The Engineering Highway:
A New Metaphor Especially Appropriate for Women

Abstract
For years the "engineering pipeline" has been used to describe the dearth of women and underrepresented minority engineers. This "pipeline" starts with all possible young girls and minority students and year by year young people drip out of the leaky pipeline until there are only a very few actually becoming an engineer. A major problem with this metaphor is that once a person has "dripped out" of the pipeline, there is no way to get back in.

The "engineering pathway" better describes the flow of people to becoming an engineer. There is not just one pipe, but several paths that lead to and from a major pathway. Even though a person did not start at the beginning of the trail, there are still ways to get on the pathway. On the other hand, a pathway gives the image of a meandering, leisurely path.

This paper presents a new metaphor for the engineering career: the engineering highway. The paper will discuss how the new metaphor fits the various ways that women travel in their careers as engineers. This metaphor should be encouraging to women who are not taking the usual path in engineering.

Introduction
The National Science Foundation was one of the first organizations to graph and to talk about the engineering or STEM pipeline. The engineering pipeline for women, for example, is very wide at the beginning with close to 50% of all babies born being female. By the time the young women are in junior high, they are shying away from math and not taking the math and science courses in high school needed for a college major in engineering or STEM. Although women are gaining on men in taking the proper mathematics and science in high school, the percentage of women choosing engineering as a major in college is not increasing. The engineering pipeline narrows further as we consider the number of women who graduate with a Bachelor's degree in engineering. The pipeline is very, very narrow as we consider the number of women getting a Master's or PhD degree in engineering each year.

Although the pipeline graphic was clear in portraying the message of the very few women who were college graduates in engineering or STEM, some of us felt early on that a pipeline was not a very good way to describe the women in the engineering drought. The pipeline was "leaky" and once the women left the pipeline, there was no way to get back in. We thought that the "engineering pathway" better described an engineering career. A person may leave the main engineering path for another pathway that may or may not lead back to the main path. In addition, new pathways may join the main pathway. However, it is hard to shake the pathway imagery of a rather narrow footpath that meanders among trees and streams. The pathway does not seem to be concerned about getting to a particular destination in an efficient manner.

This paper presents a new metaphor for the engineering career: the engineering highway. Not all people, especially women, start at the beginning of the pipeline. A highway has many on ramps as well as off ramps. Some lanes are fast; some are slow. There is interesting scenery (contrasted with the dark pipeline) and interesting destinations along the way, in addition to the primary destinations of the highway.

The paper will expand on these ideas and show how the new metaphor fits the various ways that women enter, travel, off ramp, and on ramp their careers as engineers.

The Pipeline

The National Science Foundation and the Engineering Manpower Commission (EMC) were leaders in recognizing that there were far too few women in engineering in the 80's. An AAAS Symposium was held on "Retaining High-achieving Women in Science and Engineering in the Pipeline" in July 1987 (Arnold, 1987). Betty Vetter, who worked for the EMC, wrote about the "pipeline problem" in 1987 (Vetter, 1987) and, in 1991, another paper "Changing demographics. Shrinking engineering student population in the pipeline" (Vetter, 1991). She discussed the shrinking pipeline and emphasized that the talent pool for engineering must be enlarged to include women and minority men if we are to make sure that the United States has an adequate future supply of engineers. The NSF publication, "Women, Minorities, and Persons with Disabilities in Science and Engineering" talked about and gave data showing how broad the pipeline was for young girls who all had the option to be a scientist or engineer (National Science Foundation, 1994). However, by the time the self-selection of girls out of math and science classes in high school occurs, the pipeline is already getting very narrow. The numbers of young women who choose to begin their college studies with a major in science or engineering are few and even fewer of them actually graduate with a science or engineering degree. In the early 90's, about 50% of the US population were women and about 46% of the labor force were women, however only 9% of engineers were women. In the early 90's, only 16% of the Bachelor's degrees in engineering went to women, 15.2% of the Master's degrees, and 12.9% of the Ph.D.'s in engineering. These numbers have not changed much in the last 20 years.

