A PC Based Virtual Reality Simulator for Forklift Safety Training

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Final Report

Submitted by:

Jim Mayrose, Ph.D. (ARO)

Tactus Technologies
2350 North Forest Road
Suite 16A
Getzville, NY 14068

mayrose@tactustech.com

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Table of Contents

Abstract

The occupational safety and health issue addressed in this research dealt with the reduction of forklift injuries and fatalities through improved safety and injury prevention training technology by building a widely deployable, low cost, Virtual Reality forklift safety trainer (and similar powered industrial devices in the future). The specific goal is to significantly reduce the mortality and injury rate caused by forklift accidents by building an intuitive, low cost training platform that gives forklift operators the opportunity to study operating safety standards, rehearse them, and then be tested and evaluated on their understanding of them without the inherent risks of training on a real forklift, and with the benefit of getting the constructive and active cognitive experience of operating a forklift, which cannot be attained using video tapes or other training materials currently on the market.

The importance of the forklift safety problem cannot be overstated. Forklifts are by far the most dangerous industrial vehicles in operation based on the number of fatalities and injuries that occur every year in the United States. Annually, there are nearly 100,000 reported injuries and over 200 fatalities directly attributable to forklift accidents[1]. There are roughly 1 million forklifts in service in the United States and more than 1.5 million operators (closer to 6 million if you include occasional operators). This means that there is a roughly 10% chance that a given forklift will be involved in an injury annually. The ubiquity of the forklift in modern commerce combined with the faulty assumption of intuitive operability result in this astonishing level of danger to an equally astonishing segment of the population. The cost of such accidents involves more than just fatalities. It is estimated that at least 20,000 work days are lost each year due to these injuries[1], representing not just a major cost to the economy, but more importantly, a major public and occupational health concern.

The approach taken to address this occupational safety training issue involved 4 key elements namely, physically accurate forklift model creation, workplace environment development, training curriculum, and industry vetting. Three environments and three different style forklifts with real physical attributes were developed to show the breadth of applications possible with this technology. Educationally effective course curriculum was developed based on OSHA mandated training specifications as well as the universally accepted cognitive constructivism approach to developing teaching tools. The prototype Virtual Forklift Trainer (VFT) was then vetted by end users, trainers, and industrial users for feedback.

The responses received during the vetting stage as to the functionality and usability of the Virtual Forklift Trainer were overwhelmingly positive and have provided the Tactus team with great insight as to future, Phase II enhancements. Some of the specific comments received are shown in the next section regarding significant findings.

The Virtual Forklift Trainer will be used in the workplace for training forklift operators on proper handling and safety procedures as set forth by the Occupational Safety and Health Administration (OSHA). Potential users will range from small companies with only a few forklift operators to the largest of companies that have high employee turnover and a need for continuous forklift safety training. Our VFL product is also intended to be used by professional safety training centers in combination with their classroom and hands-on training environment.

SECTION I

Significant/Key Findings

The specific aims of this Phase II work were to develop a prototype virtual reality simulator and then establish its feasibility in terms of its potential to reduce injury and mortality through superior training, technical issues, and commercial success. All of these were achieved and each is highlighted in its own section below:

1) Developed a Prototype

A low cost PC based virtual reality forklift simulator was developed, which allows a user to drive a simulated forklift through a variety of environments, giving him or her a hands-on, active learning experience in safe forklift operation. The simulation provides superior training versus textbooks and videos, because it allows actual hands-on constructivist learning to take place. Figure 1 shows the system. The left pane shows a user operating a virtual forklift, the right pane shows a sample forklift model (many were developed and each one has its own appearance and physical parameters to accurately portray the variety of behaviors of different models).

Figure 1 - The Virtual Reality Forklift Safety Trainer

2) Established Technical Feasibility

There were many difficult technical challenges to overcome in order to establish feasibility. They included the following:

- Ability to process commodity PC gaming hardware to simulate forklift controls
- Real time physics calculations to accurately portray forklift behavior
- Ability to compute collisions between forklifts and pedestrians, forklifts and shelving, etc.
- Ability to deliver content in a virtual environment
- Ability to record and playback training sessions for review
- Ability to quantify safety performance in virtual environment

All of these technical obstacles were overcome, and each is detailed in the scientific report.

3) Established Commercial Feasibility

Establishing commercial feasibility entailed conducting market research to determine whether there was support for the product as well as vetting the product with potential industry users. In addition to our market research and vetting the technology with industry, a formal market analysis was carried out in Phase I by the Foresight Science and Technology Company, a market survey firm that was retained by NIH. They concluded that our technology was "revolutionary due its innovative component" and that end users will find "this technology very attractive". This was based on market survey and direct conversations with potential end users, safety experts and trainers from some of the largest forklift end users in the world such as Wal-Mart and Costco. Based on this market analysis, Foresight concluded that, once completed, VFL has the potential of generating revenue of $8 Million/year within the next 5 years. The commercialization study concluded that VFL technology is a commercially viable and a timely safety product with tremendous demand.

4) Established Potential Industry Adoption with Vetting and Feedback

The most important highlight of the research carried out was the feedback that was solicited from potential end users. The users that evaluated the Virtual Forklift Trainer prototype were overwhelming impressed with its visual and physical realism as well as its potential to improve the current state-of-art in forklift safety training. The following table lists the feedback obtained from potential customers, partners, and end users.

Partner/Customer/End User	Feedback on Virtual Forklift (VFL)
NCCC – Western New York Safety Resource & Training Center	Richard Gorco, Director of Corporate & Business Development for NCCC says VFL will greatly enhance current classroom training techniques. It will also provide trainees with an opportunity to practice while they wait for their turn to train on the actual forklift in class.
Emedco Inc.	Our distribution partner Kelly Cunningham, Product Manager for Emedco says End-users will flock to a forklift specific training package.
JLG Industries	Mike Popovich, Director of Safety, expressed interest in this technology for JLG's military group because this group needs to have a simulator before selling to the military.
Costco	Dale Anderson, Director of Safety, is interested in a new method for training forklift operators.
Sunbelt Rentals	Jeff Stachowiak, a Forklift Safety Trainer, stated that virtual reality simulation for forklift training is a great idea and that there is definitely a need for it, due to injuries and fatalities incurred in operation of forklifts.
Washington State Dept. of Labor	Lou Flores, a Forklift Safety Expert and Operation Trainer, stated that he believes a simulator could be very useful. As a comparable, he noted that aircraft simulators are used extensively for training pilots, and he saw no reason why this approach could not be successful. The need for this technology is apparent from the fact that there have been several fatalities in Washington state this year involving forklifts.
Sherman Safety Management	Larry Sherman, Safety Consultant, believes this could be a good training tool for people who are new to forklift operation. He also noted that OSHA legally requires forklift operators to receive re-training if the worker is involved in an accident or has to operate a new type of forklift. This product would be useful as a supplement to onsite training, but will not replace it.
Wal-Mart	Wal-Mart's training programs for forklift operators lack an interactive component. Jon Blevins, Risk Control Director, expressed interest in this product for this reason.
Nissan Forklift	Wayne Wilde, Director of Training, Ralph Petrek, Vice President for Customer Satisfaction, and John Kazmol, Manager of Customer Service Sales all saw potential to present many different safety concepts in this environment that are otherwise difficult to convey. They also saw a great potential for more efficient training, as every trainee has instant access to a virtual forklift.
Mitsubishi Forklift	Arnold Witt, Director of Dealer Training, and Bob Mundson, manager for safety training saw an opportunity to have drivers

