There are opportunities for engineering to make transformative contributions to the curtailment of human trafficking.

A Call to the Engineering Community to Address Human Trafficking

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Human trafficking (HT) is a horrific and seemingly intractable problem that is typically construed as falling beyond the purview of engineers.

This paper argues that engineering systems analysis can produce important insights concerning HT operations and ways to reduce its frequency. Three cases of such systems analysis illustrate (a) the limitations of individual-level interventions against sex trafficking, (b) the benefits of applying network analysis and interdiction models to HT supply chains, and (c) options to reduce the use of trafficked labor in the preparation and distribution of fish products.

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The International Labour Office (ILO 2017) has estimated that there are 25 million victims in forced labor around the world, including 4.8 million in forced sexual exploitation. There are opportunities for engineering to make transformative contributions to the curtailment of human trafficking.

Introduction

Human trafficking is a fundamental human rights abuse and far more common than the average person imagines. It has not traditionally been viewed as a problem for engineers to address, but it can be thought about as a complex system and deserves attention alongside other significant challenges for engineering.

Terminology

Despite the word "trafficking" in the term, HT is defined not by the movement of victims but rather by their inability to escape exploitation. Victims are restrained by debt bondage, threats to family, fear of deportation, and shame more often than actual shackles.[1]

> *Human trafficking can be thought about as a complex system.*

HT is not the same as *human smuggling*, the facilitation of illegal border crossing by willing travelers. While some HT victims are smuggled across borders, HT victims can be exploited in their own country, and undocumented immigrants may not work at all or work under conditions that they are free to leave.

Sex trafficking is commercial sexual exploitation through force, fraud, or coercion. Because only adults can give consent, any commercial sexual exploitation of minors is considered sex trafficking; the adult sex industry is composed of both trafficked and nontrafficked individuals (Martin et al. 2017). Sex trafficking networks in the United States differ depending on the citizenship of the victim (Busch-Armendariz et al. 2009). Organizations that exploit US citizens often both recruit and exploit their victims, and are often fairly autonomous; networks that traffic foreign citizens often include multiple interdependent organizations, including some that specialize in recruitment and transport and others that "employ" the victims in sex work.

Labor trafficking is most common in agriculture, health and beauty services, landscaping, domestic work, construction, and manufacturing (Polaris 2017). Victims in the United States include citizens and foreign nationals, for whom recency of immigration is a significant risk factor. Imported products may have been produced by trafficked labor abroad.

Trafficking Goods vs. Services

It is easy to spot similarities between HT and trafficking in drugs, weapons, and wildlife. They are all transactional crimes and, while HT clearly has victims, they usually do not report the crime. Yet there are important differences. The other forms of trafficking involve criminals delivering goods to consumers, whereas, from the traffickers' perspective, the "object" in human trafficking is more akin to a capital asset: it is exploited to produce services (sex acts, labor) and the services are sold to consumers.

This distinction has implications that some simple calculations can elucidate. The parameter values used here and elsewhere in this paper are not laboratory-measured with high precision; it is difficult to gather reliable data on HT because it is hidden, illegal, and dangerous. Yet even approximate values can produce insight through the sorts of calculations engineers do.

Consider how often a gang with \$500,000 in annual revenues purchases a trafficked "product" (human or drug) from its "suppliers." A gang that generates such revenue by forcing HT victims to provide commercial sex services might at any time be exploiting five HT victims, assuming a typical HT victim in the United States can produce about \$100,000 in revenue per year, e.g., by averaging ten \$30 sex acts per day (Kara 2009). If victims were exploited for an average of 2½ years before being released, sold, or killed (Kara 2009), the gang would need to acquire only two HT victims per year, on average. In contrast, a drug gang with \$500,000 in annual revenues might purchase drugs from its supplier almost daily if, as is typical, drugs were acquired in lots of 50 retail units that sold for \$30 each (Caulkins et al. 2016), since \$500,000/(\$30 * 50) = 333 days of purchases. That difference in the number of "product acquisitions" (two per year vs. almost daily) has implications for the supply chains' structure, scale, and vulnerability to law enforcement.

