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The newsletter of the Massachusetts Institute of Technology System Design & Management program

sdm pulse

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Waymo © 2017

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MIT System Design & Management is offered jointly by the MIT School of Engineering and the MIT Sloan School of Management.

For further information, visit **sdm.mit.edu**.

On the cover: During the annual SDM spring tech trek, students visited Waymo, the technology company responsible for the world's first fully self-driving ride on public roads.

Cover photo courtesy of Waymo.

MITsdm

Welcome

We're celebrating SDM's new master's cohort, which recently completed the program's traditional two-week August boot camp. The group is diverse, accomplished, and enthusiastic about its upcoming opportunities within System Design & Management (SDM) and throughout MIT. You can read more about our new fellows on page 30. We're thrilled to have them on board!

We are also celebrating Dr. Bryan Moser, who was recently appointed SDM academic director and senior lecturer. Many of you already know Bryan, who has been teaching in the SDM core for the past several years. He is an extremely accomplished professional in academia, research, and industry. You can learn more about him on page 3. We are delighted to have him in this new leadership role!

In this edition of the *Pulse*, we have several excellent articles by or about SDM alumni, students, and faculty. Together they illustrate the many ways systems thinking can be applied to complex challenges across industries and around the world. Topics include:

- designing an MIT space hotel,
- using technology readiness levels and system architecture to estimate integration risk,
- an update on an SDM alum's successful venture in providing milk-chilling capacity for dairy farmers in small Indian villages; and
- drawing lessons from SDM to teach entrepreneurship in India.

You will also find news, as well as information on recent and upcoming activities, including:

- the 2017 MIT Teaching with Digital Technology Award, presented to Ed Crawley, Bruce Cameron, Oli de Weck, and Bryan Moser;
- the spring 2017 SDM Tech Trek to Silicon Valley and the local trek coming up this fall;
- employment data for self-sponsored fellows who graduated in 2016; and
- a calendar of upcoming SDM events such as on-campus and live, virtual information sessions; the MIT SDM Systems Thinking Webinar Series; and more.

As always, we hope you enjoy this edition of the *Pulse*, and we welcome your feedback and suggestions.

Sincerely,

Joan S. Rubin
Executive Director and Senior Lecturer
MIT System Design & Management
jsrubin@mit.edu

Bryan Moser Named SDM Academic Director

Dr. Moser to Serve on SDM Leadership Team, Oversee Quality of Education and Research

Bryan Moser has been named academic director and senior lecturer for MIT System Design & Management (SDM). Moser has been lead instructor and a member of SDM's core faculty since 2013, along with Professor Edward F. Crawley, Professor Olivier L. de Weck, and Dr. Bruce G. Cameron. This team of faculty recently won an MIT 2017 Teaching with Digital Technology Award (see photo on page 5).

"As a distinguished researcher, a superb educator, and an industry practitioner highly recognized for his contributions to diverse and technically complex projects, Bryan will be invaluable in helping SDM and MIT continue to be at the forefront of interdisciplinary research and education," said Joan S. Rubin, executive director of SDM. "We are thrilled that he is joining the SDM leadership team."

In the past, Moser has taught leadership development in MIT's Technology and Policy Program (TPP). He currently serves as associate director of MIT's Strategic Engineering Research Group and is a project associate professor at the University of Tokyo and director of its Global Teamwork Lab.

Moser earned his doctorate at the University of Tokyo's Graduate School of Frontier Sciences, where he was mentored by Professors Fumihiko Kimura and Hiroyuki Yamato. He researched the dynamics and coordination of complex, global engineering projects.

Moser has more than 26 years of industry experience around the world in technology development, rollout, and sustainable operations in aerospace, automotive, heavy machinery, transportation, energy, telecom, and global services. His research focuses on developing high-performance teams for technically complex projects through the design of socio-technical systems.

"Because SDM students are already accomplished professionals when they matriculate, SDM faculty are required to have deep, relevant, and recent industry experience as well as cutting-edge research expertise in global leadership, teamwork and complex product development," said Steven D. Eppinger, SDM industry co-director (management) and General

continued on page 4

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Motors Leaders for Global Operations Professor of Management. “Bryan brings experience, expertise, and vision that will greatly enhance SDM’s already rich classroom exchanges.”

“Bryan’s track record of innovation in on-campus and distance education, coupled with his research and his commitment to the Institute, will benefit the SDM program’s industrial collaborators as well as our SDM students,” added Warren Seering, Weber-Shaughness Professor of Mechanical Engineering and SDM co-director (engineering). “We are pleased that he will be an integral part of the SDM leadership team and help us evolve SDM’s pedagogical and research agendas.”

A long record of service to MIT

Beginning with his early academic years at MIT, Moser has had a long record of service to the Institute. He believes strongly in the engagement of scientists and technologists in public life.

As an undergraduate, while a student in Course 6 (Electrical Engneering and Computer Science), Moser twice served as president of the MIT student body and was subsequently awarded the Karl Taylor Compton Prize for outstanding achievements in citizenship and devotion to the Institute’s welfare.

As a graduate student he was selected as a Hugh Hampton Young (HHY) fellow. The award not only recognizes academic achievement, but also exceptional personal and character strengths, with heavy emphasis on the perceived overall potential of the candidate to have a positive impact on humanity. Today Moser serves as a trustee of the HHY Council, selecting fellows each year.

When he received his master’s degree from TPP, Moser was also awarded the MIT Alumni Award for Excellence in Technology and Policy.

A career distinguished by innovation and excellence

Moser was one of the first foreign engineers hired by Nissan Motors to work in its Oppama, Japan, factory and Central Research Labs. There he applied artificial intelligence to computer-aided design, multi-objective optimization, and robotic control problems. He later worked at United Technologies Corporation (UTC), where he established the company’s first technology and research center in Asia. He received UTC’s Outstanding Achievement Award for building the organization as well as UTC’s collaboration with industrial partners, universities, and national R&D programs across Asia.

In 1999, he founded Global Project Design (GPD), a company that brings system thinking, model-based project management, and teamwork design tools to complex engineering projects. GPD is still active today in the United States, Japan, and Germany.

Moser said he has been guided throughout his career by the MIT seal and motto. “The craftsman and the scholar, demonstrating ‘mens et manus’ (mind and hand), are a necessary combination to stimulate discovery, rigor, and practicality, which yield important innovations for our increasingly complex world.”

Raised in Northern Kentucky, Moser has lived around the world. He now resides in Winchester, MA, with his spouse, Harunaga Yamakawa Moser.

Team members receiving the 2017 MIT Teaching with Digital Technology Award include, from left: Olivier L. de Weck, professor of aeronautics and astronautics and engineering systems; Bryan Moser, SDM academic director and senior lecturer; and Bruce Cameron, director of the System Architecture Lab and lecturer in engineering systems. (Not shown: Edward F. Crawley, Ford Professor of Engineering.)

Photo courtesy of Office of Digital Learning

SDM Core Faculty Honored with 2017 MIT Teaching with Digital Technology Award

Moser and his SDM faculty colleagues recently received the 2017 MIT Teaching with Digital Technology Award for online/in-class instruction, real-time communication, and polling technologies. Together with Moser, the group included Edward F. Crawley, Ford Professor of Engineering in the Department of Aeronautics and Astronautics; Olivier L. de Weck, professor of aeronautics and astronautics and engineering systems in the Department of Aeronautics and Astronautics; and Bruce Cameron, director of the System Architecture Lab and lecturer in system engineering systems for MIT SDM.

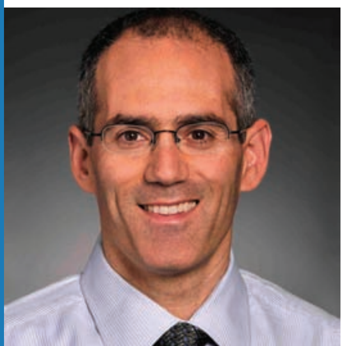
Please join us in congratulating them!

http://

The MIT Teaching with Digital Technology Awards were established in 2016 to celebrate innovations in digital technology and the faculty who develop them. For more information about the awards visit

news.mit.edu/2017/second-annual-mit-teaching-digital-technology-awards-recipients-selected-0725

About the Authors



Steven D. Eppinger is MIT's General Motors Leaders for Global Operations Professor, a professor of management science and engineering systems, and the codirector of MIT System Design & Management. His research centers on improving product design and development practices. He holds SB, SM, and ScD degrees in mechanical engineering from MIT.

Tushar Garg is a program manager in the low-voltage and system integration groups at Tesla. He has spent most of his career launching new products at automakers, including Kia, Hyundai, and Toyota. He received an SM in engineering and management from MIT as a graduate of System Design & Management. He also has a BS in mechanical engineering from the University of California, Irvine.

Using Technology Readiness Levels and System Architecture to Estimate Integration Risk

The challenge: Risk management is one of the most critical activities in new product development. Improper or insufficient risk identification practices can result in unanticipated schedule overruns, significant rework, budget inflation, and reduced capability for delivering the project's chartered scope. Although several decision support tools exist to help project managers identify and mitigate risks, few explicitly consider the impact of a system's architecture.

The approach: This article describes a practical risk identification tool that can be used by engineers and technical managers on projects involving integration of new technology components into systems. Its framework combines system architecture concepts and analysis with technology readiness levels (a metric describing where a given technology is on the path to full maturity) to focus attention on high-risk components and interfaces. It focuses specifically on technical risk, which deals with the uncertainty related to developing and integrating new or complex technologies.

Our goal is to offer a novel risk estimation framework that:

- includes system architecture considerations;
- embraces traditional project management literature;
- defines risk as a combination of likelihood and impact;
- uses technology readiness levels as a proxy for the likelihood that a component will require a change to fulfill its function;
- and, given that change propagates through interfaces, employs network measures to estimate impact related to connectivity.

