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Trek B-cycle
Designing a Drive Train

"… and starting in January 2008, Boulder will be the most bicycle friendly city in the United States!" proclaimed Mayor Shaun McGrath. With that, Trek's new program – B-cycle – was launched.

It is March 2007, in the west end of the Pearl Street Mall, downtown Boulder, Colorado. The Trek Bicycle Corporation and the city of Boulder are announcing the launch of the first urban-shared bicycle program in the United States. "Our mission is to help the world use the bicycle as a simple solution to complex problems," said John Burke, CEO of Trek Bicycles. "It can combat climate change, ease urban congestion, and build human fitness. It brings us together, yet allows us to escape. And it takes us places we would never see any other way. We look forward to working with the city of Boulder." Burke concluded to a round of polite applause, shook hands with the mayor and stepped off the speakers platform.

In the front row of city dignitaries sits Mike Post, the newly appointed Product Manager of Trek B-cycle. Mike graduated from Rose-Hulman Institute of Technology in 2003, with a Bachelor's Degree in Mechanical Engineering and a concentration in Manufacturing and Production Engineering. He was working for an exercise equipment manufacturer when he learned of an opening at his "dream company," Trek Bicycle. Mike came to Trek as a production engineer working on the "kids and cruiser" team while he learned the Trek business model, from part procurement to the retail stores. Mike showed an ability to thrive in a multi-functional team environment and when the B-cycle idea started to take hold at Trek, he jumped at the opportunity to lead it.

"January is just around the corner, you know," said John Burke sitting down next to Mike. Mike knew only too well how little time they had to launch B-cycle. They needed to make a decision about the all-important drive train components in two weeks, so parts could be ordered and production begin on the B-cycle bicycles. "I've got some ideas I want to share with you about the drive train design," said Burke. "Let's talk on the airplane on the way back to Madison."

Trek Bicycle Corporation and B-cycle -

Trek Bicycles was founded in 1976 by two friends, Dick Burke and Bevil Hogg, in Waterloo, WI and focused on making high-end steel bicycle frames to compete the then dominant Japanese and Italian manufacturers. From the very beginning, Burke believed in technology as the path to a better bicycle and over the years Trek has lead the development of molded carbon fiber frames, aerodynamic testing, compression suspension, the hybrid design bicycle, and the popular "y-frame." In 1997, John Burke, son of the founder Dick Burke, took over as CEO and dramatically increased the hiring of engineers to drive design. Today, Trek Bicycle is one of the largest and most respected manufacturers of performance bicycles in the world, with sales approaching $1B, marketing brands like Trek, Gary Fischer, Bontrager, Villiger and Diamant.

The concept of urban-shared bicycles as way to reduce traffic congestion and pollution has been around since the 1970's. The urban-shared bicycle concept involves bicycles that can be rented by the hour or day, checked out from docking stations using a pass or credit card and returned to another station when the rental is finished. Perhaps the highest profile urban-shared bicycle program is called *Vélib'*, a combination of the words *vélo* (bicycle) and *liberté* (freedom), operating in Paris, France. *Vélib'* was launched with much fanfare in 2007, and has quickly grown to 18,000 bicycles and 1,225 docking stations scattered throughout the city. The city of Hangzhou, China is also planning an urban-shared bicycle system of 66,500 bicycles and 2,500 docking stations. As of 2007, however, no significant urban-shared bicycle system existed in the United States.

John Burke embraced the idea of bringing urban-shared bicycles to the United States. In partnership with Humana (a heath-care company) and Crispin Porter + Bogusky (an advertising agency), Trek Bicycles launched a program called B-cycle, an urban-shared bicycle program for US cities. The B-cycle program was designed to take advantage of the internet, with internet connected docking stations, a reservation/drop-off system, smart-phone enabled searches of location availability as a well as flexible pricing from minute-by-minute rates, hourly rates, daily rates and even annual rental rates. Several cities expressed interest in the B-cycle concept, with Denver and Boulder, Colorado among the most interested.

Figure 1 - Artist sketch of the proposed B-cycle program (from right to left): the B-cycle bicycle with basket, the B-cycle logo and a solar powered B-cycle docking station.

