LEARNING CURVES EXPERIMENTED OVER A VIRTUAL PORT: SIMULATION TRAINING AND ITS IMPACT IN TERMINAL ACTIVITIES

Agostino G. Bruzzone, Marina Massei,
Francesco Longo, Simonluca Poggi, Matteo Agresta (Italy)

1. INTRODUCTION

This work is introduce the definition of a a Learning Curve (LC) for STVP simulator by witch evaluating the effectiveness of the training process and predicting the amount of activity that are needed to reach a predetermined level of skills. LC has been calculated with data collected from trainees with different background and different previous experience with that kind of simulator. In order to do that, the ability of a group of students doing a repetitive task with the virtual equipment have been monitored and a first mathematical formulation for LC is purposed. Finally, since port operations can be very dangerous in reality, errors and accidents during the activities have been converted into time penalties in order to define a LC that takes in account the quality of the training.

2. LEARNING CURVES

Learning curves (LCs) are proven to be powerful instruments to evaluate worker performance in repetitive tasks, and the way workers and trainees improve their performance has been studied both in education and in many industrial segments, such as electronic, construction, automotive, software and aerospace (Madden 2006), (Hanakawa et. al. 1998), (Anderson 1982). A learning curve is a function displaying the relationship between unit production time and the cumulative number of units produced; it can be represented graphically with the evolution of learning (vertical axis) and Experience (horizontal axis). LCs have been introduced for the first time by (Hebbinghaus 1913) and later by (Wright 1936) that observed how repetitive procedures affect cost of production in assembling facilities in airline industry plants, in particular it observed that assembly costs was reduced by 20% each time that production doubled. That is due to the fact that when people or organization repeat a process the gain skills and efficiency from their own experience.

LC theory is generally based on three assumptions:

I) The amount of time required to complete a given task or unit of a product will be less each time the task is undertaken

II) The unit time will decrease at a decreasing rate

III) The reduction in lime will follow a predictable pattern.

In the course of history many scientist have improved and modified the first mathematical model of the LC, and a state of the art on the several analytical functions representing different shape of the learning curve can be found for example in (Anzanello and Fogliatto, 2011). As reported in (Anzanello and Fogliatto, 2011), learning process can be influenced by several factors such as: a) the structure of training programs b) workers' motivations in performing the tasks, c) prior experience in the task d) task complexity. For that reason, different mathematical formulations for LCs have been purposed, with different shapes, different number of parameters and different factors taken in account, such as trainees' forgetting factor and prior experience in the same task. In (Tab 1) some of the several mathematical formulation are reported; as it's possible to see, an higher number of factors should be considered at the cost of increasing the number of the parameter and the complexity of the model. Starting from the simplest model of Wrights that is the simplest, there are other models able to model the forgetting factor (De Jong, S curve, and 2-parameter hyperbolic), and other that include the prior experience in doing the same task (3-parameter exponential, Constant time, and Stanford-B) while only the 3-parameter hyperbolic considers both the two factors. Anyhow it hasn't been found in literature a mathematical formulation able to consider the cost of errors during the process.

Model	Mathematical	N, of Par.	Forg. Model	Prior exp.
2-par. hyperbolic	$y = k\,[x/(x + r)]$	2	X	
3-par. hyperbolic	$y = k\,[x + p/(x + p + r)]$	3	X	X
3-par. exponential	$y = k\,(1 - g^{-(x + p)/r})$	3		X
Constant time	$y = y_c + y_f(1 - e^{-x/\tau})$	3		X
Wrights	$y = Cx^{-b}$	2		
Plateu	$y = B + C_x^{-b}$	3		
Stanford-B	$y = C\,(x + B)^{-b}$	3		X
De Jong	$y = C\,[M + (1 - M)\,x^{-b}]$	3	X	
S-Curve	$y = C\,[M + (1 - M)(x + B)^{-b}]$	4	X	

Tab l: Mathematical models for learning curve; source (Anzanello and Fogliatto, 2011)

