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On the Feasibility of Speed Limits in Ocean Container Shipping

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ABSTRACT

The maritime industry is witnessing an increasingly loud call to contribute to the global trend towards environmental sustainability and decarbonization. One possible policy measure is the use of speed limits to reduce harmful emissions from ocean shipping. While the idea of slowing down ships to obey speed limits might seem intuitive, one key distinguishing characteristic of container shipping is that it is designed to adhere to a fixed, typically weekly, sailing schedule. This paper contributes to the literature investigating the feasibility of speed limits by demonstrating that speed limits are not always feasible in container shipping because of the rigid scheduling requirement. Conditions under which speed limits would become infeasible are derived, illustrated, and discussed.

1. Introduction

With around 90% of world trade carried by sea, the maritime industry is witnessing an increasingly loud call to contribute to the global trend towards environmental sustainability and decarbonization. It is within this context that the International Maritime Organization (IMO) has set the ambitious goal to reduce greenhouse gas (GHG) emissions from shipping by at least 50% by 2050, compared to 2008 levels (Ng and Talley, 2021). Stepping up to this challenge, the maritime community has proposed a range of different alternatives to reduce GHG emissions, from the use of alternative fuels, market-based measures to speed optimization and speed limits for ships (e.g. see Foretich et al., 2021; Psaraftis et al., 2021; Lagouvardou and Psaraftis, 2022). With speed limits – the focus of the current paper – there is a maximum speed at which ships can sail. The rationale for such measure derives from the fact that reducing speed is known to be one of the most effective operational measures to cut GHG emissions.

To our knowledge, speed limits in maritime shipping has barely been examined in the academic literature. The first study is by Cariou and Cheaitou (2012) who studied speed limits for ships entering ports within the European Union. One of their main conclusions was that speed limits can be counterproductive as ships can speed up outside the regulated waters to make up for the lost time. The second study is Psaraftis (2019) who analyzed “a rudimentary scenario comparing speed limits with a bunker levy”. The conclusion from this comparison was the conjecture that a bunker levy is preferable over speed limits to reduce GHG emissions. Unlike research on speed limits in shipping, the related, but distinct, research area of speed optimization has received a lot more attention. For a flavor of these speed optimization studies, which is not the focus of the current paper, one can, for example, refer to Fagerholt et al. (2015), Wang (2016), Ng (2019) and the references therein. The goal in speed optimization studies is to set speeds optimally, with various objectives, ranging from minimizing bunker cost to meeting certain emission criteria and maintaining schedule integrity.

With no definitive decisions at the IMO level, the discussion on speed limits is still on-going. The current paper deepens our understanding of this policy measure and contributes to the literature by investigating the feasibility of speed limits in container shipping. (An exact definition of (in)feasibility is provided in Section 2.) While the idea of slowing down ships to obey speed limits might be
intuitive, one key distinguishing characteristic of container shipping is that it is designed to provide a fixed, typically weekly, sailing frequency. As will be shown in this paper, this requirement of a fixed schedule can lead to some interesting consequences for the feasibility of speed limits.

The remainder of this paper is organized as follows. In Section 2, a detailed analysis of speed limits is presented, revealing conditions when speed limits are infeasible in container shipping. Section 3 illustrates and discusses the technical results from Section 2 using realistic scenarios. Finally, Section 4 concludes the paper.

2. Speed Limit Analysis

Container ships deployed on a given service route \( r \) visit a fixed sequence of ports. Furthermore, the ships deployed are designed to operate within a certain speed range \([s_\text{min}^r, s_\text{max}^r]\), where \( s_\text{max}^r > 0 \), e.g. see Ronen (2011). These speeds can be thought of as either technical or commercially viable minimum and maximum speeds. Consequently, the transit time of a ship (i.e. excluding the time spent at ports) to complete one rotation, denoted by \( t_r \), is also bounded, i.e. \( t_\text{min}^r \leq t_r \leq t_\text{max}^r \).

The fundamental relationship capturing the trade-off between transit times/ sailing speeds, port times, and the number of vessels that must be employed to provide a weekly shipping service frequency is (Ronen, 2011):

\[
t_r + t_e^r = 168x_r
\]

where \( t_e^r \) and \( x_r \) denotes the total port time on route \( r \) and the number of vessels deployed on route \( r \), respectively. The main message from (1) is that when vessel transit times are longer, i.e. when vessel speeds are lower (or when port times are longer), more vessels are to be deployed (and vice versa) in order to maintain a weekly service frequency. It is interesting to note that Cariou and Cheaitou (2012) did not consider the option of deploying additional ships in their analysis of speed limits. Indeed, they stated that "... given the weekly service requirements, the owner has no alternative other than to speed up vessels on the non-European leg, and therefore to increase emissions on the cycle." In the current research, because of the possibility of deploying additional ships, speeding up is no longer required.

Before presenting the main results, let us first define what we mean by speed limits being "infeasible" in this paper.

