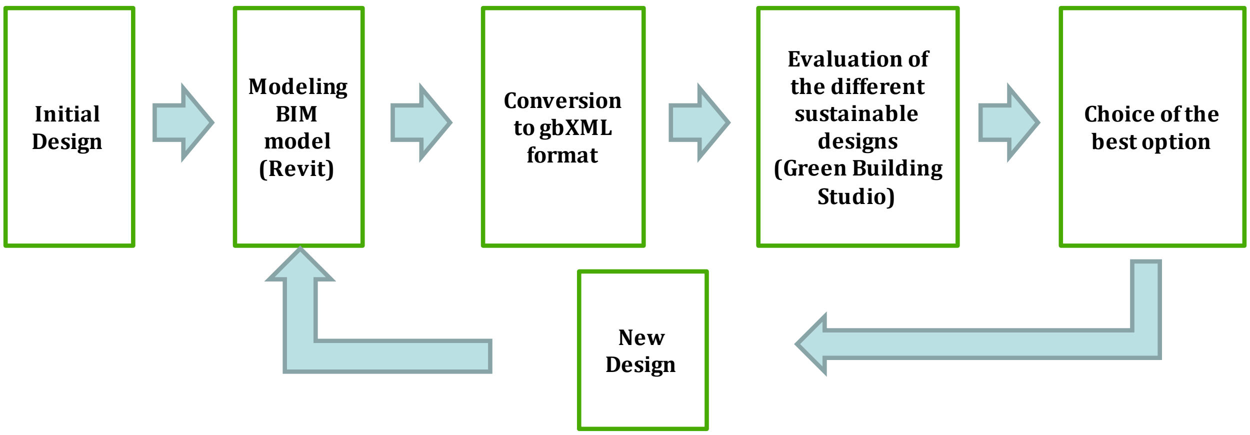


Figure 4. The Process of Green Building Strategies Analysis.

Sample of the Student Result

The student started by developing his own design project. The initial design was a three-story 23,041 square feet office building located in Macomb, IL. After developing the initial design, this BIM model was converted into gbXML format to evaluate energy cost using Green Building Studio. Table 1 and Figure 5 show the basic information of the initial design before applying green strategies. Default values were used for all thermal properties such as U-values of roofs, wall, and windows from Green Building Studio. After the first base run, it was found out that total annual energy cost was $30,822. Figure 6 shows the screenshot of energy consumption from Green Building Studio.

Table 1. Architectural Features of the Initial Design

Architectural features	Description
Orientation	South
Shading	No shading device
Roofs	R-15 over roof deck (U-value: 0.06)
Exterior walls	8 in concrete wall with brick veneer (U-value: 0.42)
Windows	Double clear (SHGC: 0.25, U-value: 4.99 W/m^2-K)
Toilets, Urinals	Standard flow (3.5 gallon/flush for toilet and 1.0 gallon/flush for urinal)
Cooling and heating systems	11 SEER and 78% AFUE
Rainwater harvesting	No
Daylighting and occupancy sensors	No
Electric and fuel cost	$0.09/kWh and $1.17/Therm

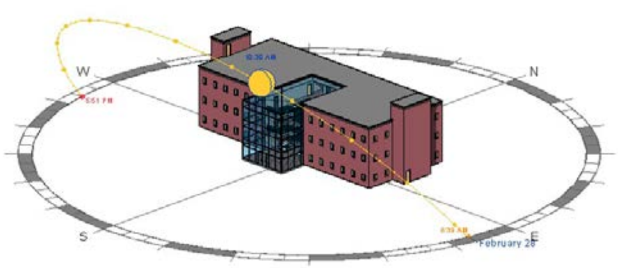
Figure 5. Initial Design of the Final Project.

Floor Area (ft²)	Total Annual Energy Cost	Annual Electric Cost	Annual Fuel Cost	Annual Peak Electric Demand (kW) ?	Annual Electric Use (kWh)	Annual Fuel Use (MBtu)	Energy Use Intensity (kBtu/ft² /year) ?
23,041	$30,822	$24,495	$6,327	128.9	288,178	540	66.1

Figure 6. Energy Consumption of the Base Case Building.