The 'engineering pipeline" continues to be prevalent in engineering education research and published papers from the 90's to present. Many papers were written on how to expand the pipeline. In 1993, "ASEE student chapters: An engineering pipeline for higher education" was published telling about the establishment of such a chapter at Purdue University to education undergraduate students about graduate school, to prepare interested graduate students for academic careers, and to encourage under-represented groups such as women and minorities to seek advanced degrees and academic careers. J. Paul Myers proposes that the number of women "in the pipeline" is not large enough to mentor and support CS interests among current young women in the field and so men need to help build the pipeline (Myers, 1992). Expanding the pipeline means that each step where women leave the pipeline must be examined, understood, and strategies developed to counteract the pressures forcing them to leave (Leveson, 1990). Metz

painted a picture of the pipeline that feeds into college-level study of engineering in 2001 (WEPAN Press Room, 2001).

The "women in engineering pipeline" has several common adjectives associated with it, one of which is "leaky". At an American Association for the Advancement of Science meeting in 2002, a main topic of discussion was strategies for raising the number of women scientists in academe. A panel discussed the necessity to review hiring guidelines, family-work policies, and issues involving what many scientists referred to…as "the leaky pipeline," wherein more women than men drop out of careers in science and engineering at every stage (Guterman, 2006). In "Women, Girls and SMET: Some Reflections on Retention," the patterns for the "leaky" pipeline are sometimes difficult to follow (Campbell et al., 2008). In 2002, "using data that did not include psychology and the social sciences, the US Department of Education concluded that 'female students in S&E programs did not fall behind in the pipeline; they actually were more likely than male students to complete an S&E program" (Huang, Nebiyu & Walter, 2000). However, this data included biology where women earn a majority of the degrees and engineering, where women earn less than 20% of the degrees. Another example of the use of the term "leaky pipeline" is the "continued 'leak' of women from the engineering pipeline at every level of advancement" was the motivation for a speaker series called "Plugging the Leaky Pipeline: Keeping Women in Engineering" (UC Berkeley, 2007).

Another aspect of the pipeline is the "pipeline theory". In this case, the fact that there are not that many women emerging with PhDs in engineering is used as an excuse for other events. For example, a 1994 paper by Layne on "Glass ceiling: Is it really there?" asks if there is a "glass ceiling" for women in engineering or is it simply a "pipeline problem"? The question is asked if the fact that there are not very many women in management and leadership positions is really due to the lack of qualified women for these positions. In 2006, a committee of the National Academies was charged with gathering and analyzing the best available information on the status of women in academic science and engineering. This committee found that a justification often used for why there ware so few women in leadership position is the "pipeline" theory: "There aren't enough qualified women in the science and engineering pipeline to fill top academic positions." The committee noted that "the data indicate it simply isn't so" (Milwaukee Wisconsin Journal Sentinel, 2006).

Sometimes the pipeline is used to describe only a part of the science and engineering fields. "The Incredible Shrinking Pipeline" is "the name given to the phenomena where fewer women are entering the computer science field" according to one publication (Gurer & Camp, 1997). The computer science field has seen the numbers of women shrink from a high of 37.1% CS degrees in 1983 to only 27.5% in 1996 (IEEE Cedar Rapids Section, 1997 and Camp, 1997). In 2006 the numbers of women in computer science are still down and women only received 28 percent of all computer science bachelor's degrees (ACM's TechNews, 2006).

The word “pipeline” also appears with diversity recruitment and retention programs and introduction to engineering courses. At UT Knoxville, a program, the “Pipeline Engineering Diversity Program” funded by the Department of Energy (DOE) is designed to increase the number of African-American, Hispanic-American, and Native-American students graduating with advanced degrees in engineering. This program includes pre-college programs, undergraduate mentoring and summer research opportunities, as well as competitive graduate research assistantships (The University of Tennessee, Knoxville, 2009). A Summer CHOICES program at Lehigh University in 2005 was “designed to increase the pipeline of women into engineering” (Engineering Information Foundation, 2009). Ten years earlier, Ramesh (1999) presented a paper “Introduction to engineering: attract students and strengthen the pipeline” to describe a course developed for high school and college students as a motivational tool that help attract students to engineering and engineering technology programs. In 2001 “A First Step for Women into the Engineering Pipeline” reported on programs to work with fourth through ninth grade girls during the summer on problem solving skills, science, mathematics, engineering, and technology (Cano, 2001). In 1978 the New Jersey Institute of Technology (NJIT) established its Center for Pre-College Programs for inner-city youth and to improve education in the elementary and secondary local schools. In “K-12 and Beyond: The Extended Engineering Pipeline” the author states that NJIT has long recognized the “minding” the pipeline is not enough. They recognize that more must be done to make sure that there are more women stay in the pipeline through the early years of school in order to minimize the “leakage” (Kimmel & Cano, 2001).