The Tourist -

"Remember what we saw in Paris?' asked John Burke. Mike was sitting in the middle seat of the coach section, right next to his CEO, John Burke, as they returned from the Boulder launch. Burke always flew coach, not so much to prove a point but to stay connected with the people who used his products. "Sure, I remember seeing lots of tourists renting Vélib' bicycles," said Mike. Burke had arranged for a team of Trek managers to hang out for a week in Paris watching Vélib' bicycle stations, taking notes on who was renting and returning bicycles. The rule was that every fifth customer who rented a bicycle was approached for an interview with the help of an interpreter. They estimated about 40% of Vélib' customers were visitors to the city.

Figure 2 - Mike's sketch of a Tourist using the B-cycle

"Boulder has lots of tourists!" replied Burke, "And I'm thinking tourists should be our target customers for B-cycle in Boulder." Certainly, Boulder is a tourist town. With a population of a little over 100,000 (that includes about 25,000 students at the University of Colorado Boulder), the Chamber of Commerce estimates that the city hosts about 150,000 visitors each year. "And our economic data suggests that tourists will spend about $20 per day renting a bicycle and they are easy on the wear and tear. The big concern is stations. We'll need to have more stations to make pick up and drop off easier," continued Burke.

While they are talking, Mike is taking notes and sketching in his notebook. This is a habit he picked up in college, in a design class, where he learned that sketching by hand was a way to engage thinking that otherwise might not become evident.

As he thought about a tourist as the primary customer for B-cycle, he sketched his impression of a tourist.

The Bicycle Drive Train -

Bicycles began to be considered serious human-powered transportation devices about the mid-19th century. These bicycles were direct powered, meaning the crank and pedal were directly attached to the wheel, so one turn of the crank resulted in one turn of the bicycle wheel. In the 1890's, gears and a drive chain were introduced to bicycle design and this remains essentially the drive train for modern bicycles.

The bicycle drive train consists of four major components – chainring, cassette, derailleur and the drive chain – as shown in Figure 3. Bicycles have a special kind of gear called a **sprocket**. Sprockets convert rotational energy into mechanical work though a chain rather than meshing directly with other gears. The sprocket (or sprockets)

attached to the pedal called the chainring, while the sprockets attached to the rear wheel are called the cassette. The chainring and cassette are connected with a chain and the rider pushes on the pedal, turning the crank and rotating the chainring. This pulls the chain forward rotating the cassette and rear wheel. The derailleur shifts the chain location to individual sprockets.

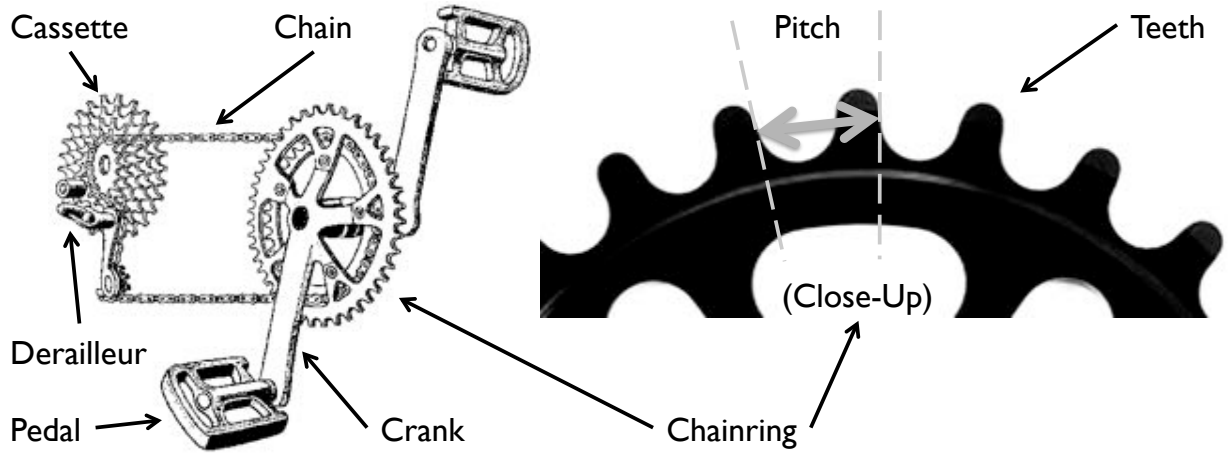

Figure 3 - The Bicycle Drive Train with an overview of the key components (left) and a close-up view of the chainring (right)

Each sprocket has a specific number of teeth around its circumference (larger sprockets have more teeth than smaller sprockets). The pitch of all teeth must be matched exactly to insure that the chain smoothly transfers the power generated by the chainring to the cassette. With equal pitch, counting teeth on a sprocket becomes a quick way to compare the circumference of various sprockets. On a bicycle, the chainring, cassette and drive chain are sold as a set and cannot be "mixed and matched."

