Bicycle Helmet Laws, Safety-in-Numbers, and Bikeshares

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At https://github.com/bwpearre/public/tree/main/2024-08_ISDC: Full paper; Poster; Slides; Model

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Background: Active transportation (walking and bicycling) dramatically improves wellbeing through numerous mechanisms including health, empowerment, social equity, childhood cognitive development, resilience, pollution reduction, scalability, global equity, and sustainability. The popularity of cycling is modulated by safety and convenience. The safety of cyclists is strongly correlated with the number of cyclists, with both mechanistic and empirical support for bidirectional safety-numbers causality. Bikesharing can quickly increase the convenience of cycling, especially for new and occasional riders.

Helmet laws have two competing effects on safety: they protect some cyclists during collisions, but also reduce the number of bicycle trips, especially impacting bikesharing. This paper sketches some likely causal loops that link helmet laws and safety-in-numbers to bicycle modeshare and, ultimately, to life expectancy, which we use as a proxy for wellbeing. The model illustrates the potential for reinforcing feedback loops that encourage cycling to quasi-exponentially increase bicycle modeshare, and for helmet laws to slow and limit bicycle adoption, or even to push bicycle modeshare into a death spiral. The results presented here are not intended to be predictive, but rather to demonstrate a potentially dangerous system behaviour, and to motivate more careful study.

Methods: We examine the effects of bicycle modeshare on life expectancy, estimated as a sum of contributions from exercise, deadly crashes, and air pollution. We model three factors contributing to mode choice (car or bike), each of which forms a reinforcing feedback loop with the popularity of cycling: traffic safety, convenience infrastructure, and bikeshare availability:

Safety-In-Numbers: More biking ⇆ Safer biking

- Collisions $\propto (\Delta x)^\beta$, risk $\propto \frac{(\Delta x)^\beta}{\Delta x} = (\Delta x)^{\beta-1}$, $\beta \approx [0.25 \dots 0.4]$
  - e.g. when bicycle use doubles, collision risk decreases by $\sim$35%
- Mode choice is based on perceived risk. We assume that this is based primarily on experiencing and witnessing close calls. It varies proportionally with true risk, but is sufficiently amplified to yield observed modeshare.

Convenience infrastructure: More biking ⇆ More bike-friendly destinations, routes, policies

Bikeshare business model: More biking ⇆ More bikeshare stations

We model three contributors to life expectancy:

- Bike commuting at typical intensity for $\sim$150–300 minutes/week reduces all-causes mortality by $\sim$30–35%. Roughly, an hour of bike commuting increases life expectancy by $\sim$3 hours.
- There is controversy on how effective helmets are. We sidestep this by assuming a perfect helmet that prevents 100% of fatalities from head injuries: one hour of use increases life expectancy by $\sim$1–10 minutes depending on the traffic safety environment.
- We assume that bicycle trips replace car trips. This can have various population-wide benefits, but here we estimate only the universal life expectancy consequences of air pollution.

Helmet requirements deter some cyclists, which modulates the probability of bicycling:

- Among bicycle owners, helmet laws reduce the number of bike trips by 10–40%.
- The deterrent effect is higher for regular bikeshare members, who may not always carry their helmets or enjoy wearing a rental helmet.
- For occasional users or susceptible non-cyclists, we assume an even greater reduction.

Results: Since we do not include any balancing feedbacks, the model is bistable, either converging to a stable bicycle-friendly fixed point in which ridership influx rates balance attrition rates, system funding and infrastructure improvements balance deterioration rates, etc, or a bicycle-hostile environment in which the risk/benefit ratio of cycling is too high for safety, convenience, and bikeshare reach to grow.

The population-wide probability of making any given trip by bike is ψ. In many parts of North America, $\psi \approx 0.01$. In the world's most bike-friendly cities, $\psi \approx 0.5$. In excellent implementations of urban technology such as 15-minute cities, the hope is to push that number even higher.

Bicycle helmet requirements (assuming perfect helmets):

- By making collisions more survivable, they extend cyclist life expectancy by minutes per day, or $\sim$**1–10 weeks** over a lifetime, depending on traffic safety environment.
- They benefit those cyclists who continue riding despite the requirements and the deteriorating safety and infrastructure. Thus, the average gain across the whole population is $\psi\cdot$(1–10 weeks).
- They limit activation of safety and convenience feedback loops, dynamically decreasing ψ.

Increasing ψ activates the reinforcing feedbacks that can make cycling safer and more convenient:

- As ψ grows, safety and convenience feedbacks further drive ψ to saturation (s-curve growth).
- By addressing diseases of inactivity, cyclist life expectancy can increases by $\sim$3 hours/day, or $\sim$ **2–4 years** over a lifetime, depending mostly on activity intensity and duration. Traffic safety environment makes a relatively small direct contribution to individual life expectancy, chiefly affecting perception of safety, therefore mode choice and thus ψ.
- Benefits accrue to an increasing number of people, roughly proportional to ψ.

Dynamic feedbacks between ψ, cyclist safety, convenience, and bikeshare access reinforce each other, driving a virtuous cycle. The benefits of helmet laws operate outside these feedback loops, and thus are limited to a constant factor. In contrast, the drawbacks of such laws operate inside those loops, so their consequences are amplified through time.

Introducing a helmet law into an environment with good infrastructure immediately reduces fatalities, but as the safety-in-numbers effect wanes, fatalities per trip rise. As perceptions of safety deteriorate, ψ falls, reducing demand for infrastructure maintenance. Eventually the bikeshare system is not self-supporting, depriving occasional riders of easy opportunities to enter the system.

One notable oversimplification is that the model does not represent safety infrastructure: infrastructure only contributes to convenience. Adding this missing link dramatically increases the rates of change and convergence, and broadens the parameter space over which the virtuous feedbacks take hold. However, how infrastructure investment shapes safety is less well quantified: the effect is powerful but more research is required. Similarly, we could posit a third aspect of infrastructure, contributing to pleasantness of trips, but guessing realistic parameters would be even more challenging.

Many life-expectancy effects apply to cyclists and non-cyclists. For example, the dose-response relationship of particulate air pollution is thought to be fairly linear over a wide range, so in this model the benefits track ψ. We estimate that at optimistic levels of modeshare shift, life expectancy gains due to reduced air pollution in countries with modern environmental regulations may be on the order of minutes/day. Unmodelled benefits, such as decreasing car traffic congestion, are highly nonlinear.

Most of the model's health and safety parameters come from a robust literature. However, some parameters—and especially rates of change—are less well studied, so we investigate the system's dynamics over reasonable ranges. Thus, while the timescale of the dynamics is somewhat arbitrary, the results nonetheless show plausible effect sizes of infrastructure and helmet policies on population health.

Conclusions: If pressure not to bicycle without a helmet even slightly suppresses feedback loops that affect ridership, the disincentive is expected to erode life expectancy and health far more severely than can be restored even by perfect helmets. Thus, extant static estimates of the public health effects of helmet laws are likely to dramatically underestimate the long-term harm done by unintended consequences, which can push the cost:benefit ratio of helmet laws well beyond 100:1. Given even the remote possibility of this, the potential size of the effects and the far-reaching societal consequences make it vital that any bicycle helmet policy be examined with extreme care.

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