# Developing and Validating the Automatic Log Transfer Mechanism between Two Carriages

**Tetsuhiko Yoshimura*, Bruce Hartsough and Hirotaka Otsu**
Shimane University
1060 Nishikawatsu-cho, Matsue 690-8504, Japan
t_yoshimura@life.shimane-u.ac.jp

***Abstract:*** *The productivity of cable harvesting systems must be improved for economically feasible forestry operations especially on steep slopes where ground harvesting systems are difficult to use. In this study, we proposed a new cable harvesting system, which used two carriages on one skyline: one had a self-locking mechanism and moves on the skyline between the loading and unloading points while the other was fixed to the skyline at the loading point and pulled in logs laterally. We made a test model of the log transfer mechanism using a cone-shaped hanger and carabiner hook and validated the function to transfer logs from the fixed carriage to the moving one. We also estimated the productivity of five cable harvesting systems: conventional gravity system, new cable harvesting system with/without the log transfer mechanism, log exchange system halfway on the skyline and three-stage log transfer system. Through system dynamics simulation, we estimate that the three-stage log transfer system would have the highest productivity when the yarding distance is 260m or more. On the other hand, the new cable harvesting system with the log transfer mechanism would have the highest productivity for yarding distance of 240m or less.*

**Keywords**: cable harvesting system, log transfer mechanism, productivity, test model, system dynamics simulation

## 1 Introduction

Ground harvesting systems achieved the higher productivity than ever before by introducing up-to-date forestry machines such as harvesters or harwarders. In Sweden, Bergkvist et al. (2007) reported that Beast, unmanned harvester remotely controlled by two manned forwarders, had been field-tested. In Japan, harvesters with a 10-20m long arm are practically used on forest roads to harvest trees on 30-degree slopes (Nitami and Abe 2008). On the other hand, cable harvesting systems used on steep slopes have not been greatly improved since 1995 when the combined tower yarder and processor head was introduced by Koller GmbH (Fischbacher and Mairhofer 2007). To improve the productivity and reduce harvesting costs on steep slopes where ground harvesting systems are difficult to use, innovative techniques must be introduced to cable harvesting systems especially for thinning and collecting small trees, and the development of such innovative techniques requires revolution rather than incremental improvements to the existing cable systems. Therefore, in a previous study (Yoshimura and Hartsough 2007a), we proposed new concepts of cable harvesting systems that could improve productivity: gondola cable system, draw-well system, double-track system and double-carriage system. However, these new concepts have not yet been brought to realization because there are more steps to be taken before they are put into practical use through intensive investment and technology development.

In this study, we estimated and compared the productivities of five cable harvesting systems by using system dynamics simulation: conventional gravity system (gravity system), new cable harvesting system with/without the log transfer mechanism (log transfer/ground transfer system), log exchange system halfway on the skyline (log exchange system) and third-stage log transfer system (third-stage system). By using such simulation, we can estimate the productivity of the new cable harvesting systems before the actual development of them. The advantage of using system dynamics simulation is to make a flexible and customizable model to better fit the actual conditions as we did in the previous studies (Yoshimura and Hartsough 2007a and Yoshimura and Hartsough 2007b). In addition, McDonagh et al. (2004) applied system dynamics simulation to select an appropriate harvesting system for a given stand by comparing the productivity of several harvesting systems: manual fell/cable skid, mechanized fell/grapple skid, shovel bunching/grapple skid and cut-to-length harvesting/forwarding. Nitami (2005) showed the possibility of making a model of forest operations based on the transition probability by using system dynamics. Nitami (2006) applied system dynamics simulation to estimate the productivity of a harvesting system that included forest road construction, felling by chainsaw, extraction to forwarder trails by grapple-equipped excavator, bucking and delimbing by chainsaw, log collection by forwarder and log piling. Sugimoto et al. (2010) compared the operation time, cost and productivity between a flow harvesting system and a disjointed system by using system dynamics models.

The objective of this study is to validate the new cable harvesting systems with the log transfer mechanism by making a test model of it, conducting the feasibility assessment, estimating the productivity using system dynamics simulation and comparing the productivity of it with that of the other cable harvesting systems.

## 2 Material and Methods

### 2.1 New cable harvesting systems

In this study, we propose new cable harvesting systems, which are expected to improve the productivity with less intensive investment and technology development. The key idea for improving the productivity is to allow lateral yarding to continue during inhaul and outhaul by introducing a fixed carriage working exclusively on lateral yarding, as the previous study (Yoshimura and Hartsough 2007a) suggested that waiting time for carriage return should be reduced to improve the productivity of cable harvesting systems. As an aside, we note another approach: the line thinning system (Watanabe 2005) used to minimize the time for lateral yarding by harvesting only trees near the cable has been successful in terms of productivity in Japan.

