

## **System Dynamics Modeling of the SmartWay Transport Partnership**

Kwan C. Tan<sup>1</sup> and Edgar E. Blanco<sup>2</sup>

*MIT Center for Transportation and Logistics, Cambridge, Massachusetts, 02139*

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### **Abstract**

*The freight industry and in particular heavy trucks are a significant source of greenhouse gas emissions accounting for 541.3 million metric tons of carbon dioxide in 2006. Despite cost effective technologies able to improve the efficiency of heavy trucks by at least 12% readily available today, the mileage of heavy trucks has remained stagnant between 5-6 miles per gallon over the past 25 years. Several factors account for this apparent market failure including the lack of accurate and verifiable fuel economy information in the industry and the fragmented nature of industry where smaller owner operators make up a sizable proportion but often lack the resources and capital to test and implement technology opportunities. The SmartWay Transport Partnership is a highly successful U.S. Environmental Protection Agency initiated voluntary public private partnership that is targeted at addressing these market inefficiencies. In this paper, we demonstrate the use of applying system dynamics in eliciting the mental models of key stakeholders to better understand the factors for the program's success. The study highlights the importance of close communication and discussion with key stakeholders during the design phase of a program to ensure that its final structure is attractive to participants and is successful in achieving its objectives. System dynamics is also applied quantitatively to evaluate the potential greenhouse gas emission reductions under various policy scenarios. This is potentially useful in the design and analysis of future voluntary partnerships where results may not be deterministic and benefits only start to become evident once the program has gained sufficient momentum. A lack of understanding of the reinforcing growth dynamics of such programs may lead to their unnecessary premature termination.*

### **Key words**

SmartWay Transport Partnership, Voluntary Public Private Partnerships, System Dynamics, Engineering Systems, Climate Transportation Policy, Freight Logistics, Technology Diffusion

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<sup>1</sup> Research Assistant, MIT Center for Transportation and Logistics, 77 Massachusetts Ave, E40-276, Cambridge MA 02139

<sup>2</sup> Executive Director, MIT Center for Latin-American Logistics Innovation (CLI) Alliance, One Amherst Street, E40-295, Cambridge MA 02139

## 1. Introduction

In 2006, the total carbon dioxide (CO<sub>2</sub>) emissions from the freight industry were 541.3 Million Metric Tons of Carbon Dioxide Equivalent (MMTCO<sub>2</sub>E) which made up 27.5% of the total transportation industry and 7.7% of total U.S. emissions. In addition, emissions from the freight industry have increased by 52% from 1990 to 2006 and are expected to continue growing. Within the freight industry, emissions from trucks constituted about three quarters of this total [1]. Notably, class 8 trucks consumed 78% of the fuel use among class 3-8 trucks despite making up only 42% of the class 3-8 trucking fleet [2]. This makes the freight industry and in particular heavy trucks one of the most prominent targets for CO<sub>2</sub> emissions reductions.

The average fuel economy for combination trucks has however remained mostly constant, fluctuating between 5-6 miles per gallon from 1980 to 2006 [3]. This is despite technology presently available that could increase fuel efficiency by at least 12% cost effectively and up to a potential of even 90% [4] [5]. There are clearly significant market inefficiencies and barriers to the optimal diffusion and uptake of technology into the heavy duty truck sector including:

- **Lack of accurate, verifiable fuel economy information:** The structure of the truck manufacturing and component industry poses several obstacles to the flow of accurate and useful information. Combination trucks are often highly customized and produced in limited quantities. Component manufacturers operate independently of truck manufacturers resulting in it being more difficult to demonstrate and market their efficiency enhancements. In addition, there are no clear standards or methodologies for measuring the efficiency of heavy trucks nor are these easily replicable. This leads to much uncertainty regarding payback times of technologies which often have high initial capital costs associated with them.
- **Failure to incorporate costs of CO<sub>2</sub> emissions and other air pollutants:** While a price on carbon might affect some of the cost and payback dynamics, it is unlikely that such a price will be incorporated at the necessary level early enough to stimulate the needed change in behavior and uptake of technology. Complementary, non price based mechanisms including consumer purchasing pressure might provide the much needed additional push. This is presently limited due to the lack of information transparency regarding fuel economy and carbon emissions along the supply chain.