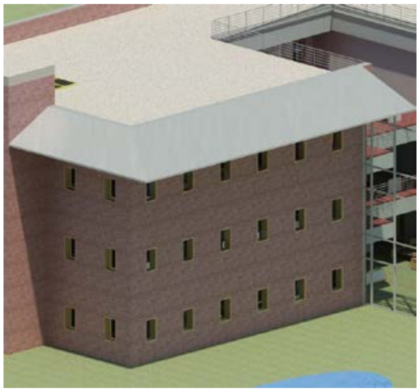
Building Orientation and Shading Devices

Building orientation can have a significant impact on heating and cooling, and lend itself to the effective use of shading features. The student used Green Building Studio to determine the optimum orientation for the initial design to minimize the total annual energy cost. He created several design alternatives to evaluate the impact of rotating the BIM model by 15-degree increments. It was found out that 15 degrees from south to east was the best orientation. Also by using Revit Architecture, the student could explore roof overhang and shading design options to optimize the use of sunlight throughout the year—allowing sunlight to warm the room during the winter, but blocking the sunlight during the warm summer months (Figure 7). According to the analysis (Figure 7), the whole building face had the shading during the summer and allowed sun during the winter. After applying the shading devise and the best orientation, the student could get the amount of energy used and compare it with the estimate from the initial design; this option showed $165 of annual savings.

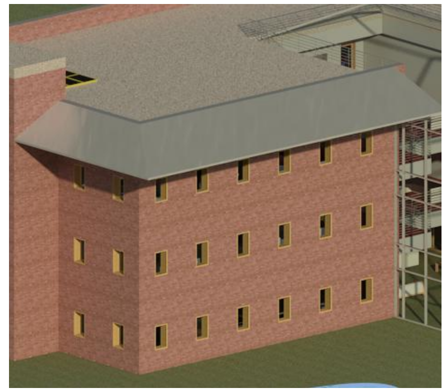


a. Use of sun path in Revit Architecture

b. Original design without a shading device



c. Shading design – Summer



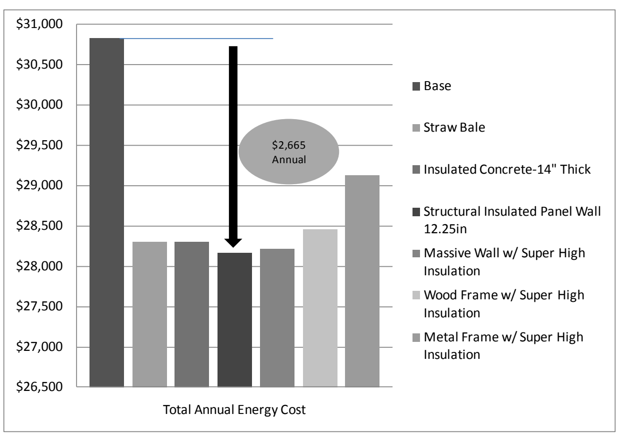
d. Shading design - Winter

Figure 7. Shading device design.

Thermal Properties of the Wall and Roof

Understanding the properties of materials is part of a green design process as it influences energy consumption of a building. Therefore, specifying building materials and their thermal properties in a BIM model is important in evaluating the energy use impact of building material alternatives.

The student chose different materials for the walls and roof and ran the analysis using Green Building Studio. After the simulation, results were compared and the most efficient wall and roof was selected. The student needed to reconfigure materials in BIM to reflect the changes. Figure 8 shows the results from each simulation. Changes is wall material saved $2,652 annually, and changes in roof material resulted in $291 of annual energy savings.



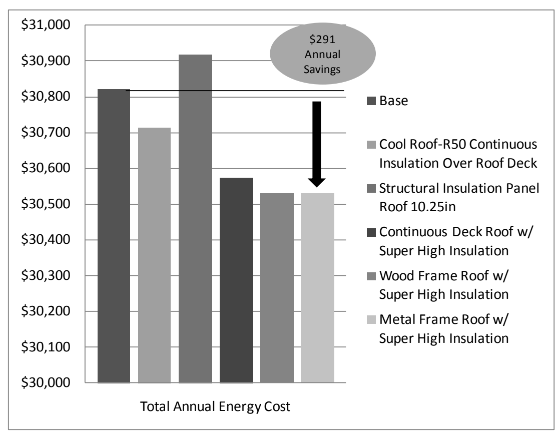


Figure 8. Energy consumption comparison: wall (left) and roof (right).