**Definition 1.** Speed limits are called infeasible on route \( r \) if they lead to \( t_r + t_e^r > 168x_r \).

In words, Definition 1 states that speed limits are considered infeasible on a given route \( r \) if they lead to ships not being able to complete the rotation within the maximum allotted time of 168\( x_r \) hours (cf. (1)). Indeed, this would violate the very premise of container shipping to provide a fixed weekly service.

One interesting observation from Definition 1 is that the feasibility of speed limits for container ships is not only governed by seaside operations, it is also affected by cargo handling shoreside. More specifically, more efficient container handling at ports makes it less likely for speed limits to be infeasible. This shows that reducing GHG in the ocean shipping industry should be a joint effort, and not the responsibility of one particular party.

A natural response to infeasibility is to increase the number of ships deployed, so that 168\( x_r \) is increased in Definition 1. Unfortunately, even when additional ships are available, deploying more ships does not always solve the problem, without introducing artificial inefficiencies such as vessel idle time. Proposition 1 gives a condition when this is the case.

**Proposition 1.** If for a given service route \( r \),

\[
\left[ \left( t_r^\text{min} + t_e^r \right) / 168 \right] = \left[ \left( t_r^\text{max} + t_e^r \right) / 168 \right]
\]

then imposing a speed limit that would require ships to slow down is infeasible on this route.

**Proof.** Consider a given service route \( r \). Using (1) and \( t_r^\text{min} \leq t_r \leq t_r^\text{max} \), it follows that

\[
\left( t_r^\text{min} + t_e^r \right) / 168 \leq x_r \leq \left( t_r^\text{max} + t_e^r \right) / 168
\]

Since \( x_r \) is an integer, these bounds can be tightened:

\[
\left( t_r^\text{min} + t_e^r \right) / 168 \leq x_r \leq \left( t_r^\text{max} + t_e^r \right) / 168.
\]

If (2) holds, then \( x_r \) can only take on one value on this particular route. In other words, it is not possible to deploy additional ships to meet the speed limit. To satisfy the speed limit, the only option would be to slow down the existing ships on this route. However, this would result in an increase in the transit time, from \( t_r \) to \( t_r^{\text{new}} \), with \( t_r^{\text{new}} > t_r \), so that \( t_r^\text{new} + t_e^r > 168x_r \). Q.E.D.

One possible difficulty in using (2) to check for the feasibility of speed limits is that it depends on the port times that might not be easily available. (Especially in times of port congestion, port times might also be highly uncertain.) Proposition 2 provides a sufficient condition for (2) to hold.

**Proposition 2.** If

\[
t_r^\text{max} - t_r^\text{min} < 168
\]
then speed limits are infeasible on route $r$.

**Proof.** Since

$$\left\lfloor \frac{(t_{r}^{\text{max}} + t_{p}^{r})}{168} \right\rfloor - \left\lceil \frac{(t_{r}^{\text{min}} + t_{p}^{r})}{168} \right\rceil \leq \left( \frac{t_{r}^{\text{max}} + t_{p}^{r}}{168} \right) - \left( \frac{t_{r}^{\text{min}} + t_{p}^{r}}{168} \right) = \left( \frac{t_{r}^{\text{max}} - t_{r}^{\text{min}}}{168} \right)$$

It follows that $\left\lfloor \frac{(t_{r}^{\text{max}} + t_{p}^{r})}{168} \right\rfloor - \left\lceil \frac{(t_{r}^{\text{min}} + t_{p}^{r})}{168} \right\rceil \leq \left( \frac{t_{r}^{\text{max}} - t_{r}^{\text{min}}}{168} \right)$. Hence if $(t_{r}^{\text{max}} - t_{r}^{\text{min}})/168 < 1$, condition (2) will be satisfied, and speed limits are infeasible. Q.E.D.

In words, Proposition 2 states that if the difference between the fastest and slowest possible transit times is less than 168 hours (i.e. one week), then speed limits are infeasible. Note that the condition in Proposition 2 can also be expressed in terms of the length of the route $l_r$, which gives the equivalent condition:

$$\frac{l_r}{s_{\text{min}}^{r}} - \frac{l_r}{s_{\text{max}}^{r}} < 168 \quad (4)$$

One assumption encountered in the literature is that $s_{r}^{\text{max}} = 2s_{r}^{\text{min}}$ (e.g. see Ronen, 2011). Under this assumption, (3) can be further simplified.

**Proposition 3.** Let us assume that $s_{r}^{\text{max}} = 2s_{r}^{\text{min}}$. If

$$l_r < 336s_{r}^{\text{min}}$$

then speed limits are infeasible on route $r$.

**Proof.** If $s_{r}^{\text{max}} = 2s_{r}^{\text{min}}$, then

![Figure 1. $(t_{r}^{\text{max}}, t_{r}^{\text{min}})$ pairs that would render speed limits infeasible according to Proposition 1.](image-url)
\[
\left\lfloor \frac{t_{\text{max}}^{r} + t_{p}^{r}}{168} \right\rfloor - \left\lceil \frac{t_{\text{min}}^{r} + t_{p}^{r}}{168} \right\rceil \leq \left\lfloor \frac{l_{r}}{2s_{\text{min}}} \right\rfloor / 168
\]

Thus if \( l_{r} < 336s_{\text{min}} \), condition (2) will be triggered. Q.E.D.