## 2. Voluntary Public Private Partnerships

The U.S. Environmental Protection Agency (EPA) currently has 36 listed climate partnership programs catered to a range of different industries and sectors [6]. More than 14,000 organizations are currently involved in these programs, contributing to a prevention of 78 MMTCO<sub>2</sub>E and net savings to consumers and businesses of \$17 billion in 2007 [7]. These voluntary partnerships are aimed at addressing commonly faced market barriers such as the lack of information about energy efficiency and renewable energy options, competing claims in the marketplace, high transaction costs, lack of reliable technical assistance, and lack of objective basis for recognition of environmental stewardship.

Voluntary public private partnerships provide an alternative policy option to legislation which is often a contentious process and opposed strongly by industry. They are also less costly than

grants and tax incentives and target the market efficiency problem regarding lack of reliable information directly. Not all climate partnership programs have been successful and a 2008 report by the EPA Office of Inspector General (OIG) suggested they had limited potential and often faced barriers to participation due to reasons including perceived emission reduction costs and reporting requirements. The report also commented that it was unlikely that these programs could reduce more than 19% of the projected 2010 GHG emissions in their sector based on marginal abatement curve analysis [8]. A separate evaluation report done by the OIG on the reported benefits of the Energy Star program identified inaccuracies and unreliability in the emissions savings reported and recommended the need for the establishment and implementation of improved quality controls and methodology used in computing market transformation effects [9].

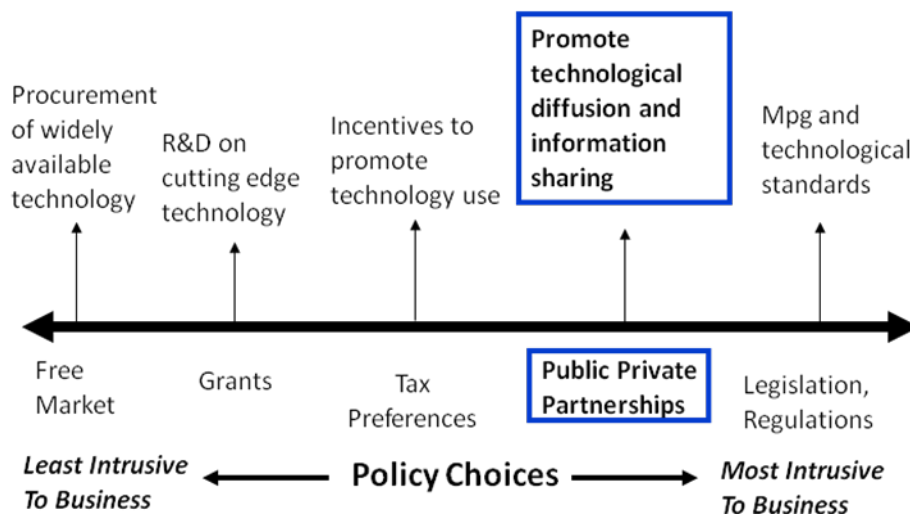


Figure 1: Freight transportation policy choices (adapted from SmartWay/ICF presentation)

### 3. SmartWay Transport Partnership

The SmartWay Transport Partnership is an innovative collaborative voluntary program between the EPA and the freight industry designed to improve energy efficiency and lower greenhouse gas (GHG) emissions and air pollution. Started in February 2004, the partnership aims to create strong market-based incentives that challenge companies shipping products, and the truck and rail companies delivering these products, to improve the environmental performance of their freight operations. Companies that provide and hire freight delivery services become SmartWay Transport Partners by committing to improve the environmental performance of their freight delivery operations. SmartWay Transport Carriers commit to integrate innovative cost saving strategies into their fleet operations. SmartWay Transport Shippers commit to ship the majority of their goods with SmartWay Transport Carriers. Companies that meet SmartWay Transport Partnership requirements benefit from reduced operating costs and enhanced visibility. In addition, partners that demonstrate superior performance earn the right to display the SmartWay Transport logo. Logistics providers and industry affiliates are also eligible to participate in the program.