The pipeline metaphor continues to be used. In 2001, an article “Concerned by Critical Shortage of Engineers, Leading CEO’s and Educators to Gather for Engineering Education Summit” has the subtitle, “Presentation by astronaut Bonnie Dunbar and others will forefront the need for More Women in the Engineering Pipeline” (Smith College, 2001). In 2003, the ERIC Digest featured an article, “Women and Minorities in the Science, Mathematics and Engineering Pipeline” (ERIC Digest, 2003). And, in 2007 during the “Global Marathon for, by, and about Women in Engineering” one of the sessions was entitled “Advancing the Pipeline of Women in Engineering: What You Can Do to Help Recruit and Retain Female Undergraduates” (eSchool News, 2007).

The author also used the “pipeline” metaphor in the 90’s (Anderson, 1994; Anderson-Rowland, 1996, 1997), but then began to realize that pathway better explained the journey of people, especially women, becoming engineers.

The Pathway

The “pathway” metaphor better describes the fact that people who leave the “pipeline” can get back on, rather than “leak out” with no way to get back in. The pipeline also implies that the only way to get into the pipeline is at the beginning of the pipeline. A pathway suggests that even if a person did not start at the trail head, there are alternate ways to join the path.

If we examine literature concerning engineering and pathways, the most common use of the word "pathway" appears to be as a "career pathway". For example, "Decision–making in first-year engineering: Exploring how students decide about future studies and career pathways" (Ngambeki, Dalrympie & Evangelou, 2008) suggests that, once you are in engineering, there are several pathways to different engineering careers. This has a different implication than continuing straight down one "pipeline." Career paths are also used to describe the specific skills, values, and thinking that will be needed to attain a particular position in the engineering career, such as "Planning a career path from engineering to management" (Souder, 1983). Specific information can be given to help an individual specialize in a particular area, such as "Steps along a Robotics Technology career pathway" (Landis, Komacek, Adukaitis, & Shoop, 2008).

Examples of other career pathway references include: "Building a career pathways system: Promising practices in community college-centered workforce development" (Rab, 2003), "R&D career paths: their relation to work goals and productivity," (Goldberg & Shenhav, 1984), "Finding your career path by finding yourself", (Sharaga, 2001), and "Taking a journey down the career path" (Wood-Black, 2004). *Pathways for Women in the Sciences: The Wellesley Report Part I, 1993* addresses why women choose to enter science and what encourages or obstructs their success (Rayman, & Brett, 1993). Finally, a North Carolina State Career Clusters Initiative was "an effort to define the knowledge and skills necessary to pursue a given career pathway (in science, math, and technology)" (Clark & Bottomley, 2003).

"Pathways" is a key word in the NSF funded *Alternate Pathways to Success in Information Technology (APSIT)* program to explore the nature of the IT and engineering educational and career pathways used by successful female and minority Georgia Tech alumni. Two particular goal of this research were "to determine the nature of successful IT and engineering educational and career pathways used by women and other under-represented populations" and "to compare the educational and career pathways exhibited by IT and different fields of engineering to determine the causes of differential attractiveness of fields to different population subgroups" (Llewellyn et. al, 2004). "Pathways" was also the key word chosen to describe "Broadening Participation in Computing: K12-Community –College-University-Graduate Pathways" (Adrion et. al., 2008). Career pathways continue beyond graduate school and the Ph.D. "Finishing the Ph.D. is always considered to be the hard part, but it is simply the beginning of a long string of challenges and opportunities, checkpoints and pathways" (Dougherty & Schrader, 2005). In their paper, three pathways are described for engineering and computer science women faculty: the non-tenure research track, industry or government experience first, and the traditional academic track.