This introduction underscores three points:

- Most HT is business activity that involves supply chains in ways that street crimes such as assault or robbery do not.

[1] See UNODC (2000) for a formal definition of human trafficking.

- HT differs from other market crimes and must be analyzed from first principles, rather than presuming that conclusions concerning drug trafficking, for example, apply to HT.
- HT encompasses diverse industries, and the particulars matter. Polaris (2017, p. 2) identifies 25 types of HT in the United States, "Each [with] its own business model, trafficker profiles, recruitment strategies, victim profiles, and methods of control that facilitate human trafficking."

This article offers three case studies illustrating how engineering systems analysis can shed light on different segments of HT and a brief guide to how engineers can help address it.

Victim-Level Interventions and the Problem of Replacement

Human trafficking is a complex criminal activity, and interventions that address one component (e.g., root causes, services for victims, or interdiction of trafficking operations) may affect other components. We show how victim-level interventions may paradoxically create a net increase in the number of victims. For simplicity's sake, we focus on sex trafficking victims. A more thorough exploration would include independent sex workers, who may experience exploitation but not trafficking per se.

Conceptual Model of Operational Costs and Market Equilibria

Sex trafficking operations profit by supplying sex to buyers through the control and exploitation of victims who provide sex. Their operations are shaped by market forces such as demand elasticity and the cost of replacing victims who escape their trafficking situation (Martin and Lotspeich 2014). It is relevant to consider how victim-level interventions affect operational costs, the market clearing price and volume, and the number of HT victims.

From the perspective of an HT operation, interventions that remove existing HT victims prompt the acquisition of replacement "workers." This replacement imposes some costs that are passed on to sex buyers, potentially deterring some of them.

If replacement costs are high, victim-level interventions could drive up prices enough to shrink the market and decrease the number of trafficking victims. However, if replacement costs are low, the trafficker could obtain a replacement without much increase in the price to purchase sex. That could leave the number of victims being exploited at any given time nearly unchanged, while reducing the average duration of exploitation, leading to a greater flow of new victims to meet demand. Thus while comprehensive services and support for victims are important and needed, they may not be sufficient to reduce impacts on victims and society.

Bringing Numbers to Bear

There is no definitive research on pricing structures for sex acts, lengths of time that victims are exploited, or victim replacement costs, all of which vary by context, locale, country, type of sex act, market segment, and more (Dank et al. 2014).

> *The number of human "acquisitions" has implications for HT supply chains' structure, scale, and vulnerability to law enforcement.*

For this exercise, we consider estimates for a brothel-type operation in New York City, where a victim costs \$3,000 to recruit, is trafficked for 2½ years, and performs ten \$30 sex acts per day (Kara 2009). In this case, the traffickers' revenues per victim recruited are \$273,750 and the \$3,000 recruitment cost thus consumes approximately 1 percent of the traffickers' gross revenue.

When replacement costs are so low relative to revenues per victim, victim-level interventions may actually increase the number of HT victims: if the interventions reduce by half the average time an individual is trafficked, then traffickers must obtain two people to provide the same volume of activity. Suppose the demand elasticity is such that the ~1 percent increase in suppliers' cost structure reduces market volume by 4 percent. Then, where there had been 100 organizations recruiting 2 HT victims per year, there are now 96 organizations recruiting 4 per year. The number of victims at any point in time has been reduced by 4 percent from 500 to 480, but the number drawn into HT each year *increases* by 92 percent from 200 to 384.

