Final Report

"m-Health for Just-In-Time Occupational Safety Training"

NIOSH SBIR Phase I 1R430HO10146-01

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Author:

Cesar Bandera, Ph.D. (Principal Investigator)
cesar.bandera@cellpodium.com
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Cell Podium LLC, 211 Warren Street, Suite 207, Newark, NJ 07103
www.CellPodium.com | info@CellPodium.com | (973)718-2450

Table of Contents

List of Figures

Abstract

The objective of SBIR Phase I project 1R430HO10146-01 is to evaluate the technical feasibility of innovative cell phone multimedia broadcasts as a mechanism to disseminate timely occupational safety refresher training. This training is intended to promote construction site safety culture with brief videos (under one minute in duration) sent periodically to the cell phones of construction site workers. This project defines technical feasibility as access to construction workers, and reusability of existing occupational safety training material. The first criterion requires that this approach bridge the digital divide, i.e., video broadcasts can be received by all workers. The second improves cost-effectiveness.

The innovation differs from online videos in four ways that can further improve construction site safety culture. First, the project pushes videos onto cell phones at any instant determined by the safety officer, similar to how a text message is pushed onto a cell phone. The pushed video is stored in the messaging inbox of the worker's cell phone, where it can be viewed, forwarded, and/or deletes. The worker need not know a URL, operate a web browser, or install an app.

Second, the videos are compatible with all cell phones and carriers, not just smartphones. Over half the construction workers in New Jersey have cell phones that cannot access the web; even if they have access to the internet at home, web videos do not reach these workers in a timely manner. Third, pushed videos can be tailored to each recipient, whereas an online video is the same to everyone who views it. Fourth, the innovation solves interoperability obstacles between carriers that have impeded device-agnostic mobile video broadcasts.

To determine technical feasibility, Cell Podium collaborated with the Hunter Roberts Construction Group, which strives to eliminate unsafe conditions at construction sites that precede incidents through a personalized approach that emphasizes concern for workers' health and welfare. A mobile multimedia campaign on thirteen topics was deployed at the Warren Street Village project in Newark, NJ, selected for its overlap with the project performance period, large size (three acres, $80M, 214,000 square feet of office, classroom, laboratory, dormitory, gymnasium, and retail space), and worker diversity.

Twenty-seven construction workers participated in the campaign. Each participant was able to enroll, select broadcast times, and view each of 13 safety videos selected by Hunter Roberts (derived from a training DVD and transmitted bi-weekly), all using her/his cell phone without having to install any app or change any phone settings. Feedback from construction workers and from Hunter Roberts site management was positive, included suggestions for additional content, and there were no complaints of the campaign being intrusive or broadcasts not being received.

The project successfully verified the technology's feasibility, and its adoption by construction workers and management. It also revealed that construction workers were comfortable with using their cell phones to contribute to the campaign and the site's safety culture; they were not just passive observers of the pushed videos, but instead added their constructive safety comments. Cell Podium and Hunter Roberts plan to exploit in Phase II this bi-directional flow of safety advice to further improve workplace conditions and collect real-time metrics of safety culture.

1 Summary of Findings and Impact

1.1 Key Findings

1.1.1 Device and Carrier Agnostic Over-the Air Broadcasting Protocol

The project selected the Multimedia Messaging System (MMS) as the mechanism with which to broadcast the safety videos to cell phones. Ratified by international standards bodies in 2002, MMS capability has been standard is in every cell phone over the last decade. However, carriers and handset manufacturers have strayed from the ratified protocol such that a video sent from a cell phone will likely not play on a cell phone of a different model or carrier. A key finding is the set of MMS parameters that ensure compatibility will all cell phones, including old legacy phones and new smartphones on all carriers. These parameters dictate how to encode and broadcast the video.

1.1.2 Majority of Cell Phones in Construction Sites Lack Internet Access

Much effort in this project was devoted to supporting cell phones that lack internet access. A key finding, based on an analysis of technology adoption studies and census data, is that over half of construction site workers in New Jersey (and a greater proportion elsewhere) do not have cell phones with internet access. This finding was used to justify technical requirements including the selection of MMS as the broadcasting protocol and the maximum duration of each video (~60 seconds).

1.1.3 Content Reuse

The safety videos broadcast by this project were derived from an existing training DVD. A key finding was that off-the-shelf tools were able to convert DVD and other media sources into short videos that comply with the above-mentioned MMS parameters to ensure compatibility with cell phones. This key finding demonstrates that construction companies can deploy their existing training media via cell phones. This new communications modality does not require new content to be re-authored, thus maintaining operational costs low.

1.1.4 MMS Adoption

Few people in the US have used MMS (it is more widely used in Europe and Eastern Asia), and there was concern that even if the broadcasts worked correctly technologically, people would not welcome them or reply to requests for comments. A key finding was that in the pilot campaign deployed at a major construction site, the videos were greeted with explicit favorable feedback. Over two dozen comments were sent by construction workers from their cell phones, demonstrating that they are comfortable using the phones both for watching the videos and for providing feedback.

1.2 Translation of Findings

The key findings of the project demonstrate a powerful tool for safety officers with which to promote safety culture in a construction site. The tool broadcasts safety videos to all workers' cell phones (not just certain smartphones with specific apps) in a way that engages the workers. These broadcasts complement toolbox talks in that they convey graphics and videos without requiring playback equipment (other than cell phones), and the safety officer can transmit at any time to all workers or a specific subset (e.g., just-in-time procedure on an uncovered hazard). Like toolbox talks, the broadcasts are interactive and can reuse existing material. The tool was evaluated in a large construction site where technical feasibility was proven and construction workers provided constructive and positive feedback on the instructional value and ergonomics of the broadcasts.

Feedback indicates this tool can further improve the safety culture at the work site and at company/contractor administrative offices when used as a data collection tool through which workers

alert the safety officer of unsafe conditions. Current procedures for such reporting are cumbersome, involve paper forms, and take the worker away from the job. In contrast, workers can report unsafe condition easily with a cell phone, including taking a photo or video of the hazard, without incurring any down time. The agnostic nature of the tool means the reporting mechanism will work with all cell phones. Future work will focus on using the tool to generate a hazard dashboard with just-in-time safety culture analytics, with the aim of reducing workplace accidents by identifying and correcting the unsafe conditions that cause them.

1.3 Outcomes and Impact

Being a Small Business Innovation Research Phase I project, the objective of this effort was to prototype and evaluate the feasibility of a technological innovation in the field of occupational safety with commercial potential. The brief performance period of an SBIR Phase I permitted the development of the prototype and its deployment in an operational setting to verify feasibility and collect feedback from workers and management. Measuring the technology's impact on site safety requires a longer period of time and control sites that do not use the technology; such an effort will be proposed as a Phase II effort.

1.3.1 End Outcomes

The safety video broadcasts to cell phones initiated discussions of safety protocols among construction site workers. Such discussions increase safety awareness and are a key part of safety culture. The fact that these broadcasts and subsequent discussions were conducted on cell phones demonstrated the adoption of this technology and the importance of accommodating all cell phone models and carriers.