The MIT SmartWay model focuses on the shippers, carriers and staff participation and interaction in the system. The MIT CTL team developed an initial framework for the model in May 2008. This was followed up with a visit to the SmartWay team in June 2008 where a series of interviews were conducted with the program staff. More interviews were conducted with selected partners enrolled in the program in October and November 2008 and the team presented our initial findings at the SmartWay International Summit in December 2008. The model has since been updated and improved upon after feedback from the EPA and participants at the summit.

The causal loop diagram shown in Figure 2 was developed after interviews with staff and partners of the program about their experiences and understanding of the dynamics of the program. Key variables in the diagram are connected by arrows which denote the causal influences between them. The hashed lines represent delays in the causal effects of the system. Through this process, we have identified four main reinforcing loops explaining the factors of success behind the SmartWay program:

1. **Word of Mouth:** As the number of partners enrolled in the program increases, the level of program advertising increases as these partners highlight their involvement in the program during trade conferences, individual meetings with other companies, and through various promotional material such as newsletters and websites. In a 2007 tracking survey conducted by Harris Interactive, the top six main sources of awareness for companies were trade publication advertising, state or national trucking associations, magazines, industry conferences, the internet, and through colleagues or friends. Industry awareness as reported by the survey increased from 13% in 2005 to 32% in 2007 [11]. As more companies become aware of SmartWay and as they realize a larger number of companies are enrolling in the program, they become more receptive to participating in it.
2. **Consumer Pressure:** Similarly, as partners are enrolled in the program, they communicate this information to consumers through marketing strategies including labeling, the internet and various forms of corporate social responsibility branding. The assumption here is that the more consumers learn and understand about the program, the greater the pressure they will put on shippers to enroll in the program through their purchasing decisions and direct communications. In 2008, awareness about the SmartWay program among consumers was estimated at around 13% to 20% depending on whether description aid is provided [12]. The effect of eco-labels on consumer behavior is still highly debatable as well with various studies supporting both sides of the argument. However, there is a general consensus that more people are becoming aware and concerned about the issue of climate change and that companies recognize and are taking steps to address these concerns.
3. **Shipper Pressure:** One of the important features about the structure of the SmartWay program is the involvement of the shippers. While carriers are in direct control of their fleet, their incentives to exhibit corporate social responsibility practices are limited as compared to shippers who have direct contact with public consumers. The requirement for each shipper to have at least 50% of their shipments moved by carriers enrolled in the program has a huge multiplying and reinforcing effect with regards to program participation. For example, Wal-Mart has offered fuel subsidies to carriers who enroll in the program and IKEA has made participation in the program a requirement for carriers that they work with. Many other

companies solicit information about a carrier's participation in the SmartWay program in their requests for proposals and factor it in their decision making. Shippers in the program also tend to be strong advocates in encouraging their carriers to join the program. One suggested reason for this is that more efficient carrier performance leads to lower operating costs and greater savings which are distributed back to the shippers as well. The resulting increase in number of carrier partners leads to more publicity and advertisement for the program and heightened industry awareness.

4. **Strategy Validation:** While increasing participatory rates is one good indicator of the program's success, it is also important to look at strategies implemented by companies and the resultant reduction in CO<sub>2</sub> emissions. In general, most of these strategies are applicable to carriers. The SmartWay program provides a valuable service in this aspect as it serves not only to perform an initial screening of possible technological innovations, but also as an avenue for carriers to share their testing results with the community. Usually only larger carrier companies have the resources to experiment with new technologies. As these technologies become validated and proven to be cost-effective, they get shared with other companies through the SmartWay program, industry confidence in the strategies grows and smaller carrier companies start to implement them as well.