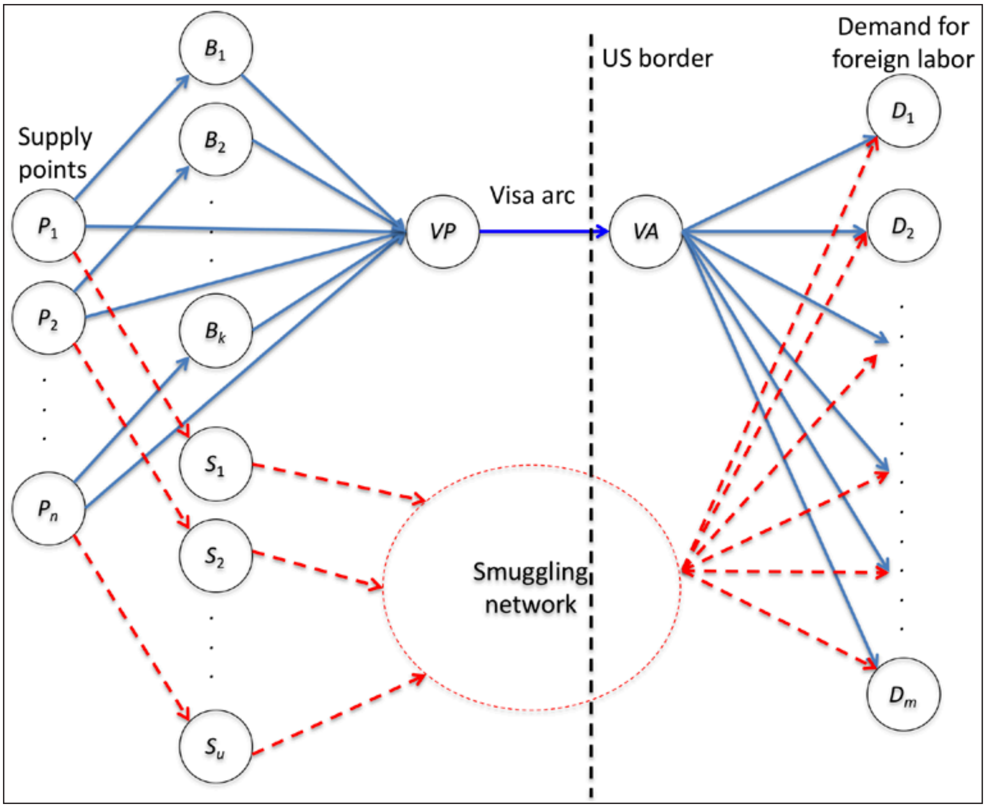

FIGURE 1 Network model of labor supply chain of foreign nationals. Blue lines denote a legal network and red dashed lines an illegal network for foreign laborers entering the United States. *B* = labor broker; *D* = employer (demand); *P* = source of potential laborers (town, region, country); *S* = smuggler (trafficker); *VA* = visa accepted; *VP* = visa process.

Of course, not all commercial sex is supplied by HT victims, and not all HT organizations are identical (Martin and Lotspeich 2014). HT is a dynamic system and improvement in one area may worsen conditions in another. While it is imperative to support victims in exiting an HT situation, such efforts may not deter traffickers from continuing their operations by recruiting replacements, particularly in market segments where the cost of replacing a victim is low, as in the New York example.

Network Analysis for Disrupting Human Trafficking

Network analysis can shed light on ways to disrupt human trafficking. A network is a collection of nodes and arcs where nodes model potential HT states, locations, or processes and arcs model the relationships between the nodes.

Figure 1 provides a conceptual network of the supply chain of foreign nationals entering the United States for work. Nodes P_1 through P_n are populations of potential laborers and countries, regions, or towns. *D* nodes represent US employers that are willing to hire foreign laborers, who move through either a legal or illegal network to work in the United States.

The network of solid blue lines represents the process of legally obtaining a visa, whether directly (the arc from the supply point to the "visa process," *VP*, node) or through a labor broker (represented by the *B* nodes). Note that the network bottlenecks at the visa arc, where the "visa accepted" (*VA*) node represents entry into the country. The network of red dashed lines represents persons illegally entering the country to work.