	experience safe forklift operation firsthand.
AHOLD International	"Software must be comprehensive to replace existing training materials and must be OSHA compliant."
Erie Insurance	Mike Bova, Risk Management Director, John Maccario, Quinton Boroi, Rex Bennet, all regional Risk Managers, saw tremendous value in training with a virtual forklift. Rex Bennett, who described how the stability triangle concept is currently taught with a paper pyramid, saw a great opportunity for showing the trainee visual feedback that wouldn't be possible in real life (a virtual stability triangle, for example).

Table 1 - End User Feedback [2]

Translation of Findings

The potential for virtual reality based safety training was clearly demonstrated by our own user observations, as well as industrial vetting. Every industrial contact who was shown the demo or who had a chance to try the trainer supported the idea as both highly effective as well as commercially feasible. Reviewers from industry included forklift operators, big box retail material handling managers, formal safety officers, small business, business insurance risk control officers, and many others.

When the Virtual Forklift Trainer is adopted into the workplace, some of the ways employers and forklift trainees will potentially benefit from the use of this technology include:

- Hands-on active training
- Experience common mistakes and pitfalls
- Learn the concept of stability triangle and apply this knowledge while operating
- Trainees can progress at their own pace
- Ability to tailor training on an individual basis
- Performance metrics computed in real-time
- Ability to train on a specific type of forklift
- Record/Playback of training session from first and third person perspective
- Determine individual and group performance statistics
- Ability to tailor remedial training sessions based on an individual's performance
- Indefinitely save training sessions for future trend analysis and comparison

Finally, this project has the potential to raise the bar on safety training by finally applying a state of the art technology to what many consider to be a mundane task. Mass safety training today employs the same technology as it has for the past 10 years - multimedia, videos, workbooks, and classroom instruction - all passive learning technologies where the trainee is disengaged. Providing an active, hands on, simulation to a mass market such as forklift operation has the potential to be a high profile, highly visible innovation in the safety market place, inspiring other safety training domains to adopt similar technologies, and demand modernized training technologies for improved safety and in turn a significant reduction of injuries.

Outcomes/Impact

An important outcome of this Phase II research was the overall acceptance of this training system and the technology as a whole by industry leaders such as Cummins Inc., Toyota, AHOLD International, Nisan and Mitsubishi Forklift as well as large industrial users and training centers like Wal-Mart and the Western New York Safety Resource and Training Center. These potential adopters realize that the Virtual Forklift Trainer combines the best of both training worlds: the opportunity to do hands-on training that provides continuous feedback and instruction as well as take advantage of, and extend, the record keeping and reporting systems available to PC-based training and believe that the Virtual Forklift Trainer will lead to a reduction in mortality and injury rates caused by forklift accidents. The following list regarding the impact Virtual Forklift Trainer will have on Industry, end users, and society as a whole was adopted from conversations with these potential adopters:

- reduction in accidents, injuries and death
- simultaneously provides specific, visible training results and records
- reduced insurance costs for industrial users and health healthcare costs related to injuries
- reduced training time for trainees
- reduced training time for trainers
- reduced loss of work time due to accidents and injuries
- reduced lawsuits and litigation expenses
- reduced fines and other OSHA sanctions
- reduced product/equipment/work environment damage and loss
- opportunities for training on multiple occasions at no additional outside cost
- lean and faster training

SECTION 2

Scientific Report

1) Background

The forklift is the most widely used industrial vehicle and is also by far, the most dangerous. In the United States, there are over 1 million forklifts in operation[3], and nearly 2 million operators[4] (nearly 6 million if you count part time and occasional operators[5]). Worldwide there are more than 20 million operators [4]. Each year, OSHA estimates that there are over 100,000 reported injuries and over 100 fatalities in the United States alone specifically involving forklifts[3]. The annual cost of property damage attributable to forklift accidents is 1 Billion,[6] and it is estimated that over 20,000 work days are lost each year from these accidents and injuries[3].

The danger of forklift operation has two primary causes. First, the sheer number of forklifts in operation in the United States alone tops 1.2 million [7]. This ubiquity reflects the utility of the forklift and its relatively low price. The second cause is that the forklift is an inherently difficult vehicle to operate, while appearing to be highly intuitive. A new forklift user believes he or she can operate a forklift much like he or she operates a car. Similarly, many operators believe that balancing loads and controlling the velocity, tilt, and other states of the forklift are intuitive. This false sense of security is a major contributor to forklift accidents and injuries. Exacerbating this problem is a relatively untrained pool of manpower from which retail giants and large companies hire coupled with a high turnover rate. It is reported that in some industries, such as retail shops, the annual turnover rate is as high as 500%[8].

As alarming as these numbers are, industrial trends indicate that the problem will only get worse. First, the number of forklifts being produced in the United States and worldwide is increasing (between 12 to 16 % in 2004[9]. The last year for which statistics are available, 2004, saw the most number of new forklifts put into production in history- 700,000[9]. Because of the rapid increase in the number of forklifts in use and high employee turnover in industry, forklift users are less willing to pay for extensive training for operators, and accordingly, forklift manufacturers are developing rapid training programs, which often consist of reading a safety manual and watching a video. Trainees are subsequently put on a forklift and are expected to be prepared to overcome many dangerous situations that occur in day-to-day operation (e.g. tipping over while going up or down a ramp with a load, improper placement of load, following traffic rules in a shop, including respecting other forklifts and pedestrian traffic, etc).

To address forklift safety, OSHA mandates that every forklift operator is trained prior to operating a forklift, but OSHA does not allow training on a forklift, which eliminates the opportunity for hands-on learning. Current training methodology is limited to videos and workbooks, thus, as already alluded to, operators are put into hazardous industrial environments with little or no hands on experience with safe forklift operation.

While the public is, in general, unaware of how serious a risk forklifts are for forklift operators and their co-workers in their daily working lives, large and small businesses that use forklifts, government agencies, insurance companies, and many others are intimately aware of the danger level. Further, the loss of life and limb, property damage, and increased insurance costs affect everyone, making forklift danger a serious public health and public policy issue.