The log transfer system (Figure 1) uses two carriages on one skyline: one has a self-locking mechanism and moves on the skyline between the loading point and unloading point (moving carriage) while the other is fixed to the skyline at the loading point and pulls in logs laterally with an internal engine or motor (fixed carriage). While logs are pulled in to the skyline laterally, the previous turn is transported to the unloading point or landing. The key development of the new cable harvesting systems is a mechanism to transfer logs from the fixed carriage to the moving one as simply and rapidly as possible. The ground transfer system is almost the same as the log transfer system except that logs are manually transferred from the fixed carriage to the moving one on the ground without the log transfer mechanism.

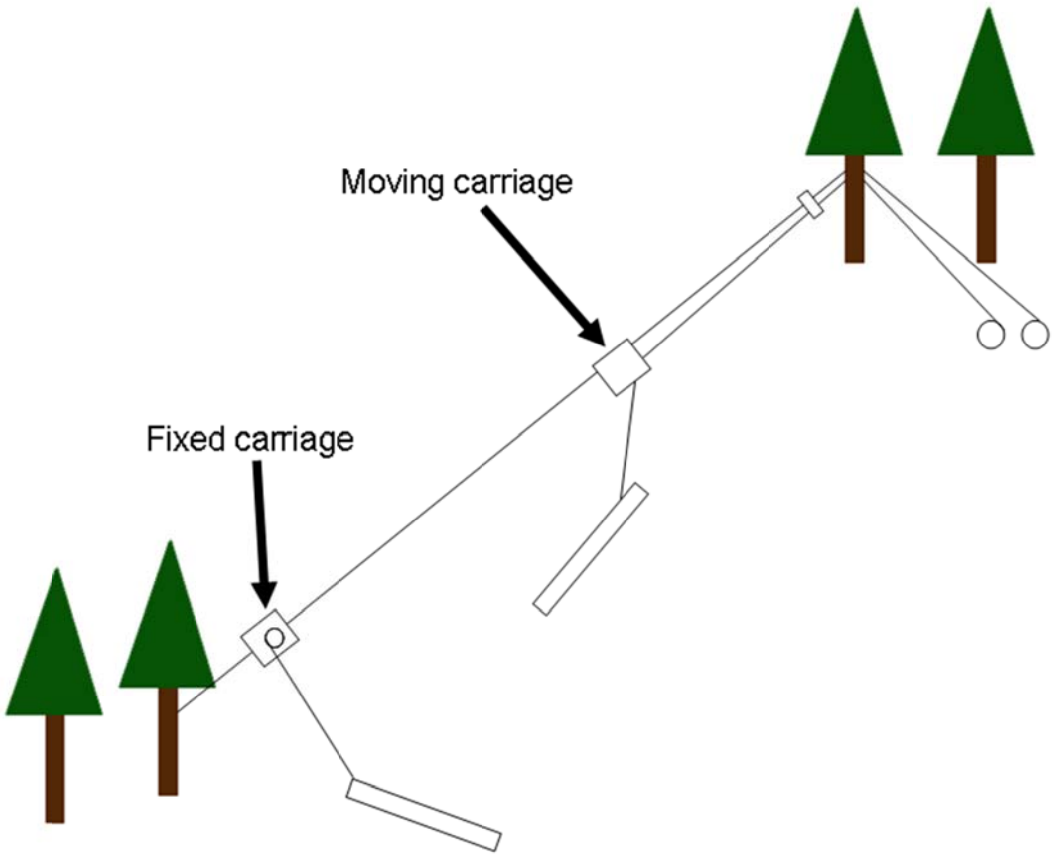


**Figure 1: Log transfer system using the fixed and moving carriages**

A log exchange system has been experimentally developed and examined by Tasaka et al. (2006), Tasaka et al. (2008) and Aruga et al. (2009). This system uses two carriages on one skyline, and they connect halfway along the skyline to transfer the load from one carriage to another, to reduce the total time for carriage travel. The third-stage system (Figure 2) uses the two moving carriages as well as the fixed carriage. In this system, two moving carriages (lower carriage and upper carriage) move on the skyline independently, and the load is transferred from the fixed carriage to the lower carriage and further transferred to the upper carriage.