Laborers may be vulnerable to HT whether they enter the United States through the legal or illegal network. Brokers may demand large sums to begin the visa process, creating a form of debt bondage that makes it difficult for the laborer to leave the US employer no matter the working conditions. After Hurricane Katrina, for example, brokers required Indian welders to pay a recruitment fee of $10,000–$20,000 to help obtain an H-2B visa to work for Signal International, and these workers became indentured to the brokers (Desai 2015).

Laborers who enter the country illegally are more likely to be victims of HT. For example, undocumented farm laborers in North Carolina are 2.8 to 5.2 times more likely to be victimized than are documented laborers, depending on the type of victimization (Barrick et al. 2013, 2014). Another study found that 31 percent of surveyed unauthorized migrant laborers in San Diego County had been HT victims (Zhang 2012).

Therefore, one potential intervention for reducing labor trafficking would be to decrease the flow of laborers in the illegal network. Interventions in the illegal network might increase its cost, making the flow less economical than legal employment practices. Alternatively, policies could increase the capacity of the legal network by reducing the visa bottleneck. Expanding the supply of visas should reduce HT among foreign nationals in the illegal network and will increase flow in the legal network, where HT occurs at a much smaller rate. Further, it may shift the balance between foreign and domestic laborers in the workforce.

The effectiveness of policy efforts to decrease HT will depend on the nature and extent of changes and on whether the legal network is properly designed, resourced, and incentivized. Network analysis provides a framework for accounting for these effects in order to identify the most cost-effective way to have the desired impact on disrupting HT.

Seafood Supply Chains and Labor Trafficking

Fishing is big business: aquaculture and a global fishing fleet of roughly 4.6 million vessels annually produce over 160 million tons of fish for global consumption (FAO 2014). Demand for inexpensive seafood and poor regulation have created conditions ripe for labor exploitation (Sutton and Siciliano 2016), leading to pervasive and well-documented human trafficking in the seafood supply chain (ILO 2012; IOM 2011; Pearson et al. 2006; Stringer et al. 2014), although, because illegal labor exploitation is intentionally hidden, it is difficult to quantify the extent.

US retail seafood sales are approximately $100 billion per year, of which only about 10 percent is domestically produced (White 2016). The US government is not blind to problems in the seafood supply chain. Its Seafood Import Monitoring Program (SIMP) imposes reporting and recordkeeping requirements to prevent illegal, unreported, and unregulated-caught or misrepresented seafood. Effective January 1, 2018, it requires the tracing of 13 priority species from the point of harvest to entry in US commerce. But this new program applies only to selected species and is motivated primarily by environmental concerns.

We offer the following questions to guide engineering design and to determine what it would take to effectively inspect the entire US fish supply chain to eliminate HT labor exploitation.

What is the least costly way to deploy a portfolio of monitoring tools to combat HT?

The diverse participants and the scale and complexity of the international fishing supply chain create immense challenges for monitoring HT; maritime enforcement institutions cannot simply post observers on all 4.6 million vessels operating internationally. What is the least costly way to deploy inspections, audits, automatic identification systems (AIS), voluntary compliance, satellite technology, or other methods to supervise fish harvesting and processing to guarantee that the supply chain is void of HT? How can such tools be combined in a cost-efficient manner to identify both illegal fishing and human trafficking?

How can data analytics identify vessels that use HT victims?

Algorithms could be developed to identify characteristics associated with HT in deep seas and then (using tools such as Skytruth) detect vessels exhibiting suspicious behavior. For example, gaps in satellite data may indicate that a fishing vessel turned off its AIS signal to avoid disclosing its location (Sutton and Siciliano 2016). Likewise, a meeting between two ships at sea may signal offshore transshipment to avoid landing at port, or a fishing vessel that remains at sea for extended periods of time may be more likely to be associated with human rights abuses (e.g., trapping its crew aboard).

How can engineering design enhance inspection of the US fish supply chain to eliminate HT labor exploitation?

How can a systems approach be used to determine whether monitoring efforts could be paid for with an excise tax on fish products?

Monitoring the seafood supply chain, even with an efficient design, would not be free. Would consumers be willing to pay for the cost to implement a supply chain monitoring system to ensure that fish products sold in the United States are fair trade?