1.3.2 Intermediate Outcomes

Upon seeing the above end outcomes, Hunter Roberts brought Cell Podium to the Safety Week event for discussions on integrating the technology developed in Phase I with the Construction Industry Safety Initiative and the Incident and Injury Free programs. These participating construction companies are now considering the use of cell phones in their safety programs.

1.3.3 Potential Outcomes

Multimedia communications among cell phones, both top-down from management and bottom-up from workers, have a strong potential of reducing unsafe conditions and practices at work sites, which are precursors to occupational morbidity and mortality. Quantifying this reduction will require a longer-term case-control study in Phase II.

2 Introduction

2.1 Cell Phones as a Bridge across the Digital Divide

In 2012, 59% of adults in the US searched the Web for health information (Fox and Duggan 2013). Of these, 80% started with conventional web browsers, and more than half shared their results within their social ecosystem. This online behavior reflects the reliance of public health agencies on the web to deliver outreach material, which is typically in the form of multimedia (i.e., text with graphics, images, audio, and/or video). The National Institute of Occupational Safety and Health (NIOSH) supports such resources in its libraries of online content (Figure 1) and through the National Occupational Research Agenda (NORA) Construction Sector Strategic Goal 11: Strengthening and extending the reach of quality training and education in the construction industry (NIOSH 2013). However, underserved populations lack the access to the Internet and the online information enjoyed by more affluent demographics, adding to their vulnerability and health disparities (a.k.a. "digital divide) (Fox 2011).

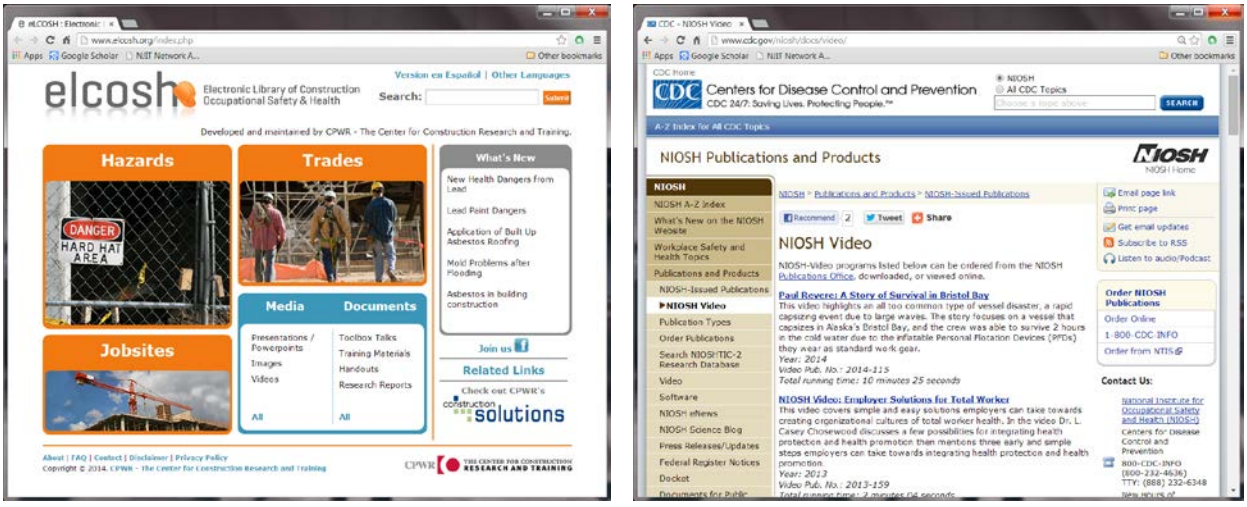


Figure 1. NIOSH web sites with construction safety educational multimedia.

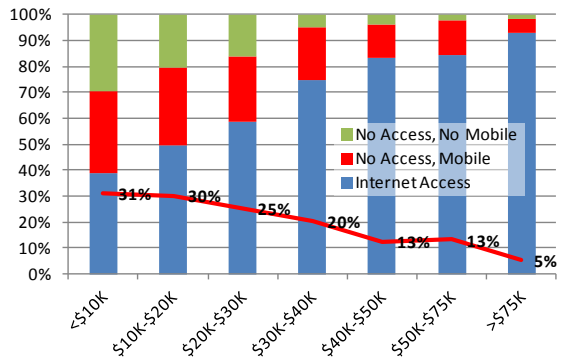


Figure 2. Internet access and cell phone ownership vs. income (*n*=2421)

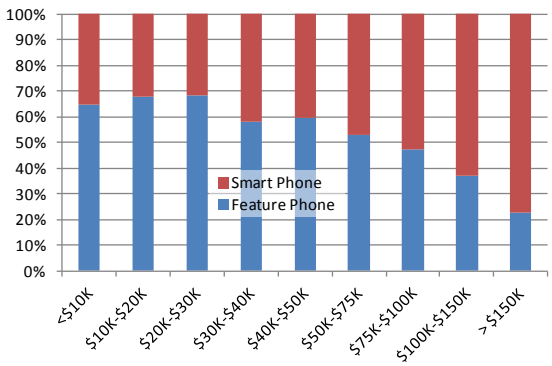


Figure 3. Type of phone vs. income (*n*=1415)

Analysis of the 2012 Pew Health Tracking survey dataset (Pew 2012) reveals that (1) fewer than half the households with income under $20,000/year have access to the internet (blue in Figure 2), and (2) the

majority of adults without access to the internet own traditional cell phones (red in Figure 2), i.e., feature phones and not the more expensive smartphone models (Figure 3). This analysis confirms that cell phone adoption exceeds Internet adoption particularly among vulnerable populations, and quantifies the significance of delivering public health multimedia to the feature phones of this demographic without access to the Internet. *For almost one third of households making under $20,000/year, or one quarter of households making under $40,000/year, this may be the only option to deliver public health multimedia*.

2.2 Health Outreach via Mobile Messaging

The popularity of mobile text messaging (i.e., Short Message Service, or SMS) has prompted its use in public health outreach. DHHS Secretary Kathleen Sebelius recently stated "We've found there are certain people who will not pick up a newspaper. They won't turn on the radio. They may not read the flyer that their doctor gives them. But they will check their text messages" (Sebelius 2011). 7.8 trillion SMS text messages were sent in 2011 generating $128 billion in revenue (Favell 2012), or roughly 1.6 cents per text message, with a profit margin of over 70% (Ahonen 2010).

Mobile health (m-Health) campaigns use text messaging to deliver health preparedness information across the digital divide to vulnerable populations because it is supported by all cell phones including the simpler models (i.e., "feature phones" or "non-smart phones") that are much less expensive to acquire and operate than smart phones (Déglise C 2012) and which account for 84% of the installed subscriber base and 66% of current sales (Favell 2012). SMS does not require internet access, which can more than double a cell phone bill, and is often the most resilient service in emergency incidents. Because text messages are pushed to the recipient, outreach is not contingent on the recipient's initiative to search for and download content, and content forwarding via person-to-person messaging has been shown to promote a wider and faster dissemination of health information (Bandera, Rosen et al. 2010).