We then:

- describe how this framework was applied to a project at a high-tech company where data was visualized in different formats to aid in analysis;
- discuss insights gained from this analysis; and
- demonstrate that the risk estimation framework provides insight that is in line with the experience of engineers at the company.

In developing this framework, we grappled with the following questions:

- how to estimate technology integration risk using concepts of technical maturity, architecture, and connectivity; and
- how to keep this assessment effort low enough to enable practical application within industry.

In defining technology integration risk, we focused on concepts of engineering change and change propagation. For highly complex systems, engineering change is required to address mistakes during the design process resulting from uncertainty. In some cases, those changes propagate through interfaces to other components in the system. When mismanaged, relatively small changes can propagate into a cascade of changes that sweep across the system, incurring significant costs and rework. We therefore began our definition by asserting that the technology integration risk of each component *i* is estimated using a common risk metric—the product of likelihood and impact as seen in this equation:

$$Risk_i = L_i \bullet I_i$$

L_i is the likelihood that the component technology requires a change to fulfill its function. This is estimated by using technology readiness levels (TRLs), which have been shown to be good estimators of uncertainty in the technology integration process.

I_i is the severity of impact if the component is forced to change. We examined the overall architecture, and the component interfaces specifically, to estimate the impact of context on change propagation.

The following sections describe the rationale and method behind the inputs for our risk calculation. Given that some of our inputs are unbounded scales, we chose to calculate relative risk rather than absolute risk by rescaling all inputs to fall in the 1–10 range. We choose 1–10 for our range as this is the standard used in failure mode and effects analysis.

A. Likelihood of change

There is a relationship between the likelihood of technical or integration problems in design and the degree of certainty that we have about the design, implementation, and capabilities of a particular component or technology. As we design, test, iterate, and integrate the product or system, we drive uncertainty out through a range of validation activities. To include uncertainty in our risk calculation, it was critical to establish a means of measurement. Fortunately, NASA's TRL scale offered a well-documented, widely used scale for measuring the degree of maturity in a given component. Maturity is also an indicator for uncertainty: Highly mature components have been well-proven in relevant environments and thus have low uncertainty levels. This is precisely the purpose of integration and testing—to minimize uncertainty within the system. The full TRL scale is presented in Table 1 (see page 8).

We evaluate each component using this 1–9 TRL scale to get the base likelihood score. Since a TRL of 9 corresponds to the lowest possible uncertainty, and thus the lowest likelihood of manifesting risks, we inverted this scale and made a TRL of 9 correspond to likelihood value of 1, and a TRL of 1 to likelihood value of 9. This produces a vector where the highest value corresponds to the highest likelihood of risks manifesting. As mentioned earlier, we also rescaled the vector linearly so that the range falls between 1–10.

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About the Authors

Nitin Joglekar is a dean's research fellow and associate professor of operations and technology management at Boston University's Questrom School of Business. His research focus is digital product management. He has a bachelor's degree in naval architecture from the Indian Institute of Technology, Kharagpur, and two SM degrees from MIT, in mechanical and ocean engineering. He also has a PhD in management science from MIT.

Alison Olechowski is an assistant professor, teaching stream, at the University of Toronto in the Department of Mechanical & Industrial Engineering and the Institute for Leadership Education in Engineering. She has a BSc from Queen's University and an MS and a PhD from MIT, all in mechanical engineering.

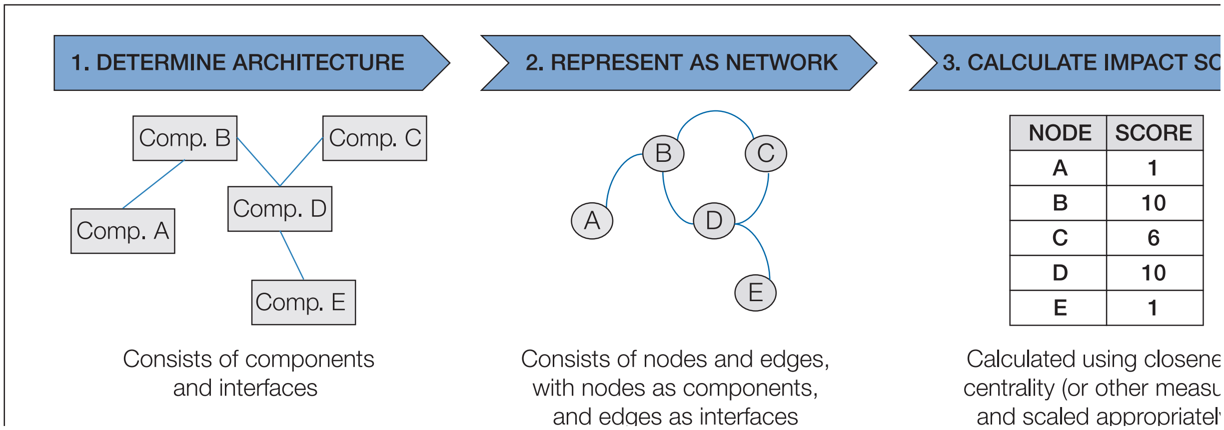

Table 1. Summary of Technology Readiness Levels from NASA's Office of the Chief Engineer.

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B. Severity of impact

When presented with a specific engineering change, a panel of experienced engineers can provide a rough magnitude estimate of the system impact with relative ease. However, without a specific change instance, it can be difficult to conceive of how impactful future changes to any particular component may be. One approach is to estimate the component's potential to propagate change.

Change propagation should be closely monitored in development programs because it can lead to unanticipated impacts to costs and schedule. It has been shown that change propagates between components through their interfaces.[1] Therefore, when estimating the potential impact on the overall system, it is reasonable to consider the system architecture and the connectivity of each component.

Because change propagates through interfaces, we propose that components with higher connectivity are more likely to spread change within the system. With this assumption, there are several tools at our disposal to estimate impact severity. System architecture can be analyzed as an undirected network where components are represented as nodes and interfaces as the edges between nodes. With this view, a simple method for estimating the severity of impact would be to count the number of interfaces for each component. In network terms, this would be referring to the nodal degree of the components. After rescaling the degree count for each node to fall between 1–10, we obtained a vector of scores reflecting the severity of risk for each component. The severity score was then multiplied by our likelihood vector to obtain a risk score for each component. The key advantage to this method is ease of calculation. Engineers can compute this risk score for their system with simple tools such as Microsoft Excel and immediately reap the insights.

While nodal degree is a simple measure that can be applied for this analysis, it does not consider architectural characteristics beyond immediate interfaces of the component. Alternative network analysis metrics that account for more indirect change propagation paths could also be useful, such as closeness centrality, betweenness centrality, and information centrality. Each provides a unique perspective on the importance of network nodes; however, they are all highly correlated and in most cases will net similar insights to nodal degree. Still, on occasion there will be some nodes where

[1] P. J. Clarkson, C. Simons, and C. Eckert, "Predicting Change Propagation in Complex Design," *J. Mech. Des.*, vol. 126, no. 5, p. 788-797, 2004.

different measures have significant differences, and generally these nodes have unique characteristics worth examining. Calculating the three centrality measures generally requires specialized software which, while freely available, may be less accessible and more difficult to understand. Practitioners must decide which centrality measure will be most meaningful for their application.

The overall method that we apply in this research is illustrated and summarized in Figure 1.

The results: Analog Devices Inc., a large multinational semiconductor company headquartered in Massachusetts, was our industry partner for this research. Together we analyzed a new product development program that is currently under way for a sensor package that could be used to precisely measure angular position. We gathered the following inputs:

- a decomposition of the system into six subsystems and 20 components,
- a list of interfaces between every component in the system, and
- a TRL assessment for every component in the system.

Using these data, we built a view of the system architecture and developed a network representation of the system as illustrated in Steps 1 and 2 from Figure 1. Once all data was collected, we calculated our impact and likelihood vectors as in Steps 3, 4, and 5 of Figure 1 to obtain final risk scores (Step 6). For simplicity's sake, we demonstrated this example using nodal degree as

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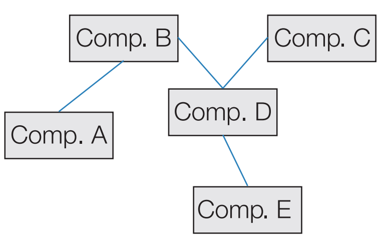
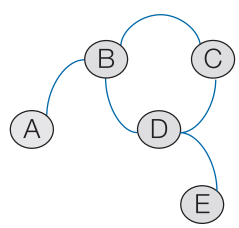
1. DETERMINE ARCHITECTURE



Consists of components and interfaces

2. REPRESENT AS NETWORK



Consists of nodes and edges, with nodes as components, and edges as interfaces

3. CALCULATE IMPACT SCORES

NODE	SCORE
A	1
B	10
C	6
D	10
E	1

Calculated using closeness centrality (or other measure) and scaled appropriately

4. DETERMINE TRL VALUES

COMP.	TRL
A	9
B	7
C	5
D	9
E	9

Determine TRL values for each component

5. CALCULATE LIKELIHOOD SCORES

NODE	SCORE
A	1
B	5.5
C	10
D	1
E	1

Calculate likelihood scores by inverting TRL values and rescaling

6. CALCULATE RISK SCORES

COMP.	IMPACT	LIKEL.	RISK
A	1	1	1
B	10	5.5	55
C	6	10	60
D	10	1	10
E	1	1	1

Calculate risk score by taking the product of impact and likelihood scores

Figure 1. Summary of method used to calculate risk involved in integrating a new component into a system.