In 2003 the National Science Foundation funded the Center for the Advancement of Engineering Education (CAEE), "dedicated to advancing the scholarship of engineering learning and teaching. The largest element of the CAEE is the Academic Pathways Study (APS), an in-depth, mixed methods exploration of the undergraduate student experience and the graduate's transition into professional practice" (Clark et. al, 2008). Along with "academic pathway", the terms "professional pathway" and "educational

pathway" are also used. Examples of the word "pathway" linked to profession or professional include "Geeks are CHIC: Cultural identity and engineering students' pathway to the profession" (Loshbaugh & Clear, 2007), "Industrial placements and sponsorship: the Professional Pathway" (Knight et al, 2002), and "Creating pathways to develop student professionalism – A new direction" (McIntosh-Elkins & Klein, 2008). Two examples of the use of "pathways" linked with education are "Project PETE: Pathways to Engineering and Technology Education" (Feldhaus, 2005) and "Careers in Biomedical Engineering Part I – Descriptions and Educational Pathways" (Greenwald, 2008).

The term "pathway" has also been used in the same way that "pipeline" has been used as in "The Minority Engineering Transfer and Articulation (META) program: Building stronger pathways and developing student achievement" (Jacquez et al, 2005). Another example is "a digital library for educators at all levels to easily identify, select, and use educational resources that have been shown through research to be effective for increasing the participation of women and under-represented minorities in information technology" described in the paper "Broadening Participation in Computing with the K-Gray Engineering Pathway Digital Library" (Agogino, 2008).

The term "Career pathways" is also used in other fields such as medicine: "Choosing primary care? Influences of medical school curricula on career pathways" (Tandeter & Granek-Catarivas, 2001) and "A career pathway for radiation therapists. Does it really exist?" (Malicki and Kresi, 2005).

However, in considering if "pathway" is a better descriptor than "pipeline", it is hard to shake the imagery of a rather narrow dirt footpath that meanders among trees, fields, and streams. The pathway does not seem to be concerned with getting to any particular destination in an efficient manner. Perhaps there is a better metaphor.

The Engineering Road (County Road, State Highway, Interstate Highway, or Freeway?)

The term "engineering pathway" allows for many options in the way a person can become an engineer. However, in order to change the metaphor away from a "casual walk" to a "journey with a destination", we consider a highway, which can range from a county road, to state highway, to interstate highway, or to a freeway." A person may travel on all of these types of roads at one time or another in their journey to become an engineer and as an engineer. In searching for literature that uses terminology about roads or highways relative to an engineering career, literature on highway engineering pops up as the most obvious. Actually, the topics of papers on highway engineering take on a second meaning if we apply them to an engineering career freeway such as "A Methodology for Computing Time-Dependent Alternate Routes Around Freeway Incidents: (Sawaya, 2005) and "Modelling drivers' compliance and route choice behavior in response to travel information" (Dia & Panwai, 2007). The terms "detours along the way" and "removing roadblocks" are used in the abstract for a paper on engineers gaining career security called "Mining for diamonds in the land of networking" (Watson, 2006).

One article title about women in engineering that does fit this new metaphor is "Pit Stops and Scenic Routes: How to Aid Women to Stay on Track in Their Careers" (Mattel & Jennings, 2008). Another example of the highway metaphor is the "On-Ramp into Academia", a new annual workshop for Ph.D.-level women scientists and engineers interested in transitioning to academic faculty positions organized by UW ADVANCE (UW ADVANCE, 2009).

Let's consider roads and their attributes and explore how the descriptors fit the journey of a person, especially a woman, who becomes an engineer.