Technical Problem

Virtual reality presents an excellent opportunity to deliver vastly superior training to forklift operators. Virtual reality has been extensively employed by the military and academia to provide highly effective state of the art training, and its sheer ubiquity in the military is testimony to how effective it is as a training tool. Intuitively, one would expect that practicing how to operate a machine as complicated as a jet on a simulation would result in superior learning versus reading a workbook on how to operate the same machine. The educational literature supports this assertion as well (see next section).

The problem with employing virtual reality as a training medium is it is prohibitively expensive for all but those with the deepest pockets, such as the United States military. Military grade flight simulators cost upwards of several million dollars, and other industrial virtual reality applications, such as school bus trainers, cost several hundred thousand dollars, including setup and installation.

The goal of this research then, was to establish the feasibility of a low cost, high fidelity (physically accurate) virtual reality forklift safety trainer that could be widely deployed.

2) Specific Aims

The specific aims for Phase II of this project were:

- Develop Prototype
- Establish Technical Feasibility
- Establish Commercial Feasibility
- Potential Industry Adoption with Vetting and Feedback
- Roll out of Product to Industry

In summary, the specific aims for Phase II included designing the virtual reality forklift simulator, building an overall architecture, and developing the curriculum. Extensive reviews were then conducted with many industrial end users and a solid plan for product rollout was developed.

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3) Results and Discussion

The goal of Phase II was to develop a low-cost turnkey virtual reality (VR) safety training system that is capable of providing high fidelity forklift simulation for improving safety. We have achieved this goal successfully – our training system provides realistic safety training environment in the context of OSHA compliant curriculum (OSHA forklift safety training specifications; OSHA 1910.178). As listed in the proposal, there were 9 major tasks in the development of our Virtual Forklift Training System (VFL), and the details of our achievements are described as following.

Task 1: Build core physics-based forklift simulation system

Forklift Building Procedure: A precise and realistic vehicle simulation is the core technology in our forklift training system. Our system builds physic objects dynamically. The dynamic object creating technology is important for a real-time VR system where objects are built only when needed by authored scenario so the computation and performance can be at the best state of performance as possible. Building a forklift truck, however, is a complicated procedure because it involves handling of many constraints for the moving parts. To summarize, there are few steps in building a drivable and collidable forklift (Figure 1).

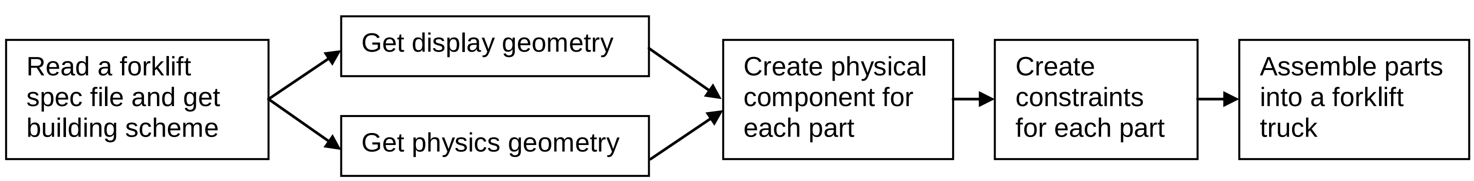
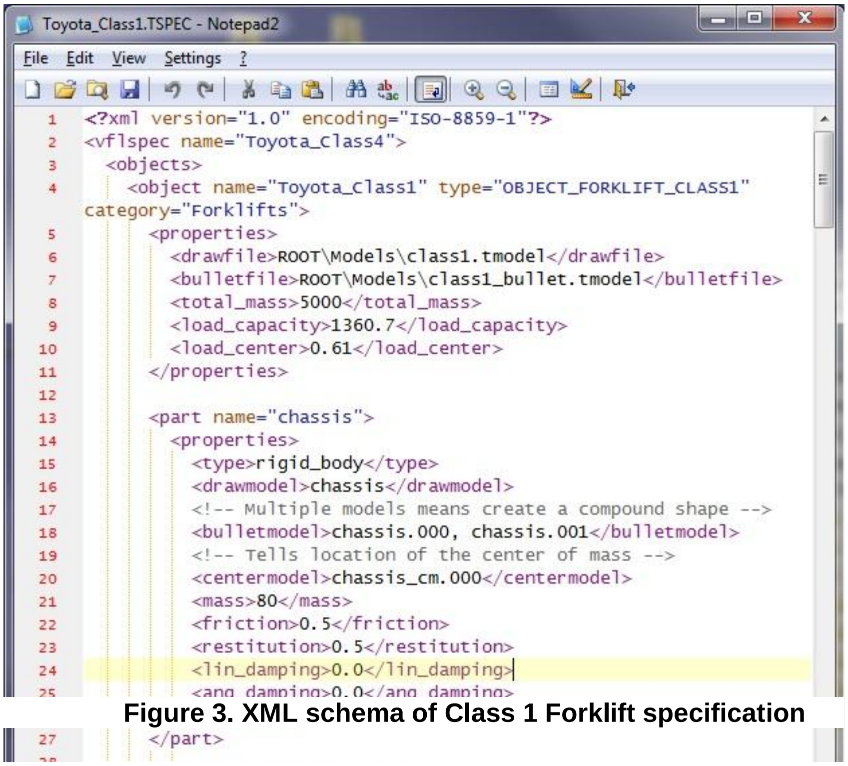


Figure 2. The procedure of forklift building




```xml
<?xml version="1.0" encoding="ISO-8859-1"?>
<vflspec name="Toyota_Class4">
  <objects>
    <object name="Toyota_Class1" type="OBJECT_FORKLIFT_CLASS1"
category="Forklifts">
      <properties>
        <drawfile>ROOT\Models\class1.tmodel</drawfile>
        <bulletfile>ROOT\Models\class1_bullet.tmodel</bulletfile>
        <total_mass>5000</total_mass>
        <load_capacity>1360.7</load_capacity>
        <load_center>0.61</load_center>
      </properties>

      <part name="chassis">
        <properties>
          <type>rigid_body</type>
          <drawmodel>chassis</drawmodel>
          <!-- Multiple models means create a compound shape -->
          <bulletmodel>chassis.000, chassis.001</bulletmodel>
          <!-- Tells location of the center of mass -->
          <centermodel>chassis_cm.000</centermodel>
          <mass>80</mass>
          <friction>0.5</friction>
          <restitution>0.5</restitution>
          <lin_damping>0.0</lin_damping>
          <ang_damping>0.0</ang_damping>
      </part>
```

Figure 3. XML schema of Class 1 Forklift specification

Forklift spec: In order to build a physical vehicle into the system, we first created a super-set forklift model that covers all parameters of a forklift class. A forklift spec file specifies all parameters that are necessary for building a forklift in the physics simulation. Such parameters include the major parts and physical properties. For example, geometries, mass, friction, restitution, damping coefficient, and assembly scheme with the constraints. An example of a forklift spec file is shown in Figure 3.