3. THE STRUCTURE OF STVP – SIMULATION TEAM VIRTUAL PORT

Starting from military field, interoperable simulation techniques are becoming more effective in new areas, in particular where many entities and components areinvolved, such as logistic, ports and infrastructures (Bruzzone et al. 1997; Bruzzone and Giribone 1998; Bruzzone et al. 20001 Merkuryev et al. 2003; Mosca et al. 2004; Bruzzone et. al 2008; Bruzzone et al. 2011); typically the item in these system are strictly correlated one each creating complex interactions. The Simulation Team Virtual Port (STVP), (Bruzzone and Longo 2008; Bruzzone et. al. 2008) is a simulator for port operations in a virtual world, where the different components dynamically interact one each other in real time in the same synthetic environment (Fig. l).

Fig 1: The virtual port, with the virtual yard, the virtual cranes and the virtual trucks

Fig 2: The virtual stacker

STVP reproduces the behavior of different intermodal equipment (cranes, stacker, trucks, etc.) by using federates, that can operate stand-alone or integrated in an HLA (High Level Architecture) federation; in that way different trainees works together simulating real activity and a the can complete a mission cooperating in the same port system. The system integrates full motion simulators with low-cost training sessions and it is designed to enable the supervisor to monitor the training process both in LAN and in WAN; the reduction in hardware and software costs as well as the stabilization of the interoperable simulation provides to these sectors the opportunity to activate pilots, Research and Development initiatives as well as product development. The simulator engine, developed by Simulation Team, makes the simulation fully scalable by giving the possibility to choose the number and the type of federates by distributing the compulation workload among each platform in order to make the simulation more efficient. Furthermore not only vehicles are simulated in this system, and the training process is also usable for planners and manager, (i.e. control room, yard planner, dock manager).

Each platform can be provided by static mock-ups (i.e. port truck drivers) or full motion 6 Degree of Freedom simulators. Actually the configuration is based on:

- one full scope simulator
- 6DOF motion platform
- advanced visualization solution integrated with eye tracking system for the crane operator
- large screen for truck drivers-crane operator
- interactive pilot station
- workstation

The system is installed in a shelter for easy mobility among different sites, this configuration includes:

1 – full motion station
2 – 3 basic stations
3 – instructor station (re-configurable for driving a vehicle)
4 – 1 panoramic observer station

In Fig. and Fig. 3 there is a picture of the virtual stacker and the virtual truck, operating in the same simulated port.

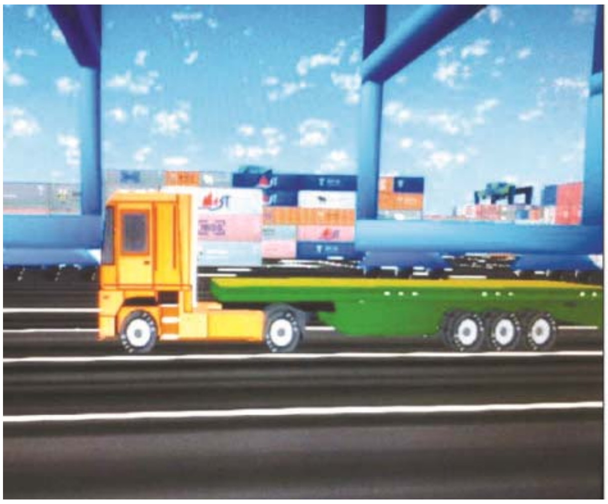

Fig. 3: The virtual truck

4. METHODOLOGY

The aim of this work was to define and test a mathematical model for LC curve representing the trend of trainees' ability in working with the STVP equipment; in order to do that, their performance was monitored and their job was evaluated both in term of quality and in term of duration. An HLA federation was set up with three trainees working respectively in a virtual portainer, in a virtual truck and in a virtual stacker and a given task. The experiment was conducted separately with two different group of 9 students characterized by different age and different level of instruction that have been observed performing their task. In particular, the first group (A) was characterized by younger undergraduates students, with an average age of 21, whilst the second group (B) was formed by more mature students, and with an higher level of instruction (Tab. 2).