The bicycle drive chain is influenced by the intended use of the bicycle because it defines both the **speed ratio (SR)** and the **mechanical advantage (MA)** of the power system. The speed ratio is a measure of how many turns the rear wheel will make with one turn of the crank. A higher SR, say 2.5, says that for every turn of the crank the rear wheel will turn 2.5 times; given a constant pedal rotation, a bike will go faster with a higher SR. Mechanical advantage is a measure of how power from the rider transfers from the pedal to the wheels through the drive train. MA takes into account the crank size, wheel diameter, chainring size and cassette size. A higher MA means more force to the rear wheel, while a lower MA means less force. The trade off is speed, with a higher MA comes lower SR while a lower MA means higher SR. This balance between force and speed is an important design choice for any bicycle engineer.

The Commuter -

"Let's grab some lunch and you can tell me about the Boulder launch," said Steve Malchin, Trek's VP of Engineering Operations, while leaning over Mike's work cubicle wall. Mike and Steve are good friends and avid road racers. One of the perks of working at Trek is that you get to "demo" the latest bike designs, usually designs headed for the Tour de France, and it was not unusual for Mike and Steve to do 150 km of road racing through the Wisconsin countryside on any given Saturday.

Figure 4 - Mike's sketch of a Commuter using a B-cycle

"I think the launch went well; they are certainly behind this 100%," said Mike putting down his tray in the company cafeteria. "We've got a lot to do on our side to get ready for January." "No kidding," replied Steve, "have you made the drive train decision? I've got to get the suppliers lined up." "Not yet, we're still talking about it," returned Mike. "John put a sales pitch on me about focusing on tourists and it seems to make a lot of sense."

"Sure, sure, but there are other options," said Steve. "Remember, Trek is a performance bicycle company built through engineering. It would be a shame if we compromised on the specifications." "What do you mean … compromised?" asked Mike. "We know about durability, we know about

light weighting and we know about drive trains," continued Steve. "It would be a shame if we built the B-cycle in a way that doesn't take advantage of this know how." Mike took out his notebook and began to write.

"I'm thinking we build a bike that can stand up to the pounding of an everyday commute. As you know, bicycle commuters are a dedicated bunch, they are fitter than average, want to get from Point A to Point B as efficiently as possible and appreciate a well-engineered bicycle. And bicycle commuting is the future; B-cycle is our way to put a dent in the universe. Let's not waste it on inferior bicycle specifications."

"Oh, and one last point … it makes good economic sense to focus on commuters," continued Steve. "They are regular users, which means big revenue. Say we charge $5 per day. A commuter will use that bicycle 200 days per year, which is $1,000/bicycle of revenue. Once we have them in the franchise we don't have to spend as much marketing money to attract users, even more help to the economics. Think about it … and pass the ketchup."

Bikes Belong Coalition -

Mike returned to his office after lunch still thinking about what Steve had to say. "$1,000 of revenue per bicycle per year is hard to ignore," he thought. Still, there were pieces missing from the puzzle. Who were tourists, who were commuters, and what were their usage habits? Mike remembered he had met Tim Blumenthal, President of the Bikes Belong coalition (www.bikesbelong.org) at the Boulder launch. Bikes Belong is a non-profit, industry advocacy group working to change public policy in a way that promotes bicycle riding and creates safe places to ride. Mike pulled Tim's business card out of his notebook and dialed the phone.