Forklift geometries: There are two types of geometries in the building process: display and physics geometry. The display geometry is a 3D polygon model for realistic rendering of the truck. On the other hand, the physics geometry is also a 3D polygon model but simplified shapes for collision detection and response. We have successfully incorporated these two geometries to achieve the realism both in graphics and physics.

Physics engine: We have developed our physics engine with the Bullet physics library. Bullet is an open-source library (www.bulletphysics.org) that gains its reputation from recent game applications, simulations, and animation movies. Adopting the library was an important decision of change we made after few iterations of development. Our original approach was to enumerate all the necessary states of the forklift parts and handle them by analytic equations. However, this case-by-case approach turned out to be too much burden for definition and handling of physics events. In other words, event enumeration and handling scheme became more complicated as the system needs more sophisticated cases. On the other hand, by using the dedicated physics engine, we had advantages not only in detecting complicated collision events, but also in presenting realistic collision responses.

Part Assembly: The last step is to assemble the physics parts into a structure. After all parts are created as collidable objects, they are assembled with constraints. For example, roll motion between the tires and the axle, prismatic motion between the backrest and the mast. Figure 4 shows a physics based forklift.

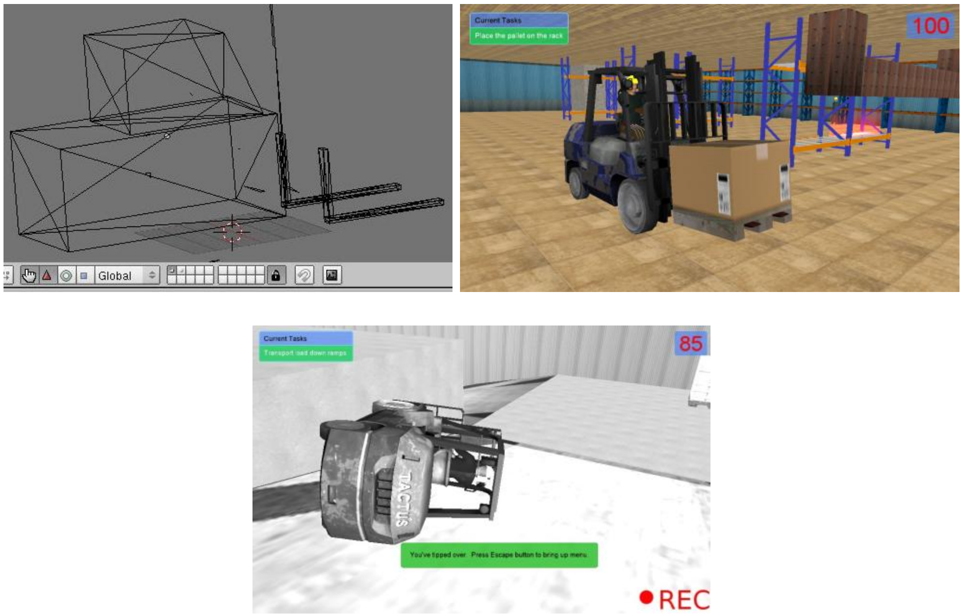


Figure 4. A dynamically built physics-based forklift: collision model of chassis (left), truck transporting a load (middle), and truck overturn on a ramp (right)

Task 2: Object/system design

Simulation engine: With advantages of our optimized real-time simulation technology and the dedicated physics library, we focused on developing a more sophisticated interface between the objects and the tasks (or missions). In other words, our system handles not only the physics events but also tasks that are assigned to the trainee. This design enables more engaging training environment, such as the live warning and the point-deduction system. Figure 5 shows a snippet of the system architecture that shows the interaction between objects and tasks.

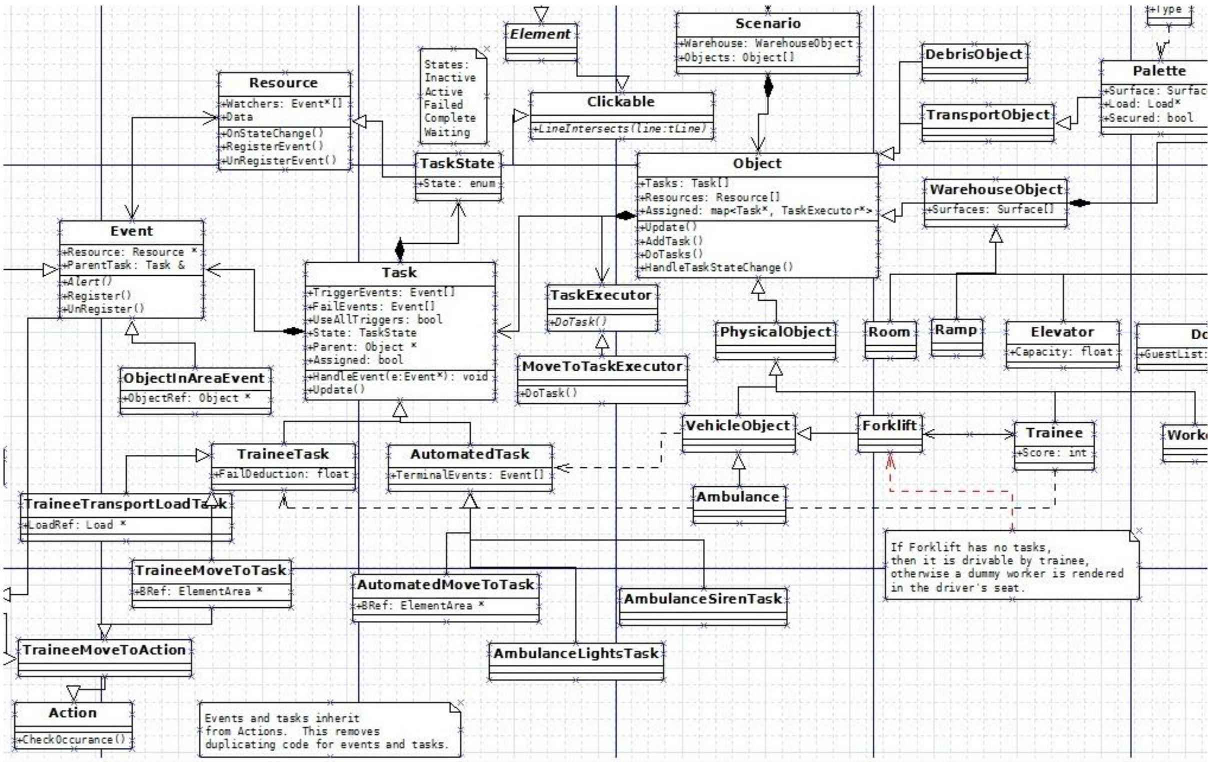


Figure 5. UML diagram of tasks and objects

Input and output: The simulator utilizes commercial off-the-shelf input hardware, including a steering wheel with pedals and joysticks. The input/output design allows generic hardware input processing as well. This enables creation of a new device interface that needs to be created in the future. For example, some truck manufacturers recently introduce the new steering system with the joystick(s), instead of the conventional steering wheel. Since the steering is generalized by a differential angle, not by any specific data from the wheel, we will only need to redefine the computation of the differential angle from the joystick(s).