Speed Limits, Stop Signs, and Warning Signs. The features of roads give a good insight into the journey that a person may travel to become an engineer. Let's begin with the basics found on even a country road. First, there is usually a speed limit. Depending on the conditions of the road, someone has determined how fast a vehicle can go and still be safe. For example, normal student loads of about 16 semester hours have been determined for a full-time student. There is some variability depending on the requirements of the courses in the load. However, if a person is working 20 hours a week, then a full-time load is 12 hours or less. The road has stop signs. At certain times, due to the intersection of other roads, one needs to stop, survey the situation, and determine when it is safe to go on. On a county road, usually nothing will happen if you do not heed the stop sign. A stop sign may appear if a student is trying to manage 17-19 credit hours in a semester. It is too much. The student needs to drop a course and get on a more realistic schedule. The stop sign may just mean take the summer off or do an internship during the summer, take a break from classes for a couple of months. There are other types of warning signs: slow, caution, curve ahead, steep grade, winding road, railroad tracks, slippery when wet, and others. A person striving to be an engineer needs to be aware of warning signs. Colleagues, a mentor, friends, and family are all good support systems to help an engineering student pay attention to warning signs and to encourage the student to act appropriately. The county road is the one going right by our home. For some students this may mean attending a community college after high school. The road is familiar, parking is free, classes are small, all students get to know each teacher, and the education is affordable.

Stop Lights, Changing Lanes. A state highway will usually have stop lights at road intersections near where people work or live. Stop lights are usually more important than stop signs and ignoring the stop lights can mean serious injury. Also many state highways are only two lanes. Changing lanes is sometimes necessary to avoid being behind a very slow vehicle. However, passing on a two-lane highway can be very dangerous. Before making a change "to save time" make sure that you can see far enough ahead to know that the move is safe.

The Slower Lane. Four lane highways are understood to have a slow lane on the right and a faster lane on the inside. It is ok to drive in the slower lane. The slower lane goes to the same places as the faster lane, but just takes a little more time. Many students need to work part-time or full-time and by necessity need to take a slower lane and be part-time students. Some engineers choose to work after their engineering degree and go to

graduate school part-time. Some women with children choose to go to school part-time or to work part-time. The slower lane is a viable and important option.

Accidents and Vehicle Breakdown. Accidents happen. Sometimes they are our fault and sometimes they aren't. The best way to avoid accidents is to drive defensively. Sometimes we can be innocently stopped at a stop sign or light and be rear-ended. It is important to get the name and number of the other driver so their insurance can take care of your vehicle. Sometimes an engine will stall. It is never a good time to have an accident or a stalled car. The best way to prevent a stalled car is with regular checkups with a trained professional. We need to watch our health and to eat and sleep responsibly.

Detours and Closed Lanes. Sometimes roads have a detour. The detour may be due to construction, a bridge washout, or flood. Unexpected, the detour or one or more closed lanes may cause a delay in reaching the destination, but usually there is a way to continue and eventually get back on the correct road. Sometimes, due to an accident, traffic lanes may be closed and the traffic flow for all is severely slowed or stopped. Patience is required. The author teaches her academic scholarship students to always have their Guaranteed 4.0 Notebook (Johnson & Chen, 2004) with them so that they can effectively use an unexpected delay in the schedule!

Toll Roads. Toll roads exist and may mean that the quickest, shortest route requires having to pay to use the road. Usually there is another route, longer and slower, to get to a destination without using the toll road. Decisions along the engineering educational road may be similar. In order to have some experiences, it may cost. The person has to weigh if the shortcut is worth the price.

Dangerous Driving Conditions. A sand storm, rain storm, fog, or snow storm can make visibility very difficult and the driving conditions very dangerous. If visibility is non-existent, then it is necessary to stop and wait until it is safe to continue. If there is a large truck outlined in red lights travelling at a modest speed right in front of you, then you may be able to safely follow. A mentor/leader is always welcome.

Rest Stops, Pit Stops. Cars need to be gassed up every so often and passengers need to stretch their legs, walk a bit, get a cup of mocha coffee, and make a restroom stop. It is good to plan these stops ahead so you are not caught without gas and many miles to go.

Emergency Stops. If you need to stop, look for a broad shoulder. Sometimes it can be costly to push on if smoke is coming out of the hood. In the long run, a stop and a tow truck may save time and money. Sometimes family affairs necessitate a reduction in the course load or that all classes be dropped for a semester. This happens, but students are able to continue their journey after this time with renewed commitment.