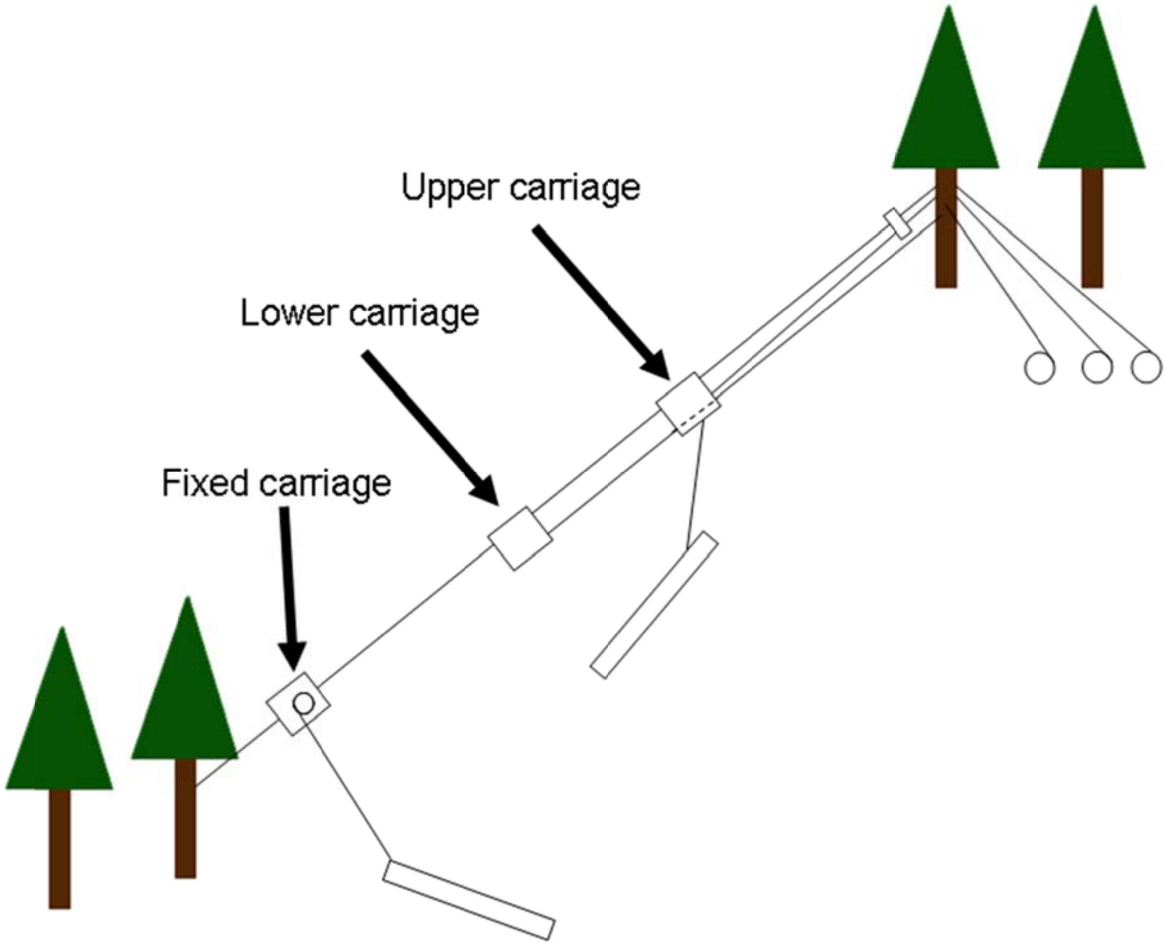


**Figure 2: Three-stage system using the fixed, upper and lower carriages**

In order to validate the mechanism to transfer logs from the fixed carriage to the moving one, we made a simple test model of the log transfer mechanism, from common materials. (Figure 3). The function and design of the log transfer mechanism is shown as follows: first, a log is attached to a choker with a cone-shaped hanger. Then, it is pulled in to the fixed carriage by a winch driven by the internal engine or motor, and the cone-shaped hanger is stored in the circular cone inside the fixed carriage. Subsequently, the moving carriage approaches to the fixed carriage, and a carabiner hook catches the cone-shaped hanger. As soon as the automatic release hook of the fixed carriage is opened, the cone-shaped hanger with the log is transferred to the moving carriage. Finally, the moving carriage starts to travel up to the landing with the log. We used the cone-shaped hanger so the carabiner hook could capture the hanger even with the rotation of the hoisting line.