Curriculum architecture: There are three levels in VFL content: curriculum, lesson, and scenario. A curriculum is consisted of multiple lessons,

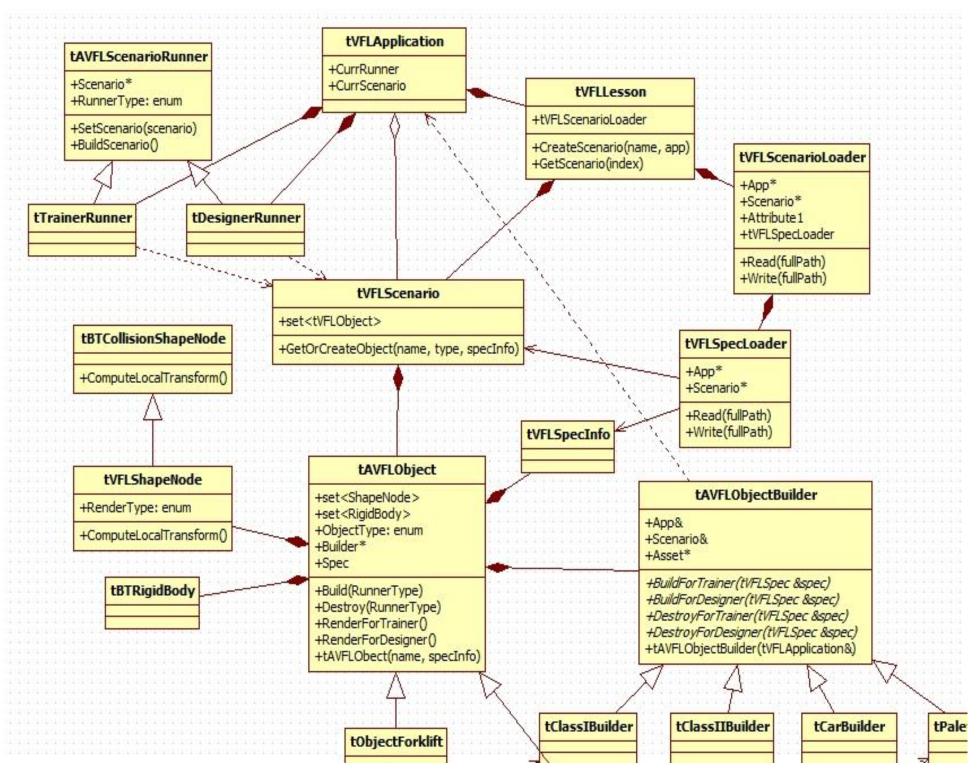


Figure 6. UML diagram of curriculum architecture

and each lesson contains multiple scenarios in it. They are all encoded in an XML files, and read dynamically when need to be created. Figure 6 shows the architecture of the curriculum. The content of a scenario is more discussed later in Task 3.

User interface: Our simulator provides both realistic driving environment and virtual assistive graphics. For example, VFL screen provides useful graphics such as truck dashboard, bird's-eye view, stability triangle, current tasks (missions), navigation guider, selecting cursor, and the training score. A trainee operates steering wheel, pedals, and joysticks. We created versatile display environments, such as single-monitor display, 3-monitor display, or 3-projector immersive display (Figure 7).

Figure 7. User interface of virtual forklift simulator: Truck dashboard (left), 3-monitor display (middle), and 3-projector immersive display

Media/content integration design: From the validation study, we have learned that text-based directions were very difficult for trainees to follow. This is because the trainees were demanded to elaborate in reading and memorizing all directions presented in the beginning. Trainees also appeared to be less engaged with the directions with the paragraphs of text. For better engaging effect, we have developed the Video Panel interface. It was especially useful for presenting introductions and reviews of each scenario in the curriculum.

Task 3: Complete XML encoding for curricula

A curriculum scenario allows the sequential presentation of a series of exercises. For this, the XML encoding (or scenario script) determines what environment should be given to the trainee and what/how assessment will be performed. Typical scenario includes description of the following: video content (introduction and reviews), warehouse model, forklift trucks (positions and properties), racks and pallets (positions and properties), pedestrians (number and position), automated vehicles (type and moving path), triggering areas (type, size, and location), tasks (missions), criteria for failure and success, violations (type and criteria), and deduction points (at each violation and failure). Figure 8 shows a encoding sample of the simulation scenario.

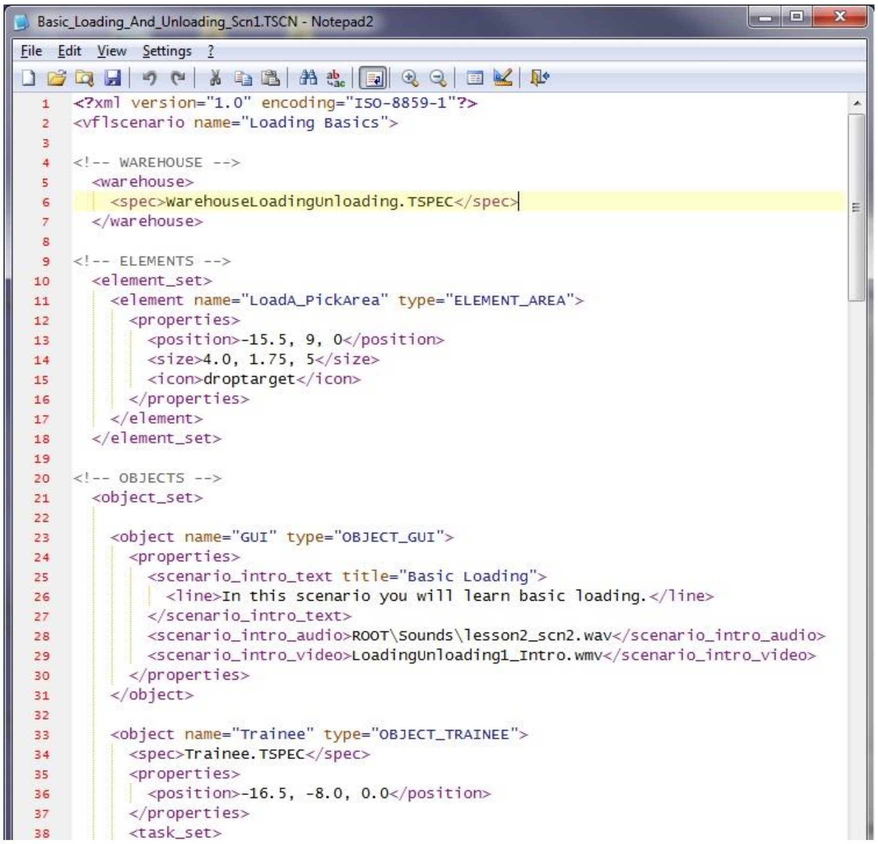


Figure 8. XML encoding of the simulation scenario

Task 4 Develop high performance simulation infrastructure

In Phase II, we have developed a more extensive and robust libraries. These libraries are an extended version of our own Tactus Libraries that include optimized algorithms that are designed to produce real-time results running on a standard PC hardware and do not require supercomputing machines.