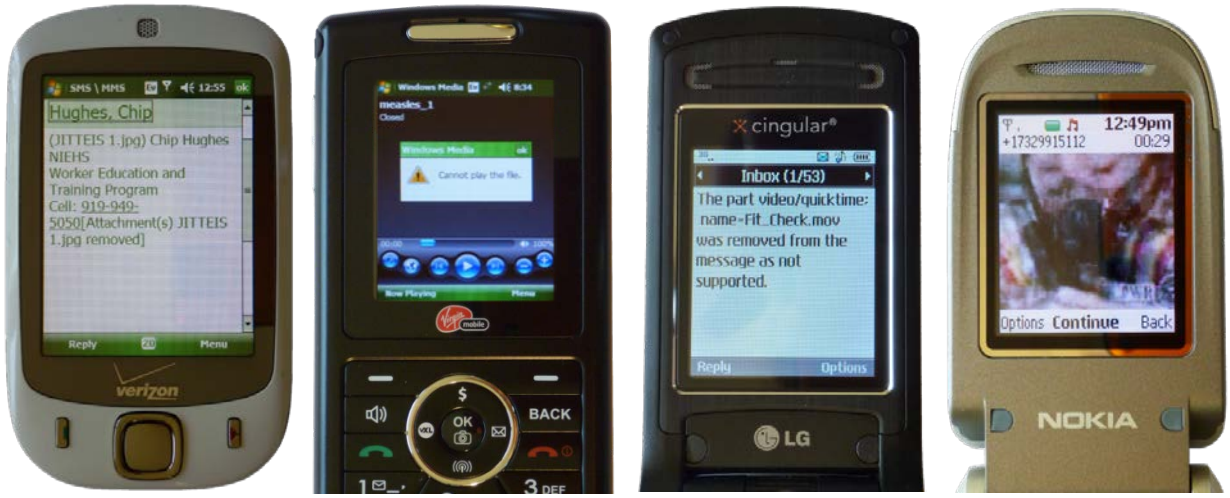
A drawback of SMS is that it only supports brief unformatted text (up to 160 characters), which severely constrains the information that a text message can convey. In 2002, the Open Mobile Alliance (OMA) of 200 telecommunications companies, building upon contributions from the Internet Engineering Task Force and the World Wide Web Consortium, ratified the specification of the Multimedia Messaging Service (MMS, a.k.a. picture messaging) with the goal of enabling new mobile multimedia services that are far more engaging and informative than what is possible with SMS (Le Bodic 2003). MMS is a more complex data protocol that conveys pictures, video, audio, and text (hundreds of thousands of characters) from one cell phone to another.

The MMS protocol can push slideshows with audio narration and videos onto a cell phone. Through the use of illustrations and voiceover, a well-constructed MMS can convey information more clearly and with greater retention than text alone, particularly to individuals with reading disabilities (Mayer 2009, Baumer, Katz et al. 2012). Like SMS, MMS does not require internet access, the installation of an "app", comes standard in all cell phones sold over the last ten years, is resilient to network interruptions, can be played at any time even when there is no signal coverage, and are easily forwarded to friends and family.

At that time and bolstered by the deployment of cell phones with cameras, the telecommunications industry projected that MMS usage would surpass that of SMS by 2005 (Lillie 2012). By some measures, MMS is a success. By 2007, four years after its initial deployment, annual revenue from MMS surpassed $14 billion; no other industry has ever achieved such revenue so quickly (Ahonen 2010). Since then, MMS has been the second most used non-voice function on cell phones (SMS being the first, surpassing voice calls), and is the fastest growing (MMS use in the US continues to increase, whereas SMS use is leveling) (Portio 2011). However, the industry projections that motivated the development of the MMS protocol did not materialize. In 2011, 207 billion MMS messages were sent generating $31 billion in revenue (Favell 2012), far below the adoption expectations initially set for MMS relative to SMS.

2.3 Challenges to Value Added Services

Market analysts agree that a key reason why MMS has not replaced SMS in popularity in spite of its technical superiority is lack of interoperability among the wireless carriers, particularly in the United States (Le Bodic 2005, Smith 2008). In order to attract new subscribers and retain existing subscribers in light of decreasing average revenue per user (ARPU), carriers differentiate their multimedia value-added services in ways that do not faithfully comply with the OMA MMS protocol. Each carrier creates for its subscribers a walled garden that does not guarantee MMS interoperability with subscribers in the walled gardens of competing carriers (Pohjola and Kilkki 2005, Wu 2007, Cheng and Sun 2012). Cell phone manufacturers similarly design multimedia features into their devices to help differentiate their products from those of the competition, at the expense of interoperability. Consequently, a multimedia message sent from a mobile phone may not necessarily be viewable by a recipient on a different carrier, or even on the same carrier but using a different device (Bandera, Rosen et al. 2010) (Figure 4).[1]



Carrier deleted an image from an incoming MMS | Media received but phone cannot render it | Carrier deleted a video from an incoming MMS | Carrier re-samples and corrupts incoming video

Figure 4. Examples of MMS errors caused by lack of interoperability.

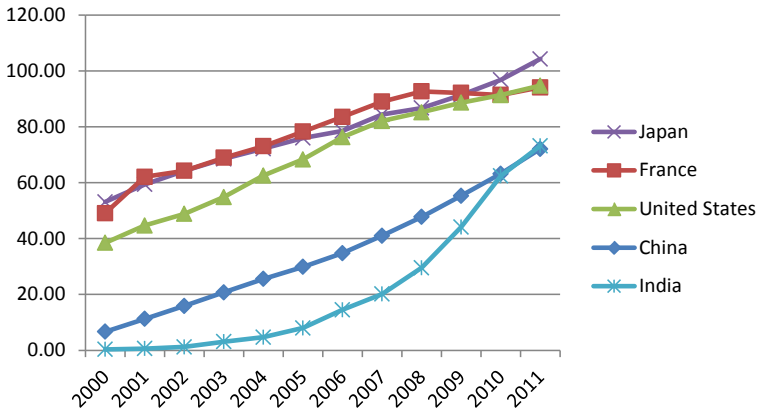


Figure 5. Number of cell phone subscriptions per 100 people in different countries

[1] Interoperability is not an obstacle for SMS users due to the simplicity of the SMS protocol and the early stage of the wireless telecommunications industry at the time of SMS deployment,. SMS interoperability was established in the early days of 2G cellular networks when the promotion of cell phone adoption was the primary growth strategy for carriers, unlike the differentiation strategy adopted by most carriers today facing a saturated subscriber market.

Cell phone adoption in developed markets, namely Europe, North America, and Japan, is relatively saturated with 128% penetration (roughly five cell phones for every four individuals) and 70 million new phone lines in 2013; in contrast, growing markets, namely Asia-Pacific and Africa had 89% penetration and 530 million new phone lines in 2013 (ITU 2013) (Figure 5). In markets that are unsaturated, carriers have the luxury of recruiting new subscribers from the pool of consumers who do not yet have cell phones. However, in markets that are saturated and where ARPU is decreasing, carriers have to compete for market share by recruiting subscribers from competing carriers, and offering new services to increase the ARPU (Ansari, Kheirabadi et al. 2013). Ovum predicts that by 2018, non-voice services will account for nearly half revenue of carriers, the greatest number of new subscribers will come from China, India and Indonesia, and the highest growth rate will be in Africa (Kaufman 2013).