Water Analysis

Understanding the importance of considering water use and innovative water reuse features are part of the green design process. These green strategies can be considered by estimating the water demand created by typical plumbing fixtures and exploring the effect of using high-performance and low-flow fixtures.

Using Green Building Studio, the student estimated the savings of water use of toilets and urinals by changing flow rate from standard fixtures to low flow for toilets and waterless for urinals. Also, rainwater harvesting on roof area could be implemented to collect, store and use the rainwater that naturally falls on a building. After applying these green strategies, it was found that 552,749 gallons of water could be saved per year, which is equivalent to $1,688 of savings per year. After the analysis, the student adjusted the fixtures in the BIM model.

Lighting Analysis

Automated timers and sensors are used to reduce unnecessary power consumption by turning off lights when sufficient daylighting is available or when a room is not occupied. In Green Building Studio, the student can use the tools to estimate the total electrical demand created by the usage patterns and performance characteristics of the electrical lights, appliance, and equipment in the BIM model. Figure 9 shows the results of different simulations. It was found out that $1,049 could be saved annually by applying daylight sensors, dimming controls and occupancy sensors.

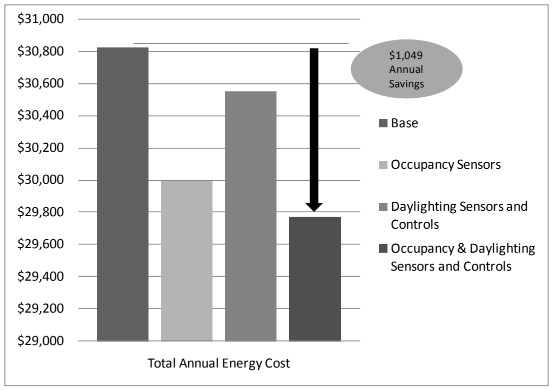


Figure 9. Energy consumption comparison: daylight control, occupancy sensor, daylight control and occupancy sensor.

Heating, Ventilation and Air Conditioning (HVAC) Analysis

The effects of changing the HVAC system must be considered carefully. After understanding variety of system efficiencies such as SEER, EER, AFUE, the student explored the effects of changing the characteristics of the HVAC system to assess the potential energy use impacts. Figure 10 shows the results from each simulation, and it was found that $3,775 can be saved annually by changing the system to 17 SEER and 0.85 AFUE.

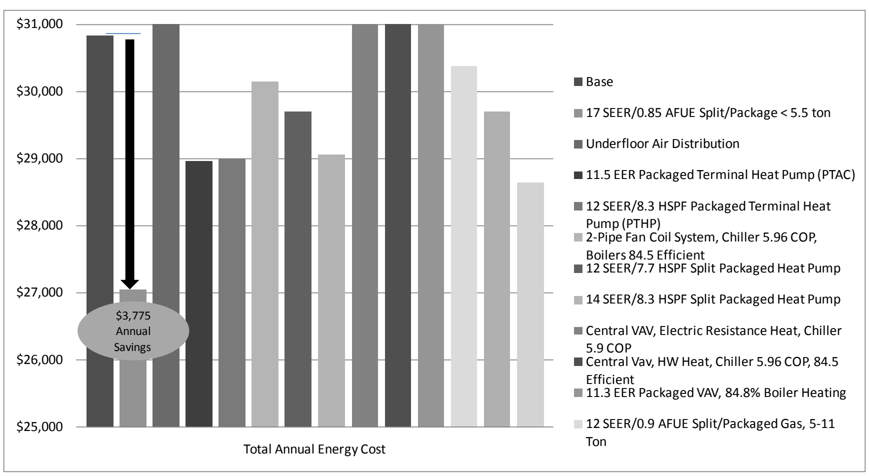


Figure 10. Energy consumption comparison: HVAC analysis.