Rendering library: We have developed an extensive library for OpenGL rendering. The 3D models shown in the VFL simulator are a large number of polygons with elaborate texture images on them. The rendering library implements optimized drawing algorithms for a complicated scene. Rather than rendering each model as individual polygons, models are reorganized as vertex arrays (or serialized vertex list) for efficient rendering. Vertex arrays result in dramatic improvement in graphics, as only one graphics command per model needs to be sent to the graphics processing unit (GPU). This optimization can boost rendering performance up to 10 times faster than polygon-by-polygon drawing.

High performance math library: A high performance math library was developed for computing most frequently used math operations in the geometry, physics, and rendering. It includes C++ classes of 2D/3D vectors, geometric primitives, data containers, and spatial hash (or special subdivision).

Collision detection: As mentioned in the previous section, we have adopted Bullet physics into our system. Though using an external library sounds convenient, actual implementation for adopting such library is not a trivial task. This was especially true when we wanted to use their classes selectively, not entirely. We have developed a collision manager that handles the compatibility issues between VFL classes and Bullet classes.

Event manager: One of the unique features of VFL is the event handling system. Unlike other vehicle simulators, VFL assigns missions to the trainee and watches what he or she does. The system has score management system. The trainee gets deduction points at the violations or infractions, and the assessment of the trainee's performance is based on the score at the termination of a scenario. In addition to the standard deduction points for common safety violations (for example, speeding, collisions, truck turnover, not stopping at signs, and missing inspection before boarding), a new definition of violation can be added by developer when needed, and deduction points are allocated in the scenario script by a content author.

Task 5: Build complete 3D library

We have built the complete 3D model library for the training simulator. The library includes warehouse/work areas, forklift models, pedestrians, and the cargo objects. As mentioned in the previous section, those models are used for building physics based objects. Examples of the 3D models are shown below (Figure 9, 10, 11).

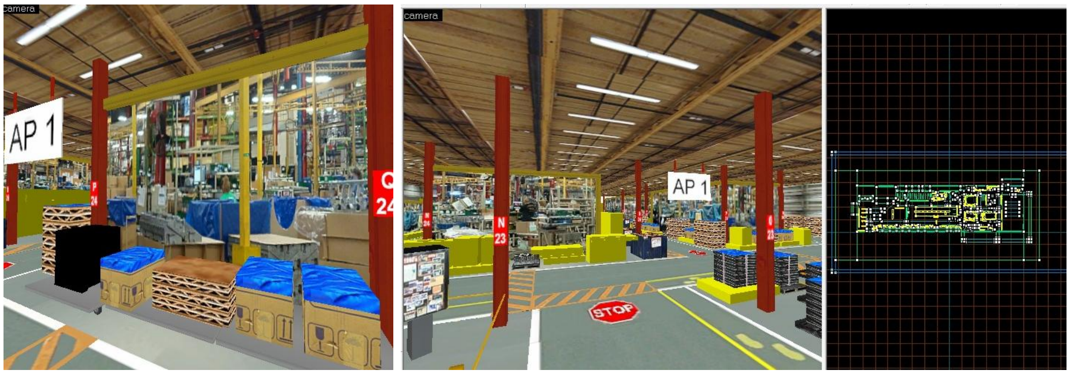


Figure 9. Warehouse/factory model (left) and its layout

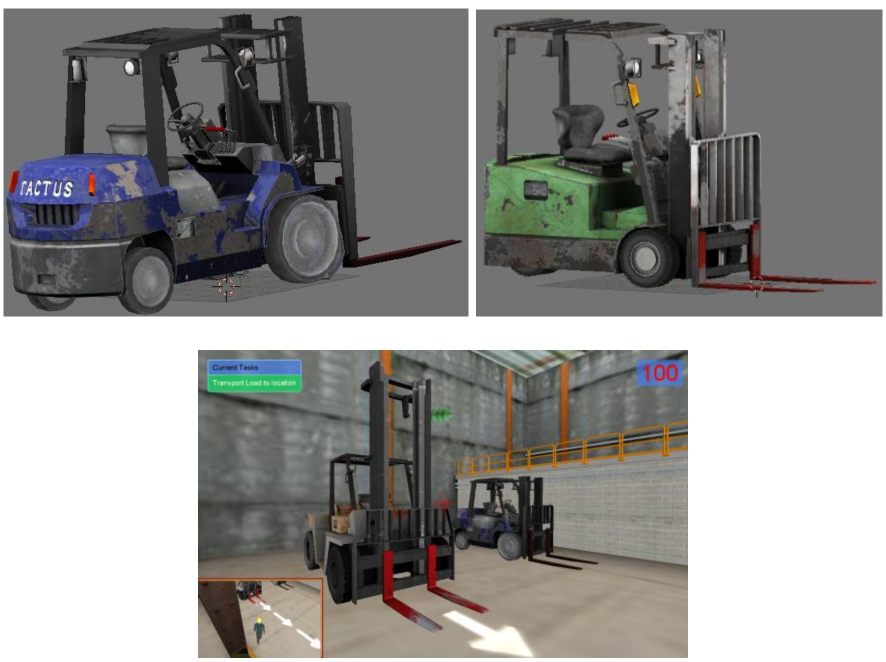


Figure 10. Forklift models: Class 1, Class 2 (middle), and Class 7

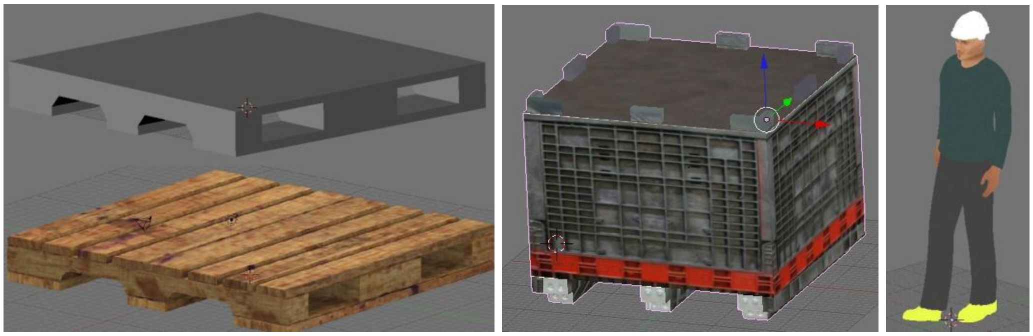


Figure 11. Pallets and pedestrian

Task 6: Complete database

Static Database: This type of data is for read-only use, where data are not modified during the simulation. Static data includes 3D models, curriculum scripts, forklift spec files, media (audio & video) data. This type of data is also stored in the computer's local directories; the system directly reads the data that are specified in the scenario script and the object script.