		Likelihood		Impact		
Subsystem	**Component**	**TRL**	**Risk Input**	**Degree**	**Risk Input**	**Risk**
Package	Die attach	8	2.5	13	10.0	25
	Leadframe	7	4	5	2.8	11.2
	Wirebond	9	1	6	3.7	3.7
	Plastic Mold	9	1	13	10.0	10
ASIC for Sensor 1	Sensor 1 Analog Front End	7	4	4	1.9	7.6
	Sensor 1 Analog-to-Digital Converter	3	10	5	2.8	28
	Sensor 1 Calibration	9	1	5	2.8	2.8
	Sensor 1 Processor	9	1	5	2.8	2.8
ASIC for Sensor 2	Sensor 2 Analog Front End	9	1	4	1.9	1.9
	Sensor 2 Analog-to-Digital Converter	3	10	5	2.8	28
	Sensor 2 Calibration	9	1	3	1.0	1
	Sensor 2 Processor	9	1	5	2.8	2.8
ASIC	ASIC Input/Output	9	1	6	3.7	3.7
	ASIC Non-volatile Memory	6	5.5	7	4.6	25.3
	ASIC Regulator	9	1	7	4.6	4.6
	ASIC Oscillator	9	1	10	7.3	7.3
	ASIC Analog Front End	9	1	4	1.9	1.9
	ASIC Analog-to-Digital Converter	9	1	6	3.7	3.7
Sensor 1	Sensor 1 Design/Layout	5	7	7	4.6	32.2
Sensor 2	Sensor 2 Design/Layout	5	7	6	3.7	25.9

Figure 2. This graphical representation of the components and their change likelihood, change impact, and overall risk scores provides an insightful view of the system integration risk.

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our measure for impact. The inputs and final risk calculation is shown in Figure 2, with bars in each cell representing magnitudes.

To preserve information about interfaces, we combined risk score information with a design structure matrix (DSM) view of the system (Eppinger and Browning, 2012). To do this, we chose each off-diagonal mark in the matrix to represent a risk score composed of the two interfacing components. The calculation is done according to this equation:

$$\textit{Interface risk}_{ij} = \max (L_i, L_j) \bullet \max (I_i, I_j)$$

L_i and L_j represent likelihood scores for the two interfacing components, and I_i and I_j represent impact scores for each component. We can see the intuition behind this choice in the following example: Suppose a highly uncertain (low-TRL) component were to interface with a highly connected (high-impact) component. If the high-uncertainty component had to be changed during the design process, it is possible that the highly connected component would require a change as well, and it could take careful design and planning to ensure that the change would not propagate beyond that component. Indeed, it may not be possible to fully contain the changes at this highly connected component, and thus you can see the need to scrutinize that interface carefully. Figure 3 enables us to see the results of this analysis. We leave the component-level risk calculations as a vector in the “risk” column as an additional reference.

Subsystem	Component	RISK	TRL	8	7	9	9	7	3	9	9	9	3	9	9	9	6	9	9	9	9	5	5
Package	Die attach	25	8		40	25	25	40	100			25	100					25	25	25	25	70	70
	Leadframe	11	7	40		15	40															32	26
	Wirebond	4	9	25	15		10									4						32	26
	Plastic Mold	10	9	25	40	10		40	100			10	100					10	10	10	10	70	70
ASIC for Sensor 1	Sensor 1 Analog Front End	8	7	40			40		28													32	
	Sensor 1 Analog-to-Digital Converter	28	3	100			100	28		28									73				
	Sensor 1 Calibration	3	9						28		3						25				4	32	
	Sensor 1 Processor	3	9							3						4	25		7			32	
ASIC for Sensor 2	Sensor 2 Analog Front End	2	9	25			10						28										26
	Sensor 2 Analog-to-Digital Converter	28	3	100			100					28		28					73				
	Sensor 2 Calibration	1	9										28		3		25						
	Sensor 2 Processor	3	9											3		4	25		7				26
ASIC	Input/Output	4	9			4					4				4		25	5	7				
	Non-volatile Memory	25	6							25	25			25	25	25		25	40				
	Regulator	5	9	25			10									5	25		7	5	5		
	Oscillator	7	9	25			10		73		7		73		7	7	40	7			7		
	Analog Front End	2	9	25			10											5			4		
	Analog-to-Digital Converter	4	9	25			10			4								5	7	4			
Sensor 1	Sensor 1 Design/Layout	32	5	70	32	32	70	32		32	32												
Sensor 2	Sensor 2 Design/Layout	26	5	70	26	26	70					26			26								

Figure 3. The technology risk design structure matrix provides an architectural view of the system integration risk for the Analog Devices project.

We presented our findings to Analog Devices team and discussed the results. Analysis suggests the riskiest components were both sensors (Sensor 1 and Sensor 2), followed by the analog-to-digital converters. This aligned with the Analog Devices team's experience and expectations. In addition, analysis shows the die attach portion of the packaging subsystem is risky. In the early phases of the data collection, the managers had mentioned that the packaging was a point of concern for them, and this is seen in the risk of the die attach.

One manager remarked that the team at Analog Devices implicitly does this kind of risk assessment mentally to gauge risk level of various components in their program. The engineer would consider the "newness" or uncertainty of a component, and the centrality to its role in the system, and use these two ideas to estimate risk. He noted that the newly developed method formalizes the thought process, making it measured and objective.

Next steps: This method could be built into an analytical tool as an add-on to an existing DSM system architecture software toolkit (for an example, see www.dsmweb.org/en/dsm-tools.html). These concepts are already being taught in MIT's System Design & Management program and in other system-based classes.

This work will be presented at the International Conference on Engineering Design in Vancouver, Canada, in August 2017. The research team continues to pursue research related to technology integration risk, and in particular the technology readiness levels.

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For more detailed information, please see our technical article

web.mit.edu/eppinger/www/pdf/Garg_ICED2017.pdf

with supporting citations and a thesis

dspace.mit.edu/handle/1721.1/110134

http://

Members of the interdisciplinary MIT team that won first place in the graduate division of the Revolutionary Aerospace Systems Concepts–Academic Linkage Design Competition Forum include, from left: Caitlin Mueller (faculty advisor), Matthew Moraguez, George Lordos SDM ’16, and Valentina Sumini. (See pages 14-15 for poster details.)

Image courtesy of the MARINA team

MIT Space Hotel Wins NASA Graduate Design Competition

By Matthew Maraguez, G, MIT Aeronautics and Astronautics

An interdisciplinary team of MIT graduate students representing five departments across the Institute was recently honored at the Revolutionary Aerospace Systems Concepts-Academic Linkage Design Competition Forum. The challenge involved designing a commercially enabled habitable module for use in low Earth orbit that would be extensible for future use as a Mars transit vehicle. The team’s design won first place in the competition’s graduate division.

The MIT project, the Managed, Reconfigurable, In-space Nodal Assembly (MARINA) was designed as a commercially owned and operated space station, featuring a luxury hotel as the primary anchor tenant and the National Aeronautics and Space Administration (NASA) as a temporary co-anchor tenant for 10 years. NASA’s estimated recurring costs, $360 million per year, represent an order of magnitude reduction from the current costs of maintaining and operating the International Space Station. Potential savings are approximately 16 percent of NASA’s overall budget—or around $3 billion per year.

MARINA team lead Matthew Moraguez, a graduate student in MIT’s Department of Aeronautics and Astronautics (Aero/Astro) and a member of Professor Olivier L. de Weck’s Strategic

Engineering Research Group (SERG), explained that MARINA's key engineering innovations include:

- the extensions to the International Docking System Standard (IDSS) interface;
- the modular architecture of the backbone of MARINA's node modules; and
- the distribution of subsystem functions throughout the node modules.

"Modularized service racks connect any point on MARINA to any other point via the extended IDSS interface. This enables companies of all sizes to provide products and services in space to other companies, based on terms determined by the open market," said Moraguez. "Together these decisions provide scalability, reliability, and efficient technology development benefits to MARINA and NASA."

MARINA's design also enables modules to be reused to create an interplanetary Mars transit vehicle that can enter Mars' orbit, refuel from locally produced methane fuel, and return to Earth.

MARINA and SERG team member George Lordos was formerly a graduate fellow in MIT System Design & Management. Lordos pointed out that MARINA's engineering design innovations are critical enablers of its commercial viability, which rests on MARINA's ability to give rise to a value-adding, competitive marketplace in low Earth orbit.

Lordos also holds a Sloan MBA earned in 2000 and entered MIT's Aero/Astro doctoral program in fall 2017. "Just like a yacht marina, MARINA can provide all essential services, including safe harbor, reliable power, clean water and air, and efficient logistics and maintenance," said Lordos. "This will facilitate design simplicity and savings in construction and operating costs of customer-owned modules. It will also incent customers to lease space inside and outside MARINA's node modules and make MARINA a self-funded entity that is attractive to investors."