Carriers in developed markets increasingly look to value-added services (VAS) as a way for to generate new revenue from subscribers in light of decreasing ARPU from voice usage, and MMS efficiently supports the delivery of VAS including news, entertainment, and educational videos, mobile marketing, and coupons (Lee, Cheung et al. 2007, Baglietto, Ballabio et al. 2011). The availability of VAS is a strong factor in consumer selection of a carrier (Singh, Sharma et al. 2011), and the usefulness of VAS as perceived by subscribers has a greater effect on subscribers' use of VAS than cost and perceived ease of use (Kuo and Yen 2009).

VAS introduce new actors to mobile markets, including media owners and aggregators for whom carriers are clients (Bhattacharyya and Sivanand 2011). Some actors are themselves clients of the carriers and thus sources of revenue for them, notably advertisers, outreach organizations and mobile commerce financial institutions who seek to reach as many potential consumers as possible through mobile channels. We refer to these client actors as VAS providers (VASPs).

Compared to a carrier's walled garden services, VAS providers typically offer more appealing content and innovative services. Currently, the most popular VAS globally is entertainment messaging, which includes songs, videos and games, ringtones and TV voting (Transparency Market Research 2012). Worldwide, application-to-person (A2P) messaging associated with VAS is expected to generate more revenue for carriers by 2016 than person-to-person (P2P) messaging (Ashdown 2011), reach $630 billion by the 2015 at a compound annual growth rate (CAGR) of 40.8% (Markets 2011), and reach $1.1 trillion by 2017 at a CAGR of 37% (Transparency Market Research 2012). These above estimates include both SMS and MMS A2P messages.

Countries that have implemented privatization or anti-monopoly proceedings exhibit competitive telecommunications landscapes in which there is no single dominant carrier (Bhattacharyya and Sivanand 2011, Frost & Sullivan 2012, Villanueva, Jude et al. 2012). No single carrier in the US or Europe commands a market share greater than 35%, and reaching 90% of the cell phone subscribers in any country requires the combined market share of at least the country's four largest carriers (Fierce Wireless 2013, GSMA Intelligence 2014). At the same time, VASPs require that their multimedia content reach their target audience members regardless of the carrier to which each member is subscribed. For example, if Deutsche Bank provided MMS client services only within the walled garden of Deutsche Telekom (which commands 32% of Germany's wireless market), it would preclude providing this service to the other 68% of its banking customers in Germany and virtually all of its banking customers outside of Germany.

Governments and carriers require VASPs to adhere to best practices intended to prevent abuse of their subscribers, including sending messages only to subscribers that have explicitly given permission to receives such messages (opt-in requirement), and ceasing to send messages to a subscriber who, by simply responding to any VAS message with the word "STOP" to the provider, has opted out of future VAS messages (FCC 1991, FCC 2003, Altschul, Guttman-McCabe et al. 2012, MMA 2012, Pasqua and Elkin 2012). These practices have been successful in protecting the mobile environment from abuses that have plagued other technologies; in 2011, 80% of email traffic was spam as opposed to only 0.06% of

mobile messages (Wood 2011, Kharif 2012), and the open rate of mobile messages is 90% within 15 minutes of receipt, whereas for email it is less than 25% within 24 hours of receipt (Landesman 2012).

VASPs pay carriers for the successful delivery of each message. Some VAS are free to the consumer, such as notifications (1) from a pharmacy that a prescription is ready for pick-up, (2) from an airline that a flight is delayed, (3) from a bank that an account has received a deposit, (4) from a weather service that inclement weather is approaching, (5) from a retailer promoting a sale, (6) from a healthcare provider reminding a patient of an upcoming appointment, (7) from the consumer to a bank confirming a transaction, (8) from the consumer to a transportation agent confirming a reservation, and (9) from the consumer participating in a social media site. Other VAS involve premium messages whereby the subscriber pays a premium either for each message or for every month of VAS, and the premium is shared between the carrier and the VAS provider, which is typically a media aggregator. Premium messages include (1) just-in-time news and financial updates, (2) highlights of movies and television shows, (3) distance learning, (4) music and ringtones, (5) wallpapers, (6) pay-per-view videos, and (7) those from consumers participating in a contest. In 2012, cell phone users paid an average of $5.80 per month for premium messages (Ahonen 2013).

Carrier interoperability is important to providers of non-premium VAS, because these providers are trying to reach a client base (e.g., the bank's clients, the pharmacy's customers, or the doctor's patients) that is not necessarily aligned with any particular carrier. In contrast, providers of premium VAS do not require carrier interoperability to generate revenue, because their primary target market is anyone with a cell phone. Without interoperability, a VASP is relegated to the role of content provider to the carrier, which often requires exclusivity and while label anonymity. For example, Verizon Wireless announced the availability of exclusive content from Fox Sports on its "Get It Now" VAS storefront in 2002, three years before its announced MMS interoperability with US carriers (Nelson 2002, Nelson 2005).

Carriers face choices along several orthogonal dimensions that affect VASPs. One dimension is the degree of MMS interoperability with other carriers. Another dimension is the extent of the value chain they seek to provide in-house versus permit to be provided by the VASPs (Chen and Cheng 2010). In China, carriers pass 85% of premiums to the VASP, and they let the VASP manage their own marketing, sales, and customer support activities, whereas carriers in the US and Europe typically insist on managing these activities and pass less than 50% of premiums to VASP (Jiehong and Jianwen 2006), and Indian carriers typically pass less than 30% to VASP (Sondhi, Biswas et al. 2011).

2.4 SMS VAS

VAS based on SMS (SMS-VAS) date back to the late 1990's in the US and Europe (Friel and Kilmartin 1998) and appeared elsewhere as soon as 2G (e.g., GSM and CDMA) service became available, e.g. in China in 2000 (Jiehong and Jianwen 2006) and later in Africa (Sybase 2011). SMS interoperability was built into the 2G service deployed by carriers, allowing SMS-VAS providers to deploy their services immediately to customers regardless of to which carriers they subscribed.

2.5 MMS VAS

A lack of MMS interoperability impedes the A2P multimedia messaging that VAS providers seek with their entire customer base, and the associated revenue to carriers (Samanta, Woods et al. 2009, Gandhi 2012). Even though the revenue per MMS to a carrier is about three times greater than that per SMS, and MMS supports more diverse payloads and thus more diverse VAS, the aforementioned revenue projections from A2P messaging come primarily from SMS traffic, which is over 20 times larger than MMS traffic due in great part to the aforementioned interoperability obstacles (Ashdown 2011).

A2P messaging is prevalent in countries where carriers have not erected walled gardens, notably China where carriers are still run by the government which mandated interoperability and openness policies to VAS providers (Jiehong and Jianwen 2006), and where cell phone adoption is still far from saturated

(Pasqua and Elkin 2012). The Chinese wireless market is larger than that of any other country, and its state-run carriers are the largest in the world: China Mobile (62% Chinese market share and world's largest carrier with 19.3% of the world's cell phone subscribers), China Unicom (23% of the Chinese market), and China Telecom (15% of the Chinese market).