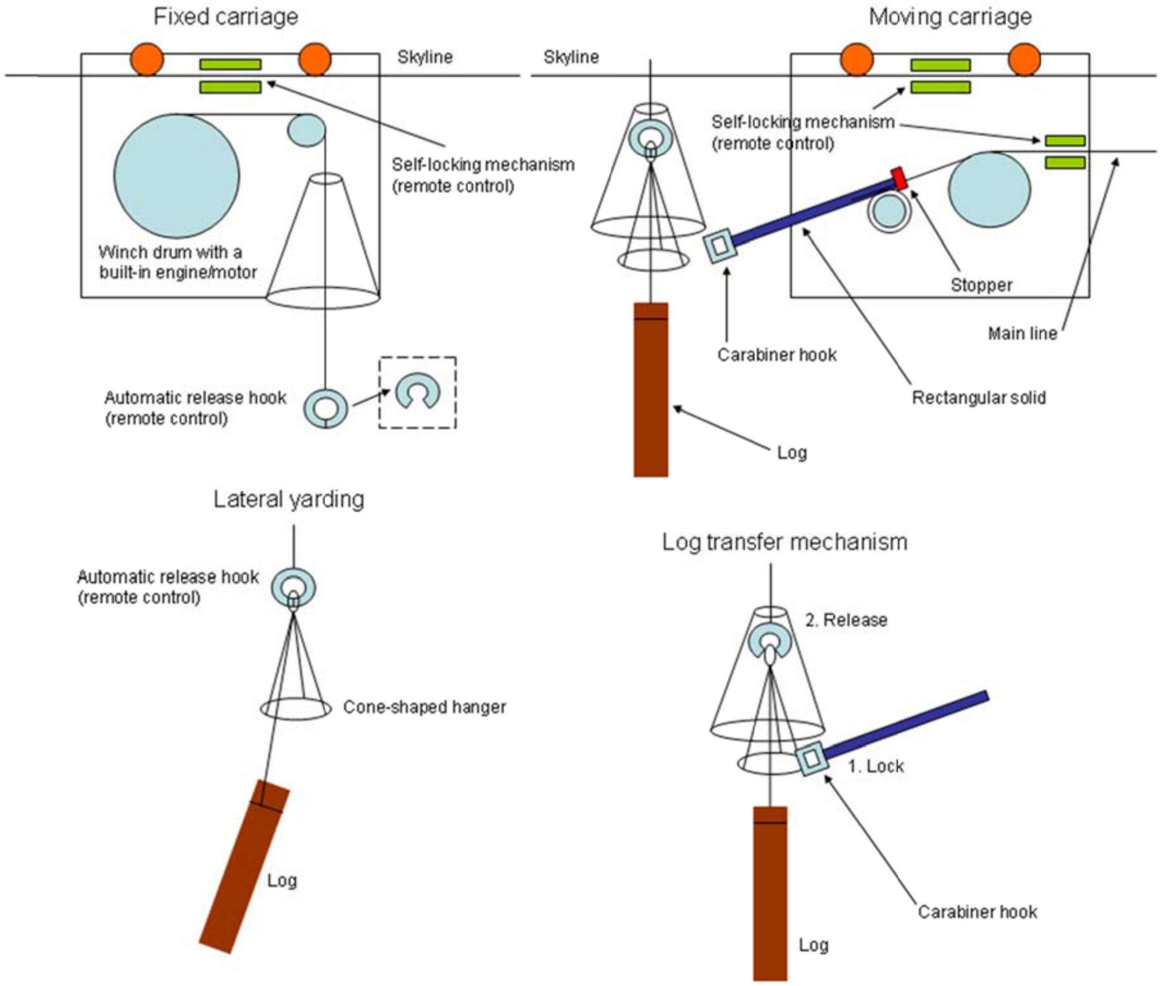


**Figure 3: Log transfer mechanism between the fixed carriage and moving one**

## 2.2 System dynamics simulation

We evaluated the gravity system, log transfer/ground transfer systems, log exchange system and third-stage system in terms of productivity by using system dynamics simulation, which helps us understand the behavior of complex systems over time. System dynamics also has the advantages of high compatibility, interchangeability, understandability and simplicity of models. It is also characterized by its methodology for modeling complex feedback systems, i.e. a closed system influenced by its past behavior. For modeling the new cable harvesting systems, we used STELLA 9.1.3 (ieee systems), a visual diagram-based simulation application program for system dynamics models. By using STELLA, we can evaluate the cable harvesting systems fundamentally and conceptually. Figure 4 shows the five components used in STELLA: stock, flow, converter, connector and oven. The definitions of these components are as follows: stock is the memory that accumulates or drains materials over time; flow is the movement of materials from one stock to another; a converter influences flows or other converters by utilizing constants, algebra or graphs; connector is the information carrier from one element to another; oven is a derivative type of stock that acts like an oven: when the limit of the oven is reached, the oven closes and holds the inflow for a certain time. Then, the oven lets the contents out through the outflow.