Summary

After the initial design, student can implement green design measures by exploring passive design, building envelope, water use and collection, power use and daylighting using BIM tools to evaluate the effectiveness of alternatives estimated as monetary savings. For this case project, he could apply eight green design measures. Table 2 shows the summary of architectural features before and after applying the best alternative, and Figure 11 shows the accumulated savings by applying additional green design measure. This measure shows total annual energy cost of the case building reduced from $30,822 to $20,929, which is 32.1% of accumulated savings per year.

Table 2. Architectural Features of BIM Model Before and After Applying Green Design Measures.

Architectural features	Before	After
Orientation	South	15 degree from south to east
Shading	No	Yes
Roofs	R-15 over roof deck	Metal frame roof w/ super high insulation
Exterior walls	8in concrete wall with brick veneer	Structural Insulated Panel Wall 12.25 in
Toilets, Urinals	Standard flow (3.5 gallon/flush for toilet and 1.0 gallon/flush for urinal)	Low flow (1.6 gallon/flush) and waterless for urinal
Cooling and heating systems	11 SEER and 78% AFUE	17 SEER and 85% AFUE
Rainwater harvesting	No	Yes
Daylighting and occupancy sensors	No	Yes
Building design		

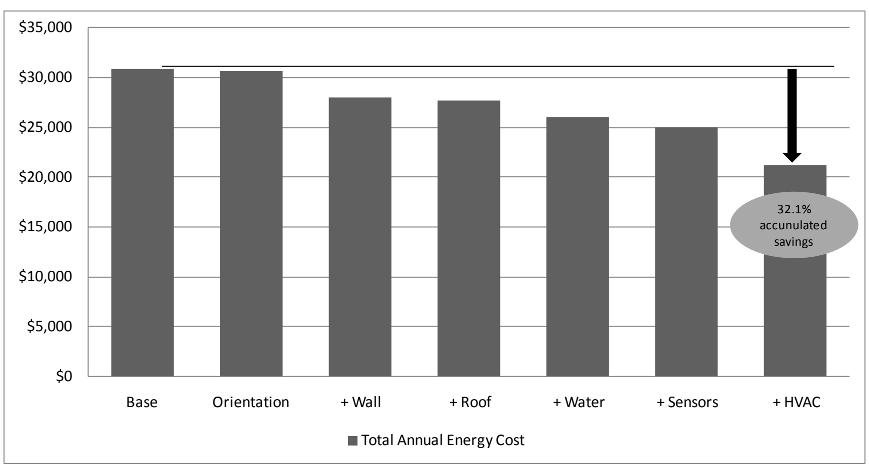


Figure 11. Total Annual Energy Cost after Applying Additional Green Design Measures.

Conclusions

The following were found from this case study. First, BIM tools were successfully used to evaluate green design measures as visualizing the economic impact. This study allowed the student to learn the uses and advantages of BIM and to integrate green design measures into the design of a building as he progressed through the semester. Second, one of the major challenges was the student's lack of prior knowledge in this new area. It took a while for the student to understand the green design measures, and to become familiar with the different functions of software tools before he could implement them to his initial design. Therefore, it might be helpful to embed incorporated sustainability topics into various courses. Third, although there are many materials and components that can be used in Revit Architecture, it was sometimes hard to incorporate green design measures such as applying solar panels into the BIM model. This option was not in the library, so the student had to create it as an in place mass which required extra time.

Lastly, student's response to this project was as follows:
"*The whole project was extremely beneficial for me because I was able to learn how much effort goes into designing a green building. There are so many consideration that you need to take and it just gave me a whole different perspective*."

Accomplishing BIM modeling with application of green design strategies within one semester was a challenging endeavor. However, the results were very positive. The student gained valuable knowledge on sustainable design, and the long-term environmental impacts of design decisions.