Group	Number of trainees	Avg age	Level of study
A	9	21	Undergrad.
B	9	27	MA. Grad

Table 2: The sample survey

Platf orm	Type of equipment	Task for each cycle
1	Portainer	Look for a given niuuber of container (i.e. 20" or 40") inside the vessel by moving the cabin and load the truck waiting on the quay
2	Truck	Move from the yard, teach the quay where the portaniners are locaed, load the container and come back to the yard where the stacker is
3	Stacker	Unload the container from the truck and position it on a predetermined slot in the yard

Table 3: Task Assigned to the Trainees

The trainees was divided into sub-groups of three units working together and cooperating in the federation (Fig. 4); as told before, for this work, three platform have been used for the trainees, plus one for the supervisor that was connected through different active view into the simulation (i.e. an helicopter supervising the zone and controlling the operations); instructor could change weather conditions and introduce other critical aspects during the simulation. Both the group A and the group B have no previous experience with that kind of simulator, so the starting level of skills was considered the same.

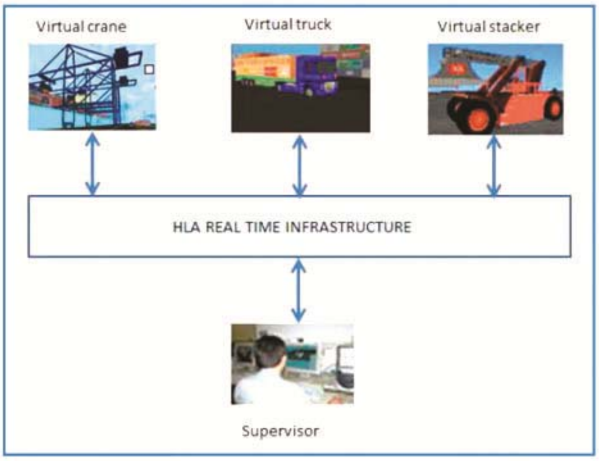

Fig. 4: HLA Real Time Infrastructure

At the beginning of the training session, the STVP have generated the mission by giving the task to each operator (i.e. which container was to be moved, and what would have been the final position/destination) with a constant difficulty level. In STVP different level of complexity should be configured in order to evaluate the response of the trainees in carrying out tasks with different difficulty level: for example it is possible to set up the climate conditions (i.e. good weather, bad weather, windy, etc...) that affect cranes and truck operations. Anyhow, for this particular test, each trainee was asked to complete the same mission with the same difficulty level of the task for eight times. Since errors and accidents are very frequent in port operation in training phase, a different weight for each type of error was assigned, and converted by adding up a predetermined penalty in the total time of the task. Each accident was classified on the basis of its gravity: small errors have a range from 0-1 and big accidents are weighted from 1 to 3 (Tab. 4).

Equipment	Typ.	Description	Weight ranqe(w)
Portainer	Small error	small scrapes between the spreader and the vessel	0-1
	Big error	huge impact moving the container in the vessel or loading the truck	1-3
Truck	Small error	wrong position under the portainer for loading the container	0-1
	Big error	huge impact inriving	1-3
Transtainer	Small error	wrong slot of destination/small scrapes with the truck	0-1
	Big error	huge impact in unloadinc the truck	1-3

Table 4: Error Weights

Each federate using the portainer had the task to look for a container by moving the cabin, then unload it from the vessel and load it on the truck that is waiting on the quay; the truck driver, that starts the mission from the yard, has to drive towards the portainer and find the right position and the right alignment for stopping and load the box. Once the box are loaded he has to come back to the yard and stop in the right position for the unloading phase conducted by the stacker. Finally the stacker has to unload the box from the truck and position it into a given slot (Tab. 3). The results of the operations with the portainer equipment for 18 trainees are reported in Fig. 5. The time to complete the cycle of the first container was between 3.5 and 8 minutes. As it is possible to note, the unit cost for cycle is decreasing more in the second cycles, where the range was between 6 and 3.30 minutes.