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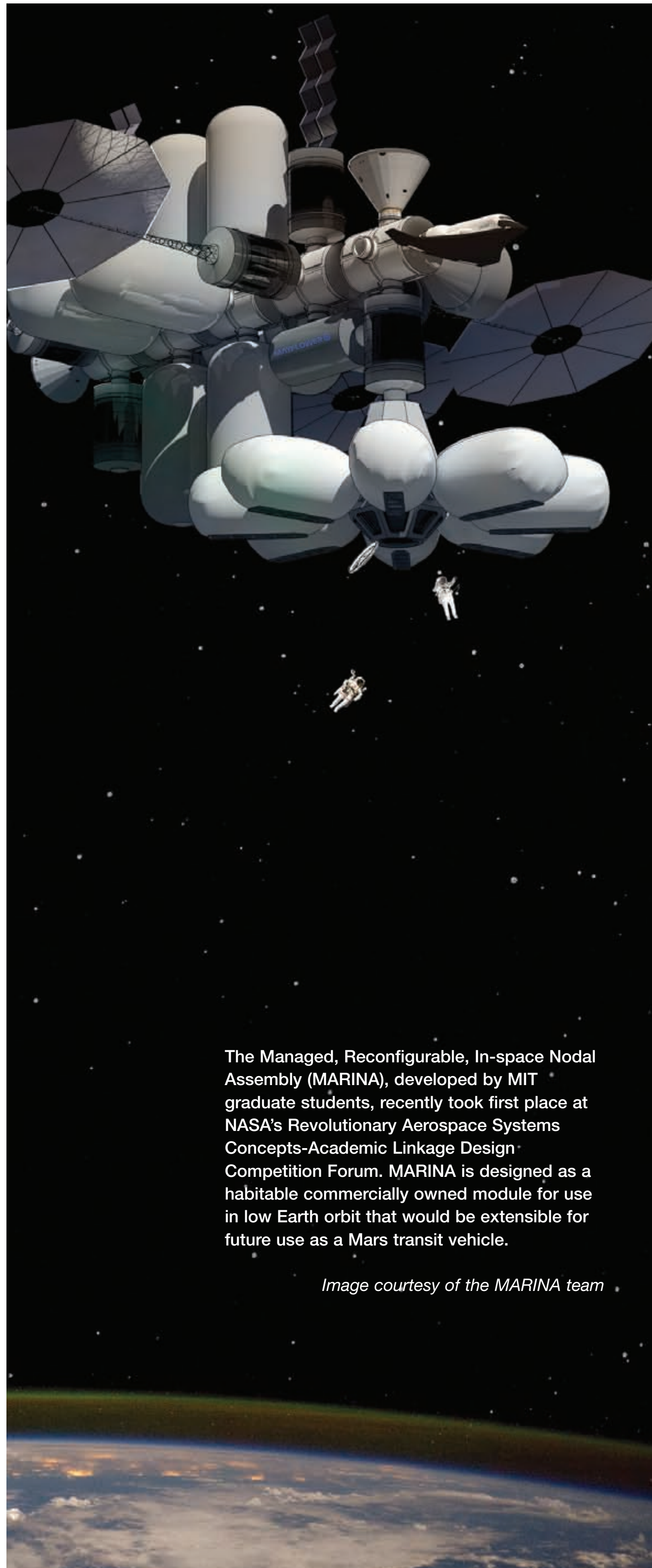

The Managed, Reconfigurable, In-space Nodal Assembly (MARINA), developed by MIT graduate students, recently took first place at NASA's Revolutionary Aerospace Systems Concepts-Academic Linkage Design Competition Forum. MARINA is designed as a habitable commercially owned module for use in low Earth orbit that would be extensible for future use as a Mars transit vehicle.

Image courtesy of the MARINA team

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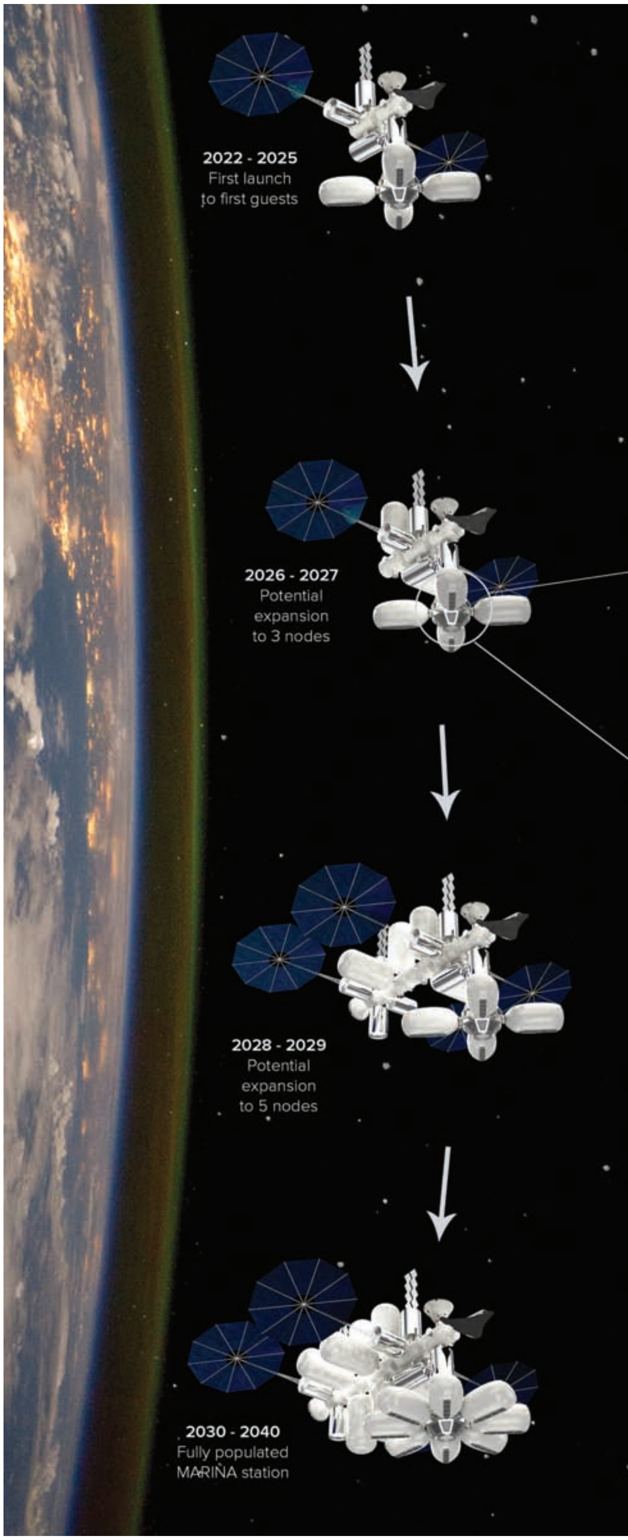
Dr. Valentina Sumini, a postdoctoral fellow at MIT, contributed to the architectural concept being used for MARINA and its space hotel, along with MARINA faculty advisor Assistant Professor Caitlin Mueller of both MIT's School of Architecture + Planning (SA+P) and MIT's Department of Civil and Environmental Engineering (CEE).

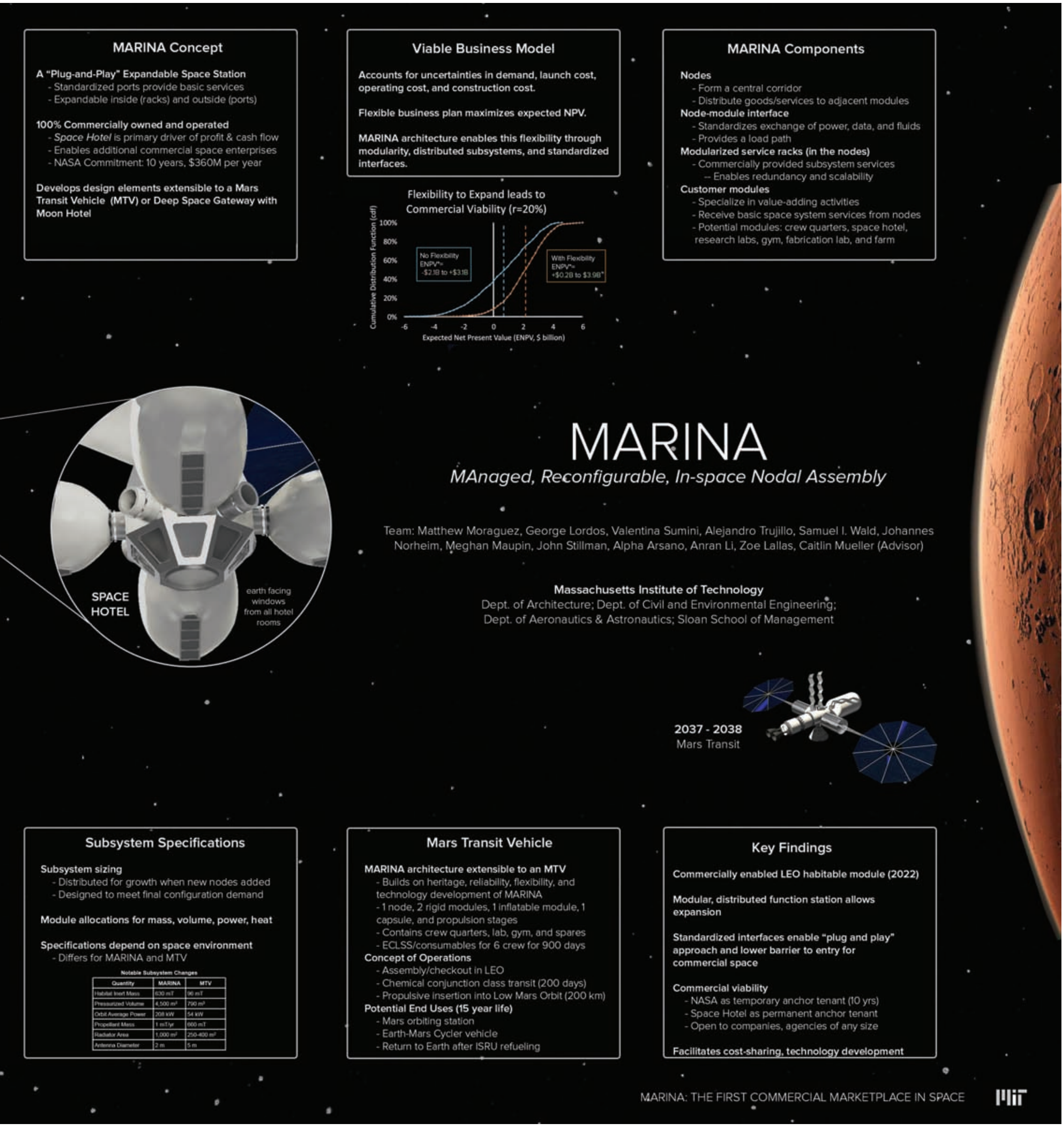
"MARINA's flagship anchor tenant, a luxury Earth-facing eight-room space hotel complete with bar, restaurant, and gym, will make orbital space holidays a reality," said Sumini.