Dynamic Database for user management: The system stores the following in the database: trainee data (such as ID, password, and authority level) and results of training sessions (such as scores, time for completion, and violations). The data are stored and retrieved by the local server (Microsoft SQL Express Server). A Visual Basic program was developed for the interface between main simulation program (C++ & OpenGL) and the MS SQL database. The system also provides presentations of the outlook of statistics.

Task 7: Complete OSHA 1910.178 based curriculum

One of the important features of the simulator is the OSHA compliancy for training curriculums. First, we have prepared an exhaustive list of OSHA requirements. This list was separated into a number of short sentences (Figure 12). Each sentence was further broken down into minimal learning objectives called Atomic Learning Objectives (ALO). Then a content scenario was composed of multiple ALO's using an in-house content creation application. The curricula of virtual forklift safety trainer are shown in Table 2. We have also created customized curricula that were based on the customers' own warehouse configurations.

	Context	OSHA Category	OSHA Standard	OSHA Sub-Heading		OSHA Sta	HA Sub-Heading	Atomic Learning Objectives	Content
354	fuel	1910.178(p)	1910.178(p)(1)	Operation of the truck				learn how to charge battery	
355	fuel		Delete	Changing and charging storage batteries			1910.178(l)(3)(i)(K)	Battery charging installations shall be located in areas designated for that purpose.	
356	fuel	1910.178(g)	1910.178(g)(1)	Changing and charging storage batteries			1910.178(l)(3)(i)(K)	Facilities shall be provided for flushing and neutralizing spilled electrolyte, for fire protecti	
357	fuel	1910.178(g)	1910.178(g)(2)	Changing and charging storage batteries			1910.178(l)(3)(i)(K)	A conveyor, overhead hoist, or equivalent material handling equipment shall be provided f	
358	fuel	1910.178(g)	1910.178(g)(4)	Changing and charging storage batteries			1910.178(l)(3)(i)(K)	Reinstalled batteries shall be properly positioned and secured in the truck.	
359	fuel	1910.178(g)	1910.178(g)(5)	Changing and charging storage batteries			1910.178(l)(3)(i)(K)	A carboy tilter or siphon shall be provided for handling electrolyte.	
360	fuel	1910.178(g)	1910.178(g)(6)	Changing and charging storage batteries			1910.178(l)(3)(i)(K)	When charging batteries, acid shall be poured into water; water shall not be poured into a	
361	fuel	1910.178(g)	1910.178(g)(7)	Changing and charging storage batteries			1910.178(l)(3)(i)(K)	Trucks shall be properly positioned and brake applied before attempting to change or cha	
362	fuel	1910.178(g)	1910.178(g)(8)	Changing and charging storage batteries			1910.178(l)(3)(i)(K)	Care shall be taken to assure that vent caps are functioning. The battery (or compartmen	
363	fuel	1910.178(g)	1910.178(g)(9)	Changing and charging storage batteries			1910.178(l)(3)(i)(K)	Smoking shall be prohibited in the charging area.	
364	fuel	1910.178(g)	1910.178(g)(10)	Changing and charging storage batteries			1910.178(l)(3)(i)(K)	Precautions shall be taken to prevent open flames, sparks, or electric arcs in battery cha	
365	fuel	1910.178(g)	1910.178(g)(11)	Changing and charging storage batteries			1910.178(l)(3)(i)(K)	Tools and other metallic objects shall be kept away from the top of uncovered batteries.	
366	fuel	1910.178(g)	1910.178(g)(12)	Changing and charging storage batteries		1910.178	Safe operation	learn how to change battery	
367	fuel	1910.178(l)	1910.178(l)(6)	Operator training	Certification	78	Safe operation	learn how to change propane tank	
368	trailer	1910.178(l)	1910.178(l)(6)	Operator training	Certification			check that chocks of trailer are under trailer tires	
369		1910.178(j)	1910.178(j)	Dockboards (bridge plates)		19	Dockboards (brid	Portable and powered dockboards shall be strong enough to carry the load imposed on t	
370		1910.178(j)	1910.178(j)	Dockboards (bridge plates)		19	Dockboards (brid	Portable dockboards shall be secured in position, either by being anchored or equipped w	
371		1910.178(j)	1910.178(j)	Dockboards (bridge plates)		19	Dockboards (brid	Handholds, or other effective means, shall be provided on portable dockboards to permit	
372		1910.178(j)	1910.178(j)	Dockboards (bridge plates)		19	Dockboards (brid	Positive protection shall be provided to prevent railroad cars from being moved while dock	
373	trailer	1910.178(k)	1910.178(k)(1)	Trucks and railroad cars		1910.178	Safe operation	check dock loading mechanism	
374	trailer	1910.178(l)	1910.178(l)(6)	Operator training	Certification	78	Safe operation	check condition of trailer	floor capacity, spills, ordors
375	trailer	1910.178(l)	1910.178(l)(6)	Operator training	Certification	78	Safe operation	know precautions of using combustion powered fork truck in trailers	
376	trailer	1910.178(l)	1910.178(l)(6)	Operator training	Certification	78	Safe operation	***exercise loading trailer***	
377	trailer	1910.178(l)	1910.178(l)(6)	Operator training	Certification			learn how to install wheel chocks for trailer	
378	trailer	1910.178(k)	1910.178(k)(1)	Trucks and railroad cars				learn how to install jackstand	
379	trailer	1910.178(k)	1910.178(k)(3)	Trucks and railroad cars				check that the brakes of the trailer are locked	
380	trailer	1910.178(k)	1910.178(k)(1)	Trucks and railroad cars		1910.178	Safe operation	check the nose end supporters	
381	trailer	1910.178(l)	1910.178(l)(6)	Operator training	Certification	78	Safe operation	check tandem wheels	
382	trailer	1910.178(l)	1910.178(l)(6)	Operator training	Certification	78	Safe operation	check the dockboard	
383	trailer	1910.178(l)	1910.178(l)(6)	Operator training	Certification	78	Safe operation	check whether truck's mast is right type for use in traile	mast height and extension behav
384	trailer	1910.178(l)	1910.178(l)(6)	Operator training	Certification	78	Safe operation	stay away from edges of the dock	
385	trailer	1910.178(l)	1910.178(l)(6)	Operator training	Certification			Fixed jacks may be necessary to support a semitrailer and prevent upending during the l	
386	trailer/railroad	1910.178(k)	1910.178(k)(3)	Trucks and railroad cars				Powered industrial trucks shall not be operated inside highway vehicles or railcars having	
387	trailer/railroad	1917.43(b)	1917.43(b)(4)	General				Brakes shall be set and wheel blocks shall be in place to prevent movement of trucks, tra	
388	trailer/railroad	1910.178(m)	1910.178(m)(7)	Traveling				Dockboard (trailer) or bridgeplates (railcar) shall be properly secured before they are drive	
389	trailer/railroad	1910.178(n)	1910.178(n)(11)	Traveling				Dockboard (trailer) or bridgeplates (railcar) shall be driven over carefully and slowly and th	
390	trailer/railroad	1910.178(n)	1910.178(n)(11)	Traveling				The flooring of trucks, trailers, and railroad cars shall be checked for breaks and weakne	