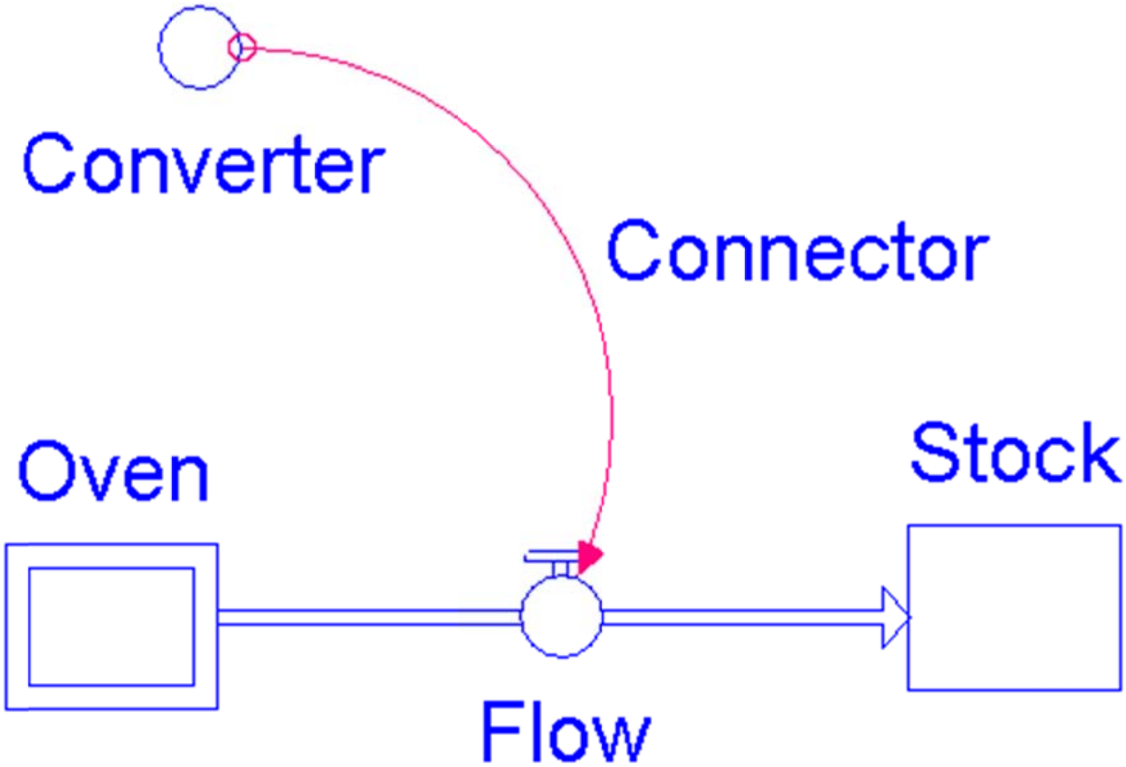


**Figure 4: Components used in STELLA**

Figure 5 shows the system dynamics simulation model for the log/ground transfer systems. We also made the system dynamics simulation models for the other three systems. It is assumed that the total volume of harvested logs is 100m$^3$, and that yarding distance is variable from 20 to 400m. The volume of a turn (load) of logs is 2m$^3$. The direction of yarding is uphill. The uphill (travel loaded) and downhill (travel empty) carriage speeds are set to 1m/s and 8m/s, respectively.

For the log exchange system, carriage speed is fixed to 1m/s, which is the same speed (travel loaded) as the others because the intent would be to use an endless (loop) line to drive both carriages. In these models, time for lateral yarding increases from 0 to 100sec as harvesting process goes on to reflect the increase of lateral yarding distance. Unloading time is 30sec. For the log exchange system and three-stage system, time to transfer the load from one carriage to another halfway on the skyline is set to 30sec. Time to transfer the load from the fixed carriage to the moving one, including hoisting time, is set to 10sec for the log transfer/third-stage systems and 110sec for the ground transfer system. To simplify the models, we do not consider empirical time relationships or stochastic time distributions.

