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APPLICATION OF HYBRID SIMULATION MODELLING FOR THE IMPLEMENTATION OF JOB ROTATION IN A FEEDMILL

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ABSTRACT

This paper promotes a unique system dynamics-discrete event simulation hybrid modelling framework. The way the hybrid model is developed is intended to simplify the modelling process and make the framework flexible to a variety of situations. In the current study, the framework is used to investigate the success possibility of introducing within-shift job rotation in the plant and its optimal frequency. The intention is to reduce worker exhaustion and by so doing increase productivity and manufacturing throughput. The improvement decisions generated from the simulation results could not have been achieved using any other means. The hybrid modelling framework presents a coherent, straightforward standardized approach that includes the main tasks in SD-DES hybrid modelling. A recommendation for future research is to test the framework's adaptability to a variety of settings.

1 INTRODUCTION

A system dynamics-discrete event simulation (SD-DES) hybrid model is a special type of mixed-method simulation model. It is special in the sense that the SD and DES sub-models interact (exchanging data), while both sub-models are run as a single model. The SD and DES sub-models in the hybrid are intended to mimic different aspects of the system being investigated. In real-life, these aspects may be continuously and discretely interacting while affecting each other. Hence in the hybrid, both SD and DES must interact and exchange data. For example, materials planning decisions are taken at an enterprise level, whereas these decisions are based on shop-level scheduling of the materials. A hybrid that is needed to model this type of system would require that the SD sub-model (enterprise level decision making) and the DES sub-model (shopfloor decision making) interact to mimic the real-life situation where they are dependent on each other to evaluate the materials requirement plans at discrete time steps (Venkateswaran and Son 2005).

Manufacturing systems comprise human beings and machines, including the information that is passed between them. Managers and shopfloor workers decisions, behaviours and their actions change as a result of changes in the production process, for example pressure to ramp up production when orders are falling behind schedule. There is reciprocal effect of these decisions, behaviours and actions on process performance, for example, skimping on maintenance so that machine downtime is minimized, in order to achieve throughput targets. This type of back and forth continuous interaction with the resulting effect on system performance is a phenomenon that is best investigated using a hybrid SD-DES modelling approach (Chahal et al. 2013).

SD-DES (or DES-SD) hybrid models have been applied in manufacturing systems (Rabelo et al. 2005). These models have focused on enterprise-wide problems where one needed to combine strategic and tactical decision making activities which occur at set times. SD-DES hybrid models are common in healthcare systems as well (Brailsford et al. 2010; Chahal et al. 2013). SD-DES hybrid modelling frameworks that have been advanced in the past (see for example, Abduaziz et al. 2015; Albrecht et al. 2014; Chahal et al. 2013; Moradi et al. 2017; Rabelo et al. 2015) are not easy to replicate in situations other than where they were initially promoted. This has been collaborated by Eldabi et al. (2016) and Chahal et al. (2013) who have implied that the frameworks are case/problem/industry specific. It is therefore not surprising to see that the frameworks are rarely adopted by others. Past modellers have typically commenced the hybrid simulation modelling study by building separate sub models (SD and DES). They use architype situations to justify the need for a SD-DES hybrid model, for example; strategic/tactical decision making (Abduaziz et al. 2015); enterprise-wide/operational level decision (Rabelo et al. 2005) and physical/non-physical concepts in a system (Alvanchi et al. 2011). But not all problems fit into a specific architype, neither does a problem that fits an architype automatically mean that a hybrid of SD and DES is needed. It is even possible to start a simulation modelling study with one method and realize that another method is needed (Brailsford et al. 2004; Greasley 2005). So, a SD-DES hybrid modelling approach is needed that is void of architype situations which tend to restrict its adaptability in diverse settings.

Not all researchers in the field of SD-DES hybrid modelling present their modelling process framework, only a hand full do (Abduaziz et al. 2015; Albrecht et al. 2014; Chahal et al. 2013; Moradi et al. 2017; Rabelo et al. 2015). The current work aims to add to the body of knowledge, a SD-DES hybrid modelling framework that is unique in the way it is built. It is unique because it does not presuppose that the problem is majorly situated in any particular paradigm whether SD or DES. This is intended to make the modelling process an iterative and interactive one that evolves as the hybrid is developed. By so doing, the modelling process as described by the framework is simple and straightforward. This is shown through a case study application. Meanwhile, the hybrid modelling framework is presented as coherent and straightforward approach that includes the main tasks in SD-DES hybrid modelling, such as: problem structuring; delineation of variables to be modelled in the SD and DES respectively; conceptualizing the data exchange operation; coding the hybrid model and experimenting with the hybrid model

2 THE PROPOSED HYBRID MODELLING FRAMEWORK

The proposed hybrid modelling framework is presented in Figure 1. Subsequently, the steps in the hybrid simulation modelling framework are described in a generic way while applying it to a real-life case study. The case study is one where the interactions between human factors and process flow elements are modelled. Human factors are rarely considered in simulation models, because it is not easy modelling them (Brailsford and Schmidt 2003).