Chines carriers do not compete against each other as carriers do in the US and Europe, and established agreements with ICVs as soon as their technology permitted, i.e., when 2G service was deployed in 2000 (Cheng and Bruns 2007). Today, China boasts the largest use of mobile VAS (Du, Zhu et al. 2012, Mary Meeker 2013). For example, 70% of MMS messages are A2P (Ahonen 2010), mobile subscribers reading newspapers via SMS and MMS equals nearly 40% of the country's daily newspaper circulation (Morgan Stanley Research 2009), and 86% of the MMS traffic recorded in one day in a south Chinese province was A2P (Gan, Zheng et al. 2011). The revenue of Chinese carriers from traditional voice decreased from 95% of the total revenue in 1999 to less than 50% in December 2011, with VAS revenue making up the difference (Du, Zhu et al. 2012).

3 Objectives and Approach

3.1 Objectives and Study Model

The objective of SBIR Phase I grant 1R430HO10146-01 is to evaluate the technical feasibility cell phone multimedia as a mechanism to disseminate occupational safety refresher training for construction safety culture. Feasibility is measured using two criteria: access to construction workers, and the reuse of existing occupational safety material. The first criterion tests the hypothesis:

H1: Outreach broadcasts to cell phones bridge the digital divide,

i.e., broadcasts are received regardless of type of carrier or cell phone. The second criterion tests the hypothesis:

H2: Outreach broadcasts to cell phones can include multimedia content,

in particular content already in use by occupational health agencies and construction companies. Together, both criteria require the approach solve the interoperability obstacles impacting MMS.

To test *H1* and *H2*, Cell Podium collaborated with the Hunter Roberts Construction Group. Hunter Roberts maintains an "Incident & Injury-Free" (IIF) safety initiative, which strives to eliminate danger at construction work sites through a highly personal approach that shifts focus away from a compliance requirement to a concern for workers' health and welfare. The Cell Podium – Hunter Roberts collaboration consisted of deploying a mobile multimedia campaign on occupational safety at a Hunter Roberts constriction site to determine if *H1* and *H2* hold.

Key personnel from Hunter Roberts selected the Warren Street Village project at the New Jersey Institute of Technology (NJIT) as the construction site for the campaign due to its overlap with the performance period of the SBIR Phase I, and its large size (three acres, $80M and 214,000 square feet of office, classroom, laboratory, dormitory, gymnasium, retail, and food service facilities) which in turn involved diverse safety topics and on-site workers (Figure 6). Hunter Roberts selected for the mobile campaign thirteen topics aligned with its IFF training material: electrical safety, fall protection, forklift safety, hoisting safety, reporting injuries, keeping clean, ladder safety, material safety, personal protective equipment, scaffolding safety, stairway safety, utility safety, and solicitation for comments.

7/19/2012 10/24/2012 4/14/2013

Figure 6. The Warren Street Village construction site (includes complexes on either side of lawn).

3.2 Innovation: Approach to Interoperable Delivery of Multimedia to Mobile Devices

Cell Podium addressed the lack of mobile multimedia interoperability by building a Cellular Multimedia System (CMS) middleware between COEC and wireless carriers (Figure 7). The middleware (1) hosts COEC outreach content in mobile-friendly formats, (2) pushes content to the cell phone of each participant through the participant's current carrier using a format and protocol supported by the participant's phone, (3) collects feedback received from participants via SMS, MMS, and voice, (4) collects feedback from wireless carriers when a message is undeliverable, (5) manages participant enrollment (i.e., opt-in and opt-out requests), and (6) generates campaign analytics derived from messaging activity log files.

The middleware design offers several advantages over cell phone "apps": (1) owners of conventional ("non-smart") phones can participate, (2) participants need not install any software, change any settings

on their cell phones, or change devices, carriers, or service plans, (3) no new software to learn or hardware to carry: recipients view courses using the same media player that came installed in their phone, and (4) support for emerging mobile formats and protocols can be added without involving the user.

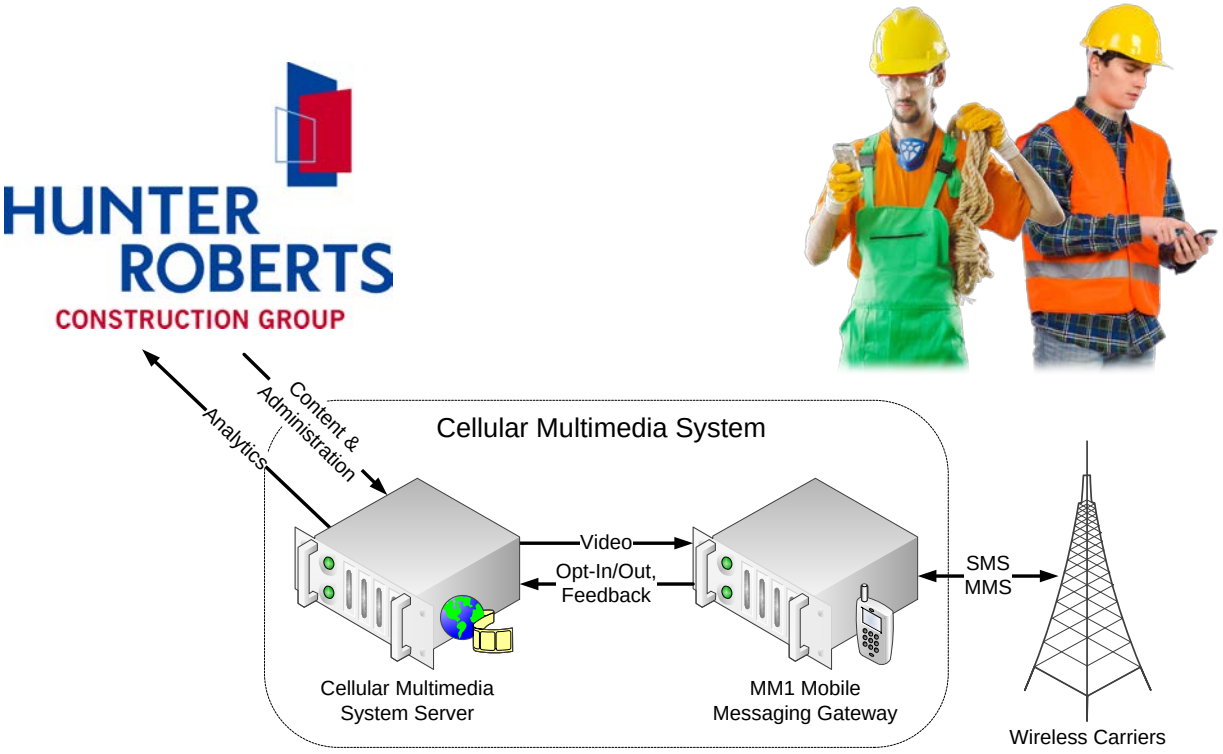


Figure 7. Phase I Cellular Multimedia System Messaging Middleware

The CMS is managed through any web browser (Figure 8). Once logged in, the campaign administrator uploads the videos to be broadcast in a campaign, and sets the broadcast schedule, the enrollment email, and the enrollment phone number associated with the campaign. At this point, the campaign is ready to begin: the CMS will accept emails and phone calls from people wishing to subscribe, broadcast to them the videos in formats that will work on their cell phones, and log all activity including messages and comments sent from subscribers.