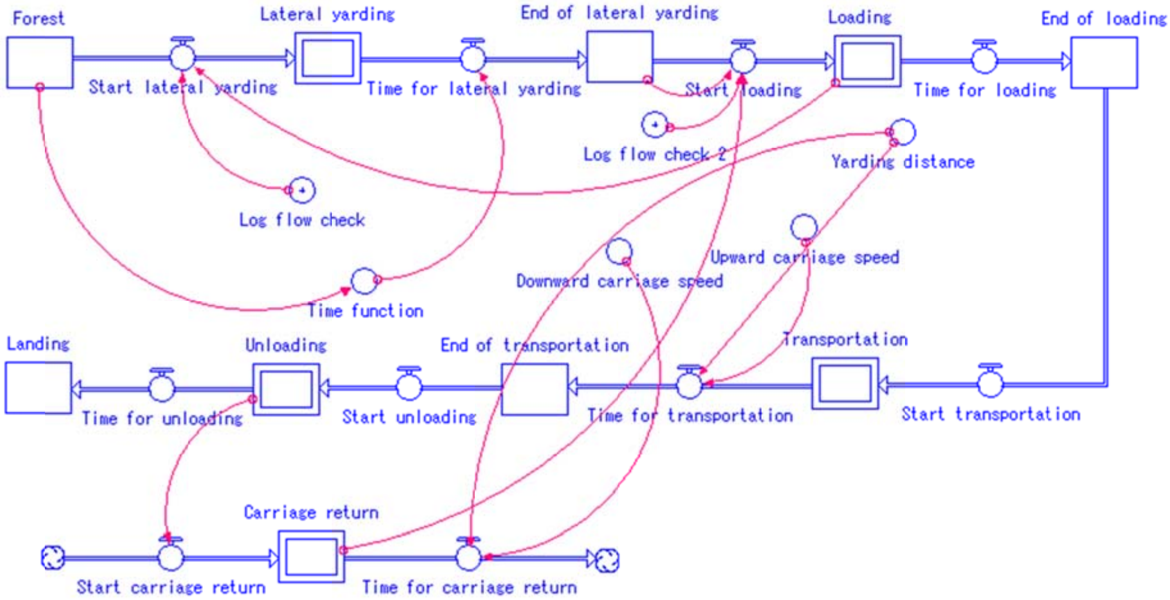


**Figure 5: Simulation model of the log transfer system**

## 3 Results and discussion

Figure 6 shows the test model to validate the log transfer mechanism between the two carriages.

As shown in the upper picture (A) of the figure, the moving carriage (right) approaches to the fixed carriage (left), and the carabineer hook catches the cone-shaped hanger. As soon as the cone-shaped hanger is released by the remotely controlled automatic release hook, a log attached to the cone-shaped hanger is transferred from the fixed carriage to the moving one. As a result of the empirical test of the model, the log transfer mechanism was found to work successfully. However, it was also found that the two carriages should be more closely and tightly interlocked before the cone-shaped hanger is released by the automatic release hook, and the log is transferred to the moving carriage.

Figure 7 shows the productivities of the gravity system, log transfer/ground transfer systems, log exchange system and third-stage system, with the variable yarding distance of 20 to 400m.