As can be expected, there are limits to growth in program participation and strategy implementation and these cannot increase forever. Three of these balancing loops are discussed below:

1. **Program Resource Dilution:** As more companies enroll in the program, the number of partner accounts each staff member has to handle increases. The amount of time each staff member has to dedicate to a partner decreases and the service he is able to render goes down. In addition, enrollment time for new partners is delayed as a result. Program staff have communicated via interviews that a ratio of 100 partners per staff would be ideally the amount of work they could handle effectively.
2. **Shipper/Carrier Brand Dilution:** Another possibility is that as more companies start to enroll in the program, it results in the program losing its initial appeal of innovativeness and elitism. At the onset, the program is attractive to "leaders" in the field of transportation efficiency and sustainability as they can brand themselves as being so through their involvement in the program. But once a sizable percentage of the industry is participating in the program, the logo and branding becomes more of a commodity, taking away part of its appeal.
3. **Diminishing Returns of Strategies:** Predictably, the "lowest hanging fruit" or strategies with the shortest payback and lowest upfront costs are typically selected first. Past a certain point, there are also technical limitations to the efficiencies which you can achieve and these usually experience diminishing returns with the number of strategies implemented. The current SmartWay recommended upgrade kit which includes a direct-fired heater, super single tires with aluminum wheels and a trailer aero kit estimates a combined fuel economy improvement of 17%. While technology is expected to improve exogenously over time, there is a theoretical limit regarding how much more efficient a vehicle can become.