"Yes, we have that data," said Tim, "we had some interns at CU Boulder collect it last summer." Mike called Tim asking if they had any data on bicycle ridership in Boulder that might be helpful. "We outfitted bikes with GPS trackers and followed the usage patterns of about 50 riders, then followed up with about a dozen interviews. The data showed some real differences." "Like what?" asked Mike. "Well, there are definitely some people that use shared bicycles to get to work. They pick up the bicycle in the morning; drop it off in the evening. On average, they travel about 12 km one-way and they are on the bike for 30 minutes per trip." "That's pedaling at a pretty good clip," added Mike.

"There is a second group that we call the 'casual user' or 'visitor'," continued Tim. "These folks would pick up and drop off the bicycle through out the day, mostly traveled downtown and out to campus. They would only go about 10 km the entire day and be on the bike moving an average of 90 minutes." "Thanks, this is helpful," said Mike.

"Oh, and one other thing. We've had some changes here in Boulder that weren't captured by this study," said Tim. "The downtown merchants have funded a new parking lot on the perimeter of the downtown shopping area in an effort to get cars off the street. They want the spaces for a pedestrian mall and for special events. They are considering a shuttle bus, but we'd like to see them use B-cycles. The new parking lot is an 8 km round trip and we think anything less than 40 minutes of biking time would compete with riding a bus shuttle."

Cycling Research Center –

Trek Bicycle is an engineering-oriented organization and nothing speaks louder to engineers than data. The world of professional cycling has ushered in a new era of performance measurement and one of the leaders in this field is Dr. Mikel Zabala, Director of the Cycling Research Center - CRC (www.cycling-research.com) in Granada, Spain. Mike had heard a presentation by Dr. Zabala on "power measurement through telemetry" at a recent industry-event and decided to make contact through email. After a few exchanges, they agreed to talk over Skype.

"You can call me Mike, Mike," joked Dr. Zabala. After a discussion of the B-cycle project and the capabilities of the CRC, Dr. Zabala began, "most of our data was generated by the performance cyclist, but we do have some data on the casual cyclist that might be helpful." The CRC had done a study with the Dutch government examining levels of bicycle physical fitness and something they called "rider comfort." The rider measured "comfort" in real-time with a turn knob on the handlebars while drive train settings, speed and distance data were collected as shown in Table 1. Dr. Zabala added data on the professional cyclist.

	Heartbeat (BPM)		Cadence (RPM)		Drive Train (MA)	
Rider Type	**Max Rate**	**Average**	**Max Rate**	**Average**	**Max**	**Average**
Professional	185	135	110	85	N/A	.08
Amateur	165	125	90	70	.10	.15
Casual	130	90	70	55	.15	.25
Non-Rider	110	80	50	40	.25	.40

Table 1 - Rider "comfort" data supplied by Dr. Zabala at the Cycling Research Center

Heartbeat was measured as beats per minutes as a maximum for the ride and average over the ride. Cadence is a term for the rate of one full turn of the crank and is measured in revolutions per minute (RPM). Target cadence was the average while the rider was in the "comfort" zone, while max cadence was the peak rate before the rider began recording "distress." The drive train mechanical advantage (MA) is determined by the gear settings while the rider was in the "comfort" zone. As MA drops, Max Rate is the threshold for dropping out of the "comfort" zone.

"Oh, and one more point," continued Dr. Zabala, "we found that the better the cyclist, they higher the cadence and the more they showed a preference for a shorter crank length. It seems that at high cadence, it's easier to turn a shorter crank even though it has an impact on mechanical advantage." "Thanks Dr. Zabala, er Mike," said Mike. "I think these data will useful in our analysis."

The Shopper -

"Got a minute?" asked Keith van Hooten leaning over Mike's cubicle wall. "For you, I've always got time!" replied Mike. Keith is the Chief Design Engineer at Trek Bicycles and has been with Trek for 25 years, over half the time the company has been in existence. Keith influences every significant design produced by Trek. "You're getting it from all sides, aren't you?" chuckled Keith. "No kidding," agreed Mike.

"We got into the urban shared bicycle market because we want to make an impact on the world," started Keith as he settled into a chair next to Mike's desk. "And the more we get people to make bicycle riding a part of their everyday life, the closer we move to that goals." "I couldn't agree more," said Mike, "and that's why I'm leaning toward to the bicycle commuter as our B-cycle customer. They use a bicycle everyday and generate a consistent and significant stream of revenue."