Superficially, consumer financing of supply chain monitoring seems feasible. If the estimated $100 billion seafood consumer market were taxed at 0.5 percent,

$0.5 million would be available to support monitoring and enforcement—far more than SIMP costs. However, such a tax would affect sales. Consumer demand, environmental sustainability, labor trafficking, aquaculture, and socioeconomic development interact interdependently and form a large system with complex, dynamic, diverse, and nonlinear characteristics. A simulation model could provide insights related to the effects of an excise tax on US fish consumption, global fish stocks, and trafficked labor, thereby addressing a range of policy and behavior questions.

Guiding Thoughts for Engineers

We offer the following thoughts for those whose interest has been piqued to consider working in this domain.

First, it is important to take account of the complexity and ambiguity inherent in these systems. Related crimes and other misconduct against HT victims are common (Aronowitz et al. 2010)—identity theft, forgery, assault, theft of documents, and forced participation in other crimes—and HT overlaps other problem domains, such as drugs, warfare, other forms of violence, and labor exploitation.

There are risks of unintended consequences to well-intentioned interventions.

Further complicating matters, substantial challenges exist in identifying and measuring victimization. For example, the criteria needed for prosecutorial proof of victimization differ from the criteria needed by those who provide services to victims. For engineers working in this field, it is important to dig deep and understand the origins of numbers, available data, and their proper interpretation.

Much current scholarship focuses analysis solely on HT victims and perpetrators. Engineers can contribute by studying the entire system within which HT occurs. There are multiple relevant decision makers—employers, agents and recruiters, public officials, retailers, and consumers—with different goals and levels of information. As illustrated by the seafood supply example, an ecosystem view may offer solutions, particularly if it incorporates the dynamics between ecosystem participants and recognizes the alternatives that are available when these actors make decisions. These dynamics and alternatives include the limited choices available to victims and the various coercive strategies used by perpetrators and their agents to lure victims.

Interventional targets for such complex systems vary in scale and effort to deploy. Technology-driven initiatives, like the monitoring tools discussed above for illegal fishing, are complicated solutions in absolute terms, but the benefits can be enhanced by parallel investment in changes to social norms through community education and training about labor and basic human rights (Battista et al. 2018). Such fundamental changes to social norms likely require more time to diffuse through communities compared to the already substantial time to design and deploy monitoring tools.

There are risks of unintended consequences to well-intentioned interventions. Anyone working in this domain needs to listen and look for potential harms as they bring important new insights from the application of powerful systems thinking. For example, a fishing tax as an intervention to fund antitrafficking programs might also reduce demand and suppress legal fishing operations with fair employment policies. Caution is warranted particularly given the lack of empirical data on so many aspects of HT.

Conclusions

Human trafficking is a morally wicked practice, and stopping it is a wicked problem in the formal sense of the term (Rittel and Webber 1973). It is a domain in which sincere efforts may absorb enormous energy without significantly shrinking the problem.

Efforts to reduce the scale of HT must be grounded in a systems-level understanding of its many interconnected and dynamically interacting parts. The primary actors—the organizations that recruit, transport, and exploit HT victims—are fundamentally business operations with supply chains. Engineers understand how to describe and manipulate supply chains. We usually work to make them more efficient, but the same systems analysis applied in reverse can shed light on ways to make those supply chains less efficient and, ideally, uncompetitive with supply chains that provide the same services without exploiting forced labor. HT is both a business operation and a violation of basic human rights.

To date, engineers have not been much involved in combating HT. But the discipline now recognizes engineers' responsibility to address society's grand challenges (Vest 2008), and defeating HT can certainly be seen as a similarly worthy challenge for engineers.

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References

Aronowitz A, Theuermann G, Tyurykanova E. 2010. Analysing the business model of trafficking in human beings to better prevent the crime. Vienna: Organization for Security and Co-operation in Europe Office of the Special Representative and Coordinator for Combating Trafficking in Human Beings.