To ensure MMS interoperability, the CMS broadcasts multimedia in a format that is fully compliant with that ratified by the Open Mobile Alliance, and which meets the lowest common denominator requirements from carriers. The CMS communicates with the carrier using the MM1 interface defined by the Open Mobile Alliance for communications between a carrier and the MMS software client on a cell phone (not to be confused with the business client of the VASP) (Le Bodic 2005). The CMS thus appears merely as a cell phone to carriers and to campaign participants, albeit one that can send and receive per second many text messages and videos of high audiovisual quality.

The MM1 interface requires the MMS to include two files: the media (in our case a video file) and a text file that describes the page layout of the MMS using the Synchronized Multimedia Integration Language (SMIL). The specifications of the video file imposed by the MM1 interface impacts the nature of campaign videos. The SMIL file instructs the MMS player of the receiving cell phone how to render the accompanying media; it is generated automatically by the CMS and is not visible to the campaign administrator or subscriber, but it impacts carrier and MMS player behavior.

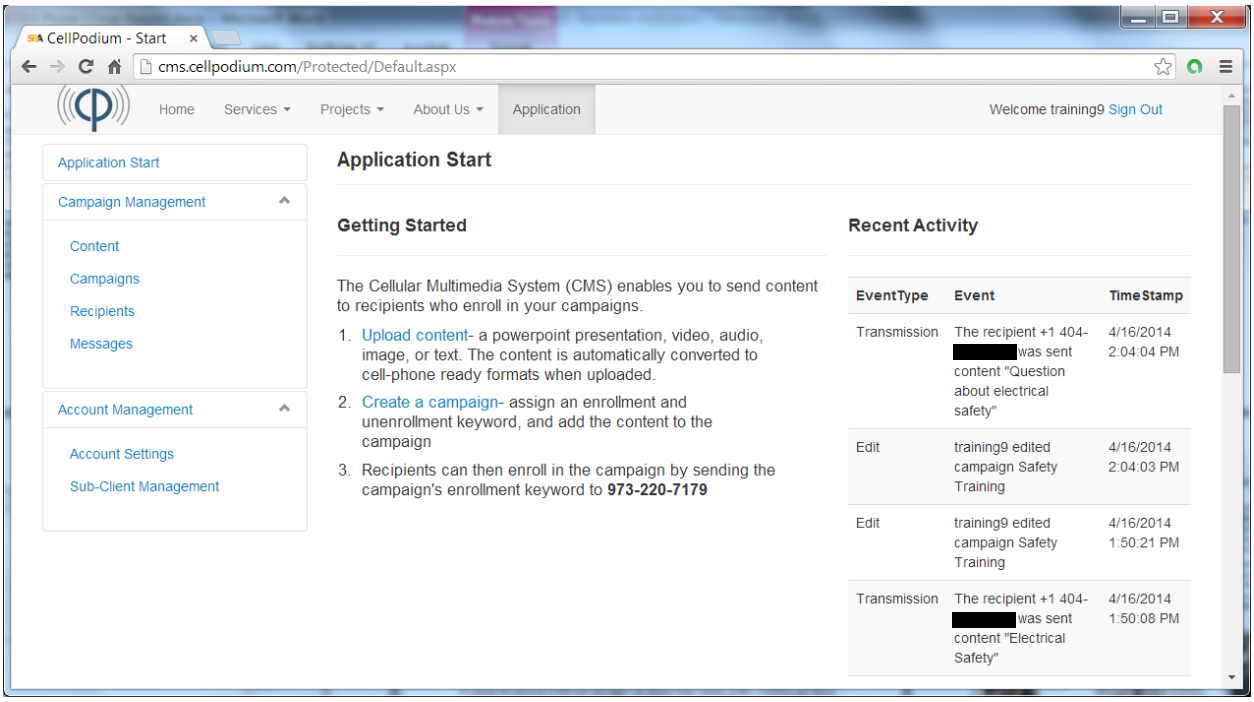


Figure 8. CMS homepage (personal phone numbers redacted)

3.2.1 MMS Media Encoding

MMS players require videos to be in a 3GP format, which is similar to the MP4 format but designed for the lower bandwidth and bit-drop error of mobile communications. Older cell phones use the H.263 codec to decompress video in Quarter Common Intermediate Format (176 pixels wide and 144 pixels tall) and Adaptive Multi-Rate audio codec to decompress audio; modern cell phones also support the mp4 codec (not to be confused with the MP4 file format) in addition to H.263, but any other format or parameters risks playback errors (Figure 4).

With these minimum but ubiquitous resources (H.263, AMR, and QCIF), subjectively good video quality requires 48,000 bits per second of video, and subjectively good audio quality requires 12,200 bit per second, for a total of 60Kbits (or 7,500 bytes) per second of content (Bandera, Rosen et al. 2007). US carriers limit the maximum size of an MMS to 500,000 bytes, which translates to 66.7 seconds of subjectively good quality audio and video. Videos with longer duration can be sent via MMS, but to meet the 500Kbyte payload limit they have to be encoded at a lower bitrate than 60Kbits/sec and quality would proportionally suffer. Videos with shorter duration can be encoded at a higher bitrate, which improves the readability of fine text or the detection of brief high motion features in the video, but otherwise does not significantly improve subjective quality.

3.2.2 MMS Behavior Encoding

Cell phones typically maintain a single in-box with received SMS and MMS messages. When the user selects an MMS in the in-box, MMS players typically put the phone in speakerphone mode so the user can hear the message and view it at the same time (the alternative would be holding the phone up to the ear as in a normal phone call, but the user would then not be able to see the screen). Some MMS players default to displaying the visual content in full-screen mode. Beyond these basic functions, however, the sophistication and behavior of MMS players varies among different cell phones.

We tested the response of fifty new and legacy cell phones from Verizon, AT&T, T-Mobile, and Sprint, to MMS messages with SMIL and media files of varying complexity, and discovered that MMS players recognize only the most primitive SMIL tags. MMS players often simply ignore tags intended to invoke relatively sophisticated player behaviors such as automatic scaling of content, looping, and sequencing of multiple media files; when this happens, the associated content is not rendered. The CMS uses a very simple SMIL program that works in conjunction with a single video file and works on all MMS players and cell phones tested (Figure 9, video.3gp is the name of the video file in the MMS).

```
<smil xmlns="http://www.w3.org/2000/SMIL20/CR/Language">
  <head>
    <layout>
      <root-layout/>
      <region id="video_region" height="100%" width="100%" left="0" top="0"
fit="meet"/>
    </layout>
  </head>
  <body>
    <par fill="hold">
      <img region="video_region" src="video.3gp" regPoint="center" regAlign="center"/>
    </par>
  </body>
</smil>
```

Figure 9. SMIL code for interoperable MMS

3.3 Content Development

A campaign was designed with thirteen 60-second videos, one on each of the aforementioned topics (Figure 10). A storyboard of each video was first developed in Microsoft PowerPoint and submitted to the Hunter Roberts project manager of the Warren Street Village construction site. The voice-over for the storyboards was provided by safety officers from the construction company Structure Tone. Once a storyboard was approved, the associated PowerPoint file and voice-over were converted into a high-definition (master) video using the commercially available standard Adobe AfterEffects.