3 CASE STUDY PROBLEM DESCRIPTION

The case is a feedmill which manufactures, processes and bags poultry and animal feed. The purpose of the study was to investigate the effect of job rotation implementation on manufacturing throughput. The type of production system is a continuous process of blending and bagging. The manufacturing process is characterized by manual material handling work. The continuous sequence of activities includes carriage of raw material bags to loading station, opening, lifting and offloading the contents of raw material bags into the blender, filling, weighing and re-filling the blended product into bags and finally stitching the filled bags to close them. The only machine is the blender and all other operations are performed manually by workers. The line is designed to be a continuous one with no delay. The blender has one inlet feeder and two outlet hoppers. When one outlet hopper is being discharged, other activities prior to filling can still be going on to discharge into the second outlet hopper. So, a worker is continuously loading the inlet feeder with raw materials to be blended, while blending is going on and filling from one outlet hopper is also going on. The timing of the discharging was supposed to be an ideal one: when an outlet hopper was fully discharged, the second outlet hopper was at the same time filled from the blender and ready to be discharged.

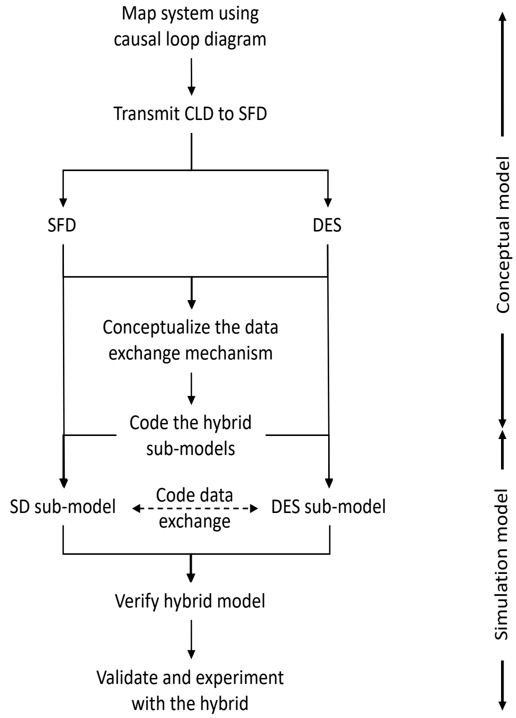

Figure 1: Proposed framework for conducting the SD/DES hybrid simulation modelling study.

During a one-day preliminary assessment of the plant, it was observed how workload was uneven between the key activities and how worker exhaustion was exerting influence on the rate of completing tasks in the plant. The auxiliary workers and those loading raw materials into the blending machine had more workload than those in the downstream process who were filling and stitching the bags. The consequence of high workload was evident in increased exhaustion which led to reduced performance and drop in task cycle time. When cycle time is reduced in one station more than it is in others, the result is un-paced work and un-balanced production. Un-balanced production causes waiting times to increase at various stations (or activities). This was noticed in the plant as the discharging from the outlet feeders was not as synchronized as intended.

Job rotation is the transfer of workers from one work station to another principally so that workers can learn new skills, making them versatile in undertaking various tasks and operating different machines. Job rotation is a cost effective way of reducing absenteeism, improving worker flexibility and line performance (Sánchez and Pérez 2001). Toyota and other Japanese automakers have been known to implement a 2-hour rotating pattern in their plants to distribute high-strain tasks (Pil and Fujimoto 2007).

Investigating the implementation of job rotation in the plant needs to be done objectively. Firstly, one needs to consider the current spread of expertise since not all workers are familiar with all tasks. It is possible that there may be a drop in the initial productivity levels where workers are unfamiliar with doing tasks they are not accustomed to. But this is likely to be reversed as workers become more familiar with all activities. Secondly, an optimal setting of the transfer frequency and schedule of job rotation is needed, so that workload is evenly distributed amongst workers during each shift work. Simulation modelling of the system seems beneficial considering the aforementioned issues that relate to job rotation. On this basis, and following the stepwise guide presented in Figure 1, the study proceeded with mapping the system using a causal loop diagram (CLD).