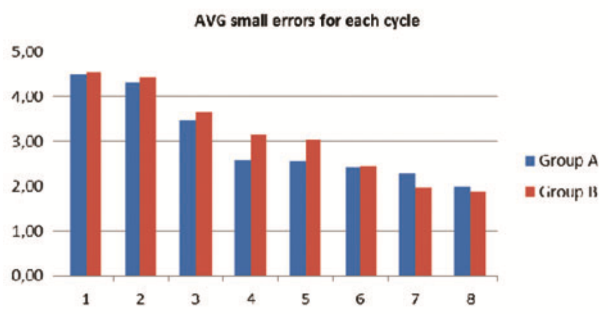

Fig. 5: Average small errors for each cycle

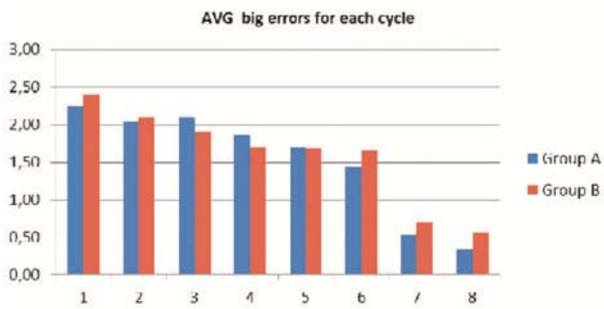

Fig. 6: Average big errors for each cycle

It emerged by the experiments that the trainees resulted more confident and has improved the cycle time in the containers processed in the second part of the training sessions.

Furthermore in Fig 6. the total number of error and accidents is reported; as it is possible to stale that the number of accident has gradually decreased during the repetition of the same operation because trainees have gained more confidence and was acquired skills during the operations.

Fig 7: The virtual portainer in action

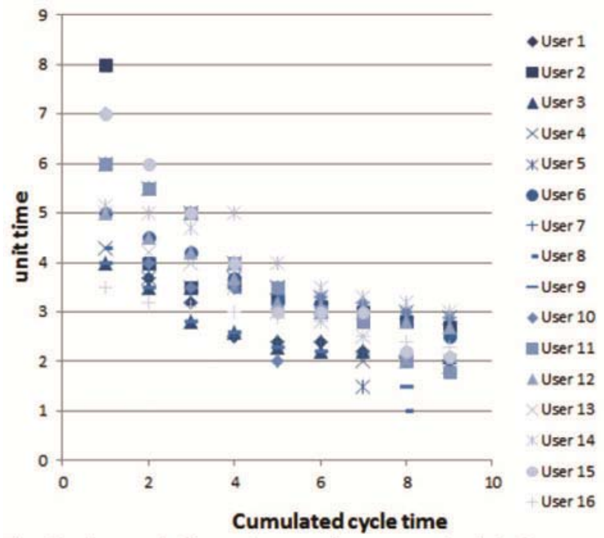

Fig. 8: time unit for each container moved with the virtual transtainer for 2 user

5. MATHEMATICAL FORMULATION FOR THE LEARNING CURVE

In this work the Wright model, also known as the "log-linear model" have been used, since it is the most used LC model for predicting production rate in repetitive operations (Blancett, 2002; Globerson and Gold, 1997; Anzanello and Fogliatto, 2011).