Other revenue-generating features include rental of serviced berths on external International Docking Adapter ports for customer-owned modules and rental of interior modularized rack space to smaller companies that provide contracted services to station occupants. These secondary activities may involve satellite repair, in-space fabrication, food production, and funded research.

Additional members of the MARINA team include:

- Aero/Astro graduate students and SERG members Alejandro Trujillo, Samuel Wald, and Johannes Norheim;
- CEE undergraduate Zoe Lallas;
- SA+P graduate students Alpha Arsano and Anran Li; and
- MIT Integrated Design & Management graduate students Meghan Maupin and John Stillman.





This poster, outlining the concept, components and business model for the Managed, Reconfigurable, In-space Nodal Assembly was presented at the RASC-AL 2017 Forum at Cocoa Beach, FL, on May 31, 2017. RASC-AL is an annual aerospace systems design competition open to graduate and undergraduate student teams, organized by the National Institute of Aerospace on behalf of NASA.

Image courtesy of the MARINA team

About the Author

Rajesh Nair is an award-winning entrepreneur and the holder of 13 US patents. He currently serves as chairman of Degree Controls Inc., a company he cofounded. He is a visiting scholar at MIT and a senior lecturer at the Asia School of Business, where he serves as director of the Innovation and Entrepreneurship Center.

He holds two bachelor's degrees: one in physics from the University of Kerala and one in electronics and communications engineering from the Indian Institute of Science. As a graduate of MIT System Design & Management, he also holds a master's degree in engineering and management from MIT.

Cultivating Aspiring Entrepreneurs Around the World

MIT Grad Reflects on How SDM Furthered His Life's Mission

The challenge: The world needs entrepreneurs for many reasons: to create jobs, to create wealth, and to develop new ways to address societal challenges. In 2007, when I was a student in MIT System Design & Management (SDM) and a Tata Fellow, I decided to find ways to create entrepreneurship communities in India's underserved areas. My goal was to nurture aspiring student entrepreneurs and thus change villages, towns, and ultimately, the nation.

Today, most government and private initiatives that aim to develop entrepreneurs in India provide them with mentoring support during a startup's early stage. However, this has not produced intended results. A simple systems dynamics model reveals that this is primarily due to the scarce supply of aspiring entrepreneurs.

This, in turn, appears to arise because not enough young people are being inspired, educated, and supported by their educational institutions, families, and communities to pursue entrepreneurship. In essence, we need to cultivate aspirants by giving them ample opportunities to learn the fundamentals of business before they take on their first real startups.

This was a challenge I understood personally. When my first company failed and I lost much of my own funds, I thought perhaps I was not born to be an entrepreneur. Close friends and family felt I should abandon my startup dreams and get a desk job. However, despite—or perhaps because of—my prior failure, I learned invaluable lessons and therefore felt better equipped than ever to succeed. I later applied the lessons I had learned to my second and third startups, which were progressively more successful.

The question was: How could I use my personal experience, my Tata fellowship, and my SDM thesis research to create a training process to catalyze and nurture young innovators and prospective entrepreneurs from underserved areas who otherwise would have simply taken a job?

The approach: As an SDM fellow and a systems thinker, I decided this would be the focus of my master's thesis. I began by exploring the existing ecosystem to better understand why potential startup founders were not getting the help they needed. I traveled to several rural towns and villages in India as well as to nearby universities to explore how entrepreneurs could be nurtured to create long-term, systemic social impact.

I found students in rural colleges were as intelligent as their peers in top schools anywhere. However, they lacked exposure to a broad range of topics. By contrast, their peers in top schools learned new concepts faster through interpolating and extrapolating from adjacent concepts that they already knew. I believe what one already knows is a significant indicator of how fast one can learn a related concept, and fast learning of new topics builds one's self-efficacy.

Self-efficacy, or the confidence to face an unknown challenge, is a key factor in determining whether one can "make it" as an entrepreneur. Self-efficacy develops through an iterative process that involves:

- attempting challenges outside one's current abilities,
- facing failures and learning from them, and
- repeating the effort and thus expanding one's zone of competence.

Author Rajesh Nair, SDM '12, poses with students at a TinkerFest held in Delhi, India. Participation in such events is one way Nair is helping to support future entrepreneurship.

However, there were several barriers to developing an academic system that could cultivate creativity, foster entrepreneurial courage, and build self-efficacy. These included:

- **Educational norms.** India's academic system largely focuses on rote memorization, not creative thinking. The goal is for students to pass technical licensing exams and get jobs.
- **Family expectations.** Families typically encourage students to get jobs, rather than start businesses, because there is a common belief in India that entrepreneurship is too risky.
- **Community limitations.** While the spirit of innovation in individuals is high in India, the actual drive to share lessons, propagate entrepreneurship, and create systemic change is not—due to cultural factors that limit the opportunities for scaling the solution across the nation.

I chose to address the entrepreneurship challenge by building students' self-awareness and self-efficacy through developing an educational program grounded in systems thinking that could be adapted as needed by others and scaled across India. As an engineer, product designer, and entrepreneur, I focused on one question: Could students learn to design multidisciplinary product systems if we helped them learn skills in different disciplines such as team ideation, user experience, mechanical and electrical systems, and basic coding?

That question led to others:

- Would applying their lessons learned to designing products enable students to relate better to what is taught in the classroom?

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- Would learning to design inspire them to create products that can help solve real-world problems?
- Would that, in turn, lead students to consider the possible commercialization of these products?
- Ultimately, would all this inspire students to take the nontraditional path of entrepreneurship?

The process: I developed and conducted a series of workshops to introduce students to different phases of product development and give them opportunities to move beyond their own thresholds of fear and limitation. I also worked with students individually to help them realize their potential to achieve entrepreneurial goals.

To move students through the process, I created a curriculum based on my own life experience and what I learned at SDM that focuses on the transitions I made—from a child growing up in a village in India, to new graduate, to product designer, and entrepreneur. This consists of four stages:

- **Zero:** Students with unrealized potential looking to graduate and find steady jobs. Most university students fall into this category, many of them influenced by their parents' career views and by social pressures to "settle down."
- **Maker:** Students learning to design and make prototypes and products. I use current technologies, such as digital fabrication, to teach students to rapidly design and create products. I created a program called 48-Hour MakerFest where attendees learn to ideate, design, and fabricate prototypes. Students learn to make things in teams and demonstrate their products in just two days.
- **Innovator:** Students learning to identify and solve unmet human needs. I introduce design thinking to teach students to observe, engage, and empathize with customers; to identify and define needs; and ultimately to develop and validate solutions. I created a weeklong workshop that takes students through the making and design thinking process to create and demonstrate solutions for real problems in the community.
- **Entrepreneur:** Students learning to launch a venture to commercialize solutions that address real-world needs. I developed a two- to four-week-long boot camp that takes the students through making, design thinking, and the startup process. In 2016, this became an accredited course at the University of Rhode Island.

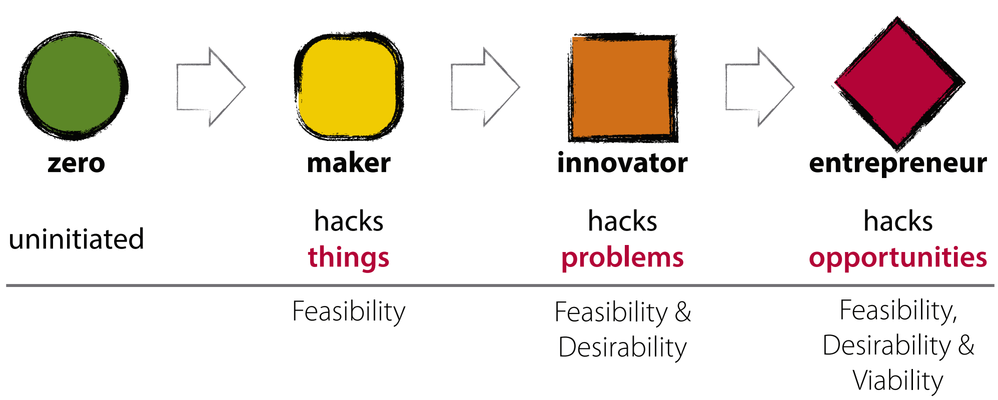


Figure 1. The author identified four stages of entrepreneurship, ranging from students with unrealized potential (zero) to students learning to launch ventures (entrepreneur). Important areas of focus are shown for each stage. A 'maker' focuses on making things that are feasible. The 'innovator' addresses both the feasibility and desirability of the solution. And, the 'entrepreneur' considers all three.

In my classes, students learn to apply design thinking principles to identify needs, evaluate them as business opportunities, and then create solutions. They are asked to:

- visit places outside their comfort zone—such as tribal villages, cattle farms, homes for the disabled, even red-light districts;
- immerse themselves in these communities by observing and interacting with people;
- use these interactions to identify unmet community needs; and
- devise solutions to these unmet needs that could create impact.

This curriculum is intended to train students to innovate, create, and begin to consider entrepreneurship as a serious career option. The goal is to help them go beyond traditional ways of thinking about their prospects and potential and ignite a change in attitude, driven by self-efficacy.

The results: I have conducted more than 40 intensive, hands-on MakerFests, innovation workshops, and entrepreneurship boot camps around the world, reaching some 1,500 people. These events have given rise to several startups, whose products and services included mobile apps, medical products, and community building.

However, these workshops are not primarily about teaching technology, solving problems, or even launching ventures. They are about helping students build self-efficacy to pursue larger missions.

I strongly believe that if we want to build an ecosystem where entrepreneurship is seen as a valid choice, it is important to start changing attitudes while students are still young and unafraid to experiment. We need to build a community of students who can support each other in innovation, and we need to support them by providing mentoring as well as maker-spaces where they can meet and work on projects.

