The newsletter of the Massachusetts Institute of Technology
System Design and Management Program

sdmpulse

in this issue

MITsdm system design and management

SDM students evaluate mowers for John Deere

By Justin Kraft, SDM '09

__Editor's note:__ In this article, Justin Kraft reviews the capstone project he completed with colleagues Tim Miller and Al Narveson to fulfill a core requirement of SDM's certificate program (a one-year program taught primarily at a distance). Kraft received his certificate in 2008 and is currently pursuing his SDM master's degree.

Justin Kraft, SDM '09

Companies interested in quickly infusing systems thinking into their technical operations often send several students simultaneously to SDM's one-year certificate program. Tim Miller, Al Narveson, and I all came to the certificate program through the sponsorship of John Deere, and we teamed up for the required capstone project. Taking on a real company problem, we applied systems thinking to the development of a John Deere walk-behind lawnmower for golf greens.

Narveson and I are both senior engineers at the John Deere SouthEast Engineering Center in North Carolina, and Miller is a

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Thesis evaluates oil projects

By Emad D. Zand, SDM '08

__Editor's note:__ In this article, Emad D. Zand, SDM '08, outlines the major points covered in his SDM master's thesis, "Risk Analysis in Oil and Gas Projects: A Case Study in the Middle East."

Emad D. Zand, SDM '08

Large complex infrastructure projects, such as those involved in the development of oil and gas fields, are inherently risky, yet the demand for energy continues to grow. According to the International Energy Agency, global energy demand will grow at a rate of 1.6 percent until 2030. In 2030, fossil fuels will account for 80 percent of the energy mix, with oil and gas contributing close to 60 percent.

In light of these facts, risk analysis and the development of strategies to manage risk in the oil and gas industry are crucial to ensuring that

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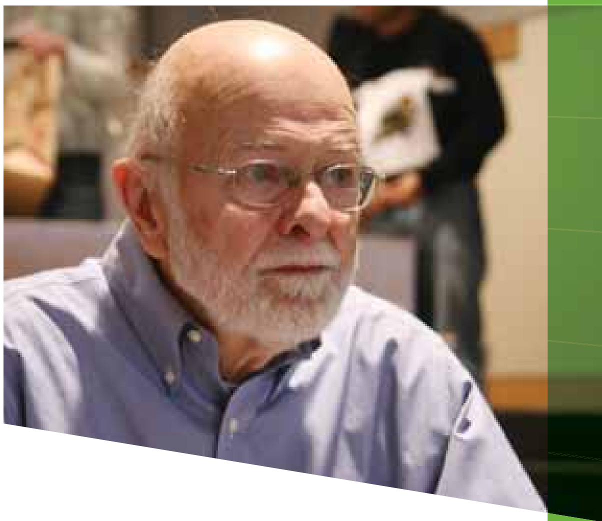


Welcome

Welcome to the summer 2009 edition of the *SDM Pulse*. In this issue, we endeavor to give you a peek at the breadth, depth, and diversity of knowledge-building experiences typical of the SDM program.

Five articles deal with new product and business development—touching upon widely diverse segments of the economy: dental surgery, digital voice recognition and content search, precision greens keeping, solar powered refrigeration, and bicycle powered machinery. These projects may seem unrelated, but they illustrate common methods and techniques, learned within SDM, that were applicable to all. Each demonstrates the need for flexibility, iteration, and close contact with the ultimate customer.

Two of these projects, the solar powered refrigeration system and the bicycle system, involved customers in the developing world—and that means fieldwork. SDM students know that designing successful products requires first-hand and ongoing experience with customer context and conditions, whether the stakeholders are down the block or around the world. This is a fundamental characteristic of SDM's approach to solving business challenges.

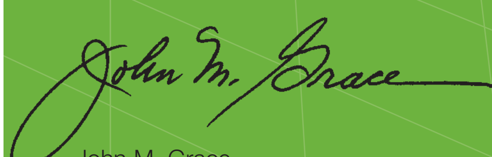
Other articles cover team projects in two different courses, Product Design and Development as well as Technology Strategy. The projects show the depth of understanding team members develop through such hands-on courses—and these are just two examples. It's important to recognize that 10-15 projects are presented and reviewed in each course, providing a tremendous amount of collective insight from experienced professionals from many fields, disciplines, and global locations, all of whom are SDM students. Imagine being present for such reviews and you can begin to understand the significance of the learning process within SDM.

The applicability of SDM's methods and approach to diverse problems can also be seen in Ragu Bharadwaj's article on applying SDM methods in the pharmaceutical industry, Dan Sturtevant's article on developing a complex systems dynamics model to analyze the impact of the educational system on the supply of engineers, and Luke Cropsey's continuing series on developing enterprise architecture requirements for unmanned aeronautical systems.

You will also get a view of a student committee at work through Mario Montoya's article on the Leadership Committee.

The great opportunities for companies to utilize the SDM program for their staff development via a distance option is explored by Kathryn O'Neill. Dr. Donna Rhodes and Kacy Gerst provide a view of potential interactions between SDM and the Systems Engineering Advancement Research Initiative in areas of human systems integration.

Finally we round out the issue with an announcement of SDM's annual conference on systems thinking, October 22–23, 2009. I hope you'll join us!



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Team Medical sticks it out to win product design competition

By Rajesh Mishra, SDM '08

The first week of the spring term had ended and the deadline for submitting team rosters for our class in Product Design and Development (PDD) was closing in. Yet 15 of us out of 98 in the class were still trying to assemble into teams for the semester-long project—to conceive, design, evaluate, and prototype a physical product.

Team Medical shows off its winning design for a needle-stick injury solution: Stikaway. Team members are, from left, Andrei Akaikine, Tieyu Li, Rajesh Mishra, Arun Balasubramaniam, and Shailendra Yadav. (Eumir Reyes is not pictured.)

Although none of us was sure what we wanted to create, six of us finally coalesced around our interest in health care, forming Team Medical: Andrei Akaikine, SDM '09, and SDM '08s Arun Balasubramaniam, Tieyu Li, Rajesh Mishra, Eumir Reyes, and Shailendra Yadav.

Our first task was to determine the most compelling unmet needs within this broad field. Each of us investigated a range of venues—including emergency rooms, pharmacies, and blood drive centers—interviewing everyone from nurses to phlebotomists. We zeroed in on three target populations: 1) drug consumers who need to organize their pills; 2) health-care workers using needles; and 3) potential blood donors.

After presenting our initial findings to the class, we eliminated the third option. Our remaining dilemma—should we develop a device that would make it easier to organize pills or one that would prevent injury and infection from a needle-stick— was resolved when another team chose to work on a pill organizer.

Initially we asked a series of questions: Who is at risk of needle-stick injury? What are the consequences of such an event? Who cares about needle-stick? How does needle-stick occur? Are there any regulations that govern needle use? What other safety solutions exist?

A preliminary investigation revealed that a host of needle-stick prevention solutions already exist, so Team Medical set out to find a solution that was novel, more effective, and easier to adopt. A variety of techniques taught in class helped us to generate product concepts. These included individual and group brainstorming—uncritically exploring various structures, materials, functions, and uses; morphological feature analysis—generating concepts by examining different operands for each solution and underlying process; and mind-map construction—organizing the concepts generated from brainstorming and morphological feature analysis methodically.

We came up with 18 different concepts, then used the Pugh concept selection method to compare them. We initially selected the three that scored highest, but to our dismay, subsequent patent and product searches revealed that all three had been either described or implemented previously. Had we chosen our target user group and needs correctly before performing the Pugh analysis? Since the results showed otherwise, the team decided to return to the proverbial drawing board and redo the analysis. This was a valuable lesson: Pugh selection is sometimes an iterative process, not just a one-time evaluation.

We took a fresh approach, posing the question: Who needs this problem solved and has not yet found an adequate solution? This line of investigation led us to examine the prevalence of needle-stick injuries in dental environments, where the syringes used are different from those designed for other medical uses—they are capable of storing vials, or carpules, of anesthetic to allow the needle and syringe to be used multiple times during a patient visit. We learned that few solutions exist to prevent needle-stick injury in dental clinics, as dentists were comfortable using existing technology and were less apt to adopt newer needle-syringe systems. Also, the Needle-stick Prevention Act of 2000 set the guidelines for dental practitioners to use a one-handed technique as a manual means of preventing injury.

We conducted a survey to assess how significant a problem needle-stick is for those in or aspiring toward a dental profession and how effective current methods are at prevention. Of the 110 respondents, 83 percent cited safety as of paramount importance and 65 percent agreed that current methods, of which the most common

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SDM helps launch voice data search business

By Ben Jiang, SDM ’08, and Cynthia Munoz, SDM ’08

Ben Jiang
SDM ’08

Cynthia Munoz
SDM ’08

SDM is a fertile environment for budding entrepreneurs, so it is not surprising that our time in the program led us to form our own business. Founded in 2008, nexiwave provides professional conference call services, but as opposed to other conference call providers, it delivers transcriptions for each call—making it possible for users to search voice data.

Our eureka moment was inspired by the SDM program itself, because we were both spending a lot of time talking about our projects by phone. Frustrated by our inability to search our previous conversations, we discovered that no tool was available that allowed people to search their own voice data. We therefore set out to create one—first for the purpose of fulfilling SDM’s thesis requirement.

Several SDM classes helped us with our startup: Product Design and Development, the Human Side of Technology, Systems Engineering, and Technology Strategy were all very useful, familiarizing us with industry trends, intellectual property law, and user-centered product design and development processes.

Our initial research showed us that more than 70 percent of human communication is conducted through voice—in face-to-face conversations, but also via telephone, conference calls, voicemail etc. This means not only that the majority of our communication content is not searchable, but that it is forever lost. We started work in earnest in May 2008, applying systems thinking to all phases of development.

Today nexiwave is being used by both SDM students and the faculty on a daily basis, and we’ve received a lot of constructive feedback.

We also assessed user problems and discovered that people have difficulty remembering long conversations and keeping track of details and important elements; most users we interviewed rely on pen and paper note-taking—often transferring notes to a computer later on. We therefore introduced bookmarking features within the audio, which helps people localize important parts of a call.