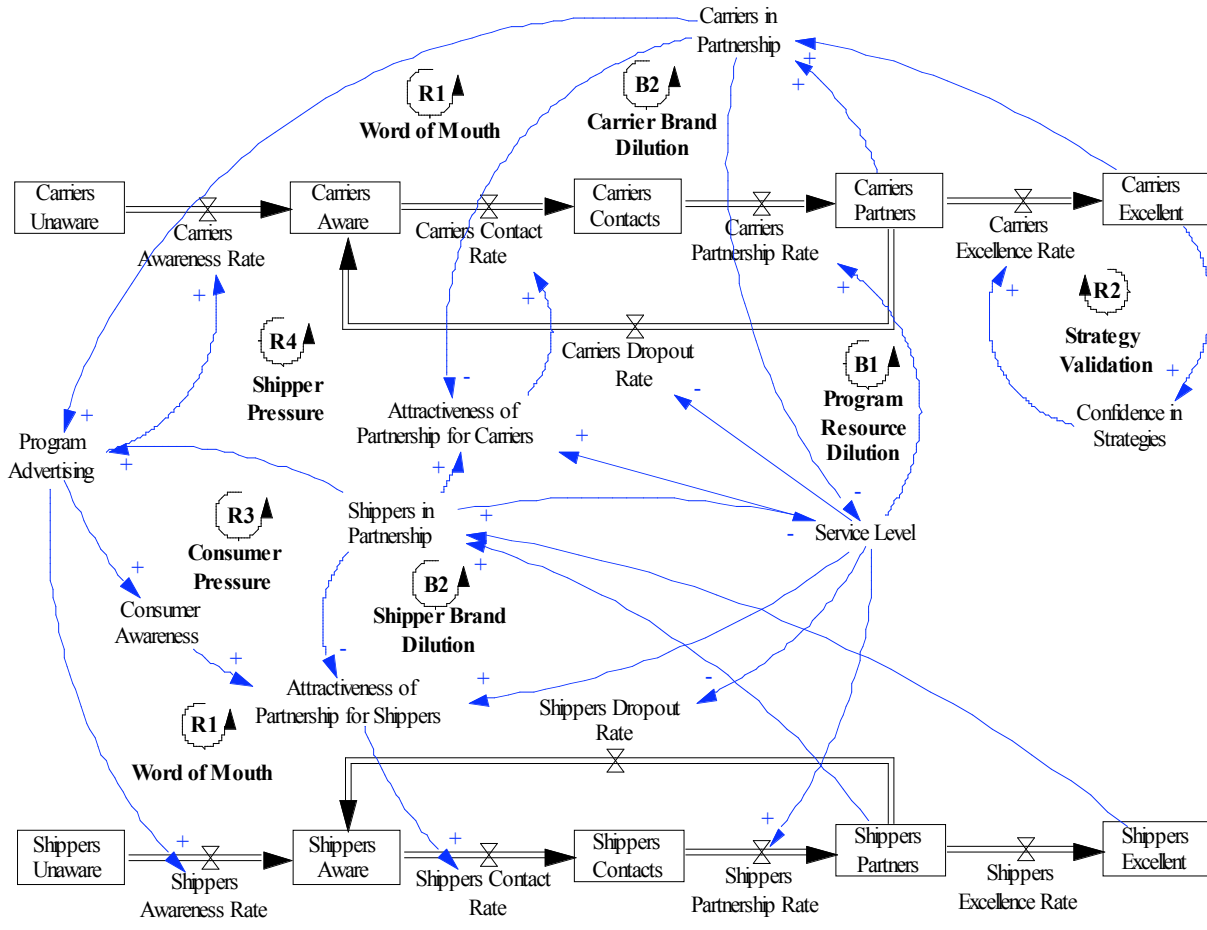


Figure 3: SmartWay Transport Partnership stock and flow diagram

Figure 3 shows a simplified stock and flow diagram that captures the main reinforcing and balancing loops of the SmartWay program. This is an extension of the previous causal loop diagram (Figure 2) and is the foundation for our final model. Every carrier and shipper company is presumed to move through five stages. The initial stage is that of “unawareness”. Once a company has heard and learnt about the program, it moves to a stage of familiarity with the program, which we have titled “awareness”. If the company is interested in the program and makes a decision to learn more about the program with the intention to join, it becomes a “contact”. A proportion of these companies then continue to enroll in the program and become “partners”. The final stage “excellence” is achieved when a carrier has implemented sufficient strategies to improve its fleet performance or a shipper has a certain proportion of its freight hauled by carrier partners. The ideal objective of the program would be to shift as many companies as possible from the left-most to the right-most stocks where tangible emission reductions are achieved. Variables in the model were calibrated based on data we received about the program from the SmartWay team, interviews with partners, industry references as well as our own best estimations.

Carriers are further broken down into large and small carrier companies. The large carrier companies represent the 300 largest Full-Truckload, Less-than-Truckload, and privately owned fleets in the U.S. These largest companies were estimated to manage about 19% of the total

combination trucking fleet. While there were 564,699 registered carriers in 2006, only 4.2% of these owned more than 20 trucks [13]. These 23,717 smaller carriers are considered potential targeted participants for the program. Shippers in the model are the 3,000 companies that use the greatest amount of freight services in the U.S. The main flow rates are described briefly here:

- **Awareness Rate** follows the Bass diffusion model used frequently in describing the adoption of new products [10] [14]. Two main coefficients used are that to reflect the external advertising effect and the internal word-of-mouth effect. In addition, shippers and large carriers are directly recruited by the program. Shippers are more hesitant and those recruited go into the stock of awareness initially before flowing into the stock of contacts after a second round of recruitment. Large carriers are well aligned with the program and flow directly into the stock of contacts.
- **Contact Rate** is affected by non-linear effects of partnership costs, program services provided, concern about environment, shipper pressure, branding dilution and consumer pressure. There is also a delay associated with the time taken internally for companies to decide whether the program is a suitable fit and initiate contact.
- **Partnership Rate** is based on program data on the realization ratio of contacts that enroll to become partners and is also affected non-linearly by service level. There is a delay associated with enrollment that is inversely proportional to the service level.
- **Dropout Rate** is based on program turnover and is likewise affected non-linearly by the service level provided.
- **Excellence Rate** is affected by non-linear effects of payback time, interest rate and implementation ratio. There is a delay associated with the time taken for fleets to be upgraded.

Service level represents the proportion of time spent by staff to the ideal time required by the program. Partnership staff are involved in helping companies in the enrollment process, submitting their annual updates and providing technical and marketing assistance where needed. To cope with initial increases in time demands as partnership numbers rise, the number of staff is increased until a maximum that is constrained by the program budget. After that, service level declines to ensure that staff overwork is kept within a limit.

The CO<sub>2</sub> emissions reduced are annual savings from combination trucks in the program that have implemented technology strategies compared to the baseline. Cost effective strategies are modeled to increase efficiency compared to current standards steadily by 12% to 39% over the next ten years. The industry accepted Best Available Technology however is lagged behind laboratory standards though the lag time decreases as more trucks are equipped with and validate the technology strategies.

## 4. Simulation Results

### 4.A. Baseline Scenario

The simulation results of the model in the baseline scenario demonstrate a close fit with historic data. The first observable takeaway is the strong initial exponential growth expected in the first

six years of the program. This can be attributed to the key reinforcing loops described earlier including advertising through word of mouth about the program and shippers incentivizing or pressuring their carriers to join the program. Service level however starts to decline as the number of staff operating the program becomes constrained by the program's budget and staffs do not have as much time as initially to provide for program services.