Proposition 3 shows that the minimum speed and the length of the route are important determinants for the feasibility of speed limits. It also shows that speed limits are more likely infeasible on the shorter trade routes compared to longer ones.

Intuitively, it should be clear that speed limits can have major operational consequences for shipping lines. From the above discussion, it can be seen that the implications can extend beyond the operational level. For example, since minimum and maximum speeds can be limited by the technical characteristics of ships, changing fleet deployment plans might be necessary to meet speed limit mandates (Ng, 2017).

3. Illustration and Discussion

In this section, we shall illustrate and discuss the main results derived in Section 2 using a set of realistic scenarios. First, consider Fig. 1 that shows the combinations of \( t_{\text{max}}^{r} \) (horizontal axis) and \( t_{\text{min}}^{r} \) (vertical axis) so that the condition in Proposition 1 is satisfied, for two different values of the port time \( t_{p}^{r} \). For example, the red dotted line shows all transit time pairs \( (t_{\text{max}}^{r}, t_{\text{min}}^{r}) \) that would render speed limits infeasible when \( t_{p}^{r} = 168 \) hours. One such combination would be \((500, 250)\). It is straightforward to verify that in this case

\[
\left\lfloor \frac{t_{\text{min}}^{r} + t_{p}^{r}}{168} \right\rceil = \left\lfloor \frac{t_{\text{max}}^{r} + t_{p}^{r}}{168} \right\rfloor = 3,
\]

thus satisfying the condition in Proposition 1.

Fig. 2 shows the region (in red) in the \((s_{\text{min}}, s_{\text{max}})\) plane so that

![Figure 2. Shaded region showing speed combinations that would trigger the condition in Proposition 2, when \( l_{r} = 5000\text{nm} \).](image-url)
when \( l_r = 5000 \) nautical miles (nm), cf. (4). For instance, it can be seen that the pair (12, 20) would correspond to the case when speed limits are infeasible on this particular route. Note that when the length of the route increases/ doubles to 10000 nm, the shaded region shrinks, see Fig. 3. In other words, it is more likely for speed limits to be infeasible on the shorter trade routes (clearly, what constitutes “short” depends on the minimum and maximum speeds).

Finally, Fig. 4 shows the region when the pairs \((s_{\text{min}}, l_r)\) would make speed limits infeasible according to Proposition 3. It is interesting to note that routes for which speed limits are initially feasible, when \( s_{\text{min}} \) increases, they become infeasible. That is, more routes become infeasible when the minimum speed increases. This observation reveals that speed limits might potentially be at odds with the interests of shipping lines. Indeed, it is well known that a key incentive for ocean carriers to increase the (minimum) sailing speed of their ships is higher freight rates. However, by doing so, speed limits could become infeasible.

4. Concluding Remarks

One recurring policy discussion in the maritime industry centers on the use of speed limits to reduce harmful emissions from ocean shipping, as a stepping stone towards decarbonization of the industry. The current paper deepened our understanding of speed limits and contributed to this discussion by examining whether speed limits are always feasible for container shipping. While the idea of slowing down ships to obey speed limits might be intuitive, one key distinguishing characteristic of container shipping is that it is designed to adhere to a fixed, typically weekly, sailing schedule. Because of this rigid requirement, this paper has shown that speed limits are not always feasible. Starting from the fundamental relationship (1) and the boundedness of the transit times, conditions were derived under which speed limits would become infeasible, each progressively easier to verify, i.e. requiring less parameters.

This study also yielded several managerial/ policy implications. First, some of the key main parameters that determine the

![Figure 3](image-url)

Figure 3. Shaded region showing speed combinations that would trigger the condition in Proposition 2, when \( l_r = 10000 \) nm.
feasibility of speed limits in container shipping include port times, minimum and maximum ship speeds, and the length of the trade routes. One consequence for shipping lines is that if speed limits were to be imposed, it will restrict the ships that can be deployed on certain trade routes. From the perspective of the academic literature, this would mean new constraints to fleet deployment problems (Ng, 2017). Second, the feasibility of speed limits is not only related to seaside operations, but is also affected by cargo handling shoreside. Particularly, it was shown that efficient container handling at ports makes it less likely for speed limits to become infeasible for a given trade route. This shows that reducing GHG emissions in the ocean shipping industry is a joint effort, and not the sole responsibility of one party. Third, generally, it is more likely for speed limits to be infeasible on the shorter trade routes. What can be classified as a “shorter trade route” depends on parameters such as the minimum and maximum speeds. Fourth, when the minimum speed increases, more routes become infeasible for speed limit implementation. This finding shows that speed limits might potentially be at odds with the interests of shipping lines since one key incentive for ocean carriers to increase the (minimum) speed of their ships is higher freight rates. Thus, there are conflicting interests that must be resolved before speed limits can be imposed.

Finally, it is to be noted that, theoretically, shipping lines would have the option to change their service frequencies to meet speed limit mandates. Besides the practical desirability of such changes, even if service frequencies were changed, similar conditions as the ones in this paper can be derived.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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