As a company, our goal is to create useful web conferencing tools focusing especially on the communications content of a conference call or any call. These tools include:

- **Conversation Search.** This is nexiwave’s key feature.
- **Automated Speech Recognition**. This is the key enabling technology.
- **Audio Bookmarks**. Audio Bookmark allows callers to insert bookmarks into the audio stream by pressing the # key during the call. This is quite useful since a one-hour conference call can produce a 20-page transcript.
- **Just-in-Time Summary**. Users can record a summary simply by staying on the line after the other caller(s) hang up and responding to the system’s automatic offer to record a summary.

After six months of hard work, the next generation of conference call and telephone tools was born. We formed our company in September 2008, and in March our team was named a semifinalist in the 2009 Business Plan Contest, run by MIT’s well-known $100K Entrepreneurship Competition.

Although we have now graduated, SDM continues to provide critical support for our venture. Recently, SDM and the Leaders for Global Operations Program began offering nexiwave services to both faculty members and students.

Today nexiwave is being used by both SDM students and the faculty on a daily basis, and we’ve received a lot of constructive feedback. The company is still in expansion mode, making plans for artificial intelligence and internationalization. We are also planning to build a bigger team for testing, marketing, and sales. Stay tuned for continual updates on our progress in the *SDM Pulse*.

SDM lessons pay off in $100K competition

By Alex Shih, SDM '09

Alex Shih
SDM '09

In many ways, MIT's System Design and Management (SDM) Program is about seizing opportunities. For me, one of these opportunities arrived in the form of the MIT $100K Competition, the nation's premiere student-run entrepreneurship competition.

There were 260 teams in this year's competition, so I was particularly proud that my team, Global Cycle Solutions (GCS), was named a finalist in the Business Plan Competition and received the Audience Choice Award. SDM students were among the top competitors, as teams Hammock, nexiwave, and InstantQ all made the semifinals—demonstrating the power of systems thinking and the value of SDM.

Elevator pitches, executive summaries, business plans, pitch slide decks—I was familiar with all these terms, but before the $100K I had never formally endured the creation process. I wanted to understand the experience—setting up business models, pitching to VCs, creating something from scratch. Perhaps it was a bit masochistic to take on the extra work, but like most SDMs, I had a hunger to learn. I was particularly interested in honing my presentation skills, having been involved with the Toastmasters group at my company, Raytheon.

Global Cycle Solutions team members pose with some of the $100K organizers. From left: Carter Dunn MBA '10 (organizer), Alex Shih SDM '10, Lisa Tacoronte '10, Jodie Wu '09, Brian Cantwell MBA '10 (organizer), Caroline Hane-Weijman '11, Semyon Dukach, Javier Lozano MBA '10, Sombit Mishra MBA '10 (organizer).

During the fall of 2008, I signed up for the $100K mailing list and began receiving notices about their mixers. At one Development Track mixer (there are six tracks, or categories, in the $100K competition), I learned about a project called Global Cycle Solutions. GCS creates bicycle-powered agricultural tools for small farmers in the developing world. I reconnected with the project again this past spring via a Design Lab course and officially joined the team.

This project appealed to me partly because of my interest in international development. But I was also delighted to discover an opportunity to directly apply the lessons I'd learned about systems thinking. For example, our efforts to identify and analyze our target market, core competencies, and competitive advantage were heavily influenced by the strategic lessons acquired in Senior Lecturer Michael Davies' course on technology strategy.

Similarly, Professor Eric von Hippel's user-centered innovation course was critical not only to how we set up our business model, but also to our sales and marketing strategies. On several occasions, members of the MIT community served as sounding boards for my ideas about models and frameworks that would incentivize our end-users (rural farmers in our case) not only to innovate, but also to collaborate with us in order to market their inventions.

It was clear that our business plan needed to reflect a comprehensive, systemic understanding of both the technology and the environment in which it operated. Not only were the technical aspects important, but the cultural and social issues were also germane to the feasibility of our project. These issues were especially important to consider because low-cost, mechanized tools are not widely adopted in most rural, developing areas, so we needed to understand the drivers and inhibitors to adoption.

The entire experience proved very rewarding. Despite the occasional all-nighters before major deadlines and the daunting experience of presenting in a small room packed with venture capitalists and judges, we all grew tremendously as individuals and as a team. Thanks to Senior Lecturer Ralph Katz, who teaches the Human Side of Technology, I improved my presentation skills and learned more about positive team dynamics as well as the types of personalities that complemented mine and who could influence the direction of the project.

In the words of an SDM cofounder, Professor Edward Crawley, this experience (among many others in just my first semester) provided a perfect "cognitive framework" to continue absorbing theories behind leading and managing complex systems. This, of course, will be enhanced through more project-based learning to come.

SDM thesis asks: Where did all the engineers go?

By Dan Sturtevant, SDM ’07

Dan Sturtevant
SDM ’07

According to the National Science Foundation, the percentage of US students earning bachelor’s degrees in engineering is almost half what it was in 1985, even though engineering and computer science graduates have significantly higher lifetime earnings than those with any other type of degree.

This situation, which appears to violate the basic laws of labor-market supply and demand, has raised major concerns among US-based engineering and information technology firms, which fear the United States is not producing enough engineers to replace retiring workers and meet demands for future growth.

At Boeing Corporation, for example, a majority of the company’s engineers will be eligible to retire in the next 10 years. I therefore teamed up with Boeing to analyze the US technology labor market for my System Design and Management (SDM) Program master’s thesis, titled “America Disrupted: Dynamics of the Technology Capability Crisis.”

I began by creating a system dynamics model to represent the institutional forces present in the real world. For example, I took into account supply and demand forces that dictate the wages of engineers and others with strong quantitative and analytical skills; the rate at which K-12 students acquire knowledge or fall behind in science and math at various education levels; and the relationship between teacher wages, alternative opportunities outside the classroom, and the quality of education.

My model simulates such societal forces simultaneously, tying them together in an artificial world starting in 1940. My goal was to reproduce what has actually happened in the US economy, labor force, and school systems over the past 70 years and then project what might happen in the future if current policies are maintained or new policies are implemented. By doing this it was possible to gain insight into nonlinear causes of societal problems that cross institutional boundaries and operate over extremely long time ranges.

By going through a system dynamics modeling process, it was possible to identify feedback relationships that could have caused normal market mechanisms to turn against themselves, leading to systemic failure. It allowed me to formulate and test a theory that high industry pay for science, technology, engineering, and mathematics (STEM) workers and low pay for STEM K-12 teachers directly causes long-term industry labor shortages that are self-perpetuating. This is because scarcity of STEM workers causes industry wages to rise as employers bid up the price of those skills in the short-term. Schools are left with fewer qualified and lower quality teachers as the best people choose to go into industry.

If you increase the wages of engineers in the short term, the market may give you a few more engineers, but you also pull people out of teaching, making the shortage even worse 10 years down the road. Already, the shortage of science/math teachers is estimated to be 200,000 nationally and rising.

My research revealed that teaching quality in STEM subjects has indeed declined significantly over the years. While it is impossible to track the abstract notion of “teacher quality” over time, proxies that correlate with it can be tracked to pick up on observable trends. Many researchers tracking these proxies have stated that teacher quality has declined significantly since the 1950s, experiencing the steepest drop during the 1970s and 1980s. Observable drops in undergraduate GPA, class rank, selectivity of undergraduate institution, and scores on standardized tests including the SAT, GRE, and ACT have all occurred over the course of this time period.

The model I created was able to reproduce the time-dependent behavior of multiple seemingly disjointed historical trends. These include the steep decline in overall K-12 teacher quality that happened in the 1970s and 1980s, the level of STEM teacher shortages nationally, a worsening balance of trade, and a rise and then fall of engineering graduates from university after 1985. All of these things are causally linked in the model. What is shown is that societal shifts that occurred in the 1950s through 1980s could have caused the unfortunate behavior seen from 1985 until the present day.

After reproducing history and seeing where the future might lie (the model predicts a worsening of the problem over time), various policy proposals to correct the situation were simulated. The purpose was to test their ability to move the system in a better direction. The model was found to exhibit “tipping” behavior: some reforms had negligible impact while others moved the system into a fundamentally better pattern of behavior.

One of the approaches I tried was simply to peg teacher pay to what STEM graduates were capable of earning in the outside market. This “architectural” difference made the discrimination against highly desired skills go away [see chart below].

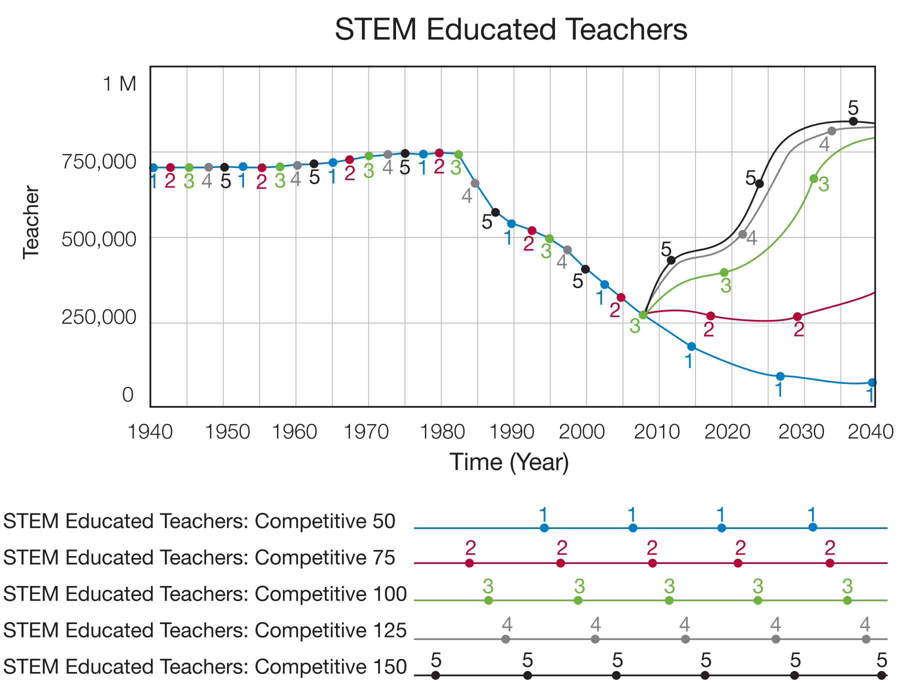
Although some policy reforms like this were able to move the system past a “tipping point” and cause it to operate in a fundamentally better way, making such a transition in the real world would take considerable investment in education, and the benefits would not be fully felt for many years.