Figure 12. An exhaustive list of OSHA document

Curricula	Lessons	Scenarios
Tutorial	How To Use VFL Trainer	Tutorial User Interface
		Tutorial Exercise 1
		Tutorial Exercise 2
		Tutorial Exercise 3
Basic Course	Forklift Do's and Do-Not's	Exercise 1
		Exercise 2
	Forklift Driving Safety	Exercise 1
		Exercise 2
	Basic Loading and Unloading	Exercise 1
		Exercise 2
		Exercise 3
Advanced Course	Load Placement on Racks	Exercise 1
	Driving on a Ramp	Exercise 1
	Tires and Grades	Exercise 1
Customized Course	(Customer's Request)	--

Table 2. Content of virtual forklift simulator curriculum

Task 8: Vet development with industry – beta testing

A prototype of the VFL system was presented to Cummins Inc. (Jamestown, NY) and Toyota (Buffalo, NY) and data on its usability and functionality were collected. Changes to the VFL system were made based on this feedback and then evaluated again. Cummins, Inc. was impressed with the system enough to place an order for the customization of a portion of their Jamestown plant. The finished customized system will be delivered in December 2011. Toyota is interested in a system as well for their training facility and negotiations are ongoing.

Tactus has entered into a sales/marketing agreement with the University at Buffalo's Center for Industrial Effectiveness (TCIE) where TCIE will present the VFL system to potential clients in order to develop additional contract work and add to the user base.

In addition to the periodic vetting of the forklift simulation, after the first complete system is in place later this year, it will be formally vetted to our industrial partners and tested for completeness, perceived value, usability, and potential effectiveness. Candidates at each organization will be asked to complete the entire training curriculum, and efficacy and general feedback will be collected.

Innovation, Potential Difficulties and Alternative Approaches

The results of Phase I were vetted with industry, and this proved to be invaluable in shaping the scope and direction of the proposed Phase II. Similarly, this tasks aims to follow this philosophy so that the final product delivered is truly market-driven. While not innovative, strictly speaking, in the virtual reality and simulation market, it is a novel concept to plan and develop a mass market product by vetting development with potential end users. As mentioned previously, the VFL will be the first commodity based mass marketed virtual reality/simulation market for training, and this will only be achieved with in depth industry vetting.

Task 9: Pilot Validation Study

Nearing the end of completion of Phase II, having received feedback from our industry partners, the next step in our preliminary evaluation of our product's effectiveness was an empirical pilot study to assess the developed software's effectiveness by assessing what trainees learn from the software. To complete this study, we partnered with D'Youville College where students were recruited to participate in the study.

There were two groups of trainees established to compare traditional training to VR training. Both treatments were matched in terms of content and duration so treatment variation was limited by treatment type (traditional vs. VR). It should be noted that the goal of safety training, whether traditional or VR, is to make the trainee aware of safe operating concerns and practices rather than develop forklift operating skills. Therefore, while the two are not mutually exclusive, the focus of the assessment was safety training.

It should be noted that a full validation study is planned for Phase III and data collected during this pilot study will assist us in designing that study.

Because it is likely that participants in the validation study varied in terms of work experience, there is a possibility that some trainees were more familiar with forklift/workplace safety issues than others. To control for this, trainees were pre-tested for knowledge of these topics. Trainees whose scores were above a minimum cutoff score (e.g., 40 percent) were eliminated from the study. The remaining pool of trainees was assigned to a treatment using stratified random sampling based on pretest score and gender. The participants were only tested by a written test and not on a real forklift. For this pilot study, we enrolled 13 participants in each treatment. For the actual validation study, we will conduct a *power analysis* using data from research comparing traditional instruction to VR. The research chosen for the power analysis was the most currently available during the time period immediately preceding the study.

Treatment 1: trainees received instruction in the form of a power point presentation, a workbook and video. The total duration of the training was 2 hours.

Treatment 2: trainees received instruction using the VR simulator along with some content in the form of animation within the simulator. Because the VR simulator is meant to be comprehensive in nature, no additional instruction was provided (e.g., power point or video). The total duration of the training was two hours.

To access the efficacy of the training program, both groups were tested with the same 30 minute written quiz. The quiz was taken off line so that those receiving the simulation, and thus had become familiar with computer presentations during training, have no advantage. The quiz was conducted by the trainer because, at times, segments of video (not seen during either treatment) were shown as part of the question.

The results of the assessment are shown in Table 3.

Study Preference Item	**VR Group Frequency**			**Power Point Frequency**	
	VR	**PP**		**VR**	**PP**
Which lesson format did you like better?	11	2		10	3
Which lesson format was better for learning?	11	2		10	3
Which lesson format was easier to understand?	9	4		8	5
Which lesson format was more fun?	13	0		12	1
Which lesson format would you like to have more of?	12	1		10	3
Which lesson format would you like to use with your students?	10	1		10	2
Which lesson format was better for learning about forklift safety?	5	8		5	7
Total	**71**	**18**		**65**	**24**
Average	**10.1**	**2.6**		**9.3**	**3.4**

Table 3 – Results of the pilot validation study

The data presented in Table 3 clearly shows a preference by students to be trained through the VFL system. They appear to enjoy this method more than a powerpoint presentation and were more engaged and attentive in the learning process. Future research will assess knowledge retention and any measurable benefits the system may have on reducing injury and improving safety.

4) Conclusions

All of the aims and specific goals were achieved in Phase II of this project. A readily deployable, low cost high fidelity virtual reality based forklift safety simulator was shown to be feasible and there was unanimous industry support for the potential product.

The major weakness with current forklift training programs is the passive nature of these training environments. Currently available training methods and devices are limited to multimedia CDs, printed text and/or videos and are relatively costly in terms of materials provided. Current training products cannot provide tailored instruction to the individual. The VFL training environment is a revolutionary product that allows for learning and objective assessment on an individual basis. Trainees can progress through the training modules at their own pace and practice until they are personally comfortable with their training before moving on to the next module. With the VFL training system, trainees are able to practice with the same forklift they will use in the real work environment. With the management tools incorporated into the VFL software, supervisors have the ability to record and playback an operator's training experience, which allows for individualized objective assessment. Based on this assessment, a supervisor has the ability to tailor a remedial instruction program if needed. VFL has revolutionized forklift safety training, and has raised the bar in safety training in general when expanded to other vehicles and procedures, by introducing a product that is interactive, dynamic and comprehensive.

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