

Big Data's Effect on Organ Transplant Wait Lists

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Of 28,594 organs transplanted in 2013, you haven't heard about most. The stories of a few might go viral thanks to social media, but the vast majority of donated organs are harvested from deceased donors or taken from living donors in relative obscurity.

While the total number of organs transplanted seems like an impressive amount, nearly 18 people still die each day waiting for a new organ, according to the United Network for Organ Sharing, the private, non-profit organization that manages the U.S.'s organ transplant system under a contract with the federal government.

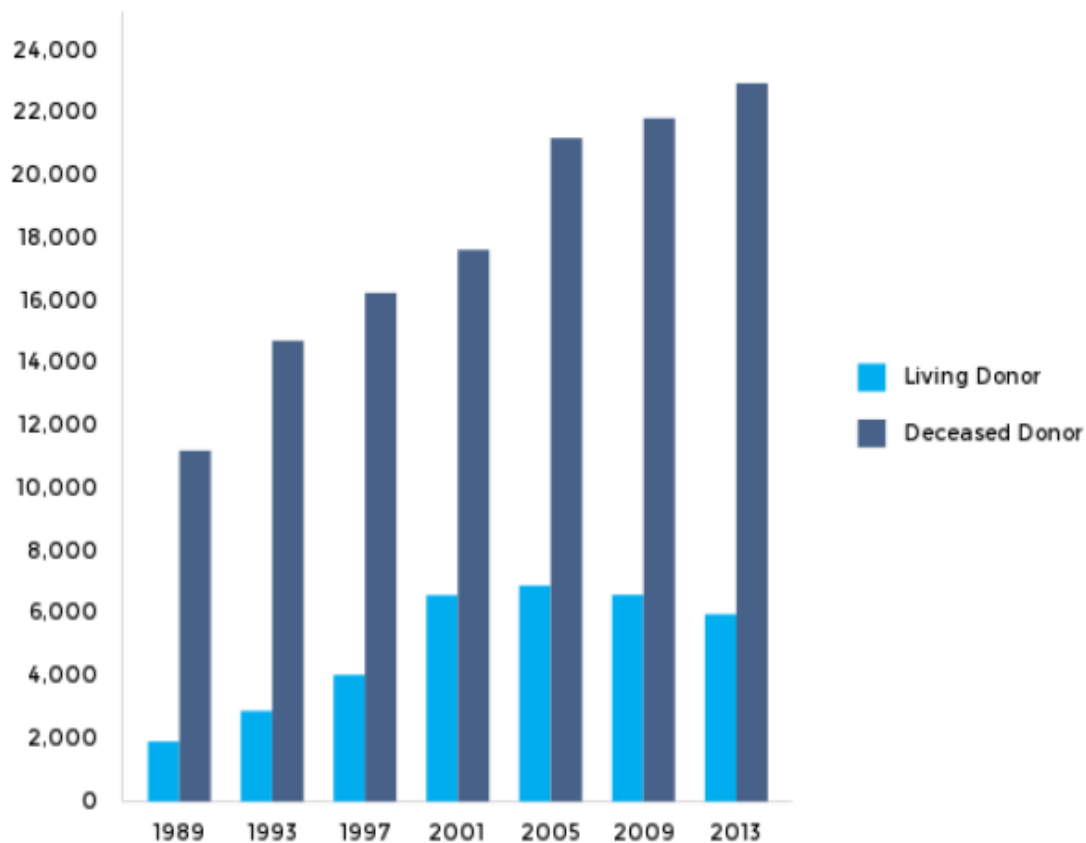
Faced with more than 120,000 people who need a life-saving organ and a constant shortage of donors, economists, doctors and mathematicians are teaming up with data to save lives.

The answer, they think, might be in the algorithm.

The two types of organ transplants

Organ Transplants by Donor Type

(UNOS.org)



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Credit: Mashable/ UNOS.org

On a very basic level, the organ transplant process can be separated into two categories: organs taken from living donors and organs harvested from deceased donors. From living donors, doctors can take one of a person's two kidneys, as well as part of his or her liver (the liver is a regenerative organ and will grow in both the donor and the recipient).

From a deceased donor, doctors are able to extract a cadaver's kidneys, liver, heart, lungs, pancreas, intestines and thymus.

Of the organs donated in 2013, roughly 80% came from deceased donors, according to UNOS.