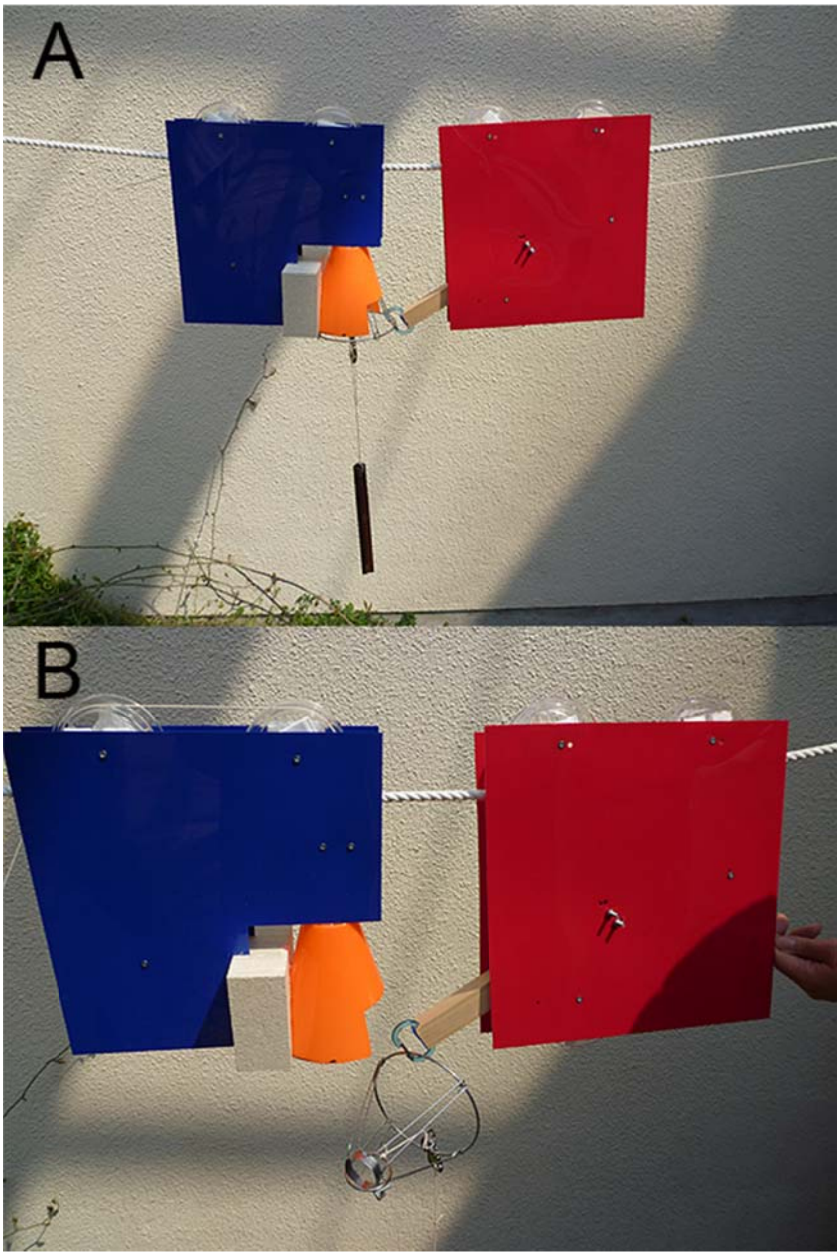


**Figure 6: Test model of the log transfer mechanism. A, Carabineer hook of the moving carriage catches the cone-shaped hanger in the fixed carriage; B, Log attached to a cone-shaped hanger is transferred to the moving carriage**