The process of mobile content development used only conventional media and tools. Only two special considerations were made to account for the fact that the final product was to be broadcast to cell phones. First, the font of text was kept large so that it was legible when rendered on a 2” screen. Both PowerPoint and the AfterEffects allow the user to scale the display screen to any arbitrary size, so that throughout the storyboarding and video development process, we were able to verify the readability of text. Second, each of the master videos was converted into a 3GP file conforming to the previously described H.263, QCIF, and AMR parameters using the free open-source FFMPEG program.

Figure 10. Screen Captures from Construction Safety Mobile Videos

3.4 Campaign Design, Promotion and Management

The Federal Communications Commission and carriers prohibit a VASP from sending content to a cell phone until its owner explicitly opts into the A2P (MMS or SMS) campaign. This reduces the amount of spam via mobile messaging and increases the likelihood that SMS and MMS will be read, but it highlights the importance of campaign promotion to attract participants to the campaign's opt-in process.

We previously discussed how content pushed to cell phones is more likely to captures attention than other communications channels. A2P SMS or MMS is thus relatively intrusive, but is well received so long as the content is relevant to the user. Campaign promotion must set expectations clearly so that participants are not disappointed or annoyed by the campaign (Epatko 2011). In this respect, promotion may be more important to mobile multimedia public health outreach campaign enrollment than to other types of public health outreach (Drew, Pettibone et al. 2012).

In addition to the above enrollment requirement, Hunter Roberts placed two requirements on the campaign design: user-selectable broadcast times and verification of viewing. The selection of broadcast times was required because there were three shifts of workers at the Warren Street Village site, and workers from different shifts might prefer to receive videos on their cell phones at different times. Note that videos delivered via MMS need not be watched the instant they are broadcast; like SMS, MMS are stored by the cell phone in a messaging inbox, and can be viewed at any time. Hunter Roberts key personnel selected as 6am, 1pm, and 5pm as broadcast times.

The MM1 interface notifies the CMS when the delivery of a MMS to a recipient fails, but does not necessarily notify the CMS when a successfully delivered MMS is viewed. The fact that some carriers and cell phones automatically provide this confirmation while others do not is another example of how MMS protocols are not uniformly implemented. The campaign design thus devised a mechanism for confirmation of media viewing that does not rely on the recipient's cell phone or carrier. Each safety video ends with a request for the viewer to reply to the message by simply pressing a specific one or two digit number on their cell phone. For example, the bottom-right image in Figure 10 illustrates the request presented at the end of the Utility Safety video. When the participant replies with the number, her/his cell phone sends this number via SMS back to the CMS. Because the CMS logs every message received, including the date and time of receipt and the phone number of the sender, the campaign administrator is able to verify which videos were viewed on each cell phone enrolled in the campaign.

Brochures promoting the safety campaign were posted at the Warren Street Village site, and distributed to site workers at toolbox sessions (Figure 11). Enrollment in the campaign was open to all at the site, including Hunter Roberts personnel, contractors, and subcontractors, and NJIT personnel. To enroll, a participant had only to text one of the three keywords ("6am", "1pm" or "5pm") to the CMS (973-220-7179). To un-enroll, the participant had only to text the keyword "stop", "end", or "quit". At the end of the campaign, all participants verified to have watched all videos (i.e., responded with the video keywords) received a $50 Home Depot gift card.

Cell Podium personnel configured three campaigns in the CMS, each with the same broadcast dates (approximately two videos per week, Figure 12) but differing in the broadcast time and enrollment keyword. Upon receiving one of these keywords, the CMS would assign the sender's caller-ID to the campaign with the associated broadcast time. Similarly, upon receiving the keyword "stop", "end", or "quit", the CMS would remove the sender from all broadcasts.

During the campaign, the CMS tracked the number of participants, when they enrolled/un-enrolled, the type of device used, and any feedback submitted including the numerical confirmation of viewing. To ensure all participants received all videos, the CMS was also programmed to immediately push to any person enrolling in the campaign any videos that were previously broadcast.

Of the thirteen videos, twelve deal with construction site safety, and one was a message encouraging participants to continue in the pilot: "Thank you for participating in safety video program and subscribing

to safe videos. There are 6 videos left to complete our broadcasting now. Please continue watching the videos and sending us your comments. We will send you a text confirmation about your Home Depot gift card at the end of the broadcasting, and then you are able to collect it from Hunter Roberts (Alexandra Carreras). Have a nice day!"

Figure 11. Campaign promotion card.

Date of Broadcast	Title of Video	Confirmation #
March 4, 2013	Electrical Safety	5
March 8, 2013	Fall Protection	8
March 11, 2013	Forklift Safety	3
March 13, 2013	Hoisting Safety	1
March 18, 2013	Injury Report	9
March 20, 2013	Keep Clean	10
March 21, 2013	Solicitation for comments	N/A
March 25, 2013	Ladder Safety	11
March 27, 2013	Material Safety	12
April 1, 2013	Personal Protective Equipment	13
April 3, 2013	Scaffolding Safety	7
April 10, 2013	Utility Safety	2
April 15, 2013	Stairway Safety	6

Figure 12. Broadcast schedule

4 Results

27 participants enrolled in the campaign: ten for the 6am broadcast, seven for the 1pm broadcast, and ten for the 5pm broadcast (Figure 13, Section 6, Cumulative Inclusion Enrollment Report). 19 participants (70%) enrolled on the afternoon of March 8, 2013 when the campaign was announced at the Warren Street construction site. The simultaneity of enrollment within a shift indicates that participants did not encounter difficulties with enrollment instructions that would have measurably delayed their completion. By the end of the campaign on May 1, 2013, 13×27= 351 videos were sent via MMS. The CMS received no failed delivery reports from carriers, indicating that they were able to successfully relay the videos to their subscribers. Feedback from participants was positive and included suggestions for additional content (Figure 14). Feedback from Hunter Roberts site management was also positive; there were no complaints of campaign promotion being intrusive or broadcasts not being received.