That said, it took a considerable amount of neglect for a long period of time to get us into the current situation. It will take a long time to get out of it.

The combination of poor student performance, increasing math illiteracy at a societal level, high STEM industry salaries, and STEM labor shortages will necessarily lead to increased outsourcing and a worsening balance of trade. The societal demand for the output of STEM labor will not simply go unmet. There’s bound to be a temptation to blame foreign competition, but if we fail to remain globally competitive in high-tech it will be because we destroyed ourselves. The problems we now face were entirely self-made.

STEM Teacher Wages as a Fixed Percentage of STEM Industry Wages

Tying STEM teacher pay to industry pay made the system more responsive and stable than fixed wage increases that are unrelated to industry pay. The following set of simulations tests various teacher wage policies that fix teacher wages to some percentage of industry pay, but not necessarily equal to industry pay. Pay levels that are tested are wages of 50%, 75%, 100%, 125%, and 150% of STEM industry pay.



Higher wage ratios increase the number of qualified STEM educated teachers faster. System response to this policy also exhibits tipping point behavior.

SDM thesis examines risks of Mideast oil projects

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our needs for energy are met with a minimum of cost overruns, delays, and other disruptions.

The lessons I've learned in the System Design and Management Program are particularly well suited to addressing such large and seemingly intractable problems, so I chose in my thesis to apply them in an analysis of two similar oil and gas projects. Based on publicly available information, I examined two distinct projects with similar geologies [see Figure 1] under two separate legal regimes in Iran and Qatar:

South Pars (Iran)

- *Companies involved*: National Iranian Oil Company formed the Pars Oil and Gas Company to develop South Pars
- *Project name*: Phases 6, 7, and 8
- *Project goals*: To produce 104 Mscm of sour and dry gas per day; 158,000 barrels of gas condensate per day; and 1.6 million tons of liquefied petroleum gas (LPG) per year

North Dome (Qatar)

- *Companies involved*: Qatar Petroleum Company established two joint ventures, Qatrgas and RasGas, to develop North Dome
- *Project name*: RGX
- *Project goals*: To produce 4.7 million tons per year of liquid natural gas (LNG) from each of three new LNG trains

Both projects undertook to develop areas of South Pars/North Dome, the largest gas field in the world, which is located on the border of Iran and Qatar in the Persian Gulf. The goals and obstacles for both were remarkably similar, but the strategies pursued in the two countries differed significantly. Examining these projects jointly not only provides a useful case study in risk management, but also illustrates the necessity of taking a systems approach to problems. In the end, the different outcomes were the result of differing management and engineering decisions.

Evaluating risk

Large engineering projects face three broad categories of risk: market-related risks, technical risks, and institutional risks. In all cases, the framework for risk management that I learned in SDM [see Figure 2] recommends identifying risks and analyzing them as early as possible in the project life cycle in order to come up with an action plan. Possible actions fall into four broad categories: avoidance (don't take the project), mitigation (shape the project to reduce risk), transference (pass the risk to someone else—as you do when you buy insurance), and embracing (accept the risk as well as any consequences and opportunities that come along).

With this framework in mind, I examined how the two projects handled technical and institutional risks, as well as the results of their different strategies. (Note that I was unable to study market risks because such research requires access to proprietary corporate information.)

In analyzing the technical risk, I considered three categories: technological, construction, and operational risks. In the case of Iran's Phase 6, 7 and 8 project, I found the technological risks were minimal because the required technology for both offshore and onshore facilities were well known. The project also mitigated its operational risk by using an experienced company to operate its facilities.

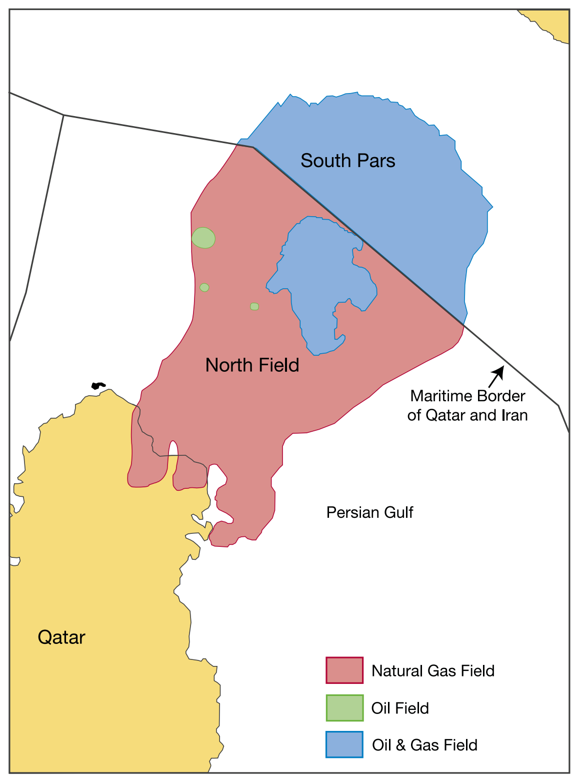


Figure 1: The South Pars/North Dome gas field is divided by the Iran/Qatar maritime border.

However, one of the goals of the Iran project was to develop domestic technical and managerial expertise for executing complex oil and gas projects. Since local contractors had limited managerial and technical capability to execute the project, the Iranian project faced increased construction risks. The risk management strategy employed centered on shifting these risks to other firms (transference)—for example by giving the responsibility for the offshore project to Statoil, a Norwegian company. But, while Statoil managed its own overall risk through diversification, it failed to manage construction risk at the project level in South Pars. Pipeline and platform construction issues contributed to severe delays and cost overruns.

By contrast, the Qatar project confronted increased technological risk because its design was based on an innovative solution—creating the largest liquid natural gas train (or processing facility) at that time in the world. However, the risk was specific to the project and therefore highly controllable. The Qatari firm, RasGas, was able to mitigate risk by shaping the project—for example by awarding multiple projects simultaneously to a single set of contractors and replicating the design and execution for additional trains. Replication in design and execution resulted in cost reduction, schedule reduction, more effective commissioning and start up, and safety and quality improvements. This strategy also facilitated applying execution lessons learned in the first LNG train to the future ones and therefore reduced construction risk. As in Iran, an experienced operator was used to reduce operational risks.

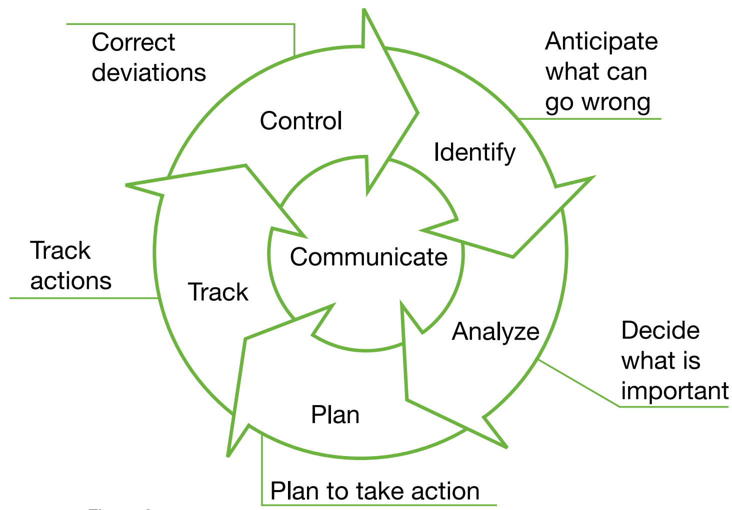


Figure 2

Institutional risks

Institutional risks can also be divided into three categories: regulatory risks (such as delays in obtaining licenses), social acceptability risks (i.e. public protest), and sovereign risks (which refers to cases in which the government abrogates or renegotiates the terms of agreed contracts).

In the two cases under discussion, regulatory risks differed because the hydrocarbon industry in Iran is highly fragmented, while in Qatar it is monolithic. Those working in South Pars therefore had to embrace the risk of working with multiple entities. In addition, different kinds of contracts were involved in the two projects. North Dome was developed under production sharing contracts, while South Pars used buyback contracts.

Both kinds of contracts pose risks, but with production sharing, the oil company has an incentive to prolong the life of the reservoirs and maximize the value of the project. In these kinds of contracts the state partners with an international oil company to develop the field and shares profits once production begins. The incentive to develop a domestic work force is also higher in this case because the company is engaged for a longer period of time than in a buyback contract.

In buybacks, the company develops the fields on behalf of the state and then turns over the whole operation. Once the company is paid for its work, the state gets all subsequent profits. Such contracts give the international oil company less of a vested interest.

As for the other kinds of institutional risk, neither Iran nor Qatar faced much social pressure; in both countries the public has been accepting of oil and gas projects. However, I found the geopolitical risks associated with oil and gas projects in Iran were significantly higher than in Qatar. While both countries experience the systemic risks endemic to the Middle East, Iran bears higher risks in having remained a major force against the western policies in the region.

Conclusion

These projects both faced a variety of risks. But in the Qatari scenario, replication of design and execution turned out to be a very effective risk management strategy. The project finished ahead of schedule and within budget. In contrast, the technical risk factors faced in the Iranian project were compounded by institutional risks and an absence of effective risk management. The result was significant delays and cost overruns.

Technology strategy course provides competitive edge

By Kristina Richardson, SDM '08

Kristina Richardson
SDM '08

***Editor's note:** This article introduces SDM's foundation course in technology strategy. The author, an officer in the US Army, took the class as an SDM student and served as a teaching assistant (TA) for the course this past spring.*

Technology Strategy is one of the foundation courses in the System Design and Management (SDM) Program—typically the first management course that students in the program take. The course focuses on making the connection between technology and major business decisions—those strategic decisions that affect long-term success.