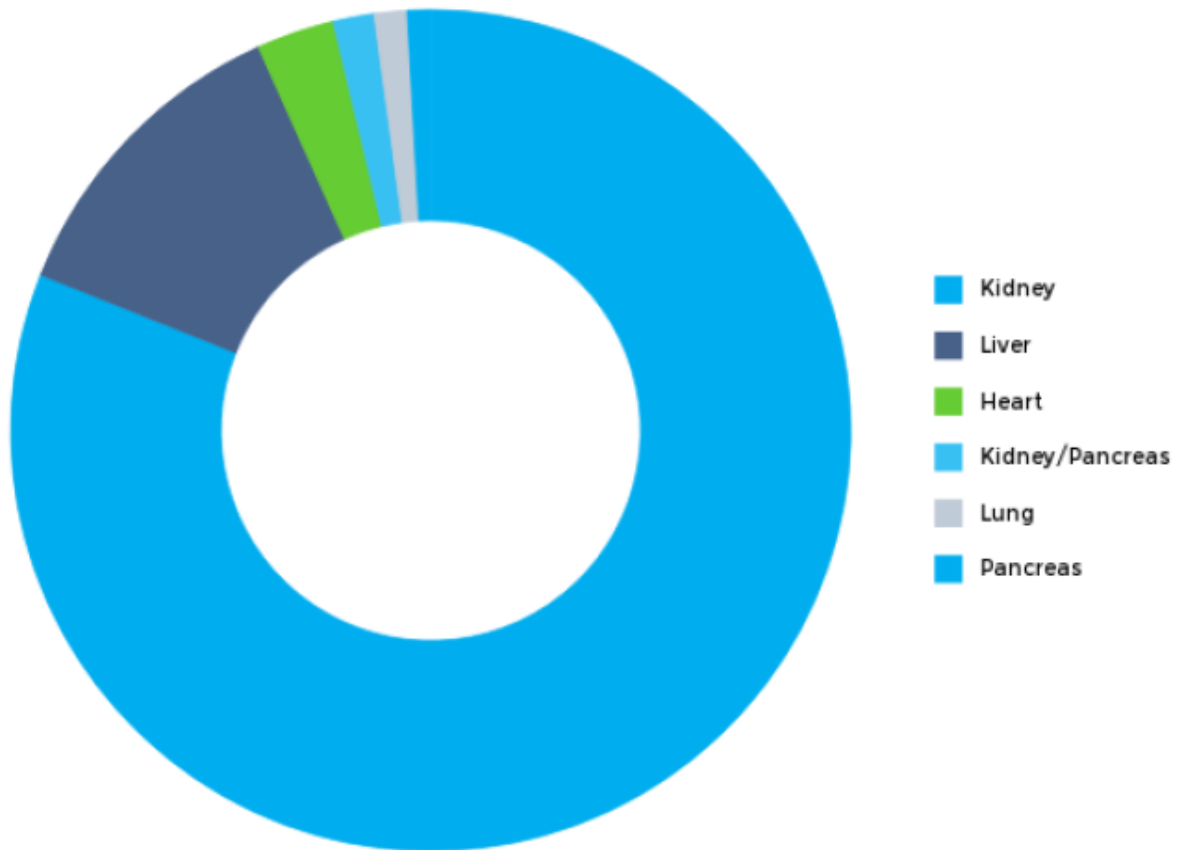
While it's preferable to receive a kidney from a living donor (those organs last nine years longer, on average, and require lower doses of anti-rejection drugs, which can have harsh side effects), donors and candidates are incompatible in approximately one-third of potential kidney transplants because of mismatched blood or tissue types. A donor and candidate can also be incompatible if the candidate has developed antibodies from a previous blood transfusion, pregnancy or transplant that will attack a new kidney.

There are more people on the list than organs available, and even if you receive an organ, there are still risks.

The waiting 'list'

Organs With Highest Demand

(UNOS.org)



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Kidneys are the most in-demand organ Credit:

In the case of incompatibility, a candidate is placed on what's commonly referred to by the public as a "waiting list," which currently has 122,963 candidates. That term, however, is a bit of a misnomer.

"It's not like waiting in line; there's a lot of data that goes into it," a UNOS spokesperson tells Mashable.

While “list” connotes that someone is waiting in a fixed line, UNOS maintains separate databases divided by organ type. Though the organization’s databases factor urgency into its algorithms (they use a MELD score to measure the severity of chronic liver disease, for instance), UNOS and its data aim to find the best matches, not crown a most-deserving candidate.

To that end, UNOS receives information from both the candidate and the deceased donor to establish compatibility such as blood type, body size (thoracic organs, like the heart and lungs, need to be transplanted into a similarly-sized recipient) and geography (UNOS’ algorithm seeks to match candidates locally, regionally and then nationally).

With that data, UNOS' algorithm rules out the incompatible. It then ranks the remainder based on urgency and geography. For example, a liver made available in Ohio would theoretically go to the closest compatible candidate with the highest MELD score.

Kidney exchanges



Credit: Sean Gallup/Getty Images

No matter how fine-tuned UNOS’ algorithms become, the organization still runs into the albatross that is a massive kidney shortage. What if, however, economists and mathematicians could work with doctors to connect incompatible donor pairs and through match theory, increase the number of available kidneys?