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Overlooked but Familiar Errors in Selecting, Using, and Maintaining Personal Protective Equipment for Vision and Hearing

Samuel E. Cotton, Ph.D. and James W. Jones, Ed.D. and Mike Mezo, M. Arch.
Ball State University
Muncie, Indiana

Many workers in a variety of occupational situations do not properly understand how to select, use, or maintain personal protective equipment (PPE) relative to tasks or situations at a worksite, especially relative to eye and hearing protection. Often proper PPE is not even available in some work environments because of this lack of understanding or appreciation of typical hazards. Improper selection of eye protective devices and lack of use of hearing devices when needed are both extremely common issues at the typical worksite in construction situations. Workers should be fully aware of potential situations at a worksite and how to determine what PPE is most appropriate in a wide variety of situations. Understanding the nature of typical hazards is an essential part of selecting and using proper PPE. The nature of many typical hazards and the design/purpose of eye and hearing protective equipment will be explored to better equip readers for selecting, using, and maintaining PPE. A number of common scenarios for misuse or lacking use of PPE will be explored to raise the awareness level of readers.

Key Words: Safety, personal protective equipment, PPE

Introduction

Often workers and supervisors in a variety of occupational situations do not properly understand how to select, use, or maintain personal protective equipment (PPE) relative to tasks or situations on the construction job site, especially relative to vision and hearing protection. The constantly changing work environment of a typical construction site can exacerbate this situation (Brady and OiSaeng, 2006). Sometimes proper PPE may not even be readily available in work environments because of this lack of knowledge, training, understanding or appreciation of workplace hazards. Improper selection or use of vision and hearing protective equipment, when needed, are both possible issues at a typical construction worksite.

Workers and supervisors should be fully aware of potential situations at a worksite and how to determine what PPE is most appropriate in a wide variety of situations. Understanding the nature of typical hazards is an essential part of selecting and using proper PPE. The nature of many typical hazards and the design/purpose of eye and hearing protective equipment will be explored to better equip readers for selecting, using, and maintaining PPE. A number of common scenarios for misuse or lacking use of PPE will be explored to raise awareness. It is the responsibility of employers to sufficiently train all employees regarding proper PPE use as noted in OSHA regulation: “The employer must train each affected employee in the manner required by the standard, and each failure to train an employee may be considered a separate violation.” (29 CFR 1910.9(b), 2008).

According to the Bureau of Labor Statistics (BLS), in 2008 eye injuries accounted for 37% of all head injuries and 61.8% of all face injuries involving days away from work, making this a significant concern for all employers. Reported serious hearing injuries are not as significant in reported data, accounting for only 1.4% of all head injuries in 2008 (Harris, 2011) This may be in large part hearing loss going undetected until significant. This situation normally develops slowly over a long period of time and would not appear in injury data. This health risk is still a strong reason for awareness and concern. Additionally, studies show that use of hearing protection in construction remains low and is difficult to change (Barrett and Calhoun 2007; OiSaeng, Ronis, Lusk, and Gwang-Soog, 2006; Kushnir et al. 2006.

Design Features and Functions

It is critical that employers are aware of regulations and guidelines regarding selection and use of personal protective equipment. OSHA states, "The employer is responsible for requiring the wearing of appropriate personal protective equipment in all operations where there is an exposure to hazardous conditions or where this part indicates the need for using such equipment to reduce the hazards to the employees." (29 CFR 1926.28(a)) This paper concentrates on eye and hearing protection. OSHA regulations regarding personal protection equipment for these applications are addressed in OSHA regulations 29 CFR 1926.101 (hearing) and 29 CFR 1926.102 (eye and face).

Eye protective devices can include a variety of features, such as: impact resistant lenses and frames, side shield protection, ventilating, indirect ventilating, no venting, shading for light protection, face protection, head and neck protection, and styling for appearance. Each feature has a different function and will be a factor in the selection process. Not all hazards require the same form of protection, so it is critical to understand the nature of hazards one is exposed to during the selection and maintenance process. Many workers perceive that eye protection designed to protect against flying particles is sufficient for all potential hazards in the workplace, which is a dangerous and incorrect assumption.

The three primary designs for hearing protection are inserts, canal caps, and earmuffs. Each of these is best suited to different conditions. Inserts are best suited to expended exposure to high noise levels. Canal caps are most often used by supervisors or others who are in and out of high noise areas, with only shorter exposure periods. Earmuffs, which cover the entire ear, are most often used in short term exposure situation and not in areas, often placing the protective device near equipment used sporadically.