To do this, I am now moving my work into middle and high schools—helping the Indian government roll out Tinkering Labs and innovation training programs in more than 1,000 middle and high schools across the country to develop future innovators and entrepreneurs. As part of this endeavor, this summer I helped train 48 engineering and business students from top institutes around the world—including MIT—who subsequently went out to schools around Delhi and mentored students in eighth through 12th grade in basic design and making skills. This new, hands-on way of learning made a huge impression on the children, and I expect that for many the experience will seed a passion for innovation going forward.

Next steps: What began as an SDM research thesis has now become my life's mission—my current goal is to incubate 1,000 entrepreneurs. These entrepreneurs will stumble and learn their way to founding companies that create jobs and wealth. I believe that catching them young will allow students to be unafraid of bypassing conventional routes to employment and live up to their full potential.

About the Author

Sorin Grama, SDM '07, is the cofounder of Promethean Power Systems, which manufactures and sells milk-chilling systems in India, Bangladesh, and Sri Lanka. After living in India for a few years, Grama is now back at MIT as entrepreneur-in-residence at the Martin Trust Center for MIT Entrepreneurship and the Legatum Center for Development & Entrepreneurship.

Alum Navigates Systems Challenges to Launch Successful Milk-Chilling Business

The challenge: Milk is India's lifeblood. Indians depend on milk for much of their daily nutrition. It is used in curries, the beloved chai, and even for religious rituals. India draws its milk supply from millions of small farmers in villages scattered across the vast countryside. Milk must be collected twice every day, 365 days a year, and rushed to a processing center before it spoils. As a result, the milk supply chain presents a huge challenge for dairy processors.

I learned about this challenge in 2007 when I was visiting India for the first time looking for business opportunities. One of our hosts was a dairy in Bangalore that was having a problem collecting fresh, quality milk. I learned that milk is collected in three steps:

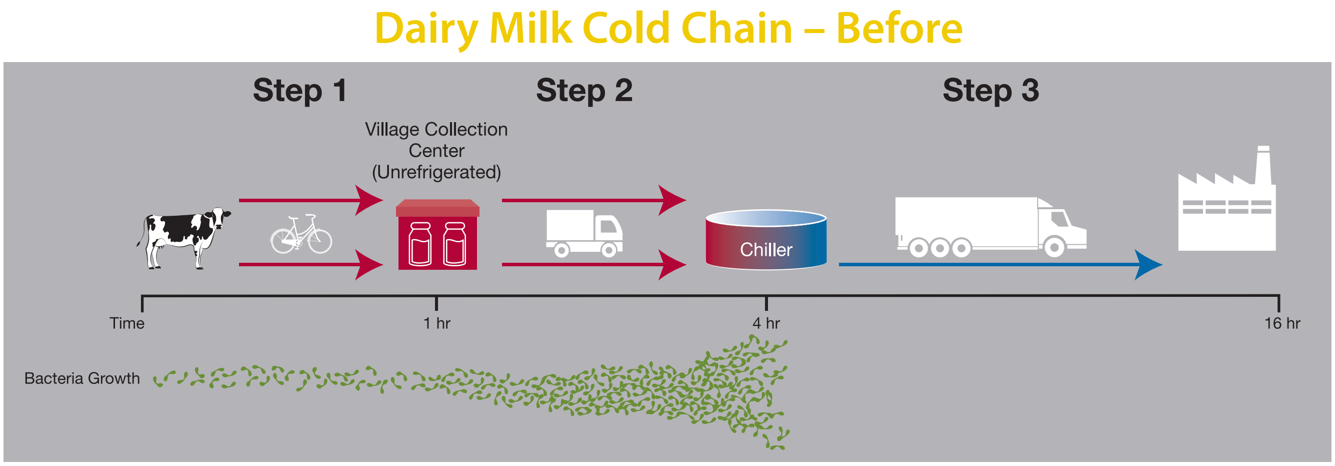
- **Step 1**: Individual farmers deliver 5–10 liters of milk to a collection center in a village. A collection center may aggregate from 500 to 2,000 liters of milk per day from 20–40 farmers.
- **Step 2**: Milk is picked up and transported to a nearby chilling center. Because refrigeration is not used at the village collection center, the dairy processor needs to pick up the warm raw milk quickly, within 5–6 hours, before it spoils.
- **Step 3**: The milk is transported from the chilling center to a processing center where it is pasteurized and processed into such products as cheese and ice cream.

These steps are repeated for thousands of collection centers, twice every day, all over India. It is a huge logistics challenge, and one that I soon discovered could have significant business potential.

The approach: I began by studying the collection process fully so I could identify the pain points. In 2008 my team and I spent an entire month traveling through rural India following the "milk trail" from farmers to consumers. We made a video of this process so we could later explain the challenge to our US partners and investors.

We learned that the highest pain point in this supply chain was at the source, in the villages where the milk is produced. If milk is not refrigerated immediately after milking, bacteria starts to grow exponentially, changing the taste and eventually spoiling the milk. The sooner milk could be refrigerated, the better it would be for everyone in the system: farmers, processors, and consumers. If milk could be refrigerated at the village, multiple benefits would accrue, including:

- **Lower transportation costs.** Milk could be picked up just once a day.
- **Access to additional supplies.** Since refrigerated milk lasts considerably longer, the supply chain could extend farther into the countryside.
- **Better milk quality.** This benefit is particularly significant since it would allow processors to sell higher-value milk products such as butter, yogurt, and ice cream.



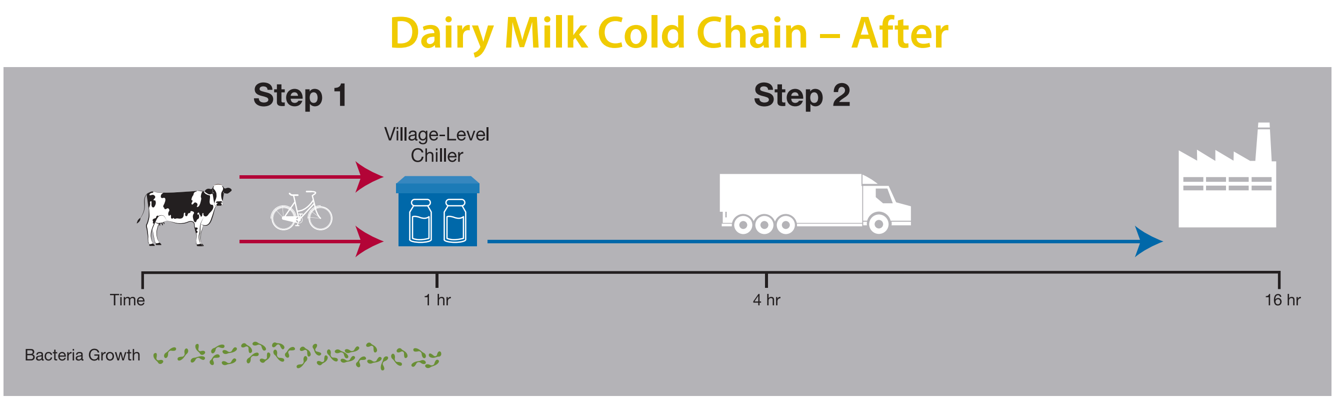


Figure 1. Traditionally, milk collection in India follows three steps (top image), which means fresh milk typically goes unrefrigerated for several hours—during which time bacteria can grow and spoil the milk. Promethean Power Systems was launched to facilitate a two-step process (bottom image) that refrigerates milk much sooner, curbing the growth of bacteria and preserving milk quality.

If there are so many benefits to refrigerating milk at the source, I had to ask: Why weren't dairies doing this? The answer is simple. Refrigeration in rural India is difficult to achieve because of an underlying problem: lack of reliable grid power. The milk supply challenge is really a power infrastructure challenge. If a refrigeration system could be reliably powered, the main problems in this supply chain could be addressed.

The tools: To understand the problem more deeply, I used contextual inquiries and immersion in my customers' world, two user-centric design methods I learned in Product Design & Development, a course I took while a student in MIT System Design & Management (SDM). Based on these observations, I decided the best solution would be a stationary milk chiller that could be operated at a village collection center to chill milk immediately after it has been delivered by farmers.

To design this solution, I used the systems architecture and product design teachings that were still fresh in my mind at the time. I tackled the problem by first decomposing the system into modules that could be designed and developed separately. I then integrated these modules into a final system.

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The two critical modules in this system are: the power module and the refrigeration module. For the power module, I quickly determined that solar power would be the best option. I had some experience with solar power—my SDM thesis was a survey of thin-film solar technologies—and believed that solar power costs would come down dramatically over time. Next, I began to explore different ways to achieve refrigeration efficiently using solar power. I investigated thermoelectrics, absorption chillers, and iceboxes, but I eventually settled on DC-powered vapor compressors.

Sources of Power	Methods of Refrigeration
Solar	Thermoelectric
	Ice
	DC Vapor Compressor
	AC Vapor Compressor
	Vapor Absorption

Figure 2. Fixing on solar power made it possible to explore multiple concepts for refrigeration.

The results: My team and I built three prototypes over a period of three years, and with each prototype we learned something new and improved the design. However, the cost of solar power was still prohibitively high, a challenge exacerbated by the difficulty of obtaining the DC components we needed at a reasonable price. The most painful and vivid lesson came when our pilot customer rejected the system as too complex, too expensive, and too difficult to install. We had spent all our time and money to design a beautiful solar-powered refrigeration system only to discover that it was impractical and uneconomical. It was a tough lesson, and it looked as if it would be the end of the road for our startup.

But there was a glimmer of hope…

During the process of designing the solar power module, I had also designed a backup subsystem, since solar is not very useful unless you can store the energy and use it later. Because we were dealing only with refrigeration, I chose a simple thermal storage system comprised of a cold water tank. During the day, water can be chilled and stored in an insulated tank. The chilled water can then be used to chill milk in the early morning and late evening. The thermal backup was almost an afterthought, a necessary but not a critical component.