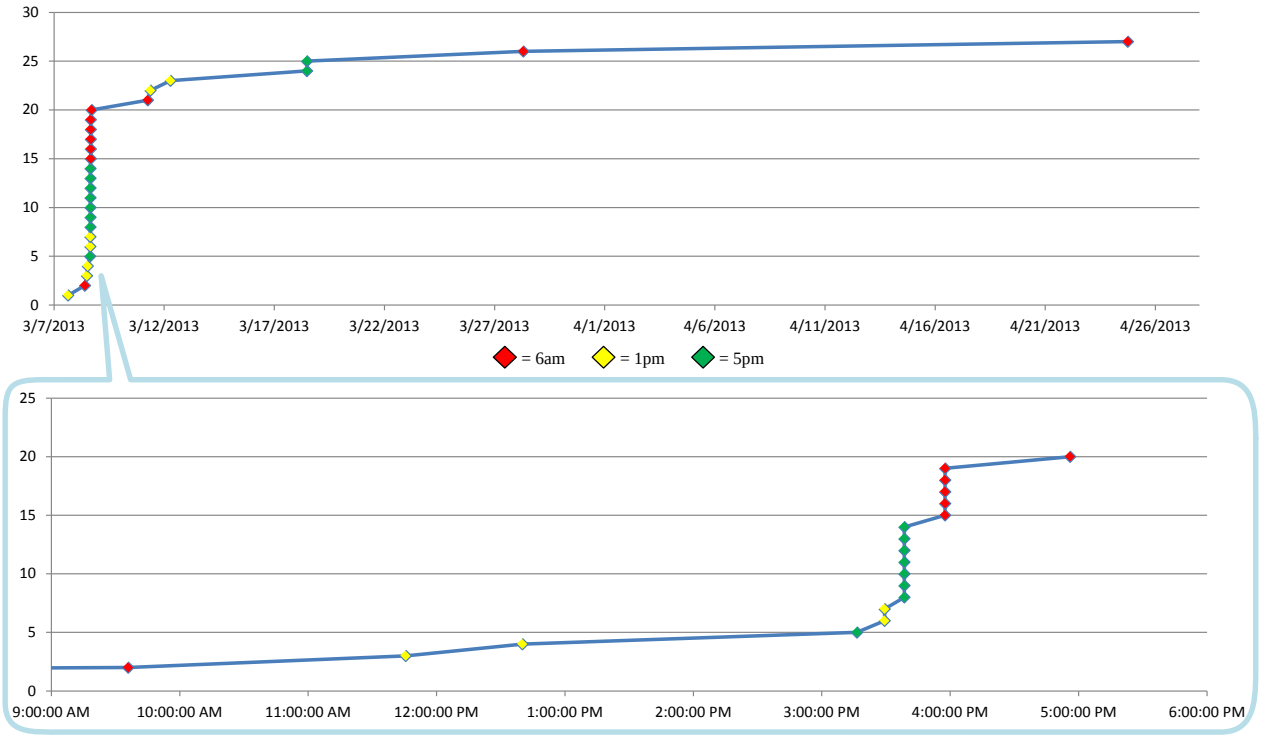


Figure 13. Enrollment color-coded by preferred time of video broadcast.

- 2 good video
- 13 there was no audio !
- 13 the video was good
- 12 good video
- 11 good video
- Any more videos?
- 10 just makes sence!
- 10 very short
- I feel this video are helpful to being safe"10"
- 9 good video but very short
- very good video
- 1 very important on this jobsite !
- This is terrific.
- the video was very good
- good video
- Videos are helpful but they should explain the codes in more detail. Ex in video: safety rails must have a toe rail, mid rail, and top rail. It does not state what heights these rails should be installed at.
- Sweet
- very good
- Good video
- Good video
- Both videos are blurry

Figure 14. Campaign feedback.

5 Discussion

The objective of the SBIR Phase I program is to verify the feasibility of a novel technology aligned with the funding agency. This Phase I project promotes just-in-time occupational safety training, and exploits two facts: (1) viewers assimilate information more readily when it is presented in multimedia format than in text, and (2) the target audience (construction site workers) has cell phones but not necessarily access to the Internet (Mayer 2009, Pew 2012). The Phase I project developed a novel m-Health technology that delivers occupational safety multimedia to a broader audience than the Web, and defined feasibility as meeting two criteria: the ability of the m-Health technology to convey rich media to construction workers regardless of the make or brand of their mobile devices, and its ability to reuse existing occupational safety material.

We demonstrated technological feasibility in a fully operational environment, namely the construction site of the 214,000 square foot Warren Street Village section of the New Jersey Institute of Technology campus in Newark. Twenty-seven construction workers participated in a pilot campaign that used the proposed m-Health technology to broadcast 13 safety messages to cell phones. All participants were able to enroll, select broadcast schedule, and view bi-weekly safety videos on their cell phones without having to install any app or change any phone settings.

Construction worker salaries in New Jersey average $46,670/year (Bureau of Labor Statistics 2013), implying that roughly 60% of cell phones owned by construction workers do not have Internet access (Figure 3) and can only receive video broadcasts in the form of interoperable MMS. *The CMS thus enables just-in-time access to a significant population that is disconnected from the mobile Internet.*

All multimedia was obtained from existing safety training material; Cell Podium staff used nothing more than Microsoft PowerPoint to import existing material into 13 presentations, and the m-Health technology broadcast each presentation as a video to each cell phone. Even animations, transitions, and audio assets embedded in the PowerPoint files were conveyed to the cell phones.

Feedback received from participants was favorable. Factors for this positive feedback include the specificity and practical nature of the videos, and the infrequency of broadcasts (two per week). Some participants commented on the brevity of the videos, desiring more content. These factors agree with prior studies showing that m-Heath participants prefer practical advice with immediate relevance over general distance learning or prescriptive persuasion (Bandera, Rosen et al. 2007, Baumer, Katz et al. 2012).

5.1 Safety Culture

Cell phones are much more personal than other communications devices; people (and legislation) will tolerate SMS spam or telemarketing calls to a cell phone much less than email spam. The fact that participants welcomed the videos is consequently significant, not only for its technical implications but also for its social applications.

Out of twelve factors influencing safety culture (training, peer support caution others, risk taking, peer support respectful feedback, reward/recognition, supervisor concern, senior management concern, discipline and investigation, incident reporting behavior, communication, supervisor/management blame, and management work pressure), the two with the strongest influence on construction safety culture are communications and training (Frazier, Ludwig et al. 2013). Moreover, frequent but brief communication has been found to be effective in promoting a safety culture (Choudhry, Fang et al. 2007).

We do not propose to replace instructor-led training and certification with content delivered on cell phones; these pedagogies may require settings and assessment that cell phones alone cannot provide verifiably. However, the Phase I project demonstrated that brief and periodic video broadcasts to cell phones are both useful and welcomed by the recipient; this type of communications lends itself to the promotion of safety culture than to formal training.

Each participant in the Phase I occupational safety campaign was able to select the time of broadcast to her/his cell phone. Further personalization of a campaign and its content is possible using conventional social media and web media techniques (even though internet access or smart phones are not required of the participants). For example, the CMS can promote safety culture further by embedding in each video to a participant a family photo provided by that participant, thus shifting the experience away from "top-down" prescription.

When a cell phone receives an MMS video, the owner can forward this video to any other cell phone (just as one can forward a text message). The Phase I project did not measure if participants forwarded safety videos; this analysis may be conducted in a Phase II effort. Nevertheless, person-to-person messaging during SMS-based m-Health campaigns has aided awareness (Suggs, Rots et al. 2011), and this can similarly promote safety culture through the proliferation of safety videos via MMS.

5.2 Commercial Feasibility

While the Phase I focused on occupational safety, the CMS is a platform that supports any MMS VAS. Just as businesses increasingly use SMS in their user experience, thereby becoming SMS VAS, businesses can use the CMS to likewise become MMS VAS. The commercial applications of the CMS are limited only by the ability of Cell Podium to educate such businesses on the benefits of MMS to their constituents, customers, and stakeholders.

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6 Cumulative Inclusion Enrollment Report

Study Title:

Comments:

Racial Categories	Ethnic Categories									Total
	Not Hispanic or Latino			Hispanic or Latino			Unknown/Not Reported Ethnicity			
	Female	Male	Unknown /Not Reported	Female	Male	Unknown / Not	Female	Male	Unknown /Not Reported	
American Indian/ Alaska Native										0
Asian										0
Native Hawaiian or Other Pacific Islander										0
Black or African American										0
White										0
More Than One Race										0
Unknown or Not Reported							2	25		27
Total	0	0	0	0	0	0	2	25	0	27

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