Matching Design to Scenarios in the Workplace

Eye Protection

Common problems in a typical workplace regarding eye protection is that the primary personal protective equipment provided is standard safety glasses with side shields regardless of environmental conditions or task. There are many scenarios for which this type of eye protection is inappropriate and may even increase the risk involved. OSHA standard 29 CFR 1926.102 concentrates on light, spark, chemical splash, and flying particle hazards but does not directly address other common hazards, such as those involving fumes (fine volatized metal particles), vapors (chemicals in gaseous forms), or airborne fine powders or dusts (such as airborne cement, wood or other material dusts (from sanding or other abrasive actions). In most of these cases safety glasses are not adequate protection. These involve materials that remain airborne for long periods which can easily pass behind and around the lenses and side shields of safety glasses. In most of these cases indirectly vented or unvented goggles are the more appropriate choice. In the case of splashing liquids, a face shield and other body protective covers would be needed in addition to goggles.

A sometimes overlooked recommendation for chemical splash and fume hazards is in severe cases, face shields should be used over goggles that are indirectly vented (also known as hooded ventilation). In some of these cases, the face shield should be included in a hood to protect other upper body exposed skin, such as the neck. When vapors or airborne mists of hazardous chemicals are involved, full face and skin protection is required, including full hoods with face shields integrated into the hood, with goggles worn behind the face shield.

Shades are also critical when working near intense light, such as welding, hot metals, bright illumination, or strobe or flashing lights. Many select shades based on convenience or availability instead of the intensity of the light involved. It is important to measure the amount of light involved and select the grade of shading based upon that measure. Proper selection of grade of shade is crucial to the health and safety of those involved with welding or other intense light producing operations or tasks. One should refer to OSHA 1910.252(b)(2)(ii)(H) for a selection guide for shade numbers for a variety of typical scenarios related to welding operations. Those involved in welding operations should also wear additional eye protection beneath welding helmets for protection in times the helmet is raised, to protect against flying particles (Crittenden, 2009).

Hearing Protection

For those who move in and out of high noise areas, experiencing only short exposure to high decibel levels, canal caps are commonly the PPE of choice primarily because of convenience. These are not the most appropriate choice for longer term exposure. Inserts, whether form fitted or expandable, are normally the best choice for extended exposure. A critical factor for this form of hearing protection is proper insertion which takes practice and training to master. Earmuffs are easy to use, but often have issues with adequate seal or sporadic seal as a wearer moves about. If fitted properly, these can be nearly as effective as inserts, but this is often not the case. If earmuffs are selected, it is recommended that only custom fitted earmuffs be used.

Proper Use

Eye Protection

Refer to OSHA standard 29 CFR 1926.102 for information regarding the proper selection of eye protective devices in a number of situations. Additional information about situations not clearly discussed in this code is including above in the Matching Design to Scenarios in the Workplace section. One should refer to OSHA 1910.252(b)(2)(ii)(H) for a selection guide for shade numbers for a variety of typical scenarios related to welding operations. Those involved in welding operations should also wear additional eye protection beneath welding helmets for protection in times the helmet is raised, to protect against flying particles (Crittenden, 2009).

Hearing Protection

One must be familiar with OSHA Table D-2—Permissible Noise Exposures from OSHA standard 1926.52 when determining the need for hearing protection. This chart indicates at what decibel (dBA) level and exposure time hearing protection is required. For example, 8 hours of continuous exposure to 90 decibels or more would require hearing protection. For a decibel level of 95, one should not be exposed for more than 4 hours of hearing protection. At the level of 115, no more than 15 minutes of exposure is acceptable. Refer to the noted chart for a full range of permissible exposures allowed. Note that the practice of using cotton to insulate against high levels of noise is expressly prohibited in OSHA 29 CFR 1926.101(c) under any conditions.