4 DESCRIPTION AND DEMONSTRATION OF THE HYBRID MODELLING FRAMEWORK

4.1 Causal Loop Diagram Of The Problem Situation

Starting the modelling process using a causal loop diagram (CLD) is deliberate, so that all the key concepts and variables relating to the problem situation are captured in one holistic map, whether SD- or DES-related. This enables one to show how the problem as a whole is initially structured. CLDs can also be used to simplify ones' understanding of a rather complex phenomenon or system. For this reason, a non-convoluted map is advised. Based on the authors' understanding of job rotation and the type of system being investigated, as well as notes taken while interviewing employees (managers, supervisors and workers) and observing behaviours in the plant, a CLD (see Figure 2) was conceptualized. Worker exhaustion is central to the problem. Subsequently, the key feedback loops are described.

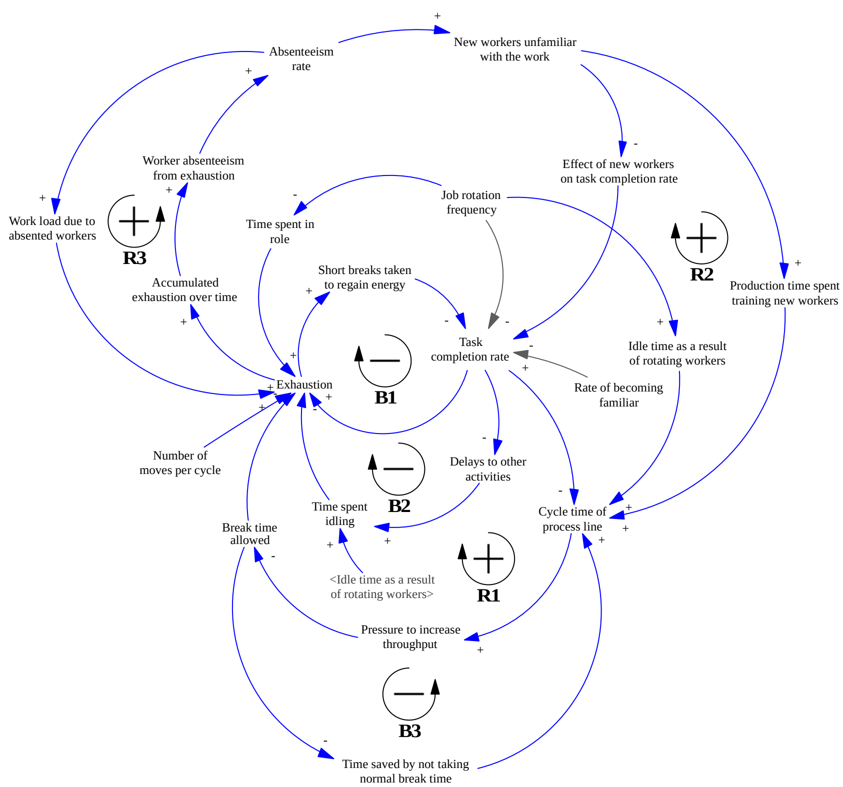

Figure 2: CLD for the case problem description.

The B1 feedback loop describes the direct impact of task completion rate on worker exhaustion. When task completion rate increases, exhaustion increases as a result of doing more tasks per unit of time. When exhaustion increases, workers tend to take more short breaks to regain energy. Multiple short breaks cause the task time to increase and task completion rate to drop. The initial situation is balanced out. B2 describes the delays to other activities when an activity is not completed on time, or when the completion rate has been reduced. It means that idle time for other activities will increase and the exhaustion of workers undertaking those frequently idle tasks will reduce. If exhaustion reduces, task completion increases, there is less delays along the line and workers are kept busy most times. Exhaustion then increases. B3 relates to the pressure to increase throughput. When process cycle time is low, throughput is low and this increases the perception that demand is not being met, and so there is pressure to increase throughput by way of reducing the breaks that workers go for. This was evident in the plant as a strategy to have workers spend more time in producing. The effect is that time is saved in in production and cycle time is reduced. The initial state where cycle time was increasing, has at the end balanced out.