Case studies form the cornerstone of instruction, as students are expected to identify the web of connections linking technologies, systems, products, customers, and competitors. The content of such case studies are specifically chosen to illustrate the links between technology and major business decisions—revealing what is different about strategy in high-tech environments, where SDM course participants actually work. This is a major strength of the SDM class curriculum compared to similar courses at other business schools.

To prepare technology leaders, the strategy course covers several key areas: decision-making under uncertainty; looking at scenarios and sensitivity (viewing products and services within their strategic context); real options and big bets; the timing of decisions; and how to have an effective process.

Senior Lecturer Michael Davies begins the class by presenting students with a series of strategic frameworks for managing high-technology businesses. The emphasis is on developing and applying conceptual models that clarify the interactions between competition, patterns of technological and market change, and the structure and development of internal firm capabilities.

Building on that framework, Davies encourages course participants to take a larger view, thinking about what is going on in the system as a whole. This work establishes the critical thinking skills required to address the cases involved in each lecture.

Davies enriches these case studies by inviting executives to discuss their business decisions—for example, recent speakers have come from A123 Systems, Millenial.net, Polaroid, and Nokia. SDM students also enhance the class experience by sharing information from their current companies (as appropriate and applicable) as well as by providing supplemental articles and additional materials to expand the class discussions.

Students are expected to read and review case studies before class, as quality class participation is fundamental to success in this course.

The case studies are updated each year, to ensure that the class remains current. This year, for example, a major discussion centered on Apple's iPhone, and how Nokia, Microsoft, Google and other major players are responding to the success of this product.

It was interesting for me to see this evolving debate as a TA, because when I was a student in the class last year, we discussed the iPhone in a different context. At that time, we considered the iPhone as an innovative technology and compared it to the Blackberry as both began to emerge as possible dominant designs for the cell phone industry. As times have changed, this core SDM class has changed too, shifting the class focus to those competitors emerging to challenge the iPhone.

One of the most satisfying features of this course from a TA's perspective was seeing the students grow and gain real depth of understanding in the subject—progress that was especially evident during the final team project presentations.

For these course-long projects, students form teams to select, evaluate and analyze chosen company problem areas. In each case, students have to identify critical strategy recommendations for the target companies. Among the projects this year, for example, teams examined the potential of ultra-capacitors for energy storage; evaluated a plan for replacing an aging fleet of buses for a metropolitan transportation system; considered the potential of cloud computing as a Microsoft Service; and worked to create and capture value in the IT health care services domain. As a collective body of work, the final presentations were fantastically insightful.

This is not an easy course, because technology strategy is not an easy subject—but students who apply themselves will be rewarded with a thorough introduction to this complex, dynamic, and uncertain area.

Grad's journey takes him from SDM program to India

By Sorin Grama, SDM '06

Sorin Grama
SDM '06

***Editor's note:** SDM students are identified by year of entry to the program, not by graduation year, which is typically one to two years later.*

Little did I know, as I sat in Professor Ed Crawley's class on a cold January morning in 2006, that I would one day be reviewing the system architecture principles I was learning to develop my own solar-powered refrigeration business.

This journey began in August 2007 when I took a field trip to India with a team of fellow MIT students to analyze the business potential for a low-cost solar-powered turbine. We conducted a market study, talking to farmers, business owners, and leaders in more than 40 different villages. Along the way we learned that dairies were facing particular difficulties.

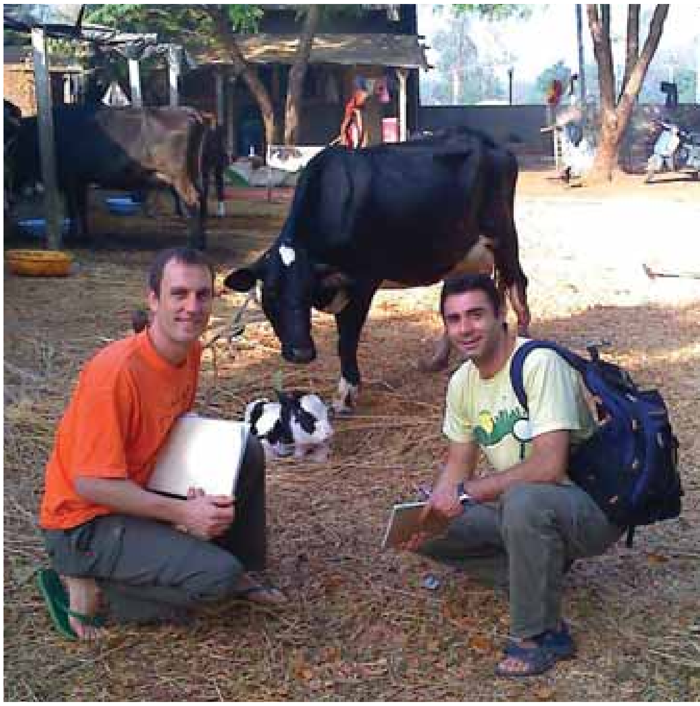
In India, where the roads and power infrastructure are not well developed, the fresh food supply chain faces phenomenal challenges. Raw milk, for example, will spoil unless it is processed within four hours of milking, yet rural India typically lacks access to refrigerated storage. Therefore, dairy staff must travel twice a day—coinciding with milking times—to collect milk from far-flung village collection centers.

We realized that if milk could be chilled at the collection center, then dairies could transport it once a day or even once every other day—cutting down on their high transportation costs. We therefore started to consider ways we could adapt our technology to meet this great need. Unfortunately, our original technology proved unsuitable. I had to make the tough decision to discard the old technology and look for a new one.

Working with a like-minded member of my original team, I cofounded Promethean Power Systems in 2007 to address the need I had discovered. In forming my technology strategy, I relied on lessons I'd learned in SDM, working to deliver value using innovative new technologies that could someday unseat the incumbent ones, disrupting the marketplace. I settled upon a novel refrigeration technology that I believe will ultimately replace conventional refrigeration compressors: thermoelectrics hybridized with traditional vapor-compressor refrigeration to improve overall efficiency.

Next I had to consider how to incorporate this novel technology into a complete product. I settled on a solar-powered milk cooler for storing milk at small, village-level collection centers throughout India. Remote milk coolers are not a new idea, but in India they must be operated with a diesel generator as grid power is often unreliable or nonexistent. Our novel solution solves this problem though the use of solar power, which reduces transportation and operating costs while maintaining the quality of milk throughout the supply chain.

Designing a product like this begins with the process of identifying customer needs and converting them to target specifications—topics I learned a lot about in Product Design and Development. This was the goal I set for my most recent trip to India. In February I spent a month traveling the country interviewing the different stakeholders involved in milk collection.



In February, Sorin Grama, SDM '06, right, traveled to Gujarat, India, to interview stakeholders with his business partner, Sam White.

My colleagues and I followed the milk trail from cattle to consumer and observed, surveyed, and documented the

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Grad's journey from SDM to India

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entire process. We woke up at 6 am to watch the farmers milk the cows, walked with them to the collection center, rode on the pickup trucks that took the milk to the processing plant and interviewed consumers purchasing fresh milk the next day. As a result of this study, I now have a good understanding of what design features are important to our customers.

The more I thought about the product the more I realized that this is an entire system, not just an isolated product. Thus any solution must be addressed at the larger system level. I considered several questions: Where are the boundaries of this system? Who is interacting with this system? and How should the different internal processes be converted to form? It was systems architecture thinking all over again—which is how I found myself reviewing my class notes from Crawley's systems architecture class, trying to extract the key lessons that could help me design a system, not just a product.

While observing the milk collection process, I also realized that this is a supply-chain logistics problem. So, I began going through my notes from my class in supply-chain logistics and reaching out to my MIT connections for help.

My journey has taken me from a simple product idea, to system-level thinking, and beyond that to a supply-chain network perspective. With all these views in mind, I am now putting together a design process involving risk analysis, project organization, design structure matrix, and earned value method—all useful tactics I learned in an MIT project management class.

It's been a great journey so far and I'm pleasantly surprised to see that my school work (and all that money I paid for the SDM program) has not gone to waste. I hope some day to synthesize this flow from idea to technology to product to system to network into a set of lessons I can myself teach to students.

Who's teaching at SDM?

Product Design and Development is taught jointly by Maria C. Yang, the Robert N. Noyce career development assistant professor of mechanical engineering and engineering systems, and Pat Hale, director of the System Design and Management Fellows Program and senior lecturer in engineering systems.

Maria Yang

An expert in the process of designing products and systems, particularly in the early phases of the design cycle, Yang earned her SB in mechanical engineering from MIT, and her MS and PhD from Stanford University's Mechanical Engineering Department, Design Division, under an National Science Foundation Graduate Fellowship. She is the 2006 recipient of an National Science Foundation Faculty Early Career Development Award.

Yang's industrial experience includes serving as director of design at Reactivity, a Silicon Valley software company now a part of Cisco Systems. She has researched collaborative design tools at Apple Computer's Advanced Technology Group and Lockheed Artificial Intelligence Center. She has also explored the user interaction issues for software design, as well as ergonomics issues of force-feedback devices for Immersion Corporation.

Pat Hale

A 22-year Navy veteran, Hale specializes in the application of systems engineering in commercial product development, complex naval system design, and engineering process frameworks and methods. He is the 2008-2009 president of the International Council on Systems Engineering.

While in the Navy, Hale qualified in both the Surface Warfare and Submarine Warfare (Engineering Duty) communities, ultimately managing the design and construction of submarines in Groton, Conn. He held executive-level systems engineering positions at both Draper Laboratory and Otis Elevator Company before joining MIT in 2003.

Hale holds a BS in geophysical oceanography from the University of Washington, as well as the degrees of Ocean Engineer and SM in naval architecture and marine engineering from MIT.

Team Medical sticks it out to win product design competition

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is the technique of inserting the needle into the cap and pulling it closed with one hand, were not adequate to prevent needle-stick.