While growth in program enrollment slows down over time due to the program losing its attractiveness with declining service levels provided and dropout rates increasing as staff have less time to work with partners on their annual updates, the strong reinforcing loops in the program ensure that growth is still positive and sustained. The emissions saved from the program are expected to rise steadily as more carriers enroll in the program and implement the technological strategies recommended. The reinforcing effects from strategy validation start to factor in as a higher percentage of trucks get upgraded as well.

#### *4.B. No Shippers Scenario*

The first scenario we simulated was if the program had been designed without the inclusion of shippers. The results are that growth in carrier enrollment would be much slower. As a result, CO<sub>2</sub> emissions reductions over the time frame examined are lower as well. Despite the fact that program staff would be able to handle a greater number of carrier partners if shipper partners were not involved, we realize that the beneficial reinforcing effect that shipper partners have on the program far outweighs the costs of incorporating them into the program. This is because each shipper works with a large number of different carrier companies. Due to the requirement for each shipper to achieve a certain percentage of its goods being moved by carrier partners, there is motivation for shippers to put pressure or incentivize the carriers they contract work with to join the program.

Focusing on attracting shippers to participate in the program results in a greater return on resources due to the leverage they can exert on carriers to join the program through their purchasing power in the market as consumers of trucking services. In addition, they assist the EPA by raising awareness about the program through their regular meetings with the carriers they work with, listing it on their requests for proposals and advertising about the program on their websites or through traditional media channels. It would have been much more difficult for the EPA to reach out and attract carriers to participate in the program initially without the support of shippers. A key take away from this scenario is how the structure of a program can dramatically affect its growth. This should be noted in the design of any future voluntary public private partnerships that typically face challenges in growing enrollment initially. The suitable use of market dynamics in a program's design as demonstrated through the SmartWay program can be crucial to its success. Looking ahead, it is important for the program to continue to develop in a manner that still remains attractive for shippers in order to benefit from this key reinforcing dynamic.

#### *4.C. Doubled Staff Capacity, Large Company Focus and No Maintenance Time Scenarios*

The second set of scenarios we simulated was to investigate the balancing loops due to limited program resources further. The results indicate that partnership growth is indeed limited by the number of program staff once enrollment numbers start to become overwhelming. This leads to decreased service levels that increase enrollment delays, dropout rates and reduces the attractiveness of the program. Simply doubling the number of staff is a quick and easy fix but

merely delays the time before which service levels start to deteriorate. The staffing capacity of the program is also constrained by the budget allocated to it and we realize from the simulations that doubling the number of staff does not necessarily lead to twice the amount of CO<sub>2</sub> emissions being saved.

Another possible alternative would be to focus more attention on large carriers and shippers. A roughly 60%-40% split in time allocated to large companies and small companies gave the optimized amount of CO<sub>2</sub> emissions savings. This allows the program to maintain a higher service level for the large partners but at the expense of neglecting smaller partners. The results however are only marginally better than those in the baseline scenario as while the larger carriers have bigger trucking fleets and the larger sized partners are most influential in raising awareness about the program and recruiting others, small carriers still operate the majority of the trucks in the industry and need to be targeted as well. In addition, smaller carriers are often the ones operating the least fuel efficient trucks and would benefit the most from learning and implementing the technological strategies.

A better solution would be to reduce the enrollment and maintenance time required by the program. Halving the enrollment and maintenance times per partner has an equivalent effect as doubling the number of staff. While reducing or eliminating enrollment time is not always possible, reducing the maintenance time and even eliminating it entirely leads to significant increases in program capacity and CO<sub>2</sub> emissions savings. This can be achieved through streamlined partner management processes and automated partner tools and systems. Hence investing in resources to complete next generation models, databases and systems that reduce maintenance time is likely to be more effective in the long run than quick solutions.