In 2004, economics professor Alvin Roth (building on the research of mathematicians Lloyd Shapley and David Gale from 1962) attacked that question by applying an economic match theory he previously used to match students with schools, doctors with residency programs and employers with job seekers.

Specifically, the match theory involves markets in which there aren't prices to facilitate a stable match. To Roth, the kidney market seemed like an ideal place to apply match theory. After all, money isn't present in the kidney marketplace (the federal government precludes it) and there's a startling lack of ideal matches because of medical incompatibility.

Could a system be built to find the best possible matches? Roth thought so and began working on an algorithm with fellow economic professors Tayfun Sonmez and M. Utku Unver to find organs for previously incompatible pairs.

For instance, a husband wants to give a kidney to his ailing wife (Pair A), but tests deem them to be incompatible. What if, however, an algorithm could find the best possible match for the candidate in Pair A from another incompatible pair (Pair B)?

In addition to finding kidneys for previously incompatible pairs, this process -- called a paired exchange or kidney exchange -- also removes names from the deceased donor waiting list.

“Kidney paired donation is a way for more kidneys to come into the system and for more people to get a living donor transplant, which has benefits like longer graft survival and a higher likelihood to function immediately,” says Ruthanne Leishman, program manager for UNOS' and the Organ Procurement and Transplantation Network's Paired Kidney Donation Program.

“You donate for someone instead of to someone. It has a great impact and the potential for more impact,” she adds.

'The power of a computer'

While kidney exchanges don't seem like the kind of labyrinthian problem you'd need an algorithm to solve, they nonetheless become hairy when antibodies are involved. If a candidate with antibodies to specific antigens receives a kidney from a donor with those particular antigens, the recipient's body will reject the kidney.

“It's easy enough to look at blood groups, but a lot of the people who are waiting for a kidney transplant have developed antibodies,” Leishman says. “You really need the power of a computer where you can enter blood type, antibody information of the candidate and the antigen information of the donor.”

In 2000, only two paired donation transplants were performed. Today, more than 2,897 have been completed, with 500 of them coming in the last two years. That, Leishman says, is evidence the algorithm is working and the practice is catching on among donors and doctors.

“From 2000 to 2004, a lot of [pairing] was being done manually -- there was no algorithm yet,” she says. “The first big jump was 19 [paired donations] in 2003 to 34 in 2004 to 111 in 2007 -- a lot of that is because the algorithm was able to find more matches.”

“It’s been increasing over the years because just like any innovation, it takes people a while to climb on board,” she adds.

For their work in matching theory, Roth and Shapley received the Nobel Memorial Prize in Economics in 2012.

Creating a larger pool

Why stop there, though?

In 2005, after hearing Roth speak about game theory and kidney exchanges at a conference in France, Carnegie Mellon Professor of Computer Science Tuomas Sandholm set out to design an increasingly advanced algorithm that could create a kidney exchange network featuring donor chains.



Credit: Bernard Weil/Toronto Star via Getty Images

In a kidney donor chain, a person who wishes to donate a kidney to no one in particular -- called an “altruistic” or non-directed donor -- sets off transplants for clusters of incompatible donor pairs. Because the cluster is initiated by a non-directed donor, it’s left with one donor who has not donated a kidney but whose partner has received one. This person then can act as a “bridge” to a new cluster of incompatible pairs, and so on and so forth.

Part of Sandholm’s plan for a national paired donation network was to create a database with 10,000 donor pairs that could give kidneys in two, three and four-way swaps. Creating clusters and chains out of that many pairs is a massively difficult computational challenge, however. For Sandholm to construct a database with 10,000 donor pairs, he would first have to create an algorithm that could crunch trillions of possible exchanges between donors and candidates without crashing a computer.

“It’s a very hard combinatorial optimization problem,” Sandholm says.

With fellow Carnegie Mellon professor [Avrim Blum](#) and graduate student [David Abraham](#), Sandholm was able to create an algorithm that approaches the matching problem incrementally, meaning a computer wouldn’t crash when processing the 10,000 pairs and billions of potential exchanges. Additionally, the algorithm can stop itself from heading in a direction that won’t produce the optimal cycle of matches.

"Organ exchange is a clever and rapidly growing form of transplantation that addresses the shortage in deceased-donor organs and the incompatibility of donors and patients in live donation," Sandholm says. "It has been extremely interesting and satisfying to design these markets and the algorithms that power them. The newest algorithms from our research automatically learn to match better in a dynamic setting."

In 2010, UNOS launched its Kidney Paired Donation Program that used Sandholm and his team's algorithm. So far, says Leishman, the program has matches have resulted in 97 transplants, with more than a dozen scheduled in the coming months.