Although this data seemed compelling, we decided to seek the advice of an expert to ensure we were on track to meet a need. We were fortunate to obtain the assistance of Dr. Kanchan Ganda, director of medicine at Tufts Dental School, whose experience investigating needle-stick injury in dental settings dates back to 1991. Ganda informed us that needle-stick occurs as frequently as 65 times a year at Tufts and the likelihood of contracting a viral disease such as HIV, Hepatitis B, and Hepatitis C is high in such settings.

Reassured that needle-stick is an important cause for dental institutions and clinics, Team Medical developed an initial proof-of-concept for the needle-stick prevention device. Our "needle clamp" [see Figure 1] was designed to allow the user to recap the needle after use with a single hand. Implemented with paper clips and an existing needle cap, this first concept led us to consider a guide on which the syringe could rest so that the needle could slide easily into the cap.

Our second prototype was created out of foam core [see Figure 2] and shown to practicing dentists and dental students, including Maulik Kotdawala at Tufts. One concern these potential users cited was how to prevent the needle from being retracted once it was capped for disposal. The "aha!" moment that occurred while brainstorming was to push the base of the needle, or needle hub, through a "trapping device" so it could not be pulled back—an O-ring seemed promising for this purpose. We also improvised our design to include a "parking area" for the syringe between uses. Based on the initial user feedback and our own improvisations, we planned the construction of a third prototype using computer numerical-controlled (CNC) fabrication. We sent our CAD drawings to a local machine shop and anxiously awaited the manufacture of our first "real" prototype. When the prototype [see Figure 3] arrived soon thereafter, Team Medical was thrilled to demonstrate it to potential "customers"!

Our excitement was short-lived, as users cited three critical issues with our latest design: 1) The needle capture hole was not well aligned with the syringe guide, so the needle could miss the cap; 2) the gap between the parking area and the syringe guide could allow a hand to get caught, which might cause the device to topple, exposing the needle; and 3) the presence of both the "parking area" and the syringe guide might confound the user as to where to rest the syringe after use. Changes to accommodate this input had to be made quickly, just days before the final product presentation.

By stroke of luck, another PDD team came to our rescue, advising us on the services of a local shop that used a rapid-prototyping method called fused deposition modeling (FDM). As a result, our final prototype was born [see Figure 4].

With our freshly minted prototype in hand, Team Medical rushed to revisit its lead users for their assessment. Aside from a few minor requests, both Ganda and Kotdawala from Tufts accepted our prototype in concept and agreed to demonstrate it on film to our class. Our team was gratified at the outcome of our toils and felt confident showing Stikaway for the final PDD presentation.

With so many interesting products on display during the finals, including an automatic door opener and a calendar for the blind, all of us on Team Medical were extremely proud to win first place in the competition.

Figure 1: Proof-of-Concept

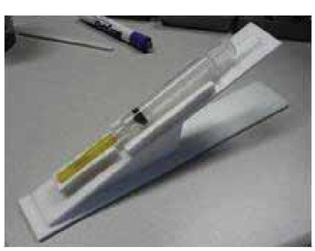

Figure 2: Pre-alpha

Figure 3: Alpha Gen 1

Figure 4: Alpha Gen 2

SDM '07 grad reflects on program's value to pharma

By Ragu Bharadwaj, SDM '07

Ragu Bharadwaj
SDM '07

***Editor's note:** This is the fourth and last article in a series following Ragu Bharadwaj's progress through the System Design and Management Program. Previous articles can be accessed through the news archive at sdm.mit.edu (summer 2007, fall 2007, summer 2008 issues of the* SDM Pulse*).*

While systems theory has made good progress in such domains as defense and manufacturing, it has barely entered the realm of pharmaceutical development. As a research scientist at a small but fast-growing pharmaceutical company in the Boston area, I was therefore exploring new territory when I entered MIT's System Design and Management Program (SDM).

Now that I have completed my degree, I can say with confidence that SDM provided me with the skills and tools needed to address many of the tough problems facing pharma. In particular, I spent my time at SDM exploring the value of systems thinking to the complex and enormously expensive problems of new drug discovery and development.

Historically, gut instinct, knowledge, and intuition have driven the research, development, manufacture, and commercialization of pharmaceuticals. And yet the three core areas explored in SDM (systems engineering, system architecture, and systems dynamics), along with risk benefit analysis, are yet to be employed to great advantage. Here are some examples.

Organizational innovation

After research yields a preclinical drug candidate, development works to make the candidate into a formulation that can be delivered to a patient for clinical trials. This process is not without hurdles. While those in development work to ensure a new drug moves quickly into manufacturing, those responsible for quality assurance constantly verify that necessary safeguards are being taken. In most pharmaceutical companies, these two groups bicker constantly, and reasonable risk assessments rarely triumph over the louder voice.

Professor Thomas J. Allen's course on organizational innovation helped me to understand why these two groups so rarely find common ground—they literally don't share any. While the development team needs lab space, the quality group only needs office space. So in addition to being functionally organized in separate departments, these groups are often housed in separate buildings. As Allen explains, this leads to lowered chance of any interaction and an "us versus them" mentality. This attitude reduces the chance that the two groups will be able to develop a common framework for risk evaluation. As a result, a stringent risk framework more suitable for mature commercial drugs is often applied to materials still under development, causing trial delays and slowing the release of new drugs.

To show how big this problem can be, consider that a blockbuster drug brings in at least $1 billion a year. This translates into $3 million per day of delay, as the limited duration of patents constricts the time available for the company to recoup costs through charges to the consumer. Each delay therefore not only loses the company money, it also makes the drug a little more expensive for patients, excludes more patients from access to the drug, and reduces time and money that could be spent by the pharma company on furthering other drugs in its pipeline.

There is a huge opportunity to apply such SDM tools as risk benefit analysis and failure mode element analysis to optimize this area. Developing a common framework of risk that could be both pragmatically used in development and accepted by the quality team would be a boon to the industry.

Quality by design

Major opportunities also exist for improving development through systems engineering and system architecture. Ideas such as quality by design (ensuring quality at every step in the life cycle, from inception to final product) offer potential gains to both the pharma companies and to regulatory authorities such as the US Food and Drug Administration, which is now encouraging its use. While the company provides more information to the FDA about its drug, it also gains a better understanding of drug properties and minimizes its risk of manufacturing errors, while in many cases increasing operational freedom.

Portfolio management and marketing groups within pharma companies are also beginning to adopt system dynamics tools such as agent-based programming (a computational way to assess the impact of individuals on the whole system) to lower financial risk and allocate resources better. As these tools gain acceptance, layering real options onto funding decisions in research, clinical trials, and manufacturing cannot be far behind. Currently very few companies (Genentech is one) are known to apply this well. But within the next few years, I expect to see far more rational decisions and a better use of scarce

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Distance option helps SDMers stay on career track

By Kathryn O'Neill, managing editor, *SDM Pulse*

In today's fast-paced, global economy, it's not always possible—or even desirable—for every midcareer professional to return to school full time. That's why MIT's System Design and Management Program offers a distance option.

Anando Chowdhury
SDM '09

Haiying Ren
SDM '09

Mark Moran
SDM '09

Like many distance students, SDMers attend classes remotely—via high-tech videoconferencing—while continuing their careers. However, there are key differences between SDM and distance programs elsewhere, including a high level of involvement with MIT faculty and colleagues on campus.

"You have a connection to the buzz of what's going on at MIT, but you also have instant application," said Anando Chowdhury, SDM '09, who works in New Jersey as a director of global science, technology, and commercialization at Merck & Co. Inc.

Applying new skills and strategies in real time is a key advantage, since SDM distance students are often sponsored by employers. "A lot of the principles I learn I can apply back to my work right away," said Haiying Ren, SDM '09, a project manager at Pratt & Whitney in Connecticut. "SDM builds up your thinking, so whenever you face a problem you can tackle it in a systematic way."

To ensure that SDM students establish connections within their cohort and to MIT, the distance program includes a number of on-campus components—including a full month on campus for the January Session (sometimes called "SDM boot camp"), one semester in residence at MIT (an Institute requirement), and three one-week business trips to campus per year.

"The whole concept of getting folks together for that concentrated period of time is absolutely the right thing to do. It just builds the network much stronger," Chowdhury said.

"With a top-tier institution, you want to walk away with a feeling of connection. I think MIT absolutely hit the mark with this program," said Mark Moran, SDM '09, a technology architect at Deere & Company in Illinois.

Moran said he previously tried a more traditional distance program—downloading materials and communicating with professors by email. "That didn't really work for me." At SDM, he noted, "If the lecture is at 10 am, I'm sitting in front of my computer at 10 am. The really good professors will even call on us in distance land."

During a lecture in MIT's high-tech classroom, a screen split into nine segments shows some of the distance students attending in their various videoconference rooms. Students who want to ask questions in class press a button to ensure their remarks can be heard wherever distance students are listening. There can be slight delays—students onscreen smile a little after a joke has passed—but comments from distance students are easy to hear, and the screen automatically zeroes in on one screen so everyone can see who's speaking.

"A thousand miles or so melts away pretty well," Moran said.

In addition, distance students typically team up with on-campus students—and each other—for project-based assignments. SDM thus intentionally replicates the kind of geographically dispersed teams common in today's global workplace.

This close connection to business is a hallmark of the SDM program.

"Having distance students keeps MIT engaged in current challenges in industry," said Pat Hale, director of the SDM Fellows Program, who noted that about a third of a typical SDM cohort uses the distance option.

Moran, for example, is making the most of his time at SDM by working with Deere to address a pressing company issue in his SDM thesis. "The way we look at it internally is that if we find the right thesis project, we can bring our resources and MIT together—which is a great value proposition."

"The master's thesis is an ideal way for sponsoring

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SDM helps US Air Force integration project take off

By Luke Cropsey, SDM '08

Luke Cropsey
SDM '08

***Editor's note:** This is the third in a series of articles by SDM alumnus Luke Cropsey, who is integrating knowledge from various MIT resources and transferring it to his employer, the US Air Force. The first two articles examined tools taught in the SDM program for the purpose of breaking down and analyzing complex problems. In this article, Cropsey begins to formulate solutions. (For previous Cropsey articles, view the* SDM Pulse *online at sdm.mit.edu/news_archive.html.)*

I have been using tools I learned through the System Design and Management Program to help integrate unmanned aircraft systems (UAS) into the National Airspace System—a complex challenge made more difficult because critical stakeholders appear to have value definitions that are at odds with each other.