"Spoken like a product manager!" said Keith. "What you say is true, but what worries me is that for the money they would spend on B-cycle they could buy their own bicycle. We'd be happy with that because they'd probably buy a Trek, but it's not very good for B-cycle." "I see you point," said Mike, "but I'm having a hard time thinking B-cycle is only a program for tourists. The market is too transient." "I couldn't agree more, although I know John sees it differently," replied Keith. "I've got a different direction for you – the shopper." Mike pulled out his notebook.

"You talked with Tim at the Bikes Belong coalition. Boulder is working on a new design of their city center. They want the cars out, and bicycles in," said Keith. "It's an intriguing thought," returned Mike, "but my concern is that if we design this for shoppers, almost by default, we exclude the other groups. The bike would be too hard for novice biker or tourist to operate and not fast enough for a commuter." "Maybe," said Keith, "and maybe not. Look over the drive train specifications. Perhaps there is a choice that works for a shopper and is still acceptable to other customer types." "OK, will do," said Mike. "I've got to get our drive train decision to Steve in two days, so it's time to crunch some numbers." "And I'll help you sell John, whatever you decide," offered Keith. "Deal!" agreed Mike.

Figure 5 - Mike's sketch of a Shopper using a B-cycle

Empathy Mapping and Personas -

As Keith stood up to leave, Mike turned to face his laptop. His head was swimming with data, advice and ideas. It was not clear what to do next, and abruptly he remembered the "sightless spoon." When he was a junior at Rose-Hulman, his ME120 engineering design class won an E-Team grant from the NCIIA (National Collegiate Inventors and Innovators Alliance) to develop a training spoon for sightless children. The sightless spoon used haptic feedback provided by small bumps on the indicator shaft to teach the child's hand when the spoon is tipped too far in one direction.

As part of the grant, his design team attended an E1 VentureLab seminar to help them refine their design and grant proposal. At the seminar the instructor introduced the concept of "Empathy Mapping." Empathy is the ability to recognize the emotions of another person, and these emotions influence the products they want and how they use those products. An empathy map is a method a designer uses to identify emotions, categorize them in a useful way and use this information to generate design ideas. The first step in building an empathy map is developing a "persona" or conceptual statement of the user of a design. Designers often begin the persona development process with a rough sketch of the target user, using this as a way to capture thoughts that are not easily expressed in words.

Suddenly, Mike remembered that he had been sketching personas in his notebook throughout the past week as he took notes on the various potential customers for B-cycle. He reached for his notebook and began to leaf through the pages looking over his drawings and notes. The personas he had sketched would not specifically answer the question of which drive train to specify for B-cycle, but it was at least a way to frame the discussion.

The Options -

As Mike was looking at his notebook, his laptop beeped and he looked up to see an email from Steve Malchin titled "B-cycle Drive Chain Options." Mike opened the email and it began …

Mike –

I've been working with our supplier team on possible drive train components for B-cycle. We have already agreed to use the Bontrager 26x1.5 tire and (660mm outer diameter). Below is a brief description of the options available.

B-cycle Drive Chain Options:

1. ***Shimano Traveler*** *– Shimano is our most reliable supplier with an excellent of reputation for reliability. The Traveler drive train is a 30-28/24/22 (chainring teeth – cassette gear teeth) with a 170mm crank length.*
2. ***Campagnolo Trieste*** *– The top Italian supplier who has made an aggressive price offer. The Trieste drive train is a 48-34/28/24 with a 170mm crank length.*
3. ***SRAM Cardinal*** *– SRAM supplies the top-end crank sets for our mountain bikes. The Cardinal drive train is a 52-24/20/16 with a 160mm crank length.*
4. ***Shimano Blue*** *– This is a new offering from Shimano and they think it's the best drive train they offer. The Blue drive train is a 52-32/24/18 with a 170mm crank length.*
5. ***Bontrager/Rohloff*** *– This is an out-of-the-box option. Rohloff is a quality supplier of internal gear hubs, so there would be only one gear on the cassette and shifting happens inside the hub. We'd pair this with our Bontrager 44-tooth chainring and 170mm crank length. The Rohloff has a 26 tooth external gear with a +/- 15% on mechanical advantage of the other two gear settings. This could be a good option.*

Let's set up a meeting for tomorrow and you can take the team through your thinking. Later … Steve