The mathematical formulation of the Wright log-linear model is in (1).

$$y = C * X^{-b} \tag{1}$$

Where:

y is the average time (or cost) per unit demanded to produce X units

C: is the time (cost) to produce the first unit,

b (–l < b < 0): is the slope of the LC, which mdescribes the trainees' learning rate

With (2) :

$$b = \log\ (\mathit{learning}\ \text{rate})/\log(2) \tag{2}$$

Values of b close to –1 denote high learning rate and fast adaptation to task execution. Since in port operations it is important to evaluate not only the time to complete a task, but also the accuracy of the activities of each federate, the learning curve require a method for attributing penalty and determine for each error/accident that each trainee makes what percentage of the "knowledge component" is to blame. As reported in (Nwaigwe et al. 2007), alternative methods for error attribution have not been systematically investigated and to we wasn't able to find any previous work that considers this topic. In this work the Wright log linear model have been modified by incorporating the accidents in the unit cost for each cycle with a time penalty, with the hypothesis that the reduction of the error rate and the gravity is proportional to the reduction of time in the duration of each cycle.

Equation (3) and (4) explain how the error of -federate was converted into time penalty and added in the unit cost for each cycle.

$$b_i = \frac{\sum_k \frac{\log(LR_{k,i})}{\log(2)}}{k} \tag{3}$$

$$LR_{i,k} = T_{i,k} + \alpha * \sum_j w_{i,k,j} \tag{4}$$

Where:
w_i: is the weight for each -error of each -user
T_i: is the unit time for the first cycle
k: cycle number
α: conversion parameter

6. DISCUSSION

In Tab. 5 the calculation of the learning rate related to the transtainer platform for the two groups of student is reported: it seems to be a small connection with the level of instruction and the average learning rate for each user, in fact M.A. graduated student seems slightly to have a faster learning. Furthermore it is important to note that both the group reduced the number of big and dangerous accidents, for example, for the portainer, group A moved from an average of 2.4 to 0.5 and group B from 2.2 to 0.3.

Round	Group A	Seq.	Group B	Seq.
1st Round	User 1	XYZ	User 1	XYZ
	User 2	YZX	User 2	YZX
	User 3	ZXY	User 3	ZXY
2nd Round	User 4	XYZ	User 4	XYZ
	User 5	YZX	User 5	YZX
	User 6	ZXY	User 6	ZXV
3rd Round	User 7	XYZ	User 7	XYZ
	User 8	YZX	User 8	YZX
	User 9	ZXY	User 9	ZXV

Tab. 5: Value of b for in the portainer

Anyhow, since the students were divided into subgroups of three people working together and rotating in the three position (stacker, truck, and transtainer) some of them had the chance to try other platform before using the transtainer one. Furthermore, the activities was performed in three round for each group, and the groups of the second and third round was assisting at the operation of the first group, consequently learning the basic skills just with looking what they were doing.

Group A		Group B	
learning rate	b	learning rate	b
0,8I	-0,31	0,74	-0,44
0.76	-0,40	0,71	-0,48
0,82	-0,29	0,76	-0,40
0,82	-0,29	0,80	-0,32
0,75	-0,42	0,71	-0,50
0,85	-0,24	0,80	-0,32
0,85	-0,23	0,74	-0,44
0,87	-0,20	0,84	-0,25
0,82	-0,29	0,76	-0,39

Tab 6: Sequence of the operation in the three platform
(X=portainer; Y = truck; Z=stacker)

The result was that the last group had cycle time shorter and with a lower number of mistakes than the first one.

7. CONCLUSIONS AND REMARKS

A learning curve (LC) for the training by means of STVP, Simulation Team Virtual Port has been defined. Since this is a first attempt to determine a LC curve, the classical Wright log-linear model with two parameters have been used and modified by incorporating the cost of error/accident during the activities with a time penalty. By means of LC curve is possible to evaluate the trainees' skill improvement using the STGVP equipment during repetitive tasks, and it is also possible to calculate the minimum number of training cycles that are needed in order to reach a predetermined skill. In future research, a further analysis of the LC curve considering the forgetting phenomena could be developed, by monitoring the performance of the same users in the same task after a certain amount of time. Mathematical model such as the 3-parameter hyperbolic could be used; if that model is used it would also be possible to consider the previous experience factor affecting the starting level of knowledge.

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