As an overarching methodology, I'm using the value-creation framework developed by E. Murman et al. in Lean Enterprise Value, including aligning value among stakeholders with an enterprise purpose statement and an X matrix analysis (see previous Pulse articles for detailed discussion).

The next task for the enterprise architect is to synthesize potential methods for delivering the desired enterprise attributes using Object Process Methodology (OPM). The goal at this stage is to implement a process that is robust enough to handle the often subjective inputs that result from the value-alignment activities, while at the same time preserving the rigor of the analysis. Without this kind of approach, it is very difficult to defend the "solution" as the best possible alternative.

In the last article we defined the enterprise scope and purpose as "restore principle of maneuver," a higher level objective of the military that calls for placing the enemy in a position of disadvantage through the flexible application of combat power. This purpose also serves the FAA's safety needs by enabling a more maneuverable platform while meeting the Department of Defense's needs for war fighting capability.

With this in mind, one potential set of enterprise solutions for restoring maneuver to UAS platforms can be illustrated implementing the enterprise architecting framework developed by Deborah Nightingale, director of the Lean Advancement Initiative (LAI) and Donna Rhodes, director of the Systems Engineering Advancement Research Initiative (SEAri). Note that the knowledge integration between LAI and SEARi was already occurring.

This framework [see Figure 1] connects the enterprise purpose to the value attributes identified via the X matrix and puts each attribute "into action" to describe the type of activity needed to produce the desired end-state. By inserting the "enterprise views" column between the purpose and these attributes, the enterprise architect naturally begins to see potential solution paths simply by considering how the purpose can be met in a specific context (enterprise view) by acting on a specific outcome (value attribute) using one or more potential mechanisms (points of leverage).

These "points of leverage" were developed by systematically going through the previous three columns and asking how they could be combined to achieve the desired purpose of restoring maneuver to UAS platforms.

For example, consider the first mechanism listed under "points of leverage"—educated participants. This mechanism was postulated by considering what could be done within the "policy" domain to deliver the value attribute of "ensure safety." One such "policy" decision would be to mandate or encourage better education of national airspace users concerning the operation and characteristics of UAS platforms and procedures. Others might be to require more capable equipage or establish direction for procedures and standards.

The art of architecture

While Object Process Methodology is enormously useful, there is no substitute for experience in system architecture. Even for my SDM master's thesis, I didn't actually re-create the full matrices for these systems on paper because I largely knew what concept pieces would work with others and which wouldn't just by inspection.

Architecting is an art as well as a science. An in-depth knowledge of both the subject matter and architecting is necessary to avoid a massive number of potential combinations. Over time, experience gives you an intuitive sense for what will work and what won't.

Of course, the participation of several team members is necessary to tackling any complex system challenge—if only to provide the requisite knowledge to fully address all aspects of the project. For that reason, I think the more team members trained in SDM's hallmark systems thinking methods the better. I'm convinced that attempting to do an enterprise architecting job with someone who is not an expert (or at a minimum, very knowledgeable) in these tools—as well as the specific material and context—will result in a lot of rework, if not outright failure.

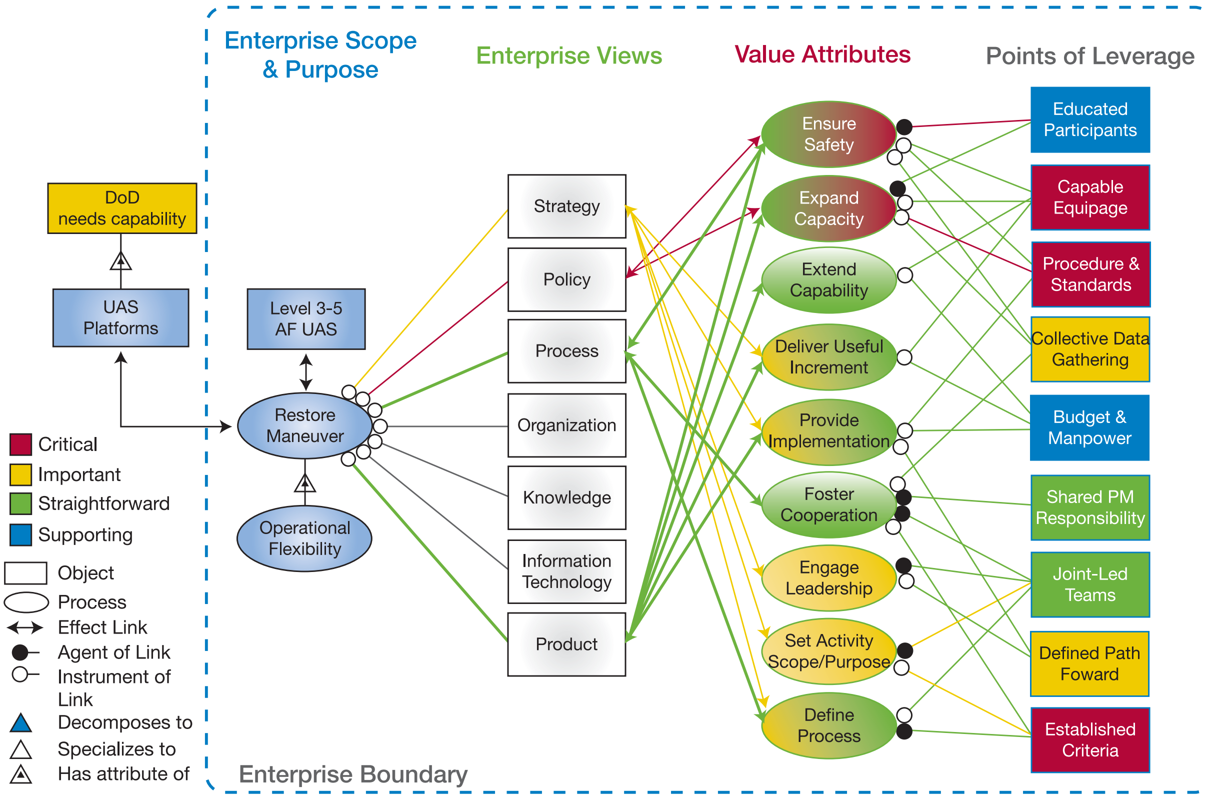

Figure 1. UAS Airspace Integration Enterprise Solution OPM

Employing OPM in this manner allows the architect to quickly amass a large number of potential alternatives, while at the same time identifying those mechanisms that have the highest degree of connectivity to multiple value attributes. These mechanisms then become “points of leverage” in the potential design space that the architect can further refine for maximum perceived benefit to the stakeholder community.

The overarching enterprise architecture represents a distillation of a host of “enterprise views – value attributes – points of leverage” combinations that were tied together, pulled apart, and recombined until the architect reached the desired level of value delivery. SDM’s class in system architecture provides a number of useful constructs for generating, assessing, and selecting such combinations to keep the problem tractable and to prevent a geometrical explosion in the total number of potential architectures that have to be evaluated.

At this point, the architect has arrived at an enterprise architecture with a high degree of confidence that it will not only create the desired value, but will likely produce more value than a relatively large percentage of any alternative architectures that could be explored. This is a direct benefit of employing a rigorous methodology.

The last remaining task is perhaps the most straightforward from a theory perspective, but also the most difficult to implement effectively. The problem is going from the current state of the enterprise to the desired one articulated by the new enterprise architecture.

Fortunately, LAI has done a tremendous amount of research on the topic of enterprise transformation. To briefly summarize its findings, the enterprise architect must now enter into intensive discussion and dialogue with the enterprise stakeholders to assess the appropriate path forward. The first order of business is to return to the key stakeholders and ensure that the value delivery needs are still valid and the proposed architecture will meet those needs. Senior leadership in each key

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SDM helps US Air Force integration project take off