With a bit of reflection, I realized that we could drop the solar component and instead use the existing power grid with our thermal storage as

One of the farmers who uses Promethean Power Systems' equipment carries a jug of milk in the village of Mottur in Tamil Nadu, India.

Image courtesy Promethean Power Systems a backup. The grid is usually available in villages; it just doesn't always work when you need it. We could charge our thermal battery when the grid was on, and use it as a backup when the grid was off. It was a simpler and more elegant solution. We quickly built a prototype, tested it, and it worked.

Sources of Power	Methods of Refrigeration
Solar	Thermoelectric
Biogas Generator	Ice
Battery	DC Vapor Compressor
Grid	**AC Vapor Compressor**
	Vapor Absorption

Figure 3. Ultimately, it became clear that the solution space for India's milk-chilling challenge should have included additional power source options.

From then on things moved quickly. We iterated and improved on the thermal storage system, which became our differentiator and the source of our competitive advantage over conventional milk chillers, which use diesel backup generators—an expensive option. We eventually patented it and used it for other cooling applications. To date, we have installed more than 600 chilling systems throughout rural India. Each system has a capacity of 1,000 liters and serves the needs of 30 to 40 farmers.

The lesson: With the benefit of hindsight, I realize the mistake I made during my system design. To be fair, it was a complex system with a lot of moving pieces. I started by fixing on a power source (solar) and investigated different concepts for refrigeration. What I should have done is fixed on a known and economical method of refrigeration (AC-powered vapor compressor) and explored different concepts for generating reliable power: solar, biogas, battery, etc. After all, this was a power infrastructure problem that I was solving, not a refrigeration problem. My bias and preference for solar prevented me from truly exploring the full solution space for this problem. I learned my lesson the hard way, but I don't regret the journey. Mistakes were costly, but they were also sources of inspiration.

http://

For more information about Sorin Grama, SDM '07, and his company, Promethean Power Systems, visit

www.promethean-power.com

Spring 2017 SDM Tech Trek Report

Each year, some of MIT's best and brightest graduate students visit several of the world's most innovative and successful companies to learn about leadership, innovation, and systems thinking from industry experts—and to explore recruitment opportunities.

The biannual MIT System Design & Management (SDM) Tech Trek is a tradition that has evolved over the past several years. Organized and run by SDM fellows, the treks were developed to enable SDM students to explore a variety of industries, examine different platforms and technologies, and speak with and learn from leaders at best-in-class companies. These up-close, personal interactions further the students' education while also strengthening the relationship between SDM and host companies, fostering future opportunities.

Two treks are held annually: one in the San Francisco Bay/ Silicon Valley area in the spring and one in Greater Boston each fall (see story on page 28).

During the spring 2017 trek, SDM visited Amazon, C3 IoT, Continental, Ericsson, Google, Intel, Planet Labs, and Tesla. Several of these have sponsored thesis research or other projects; some already have SDM alumni on their staff and/or are looking to hire SDM graduates.

SDM Executive Director Joan S. Rubin remarked on the generosity of the companies visited during the treks. "All of them opened their doors to SDM students and provided unsurpassed opportunities to hear from industry leaders, tour facilities, and experience product/technology showcases and demonstrations. Most importantly, they shared the time, knowledge, and experience of some of their most talented people with the SDM fellows—offering a privileged and much-appreciated opportunity for networking and learning."

The 2017 spring tech trek was organized and led by SDM 2016 fellows Christian West and Jose Garza. Organizational assistance was provided by all student participants, as well as by Rubin, SDM Director of Recruitment and Career Development Jon Pratt, Logistics and Administrative Specialist Amanda Rosas, and Career Development and Alumni Associate Naomi Gutierrez.

Amazon

Planet Labs

Trip highlights:

- At Continental's offices in San Jose, CA, the SDM group met with the company's vice president and head of products for intelligent transportation systems (ITS), Pasula Reddy; the director of products for Access Solutions ITS, Raj Sundar; and the head of products in China ITS, Yao Zhai. These leaders provided a general corporate overview, described overall industry challenges, discussed the organization's project development structure; and gave product demonstrations. Later, SDM fellows went on a company tour to see some of the infrastructure put in place to support the company's evolution. Throughout the visit and during an informal networking session, Continental executives encouraged questions, feedback, and suggestions from the SDMs on what they had seen and heard. Tour hosts included MIT SDM '08 alumnus Anil Rachakonda, director of products, Smart Cities ITS, and Heather Pagh of human resources.

- Speakers at Ericsson's facility in Santa Clara, CA, presented an overview and shared the company's vision for strategy and growth over the short and long terms, focusing specifically on developing new technologies and connectivity for social interactions. They described the role of innovation and the company's processes to support it, including predictive and optimization models that use data in conjunction with demographics to develop high-value products and services. Tours, product demonstrations, and access to working prototypes showed Ericsson's commitment to reinvention, innovation, and adaptation over the 140 years of its work in the technology arena. Curtis Ludwig, director of global talent management, was SDM's host for the visit. Other speakers were: Diomedes Kastanis, head of technology and innovation; Eric Qian, director of product management; Alvin Jude, researcher; and Nese Ozler, who works in the company's OnSite Experience Center.

Continental

Ericcson

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- At Tesla's headquarters in Palo Alto, CA, members of the engineering and development teams described the company's history, products, approach to innovation and design, and several roadmaps for its systems and applications. Students got a glimpse into how fast the company's culture is evolving to meet aggressive business deadlines. Learning about Tesla's approach to design and development, as well as how its leaders plan, develop, and execute projects at the highest level in one of the world's most competitive industries was invaluable.

Tesla

- In San Francisco, CA, several Planet Labs leaders met with SDM fellows to deliver presentations. Topics included a company overview; Planet's approach to agile systems; satellite construction and operation; space deployment methods; and logistics for in-orbit satellites. A discussion followed on product design; methods and tools for development and user feedback; and the discovery of new use cases. SDM fellows received deep insight into a company operating in a small niche market with large demands for data management and reliability; they also gained an understanding of Planet's business models. Planet representatives included Matthew Ferraro from spacecraft research and development; Ryan Kingsbury from electrical engineering; Cole Murphy from product design; Joseph Mascaro from impact initiatives; Lee Frantz from people services; and Alex Shih SDM '09 from product and ecosystem, who hosted the visit.

C3 IoT

- At C3 IoT headquarters in Redwood City, CA, the group heard presentations from two MIT alumni—President and CTO Ed Abbo SM '86 and Director of Products Erick Corona SM MBA '13. Students learned about the company's history; how data technologies and connected products interact with society; and what opportunities exist for employing applications in large-scale industries, cyber systems, and data learning. Together with the SDM fellows, Abbo and Corona discussed strategies for rapidly developing products, customizing projects for specific companies/industries; and providing value. The visit concluded with a networking lunch with employees from several of the company's key departments, including engineering, services, and products.

Amazon

- At Amazon in Tracy, CA, SDM fellows toured the state-of-the-art order fulfillment center, where robots are deployed for product handling, distribution, and manual labor. Students learned how this highly complex, flexible, automated system can quickly be reconfigured and adjusted for variables such as seasonal demand using a robust model that integrates data management inventory and scale. A question-and-answer session that followed the tour covered a variety of topics, including operations metrics; motivating people; the challenges of business growth; and inventory management logistics. Director of Operations Sanjeev Vaid led the visit, which was hosted by Community and Public Relations Specialist Danielle Tafoya.

- In Mountain View, CA, students learned how systems thinking was applied at Google to develop the company's autonomous car spin-off, Waymo. The hosts provided an overview of employee roles and responsibilities in system development for this complex project, and they gave students a look at project management and milestones—all of which aligned remarkably well with what fellows are learning in SDM's core course. The visit also included a trip to Google's ACME Lab where they saw how the company uses agile approaches to develop new products and applications as well as to address issues with existing products.

Google

- SDMs visited Intel's product development lab at its San Francisco campus. There they saw how Intel uses rapid prototyping tools, and fellows examined sample products developed by Intel's design team and marketed by partner companies. On-site discussions that followed focused on the design process, the challenges of developing wearable technology, and Intel's market strategy.