A significant issue with hearing protective device selection and use is a lack of instruction or awareness of how to properly use and maintain the equipment. When using inserts or "plugs" some workers fail to attain adequate depth or seals because of plugs expanding too fast for the insertion speed or technique. If a significant amount of the insert surface is visible after insertion (i.e. half or more), then there is likely inadequate contact to effect a proper seal and reduction of noise. Many workers are not aware of the technique of raising the top of the ear while inserting plugs to straighten the ear canal to more effectively slide the compressed inserts into place.

Maintenance

Eye Protection

A common issue for workers in environments of high temperature or significant airborne hazards is fogging or clouding of eye protection equipment lenses. It is essential to keep soft clean clothes and appropriate cleaning agents very close to work places, otherwise workers will develop a habit of raising glasses or goggles to see better or will use dirty and abrasive clothes to clean lenses, often increasing the hazard. Eye protection with scratched or marred lenses should be discarded and replaced, not cleaned. Any eye protection with cracks or other flaws in lenses or frames should also be discarded. The cost of new eye protective devices is much lower than the potential cost of injuries resulting from improper procedures or selection. Frames should also be frequently cleaned with antiseptics to reduce the chance of contamination resulting from dusts, chemical, or biologic agents that can develop on the devices.

Hearing Protection

It is very important to frequently replace hearing protective devices, especially plugs or canal caps due to the difficulty to attain adequate cleaning and sanitizing after a number of uses. Earmuffs can be more effectively sanitized than plugs, but there is more potential for reduced effectiveness because of the wide variety of circumstances that can affect the seal.

Common Improper Practices and Solutions

Eye Protection

Often workers use safety glasses with side shields for hazards involving airborne materials that remain suspended for long periods. This is a very dangerous practice because there is very little protection offered under these conditions. Goggles are the only choice for fine suspended contaminants. Hooded or indirect vented occasionally will suffice, but often unvented are the best choice. Vented goggles may offer slightly more protection for airborne hazards than glasses, but these are still inadequate in these situations. When vapors or airborne mists of hazardous chemicals are involved, full face and skin protection is required, including full hoods with face shields integrated into the hood, with goggles worn behind the face shield.

When significant air movement is involved with glasses, low pressure can be created behind lenses not securely sealed to the face, which can actually cause fine airborne hazards to be pulled behind the safety devices. Safety glasses are typically best suited to only flying particles, which often is only one of many hazards to the eye in many scenarios. Often workers do not understand the nature of an airborne hazard, causing them to select safety glasses almost universally even when goggles are the better choice.

Shades are also critical when working near intense light, such as welding, hot metals, bright illumination, or strobe or flashing lights. Many select shades based on convenience or availability instead of the intensity of the light involved. It is important to measure the amount of light involved and select the grade of shading based upon that measure. As noted earlier, tour glasses become a common problem because of convenience. Shaded tour glasses are often very limited protection because they are designed to be used at significant ranges from intense light. In some scenarios, these glasses are easy to access and workers will use them out of convenience instead of taking the time to select or obtain the most appropriate protective devices.

Tour glasses should never be readily available in the immediate vicinity of areas of high risk for eye safety. Only proper devices should be near the work areas. Tour glasses should only be provided to guests who will have their proximity to hazards controlled while visiting.

Hearing Protection

Many workers elect to use inserts with line attached so the devices can be hung over the neck and shoulders so they can quickly be inserted or removed. This type of device, though convenient, tends to have a slightly less effective seal than other forms of insert. These also tend to cause workers to wait longer to insert the devices or to forget to reinsert them in some situations. Also, devices of this type tend to be used multiple times more often, increasing the risk of contamination.

Disposable inserts should be readily available for guests and others who will be exposed to noise hazards only for short periods. Proper hearing protection should be selected by workers based on expected exposure level rather than convenience and should be worn before exposure begins rather than in response to it.

Conclusion

Awareness and training regarding hazard properties and the selection of appropriate PPE is essential in any work environment. Employers are charged with insuring that employees are properly trained in these areas of health and safety. A well prepared workforce regarding use, proper maintenance, and selection of PPE has the potential to dramatically reduce medical costs and loss of work time for many, if not most, employers. One should become intimately aware of the recommendations and codes in the OSHA 29 CFR standards, both general industry (29 CFR, 1910) and construction industry (CFR 29 1926) since both have application in situations in general industry and construction.

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