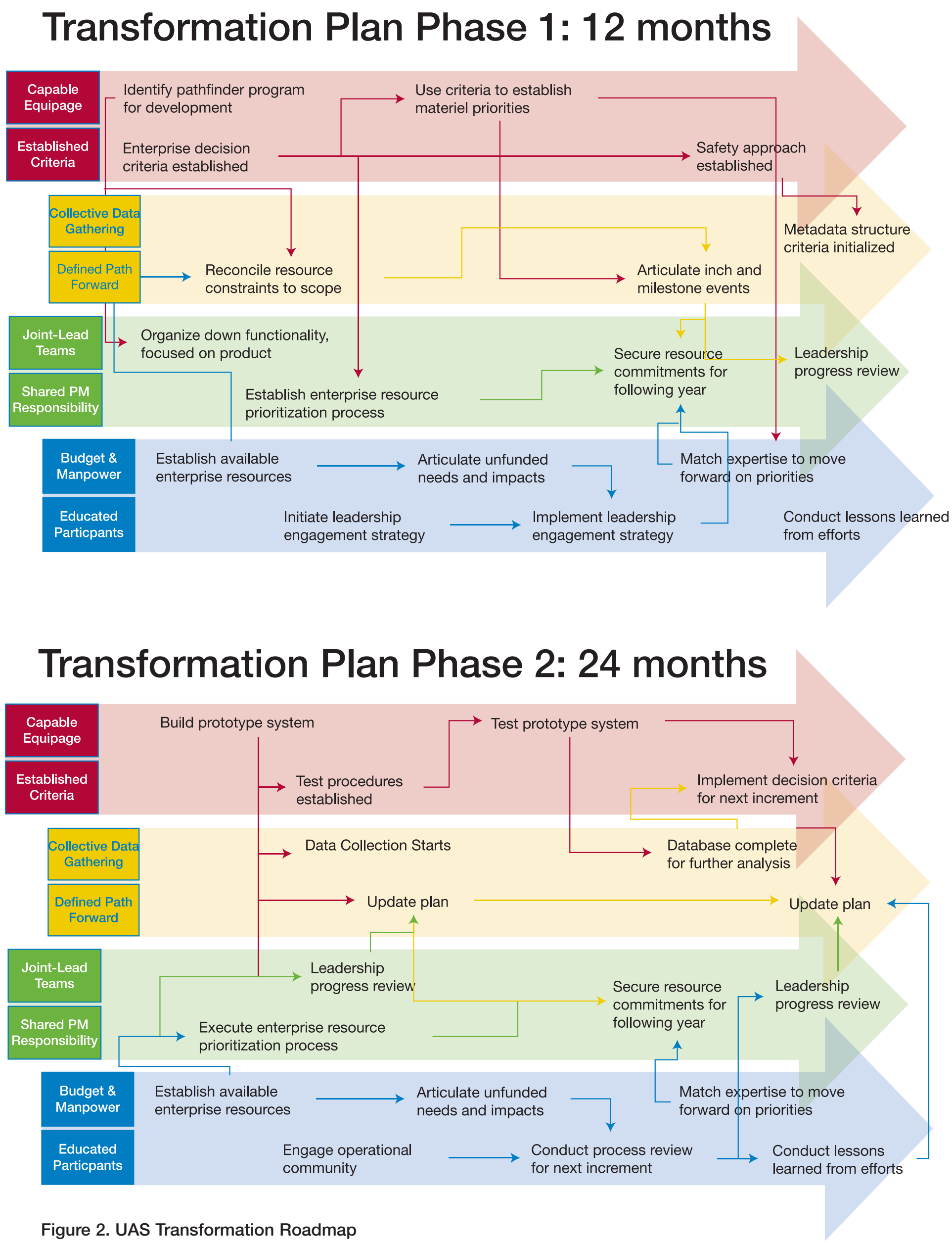

Figure 2. UAS Transformation Roadmap

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stakeholder organization needs not only to understand the nature of the proposed enterprise architecture, but to become an advocate—looking for ways to arrive at the desired end-state themselves. This is why it is so important to maintain continuous stakeholder engagement throughout the enterprise architecting process.

If senior leadership is on board, the remaining step is execution. This is where theory truly leaves off, and real work has to take place in order to build realizable plans for fundamental enterprise transformation. This task can become very involved quite quickly.

The most important thing is to address any constraints that must be observed as the transformation process unfolds. With the constraints clearly in mind, the architect must then design stable intermediate enterprise architectures that are fully functional and provide increasing levels of value delivery in their own right. For example, the UAS Integration Transformation Roadmap [Figure 2], which shows the first-order of detail for the execution of the UAS integration challenge, specifically addresses the two-year budget constraints within which the Department of Defense must operate. In addition, the transformation plan lays out a “test-build-plan” sequence on a timeline that lends itself to providing incremental improvements in value delivery.

The fourth and final article in this series will describe the key lessons learned from this research and how the integration of the knowledge generated by each of the organizations involved ultimately provided a way ahead on an exceedingly complex socio-technical problem of significant future potential—integrated UAS operations in the National Airspace System.

SDM students share leadership responsibilities

By Mario Montoya, SDM '09

Mario Montoya
SDM '09

Leadership is not just a buzzword in the SDM program—students are actually expected to lead. In every cohort, student-led committees take responsibility for shaping parts of the SDM program, including leadership.

I was fortunate enough to be elected one of the two cochairs for my cohort's Leadership Committee, along with Sunish Gupta, SDM '09. The committee is tasked with developing new initiatives and complementing the new leadership portion of the SDM curriculum, which was unveiled this year based on the collaborative work of previous cohorts, faculty, and industry partners.

We began our work with a speaker series. During March, the committee invited Lawrence Kaufman, CEO of Lightwave Power Inc., Jean Duffy, vice president of speech and language for BBN Technologies, and Eric Burger, chairman of the board of SIP Forum to speak at private, SDM-only luncheons about their professional leadership experiences.

Bringing industry leaders to MIT can provide students with some serendipitous opportunities, as we discovered while Kaufman was on campus. It turns out that Kaufman was an employee at Polaroid at the same time our Polaroid case study took place—one of several real-life examples used in our technology strategy class. Seizing on this incredible opportunity, committee member Mona Masghati, SDM '09, and I invited Kaufman to attend our class.

After introducing Kaufman to lecturer Michael Davies, we agreed not to reveal Kaufman's identity in order to prevent any bias in the class discussion. Once we'd finished going over the case study of Polaroid's decision not to pursue digitial photography, students were surprised to be offered an insider's perspective. Kaufman validated the general consensus that Polaroid's culture was not conducive to allowing a disruptive technology to be fully adopted. Management was reluctant to accept the potential of the new technology, and Polaroid's business model was based on printing photos. Kaufman shared his view that Polaroid had become too focused on the importance of technical expertise and neglected sound business strategy.

This is just one example of the ways in which the SDM program empowers students to enrich their academic experience. The Leadership Committee is also taking a look at broader trends in the business world to consider what skills SDM students need to succeed. We're considering offering some ongoing classes or workshops in negotiation skills, for example, and personal branding (in other words, how do you market yourself?).

We are also, naturally, taking a look at the bigger picture—what does the SDM program itself need to continue its success? Discussions thus far have centered on the SDM brand and ways in which we can communicate the core values of the program to future employers. As the program has grown, so has the number of self-sponsored students—students who will need to sell the value of SDM to a company that may never have heard of it. Recognizing that students are critical stakeholders in the SDM brand, we are therefore working in conjunction with the student Industrial Relations Committee in an effort to zero in on ways to spread a common message about the program's fundamental principles—even while acknowledging that flexibility is one of SDM's hallmarks.

Through all the work and planning, committee members have demonstrated excellence in initiative and accountability. Thanks to them, my service as committee cochair is an exciting and fulfilling opportunity to represent their voices and desires. I'd be remiss if I didn't give many thanks to the cohort and faculty for their support and input.

New video series offers glimpse into SDM

Readers interested in learning more about MIT's System Design and Management Program can now view the SDM video series at sdm.mit.edu.

SDM's virtual information session provides a quick introduction to SDM's portfolio of offerings, from its full- or part-time on/off campus master's degree in management and engineering to its one-year certificate program in systems engineering.

Visitors to the website can also view the SDM Best Thesis video to learn about SDM alumnus David Kim, who conducted award-winning research on generation gaps in engineering.

SDM sponsors 2009 conference

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network with other systems thinkers attending the conference.

As of this writing, the following speakers have been confirmed:

From MIT:

- Joel Moses, PhD, Institute Professor
- Olivier L. de Weck, PhD, associate professor of aeronautics and astronautics and engineering systems; associate director, Engineering Systems Division
- Patrick Hale, director, MIT System Design and Management Fellows Program; senior lecturer, MIT Engineering Systems Division; president, International Council on Systems Engineering
- Deborah Nightingale, PhD, professor of the practice of aeronautics and astronautics and engineering systems; codirector, Lean Advancement Initiative
- Stan N. Finkelstein, MD, senior research associate, Engineering Systems Division and Harvard-MIT Division of Health Sciences & Technology
- Joseph F. Coughlin, PhD, senior lecturer, Engineering Systems Division; director, AgeLab

From the health care industry:

- Blackford Middleton, MD, MPH, MSc, Partners HealthCare System Inc., Clinical Informatics R&D, Center for Information Technology Leadership
- Henry Feldman, MD, Beth Israel Medical Deaconess Center

Experts on energy and sustainability:

- Sharon L. Nunes, PhD, vice president, Big Green Innovations, IBM
- Mike Ryschkewitsch, chief engineer, NASA
- Lawrence D. Willey, PE, GE Infrastructure, energy advanced technology operations manager, Wind Conceptual Design
- John Reid, PhD, director, Product Technology and Innovation, John Deere Inc.
- Eric Cahill, senior director, Progressive Insurance Automotive X PRIZE

We invite you to join us on October 22-23, 2009. For additional information, including registration details and information on becoming a conference sponsor, visit sdm.mit.edu or contact John M. Grace, SDM industry codirector, at jmgrace@mit.edu or 617.253.2081.

Grad reflects on value to pharma

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financial resources in the pharmaceutical industry.

Applying SDM skills

Pharmaceutical research, development, and commercialization could also benefit from the application of systems principles—as I have seen in my own work. For example, using ideas from system dynamics, we have been able to highlight problems where delays in the flow of information can affect both supply and demand. We have been able to mitigate these problems by developing and using a variant of the Beer Game (a simulation developed at MIT to introduce students to the value of integrated supply chain management). In our game, by losing customers due to the lack of product, fictitious patients suffer from the lack of medicines. The game has definitely had its intended effect as participants with different functions across the company have now vowed to collaborate more intensely.

In addition, there are multiple opportunities for operations streamlining at almost every point in the pharma chain. At SDM, these opportunities were highlighted for me by elective courses in lean principles, system dynamics, and operations strategy. For example, at work I have been able to apply some very simple lean principles—with the help of my team—to reduce a 16-day cycle-time process in drug discovery to just over four days, using fewer resources and increasing employee satisfaction. As the process is iterative, this has led to faster design-build-test cycles, along with a greater overall success rate per design cycle.

I am also involved in a similar effort in development: we are hoping to take a 60-day process, involving multiple departments, down to under a week. Given the functional organization of pharma, this project involves breaking silos, challenging belief systems, and getting people to change their way of thinking about problems. Fortunately, the elective I took at MIT on power and negotiation has greatly helped me with this work.

Today, the pharmaceutical domain still has some of the most complex and inefficient operations seen in any industry. I believe SDM's emphasis on reducing complexity in large systems makes the program an excellent fit for anyone interested in improving health care by leading pharma to a more efficient future.

SEAri investigates the human side of systems

Kacy Gerst
SDM ’09

Human beings are central to all engineering systems—operating, maintaining, and supporting them. Therefore, the needs of people—for training, safety, and occupational health—must be considered and accommodated within the design of any system. Broadly termed human systems integration (HSI), this area of systems engineering examines the technical and management processes necessary to integrate human considerations within and across all system elements.

Failures to accommodate people properly can be costly—both financially and in terms of human life. With that in mind, the Systems Engineering and Research Initiative (SEAri) is currently investigating the economics of human systems integration under the sponsorship of the US Air Force Human Systems Integration Office. Nine domains of interest are specified by the US Air Force: manpower, personnel, training, environment, safety, occupational health, habitability, survivability, and human factors engineering.