Speed Bumps, Speed/lane Markers. Speed bumps are placed in neighborhoods to help slow the traffic and make the area safer for children. Speed markers that make noise when run over with tires are a warning that you have drifted from your lane or that a stop

is soon required. Frequent visits with an advisor or mentor can help make sure that the engineer is still on the correct road.

HOV Lanes. With many freeways, the inside lane is designated for vehicles with two or more passengers. Since most vehicles have only a single occupant, the HOV lane usually allows those who use it to travel faster. Engineering was not meant to be done alone. Engineers usually work in teams. Engineering students should work in study groups for each of their classes. Engineering women, especially, need to seek engineering colleagues as a sounding board and for tips on how to best make their way through their career. Engineering organizations are important for a balanced engineering life.

Off Ramps. The engineering career is not a pipeline. To get from one destination to another, you do not have to stay in the same lane all of the way. Sometimes it is necessary or desirable to leave the main road to explore or take advantage of something off the freeway. The off ramp can take us to a rest stop, to a restaurant, to another experience. An engineering graduate may take the off ramp and go to work in industry. Later this engineering may wish to return to the freeway and continue full-time in engineering graduate work. This engineer may then stay in academia or return to industry. A woman engineer may take an off ramp to have a child or children and not work for a time or perhaps work part-time while the children are young.

On Ramps. An on-ramp is a marvelous thing. Just because a person did not get on the freeway where it began, a person can join the freeway later with an on-ramp. We have to pay attention to where the on-ramps are and take the correct streets and roads to get to the on-ramp, and to increase our speed to fit in with the freeway traffic, but it does allow us to get into the flow of the main traffic on the freeway again.

Bridges and Tunnels. Bridges and tunnels are built to make the travel easy over a the obstacle of a river or a mountain. Based on a lot of work of others, our travel is made very easy where it would have been very difficult to have to travel across the river or to have to travel around the mountain. An engineer should not be reinventing the wheel, but taking advantage of the helps that are available in advisors, mentors, and study groups.

Frontage Roads. An off ramp may lead to a frontage road where an engineer can parallel the freeway, but be able to go at their own speed and make stops as necessary. Before we continue too far on the frontage road, we need to know how to find an on ramp, and resume our travel on the freeway.

Alternate Routes. The community college is a good example of an alternate route to an engineering career. Some students who attend the community college (CC) are behind in mathematics and science. They are very capable of learning the subjects, but somehow are not ready for a four-year engineering college after high school. There are many advantages of a CC including smaller classes, more individual help, and perhaps a slower pace. Once the student has learned and completed pre-engineering courses at a CC, the student should be able to go on to a four-year school and do well. Since many CC students work, if the transfer student is still working after the transfer, the student must be

very careful that they are not overloaded with classes and work and they should get into a study group for each class.

Another alternate route may be taken by the woman (or man) who has received a Bachelor's degree in an area other than engineering and after some years finds her job boring and without challenge. These career-change or re-entry students may come back to school for a second Bachelor's degree, this time in engineering, or they may take certain prerequisite courses and then earn a Master's degree in engineering. Some of these career-change students "leaked out" of the pipeline or perhaps were never in the pipeline, but through passion and commitment can catch up in the mathematics and science and earn a Master's degree in engineering and for some, even a PhD degree in engineering. A rather common alternate route for some engineering academic women is that they came up through mathematics or the sciences before realizing the wonderful challenges and opportunities in the world of engineering.

Conclusions

This paper began with a description of the use of the "engineering pipeline" which is dark, leaky, and gets narrower and narrower. This was followed by a discussion of the "engineering pathway" which allows travelers to leave the path and to rejoin it again at that point or another point down the path. The pathway is certainly more attractive, but does give the impression or a rather casual, somewhat aimless journey. The "engineering road" or "engineering highway" was then proposed as a better metaphor for a person travelling the engineering county road, highway, interstate, or freeway. Although the list of highway attributes is not exhaustive, the author hopes that enough aspects of a highway and the matching experiences of a person on the road to an engineering career will generate more thought and use of this metaphor rather than the pipeline or pathway to describe the way that women enter the engineering profession.

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