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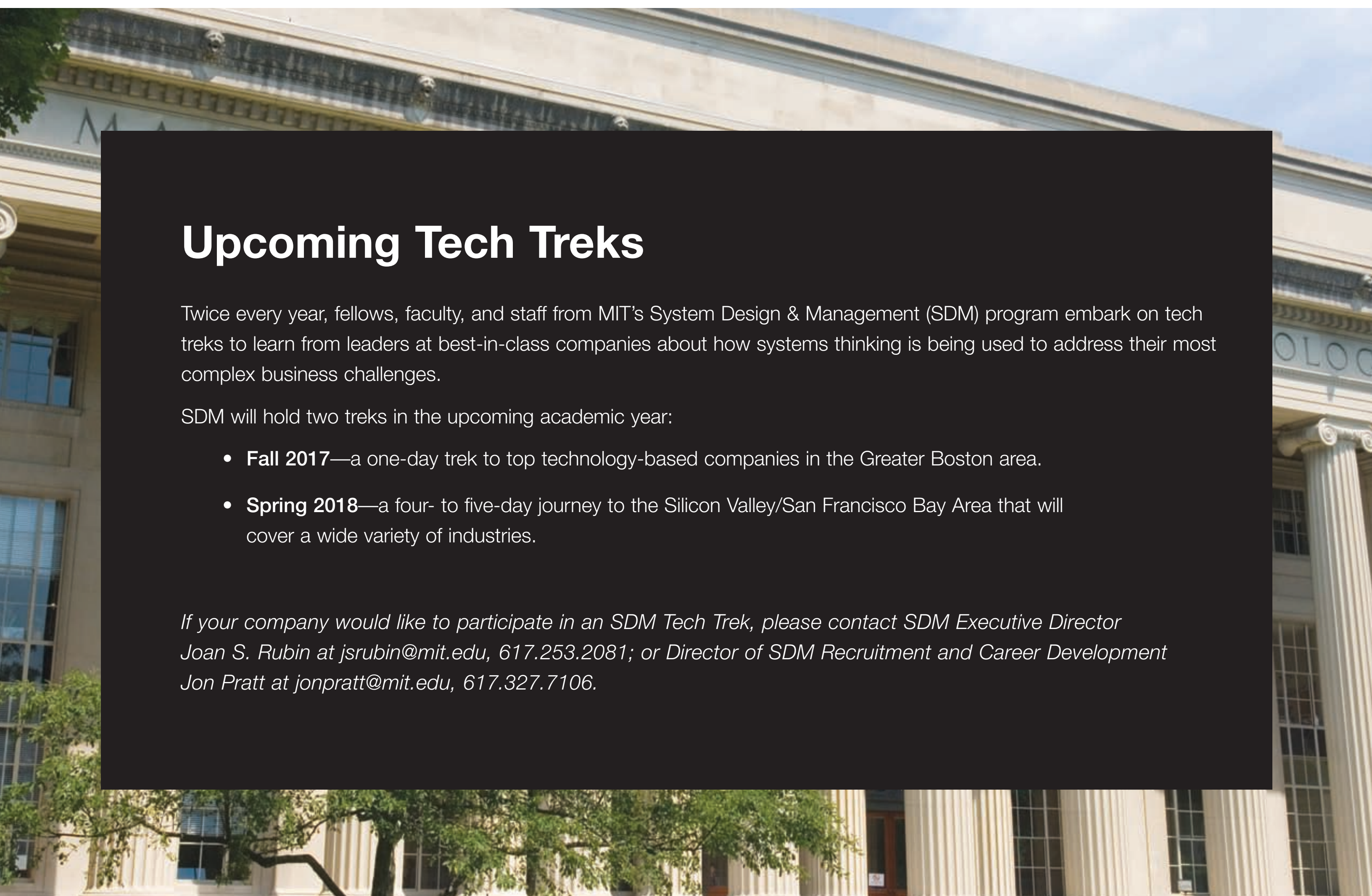
Key takeaways:

- While all the companies visited are technology-driven leaders in their fields, visiting them in rapid succession gave SDM fellows valuable insight into the differences in cultures, strategic and technical approaches, and market challenges—as well as the similarities from business to business.
- Through meeting and engaging with SDM fellows, company leaders experienced the unique character that MIT SDM fellows share: All are experienced engineering professionals with an average of 10 or more years' experience, and many already hold one or more advanced degrees. Several companies actively recruit during the trek and/or identify candidates for future recruitment.
- SDM fellows return to MIT with new professional opportunities and an expanded appreciation of the versatility and applicability of their SDM education across industries.



Upcoming Tech Treks

Twice every year, fellows, faculty, and staff from MIT's System Design & Management (SDM) program embark on tech treks to learn from leaders at best-in-class companies about how systems thinking is being used to address their most complex business challenges.

SDM will hold two treks in the upcoming academic year:

- **Fall 2017**—a one-day trek to top technology-based companies in the Greater Boston area.
- **Spring 2018**—a four- to five-day journey to the Silicon Valley/San Francisco Bay Area that will cover a wide variety of industries.

If your company would like to participate in an SDM Tech Trek, please contact SDM Executive Director Joan S. Rubin at jsrubin@mit.edu, 617.253.2081; or Director of SDM Recruitment and Career Development Jon Pratt at jonpratt@mit.edu, 617.327.7106.

Employment Report Now Available for SDM's 2016 Graduating Class

MIT System Design & Management (SDM) educates early to-mid-career technical professionals in architecting, engineering, and designing complex products and systems, providing them with the leadership and management skills necessary to work successfully across organizations. Graduates earn a master's in engineering and management from MIT, and join their employers prepared to manage effectively and creatively by using systems thinking to solve large-scale, complex challenges in product design, development, and innovation. SDM graduates' unique and powerful combination of technical and managerial skills equips them to successfully lead in positions throughout a wide range of industries, across all levels and functions.

Each year, SDM surveys members of its most recent graduating class to learn about their career paths. The resulting report provides an overview of the employment and compensation statistics submitted by self-sponsored students who graduated from SDM in February, June, and September of the preceding year. Information on the companies that hired SDM graduates is also provided.

Highlights of this year's report include the following*:

- 97 percent of SDM graduates who responded to the 2016 survey are employed;
- graduates reported an average base salary of $132,550—an increase of 53 percent over their base salaries as reported prior to entering SDM; and
- the top job functions being performed by the 2016 graduates are product development/management, engineering, and consulting strategy.

Companies that recruited 2016 graduates include: Amazon Robotics, Apple, Bill and Melinda Gates Foundation, Bose, Boston Consulting Group, C3 IoT, Deloitte, Ericsson, Google, Intel, McKinsey & Co, nuTonomy, Oracle, Shell TechWorks, Tesla, Verizon, Visa, and Yelp.

All information accurate as of press time.

contact

For the full employment report or additional information, please visit sdm.mit.edu or contact Jon Pratt, director of SDM career development and recruiting, at

jonpratt@mit.edu

Snapshot: SDM Class Entering in Fall 2017

MIT welcomed a new cohort of 58 early to mid-career technical professionals to the System Design & Management (SDM) program prior to the start of MIT's new academic year.

Like their predecessors, the class entering in academic year 2018 represent a wide range of industries, including healthcare, US military, energy, software, information technology, US and foreign governments, consulting, and more. They work for well-established companies, new industries, and startups. Several are currently or aspiring entrepreneurs.

The cohort that entered MIT System Design & Management in fall 2017 is pictured on the steps of Building 10 at MIT.

Demographics*
- 48 men / 10 women

Program
- 36 on campus
- 18 local commuter
- 4 distance

Citizenship
- Brazil, Canada, Chile, China, Ecuador, France, India, Japan, Jordan, Mexico, Nigeria, Pakistan, Republic of Korea, Saudi Arabia, Singapore, Taiwan, United Kingdom, United States

Average age
- 33

Sponsorship
- 43 company-sponsored
- 15 self-sponsored

**Admissions numbers accurate as of press time.*

Arthur Middlebrooks

Operations Research/Systems Analyst, US Army

"I am an instructor in West Point's Department of Systems Engineering, so SDM's leading-edge core courses and MIT electives will help me provide a state-of-the-art education to our cadets and continue to serve my country."

Sonali Tripathy

Business Unit Head—Women's Health, Embryyo Technologies

"Since I have been responsible for business development in women's and children's health, SDM will enable me to deep-dive into innovation, engineering, and marketing—and create higher impact in the future."

Eunjin Koo

Manager for e-Government, Ministry of Foreign Affairs, Republic of Korea

"SDM's emphasis on leadership, teamwork, and diversity will help me develop customized diplomatic information systems applications and collaborate with internal and external colleagues to strengthen e-government capacity."

Tolu Sodeinde

Global Consulting Director (Oil & Gas), Schneider Electric

"At SDM, I will focus on applying systems thinking with an entrepreneurial focus to several areas: business technology transformation in the oil and gas sector and artificial intelligence/machine learning in energy sustainability."

Frederico Calil

Engineering Manager, Whirlpool Corporation

"As an SDM student, I will learn how to manage flexibility and complexity in system design and how to organize an enterprise to effectively deliver projects."

Sandhya Prabhu

Energy Trader, Boston Energy Trading & Marketing

"SDM's systems thinking foundation, combined with electives in management, will help increase my effectiveness in business development within the energy/clean-tech space."

Elizabeth Bieler

Systems Engineer, US Air Force

"At MIT SDM, I want to learn innovative solutions to improve acquisitions engineering and project management. Eventually, I would like to become an engineering director for a major aircraft system."

2017 fall sdm calendar

> Available on the SDM website

Virtual SDM Information Session
sdm.mit.edu/virtual-sdm-information-session

Prerecorded webinars
sdm.mit.edu/news-and-events/webinars

SDM Pulse
sdm.mit.edu/pulse

Details and registration information for all events can be found at **sdm.mit.edu**.

MIT SDM Information Sessions

Learn more about MIT's System Design & Management (SDM) program and its master's and certificate offerings.
Details/registration: **sdm.mit.edu**

September 27, 2017; February 7, 2018; June 6, 2018
Live, On Campus at MIT: Wednesdays, 6–9 pm

December 5, 2017; February 27, 2018
Live, Virtual Sessions: Tuesdays, noon–1 pm ET

Grace Hopper Celebration of Women in Computing

October 4-6, 2017
MIT SDM will be exhibiting at this event in Orlando, FL. Please stop by!

MIT SDM Systems Thinking Webinar Series

This series features research conducted by members of the SDM community.
Due to requests from SDM students and prior attendees, all upcoming webinars will held on **Tuesdays** from noon to 1 pm. All webinars will continue to be free and open to all. Details/registration for live webinars and access to recordings and slides from prior presentations can be accessed at **sdm.mit.edu/news-and-events/webinars/.**

Tuesday, September 12, 2017
Creating Products, Services, and Infrastructure for the Space-Faring Economy
Eric Ward CEO, Odyne Space; CEO Aten Engineering; SDM alumnus

Tuesday, September 26, 2017
Developing and Launching Products at Google Cloud Platform
Ari Liberman, product manager, Google; SDM alumnus
Note: At Google's request, recording and slides will not be available.

Tuesday, November 14, 2017
Applying Network Theory to Corporate Strategy
Nissia Sabri, director, Strategic Business Development, Novanta

Massachusetts Institute of Technology

Event listings contain all details available at press time. Final information is available at **sdm.mit.edu** two weeks prior to each event.

sdm.mit.edu