#### *4.D. No Strategy Validation Scenario*

The fourth scenario was designed to highlight the importance of the SmartWay program in providing a platform for the validation and sharing of freight efficiency strategies. In this scenario, the SmartWay program does not emphasize the highlighting and sharing of technology verification results. While the enrollment rates in the program are not affected significantly by the lack of knowledge diffusion, the CO<sub>2</sub> emissions reduced as a result of the program are. The reason for this is because many smaller carrier companies do not have the time and resources to test and validate vehicle technologies by themselves. The program saves them the effort by testing some of the technologies in the EPA vehicle laboratories as well as getting larger and more experienced carrier companies to share about the successes they have had in implementing the technologies. From a societal perspective, this is also more efficient as various companies do not have to waste unnecessary resources re-testing technologies which have already been proven and verified. The sharing of best practices and validation of vehicle technologies is one of the key components for the success of the program in reducing CO<sub>2</sub> emissions.

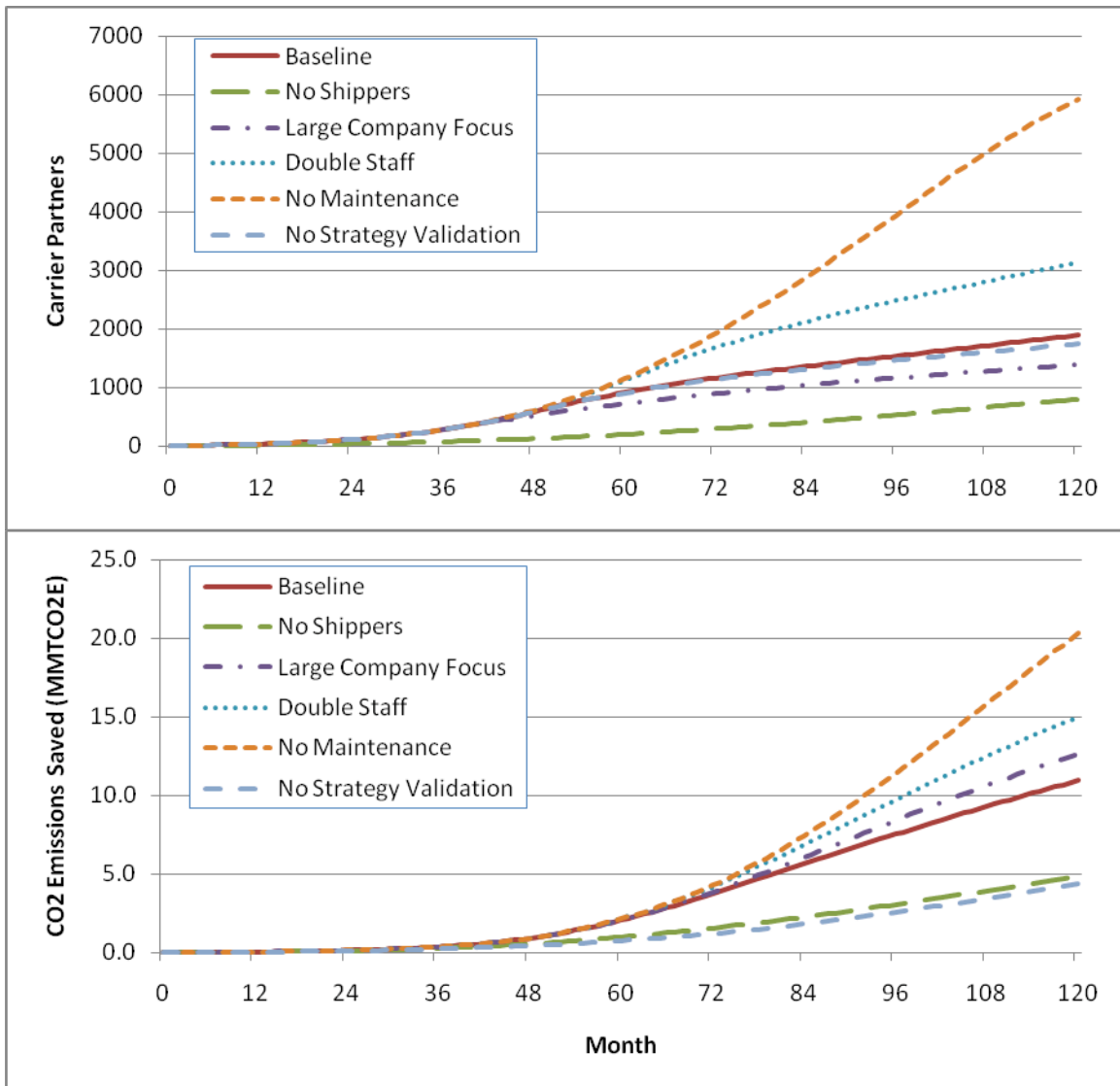


Figure 4: Simulation results for carrier partners and CO<sub>2</sub> emissions saved across different scenarios

## 5. Conclusion

The SmartWay program is an excellent example of how voluntary public private partnerships can be successful in meeting environmental goals. With over 1,400 partners enrolled in a span of five years, it has one of the highest membership numbers among all of the EPA sponsored climate change programs and has contributed to the achievement of significant reductions in CO<sub>2</sub> and other mobile air pollutants including nitrogen oxides and particulate matter in the freight industry. Policy intervention was clearly necessary due to the evident market failures present in the freight industry. These operational inefficiencies have resulted both from a lack of knowledge sharing to promote technological diffusion as well as a failure to adequately price the social cost of mobile emissions. This failure in the market is especially apparent in the heavy trucking sector where average fuel economy has not improved over the past 25 years despite technologies that could make instant improvements being readily available at cost effective prices today.

Voluntary public private partnerships are one of the many policy options available to solve market failures. Their strengths, as can be seen from the SmartWay program, lies in the fact that greater co-operation between government and industry can result in innovative and effective policy design that addresses the desired issues successfully without being unnecessarily intrusive to the market. In addition, these various policy choices can often supplement one another. For example, voluntary programs like SmartWay can complement regulations by achieving early adoption of new technology and strategies well in advance of when new regulations take effect. This is especially important in the trucking sector where the replacement of existing fleets takes a long time of up to ten years or a million miles travelled. The SmartWay program addresses this legacy fleet in the short term and helps in building the case that truck efficiency improvement can be achieved cost effectively which can help pave the way for future regulation.