Barrick K, Lattimore PK, Pitts W, Zhang SX. 2013. Indicators of Labor Trafficking among North Carolina Migrant Farmworkers. Research report prepared for the National Institute of Justice, Washington.

Barrick K, Lattimore PK, Pitts WJ, Zhang SX. 2014. Labor trafficking victimization among farmworkers in North Carolina: Role of demographic characteristics and acculturation. International Journal of Rural Criminology 2(2):225–243.

Battista W, Romero-Canyas R, Smith SL, Fraire J, Effron M, Larson-Konar D, Fujita R. 2018. Behavior change interventions to reduce illegal fishing. Frontiers in Marine Science 5:403.

Busch-Armendariz N, Nsonwu M, Cook Heffron L. 2009. Understanding human trafficking: Development of typologies of traffickers, Phase II. 1st Annual Interdisciplinary Conf on Human Trafficking, Oct 29–31, Lincoln NE.

Caulkins JP, Disley E, Tzvetkova M, Pardal M, Shan H, Zhang X. 2016. Modeling the structure and operation of drug supply chains: The case of cocaine and heroin in Italy and Slovenia. International Journal of Drug Policy 31:64–73.

Dank M, Khan B, Jay J, Downey CPM, Mayer D, Owens C, Yu L. 2014. Estimating the Size and Structure of the Underground Commercial Sex Economy in Eight Major US Cities. Washington: Urban Institute.

Desai R. 2015. Landmark human trafficking case ends with bankruptcy for Signal International, Inc. Human Rights First, Jul 24.

FAO [UN Food and Agriculture Organization]. 2014. The State of World Fisheries and Aquaculture: Opportunities and Challenges. Rome.

ILO [International Labour Office]. 2017. Global Estimates of Modern Slavery: Forced Labour and Forced Marriage—Executive Summary. Geneva.

IOM [International Organization for Migration]. 2011. Trafficking of Fishermen in Thailand. Bangkok.

Kammer-Kerwick M, Busch-Armendariz N, Talley M. 2018. Disrupting Illicit Supply Networks: New Applications of Operations Research and Data Analytics to End Modern Slavery. Workshop report and proposed research agenda. University of Texas at Austin.

Kara S. 2009. Sex Trafficking: Inside the Business of Modern Slavery. New York: Columbia University Press.

Martin L, Lotspeich R. 2014. A benefit-cost framework for early intervention to prevent sex trading. Journal of Benefit-Cost Analysis 5(1):43–87.

Martin L, Melander C, Karnik H, Nakamura C. 2017. Mapping the Demand: Sex Buyers in the State of Minnesota. Minneapolis: University of Minnesota.

Pearson E, Punpuing S, Jampaklay A, Kittisuksathit S, Prohmmo S. 2006. The Mekong Challenge: Underpaid, Overworked and Overlooked—The Realities of Young Migrant Workers in Thailand, vol 1. Bangkok: International Labour Organization.

Polaris. 2017. The Typology of Modern Slavery: Defining Sex and Labor Trafficking in the United States. Washington.

Rittel HW, Webber MM. 1973. Dilemmas in a general theory of planning. Policy Sciences 4(2):155–169.

Stringer C, Simmons G, Coulston D, Whittaker DH. 2014. Not in New Zealand's waters, surely? Linking labour issues to GPNs. Journal of Economic Geography 14(4):739–758.

Sutton T, Siciliano A. 2016. Seafood Slavery. Washington: Center for American Progress.

UNODC [United Nations Office on Drugs and Crime]. 2000. United Nations Convention against Transnational Organized Crime. Vienna.

Vest CM. 2008. Context and challenge for twenty-first century engineering education. Journal of Engineering Education 97(3):235–236.

White C. 2016. American seafood consumption up in 2015, landing volumes even. Seafood Source, Oct 27.

Zhang SX. 2012. Looking for a hidden population: Trafficking of migrant laborers in San Diego County. San Diego State University.