According to Donna Rhodes, SEAri director and principal investigator for the project, “The tight coupling of HSI processes to the overall systems engineering process, particularly in large defense and government programs, creates a challenge for assessing whether human systems integration is being sufficiently considered to ensure a successful program.”

The research includes two areas of investigation. Ricardo Valerdi, research associate and lead for the first area, is working with graduate student Kevin Liu to estimate what percent of any systems engineering effort goes into accommodating people—research that will help others predict how much HSI effort will be needed for future programs.

Rhodes and Kacy Gerst, SDM ’09, are collaborating on a second area, investigating leading indicators for systems engineering effectiveness with HSI consideration. A leading indicator is a measure for evaluating how effective a specific activity is in advance of the impacts that are likely to affect system performance objectives. Leading indicators can help program leadership avoid problems, rework, and wasted effort through advance notice—thus delivering value to stakeholders.

Building on prior work on systems engineering leading indicators, the goal is to extend these for HSI to improve the predictability of HSI programmatic and technical performance on a program.

The team is also investigating “soft indicators” or the more difficult-to-measure information that indicates HSI effectiveness. “Our initial investigation into soft indicators of effective human systems integration has been important for developing an approach for conducting case studies in the coming year,” said Gerst, who is completing her first semester of work on the project.

Research results will include guidance materials for effective HIS; augmenting COSYSMO, a cost model for estimating systems engineering effort; and contributing to the planned 2009 release of the second version of a guidance document for systems engineering leading indicators. The overall goal of the research is to strengthen the ability of leadership to effectively integrate HSI knowledge into the systems engineering process.

Recent work on the project has been published in several conference papers and is available on the SEAri website at seari.mit.edu. SEAri will also be holding a by-invitation only research summit on October 20, 2009. For further information, contact John M. Grace, SDM industry codirector at jmgrace@mit.edu or 617.253.2081.

Distance option helps SDMers stay on career track

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companies to capitalize on their SDM connection,” said John M. Grace, SDM industry codirector. “The students take on real problems, and the companies get broad-based, systems solutions—not just Band-Aids.”

“In the distance program you feel like you’ve got your feet in two boats, and each boat is going very fast,” Chowdhury said, adding that the balancing act is worth it. “There are problems that we uncover every day in the corporate process that SDM has direct answers to. For example, the very day I attended a summary class in technology strategy, I had a meeting at work to discuss our overall vaccine strategy. I was able to directly apply what I’d learned.”

SDM students evaluate mowers for John Deere

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project engineer at John Deere Waterloo Works in Iowa. No one on the team was an expert in commercial turf mowing—yet the skills we learned through SDM enabled us to provide the company with a useful analysis of potential new mower designs.

We began our work with a look at stakeholder requirements. Using information from a stakeholder survey conducted by John Deere, we determined that customers have three core requirements for greens mowers.

1) **No fluids**. A leaky mower can damage golf greens, so customers prefer that no fluids be used in the equipment. Nevertheless, current state-of-the-art mowers include gasoline, grease, and hydraulic fluids.
2) **Less vibration**. Operators need to mow up to nine greens in a single day, so the process must be fast and efficient. Customers therefore prefer a machine with less vibration, because vibrations fatigue the operator.
3) **Ease of serviceability**. Mower blades need to be sharpened daily, so ease of serviceability can reduce overall maintenance costs. Auto sharpening of blades is not currently available on John Deere equipment, but it exists on some competitive machines.

As we learned in SDM, creating the target product specification is critical to the successful development of any product. We therefore used several tools and analysis techniques to ensure a robust, valid, and useful specification. This work included zeroing in on goals with a system problem statement:

To maintain the turf to an adjustable height from 5/64 inch to 1 inch, with no contamination and maximum operator comfort by cutting grass evenly using a John Deere walk-behind greens mower that is easy to service.

Other key goals included maximum safety for the operator and bystanders and least cost of manufacturing.

Our approach to the problem was to develop several alternative concepts, searching for ideas both externally (by reviewing patents, reading competitive product literature, and reviewing the best-in-class survey conducted by

		DATUM Gas Engine Mech Drive		1 Gas Engine Electric Drive		2 Air Engine Electric Drive		3 Battery Powered Electric Drive	
Selection Criteria	Weight		Wgt		Wgt		Wgt		Wgt
Cut Quality	0.400	6	2.40	7	2.80	9	3.60	9	3.60
Feasibility	0.200	10	2.00	10	2.00	3	0.60	5	1.00
Cost of Ownership	0.150	5	0.75	3	0.45	6	0.90	2	0.30
Noise Level	0.050	3	0.15	5	0.25	3	0.15	9	0.45
Vibration	0.050	3	0.15	5	0.25	9	0.45	9	0.45
Maintenance	0.050	5	0.25	8	0.40	5	0.25	8	0.40
Power Output	0.050	10	0.50	10	0.50	5	0.25	7	0.35
Controlability	0.025	7	0.18	8	0.20	8	0.20	8	0.20
Blade Sharpening	0.025	3	0.08	7	0.18	7	0.18	7	0.18
Total summation	1.000		6.45		7.03		6.58		6.93

Figure 1: Pugh selection matrix

John Deere) and internally (by brainstorming as individuals and as a team). This concept generation process yielded five alternative designs.

We then employed the Pugh Selection Process taught in SDM to choose among design options. First we created a list of criteria weighted to reflect their importance to the target product specification. These ranged from cut quality (40 percent) and feasibility (20 percent) to noise level (5 percent) and controllability (2.5 percent). This process revealed that two of our initial concepts—an autonomous vehicle and a mower powered by a hydrogen fuel cell—were infeasible for commercial use at this time.

We therefore selected the following concepts for detailed review:

- **Hybrid gasoline-electric mower**. A traditional internal combustion gasoline engine is used to create energy in the form of a mechanical drive and electric power.
- **Hybrid compressed air-electric engine**. This concept uses a compressed air tank and engine to create energy in the form of electrical power. The air tank would need to be recharged between uses.
- **Battery powered electric mower with an electric drive**. In this case, a battery is used to store electrical power.

All three options included the same blade-sharpening technology for easy serviceability. The air-electric engine would use the fewest fluids, and the electric motor would have the least vibration.

For the final selection process, we employed a weighted average approach using a Pugh selection matrix [see Figure 1]. This process eliminated the air-electric engine from consideration—but it was worthwhile to investigate its feasibility because this was the first time Deere had evaluated this design.

The score for the battery-powered electric drive was so close to that of the gas engine that we decided to perform sensitivity analyses of the concepts by changing the weight associated with each selection criterion.

In our first analysis, we looked to the voice of the customer and decided to place less weight on cut quality and more on noise and vibration. This change puts the battery-powered electric drive on top. A second analysis, adding to the weight for maintenance as well as for vibration and noise level, similarly benefited the electric mower.

However, power output was a critical concern in the battery-powered design. The lack of power meant a golf course would need to buy additional mowers and add operators to do the same work as a single gasoline mower—a major additional cost. We therefore adjusted our analysis to reflect this higher cost as well as the lower feasibility of this design option (the power output of current battery technology cannot truly compete with the internal combustion engine in commercial applications).

As we learned in SDM, creating the target product specification is critical to the successful development of any product. We therefore used several tools and analysis techniques to ensure a robust, valid, and useful specification.

In the end, our product development team recommended the hybrid gas engine-electric motor as superior to the others in power output and feasibility. We found that the current state of the art does not allow for the other alternatives to be commercially viable at this time.

Interestingly, this capstone project was done in parallel with the actual production by Deere of a gas engine hybrid mower. I believe our work confirms that developing that mower was the correct strategy. In addition, our capstone project showed that the complete electric mower is probably closer to reality than most people at Deere believed. Therefore, an important takeaway is the future need to focus on evaluating developing energy storage technologies.

Massachusetts Institute of Technology

SDM calendar summer–fall 2009

If you or your colleagues are interested in attending any of the events listed, please contact SDM Industry Codirector John M. Grace at jmgrace@mit.edu or 617.253.2081.

July 19–23, 2009
MIT Engineering Systems Division and SDM at INCOSE 2009 Symposium

Location: Singapore
Details: www.incose.org/symp2009/

October 20, 2009
SEAri Research Summit

Location: MIT Faculty Club
Time: 8 am–5 pm

October 20, 2009
SDM Information Evening

Location: MIT Faculty Club
Time: 6–9 pm

October 21, 2009
SDM Partners Meeting

SDM industry partners are invited to review curriculum activities, hear from MIT faculty on relevant cutting-edge research, review the year's best theses, develop opportunities for internships and theses, and interact with the 2009 cohort.

Location: MIT Faculty Club
Time: 8:30 am–5 pm

October 21, 2009
SDM Alumni and Student Mixer

Location: TBD

October 22–23, 2009
SDM Conference

Location: Broad Institute
Time: 8:30 am–5 pm

Event information includes all details available at press time. For more current event information, go to sdm.mit.edu and esd.mit.edu.

Health care, energy experts to speak at 2009 systems conference

By Lois Slavin, MIT SDM communications director

SDM's annual systems thinking conference provides opportunities for systems thinkers to learn practical applications from some of the world's leading innovators—including experts from MIT and industry, as well as each other. This year's conference, focused specifically on health care and energy/sustainability, will take place October 22-23, 2009, on the MIT campus. The event has been carefully designed to provide attendees with practical information that can be broadly applied across a range of industries—from automotive and high tech to retail, financials, services, and nonprofits.

The premise of the conference is that complex challenges require a new way of thinking, working, and leading that incorporates disciplines formerly seen as separate, or at best, linked. Conference attendees will learn to apply an interdisciplinary, "systems thinking" approach to challenges that integrates technology, management, and social sciences. Designed to expand the reach of systems thinking to more and more complex systems, the event will stress the importance of designing solutions that incorporate all three areas, with an emphasis on the societal context.

Speakers will not only discuss best practices for applying systems thinking to some of the most pressing and complex challenges of our time—health care, energy, and sustainability—but also how attendees might think about using insights provided in their own work. There will be plenty of opportunity to ask questions, as well as to

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