Partner companies interviewed were strongly supportive of the SmartWay program and attributed it to getting them learning about and implementing strategies to improve their freight efficiency. This was achieved by the program requiring partner companies to complete their Freight Logistics Environmental and Energy Tracking (FLEET) Performance Model, filtering out and sharing technologies with partners that were cost effective, and arranging for financial loans to be made available to fund technological upgrades. Many partners also highlighted the fact that the program being voluntary rather than regulatory in nature was highly desirable from their standpoint and the strong involvement of industry participation in the design and planning process of the program contributed to its attractiveness and success. Other benefits of the program raised included the fostering of closer carrier and shipper relationships and the personal guidance provided by the program staff in helping companies to evaluate and understand their current environmental performance.

In this paper, we have demonstrated the potential use of Systems Dynamics as a tool in designing policy and to possibly quantify the benefits of policy choices. This is particularly useful in the analysis of voluntary programs where results may not be deterministic and benefits only start to become evident once the program has gained sufficient momentum. Insufficient foresight or the lack of applied systemic thinking may lead to these programs being cut prematurely or not even implemented to begin with when they are in fact able to generate tangible mid to long term results. While the numerical analysis involved may not be the most rigorous around, its strengths lie in the capturing of mental models to understand the key systemic causal linkages and reinforcing and balancing loops that make the results robust over a range of parameter uncertainty. The methodology can also be utilized to address questions regarding additionality such as whether the technology strategies would have been implemented in status quo. An example of this is in the “no strategy validation” scenario where reinforcing loops from technology verification and knowledge sharing were removed showing significant reductions in the adoption of technologies.

The SmartWay Transport Partnership serves as a useful case study for the successful implementation of voluntary public private partnerships to meet societal goals. Policymakers both in the U.S. and around the world can definitely learn valuable lessons on how the structuring of a voluntary program with the right market incentives can help to stimulate an industry and reduce inefficiencies. It is clearly important to take a systemic approach towards the design of such programs and to establish communication and feedback channels with key stakeholders to better understand their mental models.

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