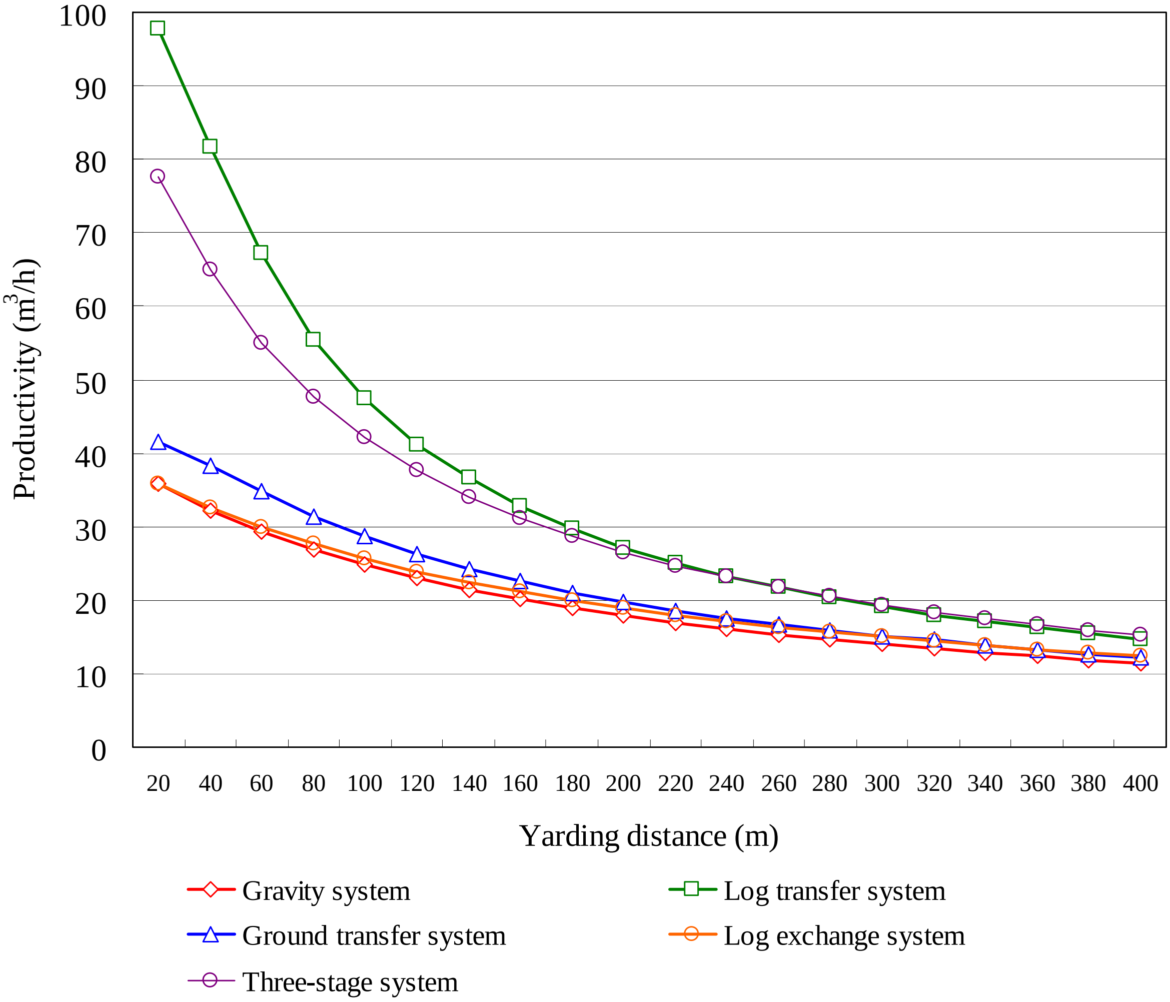


**Figure 7: Productivity variation according to the yarding distance**

As shown, the productivity of the three-stage log transfer had the highest productivity when the yarding distance is 260m or more. On the other hand, the log transfer system had the highest for the yarding distance of 240m or less. Both systems were much better than the others especially for the yarding distances of 20-200m. The log exchange system was slightly better than the gravity system for all yarding distances (20-400m), but the difference in the productivity was very slight. This system did not greatly improve the productivity because an endless (loop) line is supposed to be used to drive the two carriages, and this restricts the travel speed of carriage when it moves downhill. However, for the yarding distance of 340m or more, the productivity of the log exchange system was more than that of the ground transfer system. The result suggests that the log exchange system is suitable for relatively longer yarding distance. The ground transfer system also had slightly better productivity than the gravity system. This system can save waiting time for carriage return while lateral yarding is in process, but a rather long time for transferring logs between the carriages is still required. That is why this system did not give as much advantage as did the log transfer system with the automatic log transfer mechanism. As a result, it was found that waiting time for carriage return is a critical factor that limits the productivity of cable harvesting systems, and that the log transfer mechanism helps greatly improve the productivity by reducing waiting time for carriage return.

## 4 Conclusions

When we look back on the history of technological advancement, it took place as a combination of step by step and leaping advancements, and ground harvesting systems are no exception. Cable harvesting systems have also developed basically in this way, but leaping advancements have not occurred since the combined yarder/processor was developed in Austria in the 1990s. In our previous studies (Yoshimura and Hartsough 2007a and Yoshimura and Hartsough 2007b), we tried to make a breakthrough in cable harvesting systems by stepping back to the concepts of cable harvesting systems to be examined. This study made an additional contribution to our previous conceptual studies, at the conceptual and practical levels.

The results of the system dynamics simulation showed that the log transfer/three-stage systems had higher productivity than the other three systems, and that the log transfer mechanism proposed in this study was very promising. In addition, the issues and improvements of the mechanism were identified by developing the test model with low-cost materials that were easy to process.

We believe that there is a high possibility of putting the log transfer system into practical use. There are many types of carriages with built-in engines (Nagai et al. 1997), which can be used as the fixed carriage in the log transfer system. Furthermore, a common carriage for the gravity system can be used as the moving carriage in the log transfer system, too. However, both of the carriages need the addition of a log transfer mechanism as shown in this study. The three-stage system also showed the highest productivity when the yarding distance is 260m or more, but we are still looking for the appropriate method to transfer logs from the lower carriage to the upper one after they are transferred from the fixed carriage. In future studies, besides the actual development of the log transfer system, we will further explore more new concepts of cable harvesting systems, validate them by making test models and evaluate them in terms of productivity by using system dynamics simulation.

## 5 Acknowledgements

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