The reinforcing feedback loop, R1, represents the side-effect of reducing the break time that workers can take. Breaks allow workers to reenergize, when breaks are shorter or not taken, exhaustion increases and the worker tends to take frequent short breaks while working, thereby causing task completion rate to reduce. When task completion rate reduces, the process line cycle time increases placing further pressure to reduce break time allowed. R2 is concerned with the absenteeism rate from accumulated worker exhaustion over time. When daily worker exhaustion is high, the rate at which exhaustion builds up over time is high. Accumulated exhaustion over time is something that leads to increased worker burnout, absenteeism rate and worker turnover. When workers are absented from work, management needs to quickly fill in the vacant positions so that work flow is not affected. The new hires are unfamiliar with the work methods in the plant. Even though the work is mainly unskilled type, new hires still need to be trained or shown what to do. This takes up production time, and reduces affective cycle time. Meanwhile, it takes new workers some time to become familiar with the work and work habits in the plant, prior to this their task completion rate is low. By the time they become familiar with the work methods and are able to complete tasks at normal or expected times, they accumulate exhaustion quickly and are vulnerable to burnout and absenteeism. R3 describes a situation where workers have to do the work of absent fellow workers. Having to do additional work because a fellow worker is absented from work, increases worker exhaustion

Other relationships are also influencing the system the way the feedback loops are. The links in grey are dormant, they become active when job rotation is implemented. These links describe the effect of job rotation on lessening worker exhaustion. The effect of job rotation on rate of task completion is dependent on the workers' rate of learning or becoming familiar with new tasks. The effect is expected to cause an initial drop in the rate of completing a task, but gradually normalizing as workers become more familiar through on-the-job learning. One also needs to consider other side-effects of job rotation which will increase the idle time because when workers are being rotated, productive work movements may cease. When idle time increases, cycle time increases. However, while work has ceased, workers can use the opportunity to regain their energy and so exhaustion is reduced. One can hypothesize that it would be difficult for process cycle time to increase under the conditions portrayed using the CLD shown in Figure 2. This is predicated on the notion that worker exhaustion, is oscillating, whereas, worker exhaustion is the main determinant of task completion rate.

4.2 Transmit CLD to SFD and Justify The Need For DES

AnyLogic was used to build the hybrid model. The CLD is transmitted to a stock and flow diagram (SFD), an excerpt of which is shown in Figure 3. The progression from CLD to SFD is also deliberate. Firstly it is a natural progression when modelling in SD. Secondly, the SFD, just like the CLD can also be used to represent all the key variables and concepts relating to the problem. For example, it includes feedback structures as well as process flow concepts, which in a way can be represented by stock and flow rates.

In the SFD that was mapped, all the key activities in the process were captured. Individual activities were modelled to have separate but similar feedback loops as described by the CLD, Figure 2. In the SFD, choosing to use a stock, flow, or variable to represent a phenomenon is dependent on how the modeller intends to use the model for simulation purposes. For example, the stocks (e.g. NumberOfMovesInFillingCycle) without a flow rate in the SFD are intended to model the number of movements accomplished by each worker, accumulated over time. Job rotation frequency has been modelled as a parameter that is used to drive model behaviour. It is intended to be used to test the effect of different settings of job rotation frequency. The dynamics relating to absenteeism have been modelled using stock and flow elements. The elements are intended to mimic how exhaustion accumulates over time and how it affects absenteeism for each type of worker. It is possible that the model elements would differ slightly when using another simulation software package.

The sequence of work activities that was modelled in the initial SFD (Figure 3) represents the actual process flow in the plant. Process flows have been successfully modelled and simulated using SD-only approach (Ali and Deif 2014; Sterman 2000). In the current circumstance, if one were to model the process flow as it is in the SFD (half of which is depicted in Figure 3), it would be computationally complex to code the synchronization of the flow rates according to the various dynamics relating to each resource type, for the model to replicate reality. If a SD-only approach were to be used, a number of unrealistic assumptions may need to be made and the integrity of the eventual simulation model would be compromised. On this basis, it becomes expedient to model the process flow concept using DES where details such as resource dynamics are easier and better modelled than using SD. If a sub part of the intended SD model is to be modelled using DES, it is likely that a number of variables, their interactions and the feedback loops would eventually be subsumed in the DES sub model. Otherwise, leaving them in the SD sub model would equate to a duplication of some of the phenomena. For example, idling of workers is a typical default DES output the same way resource utilization and resource busy state are. Idling of workers may have been accounted for by the DES sub model and becomes redundant if left in the SD sub model. Based on the aforementioned, a SD-DES hybrid simulation model is relevant to the current case. The DES part of the eventual hybrid is shown in Figure 4 (the whole hybrid model is depicted). The DES model includes all the key activities, the flow sequence and the key resources (workers). The concepts and variables not transmitted to the DES model are either modified or left as is (compare Figure 3 with Figure 4).

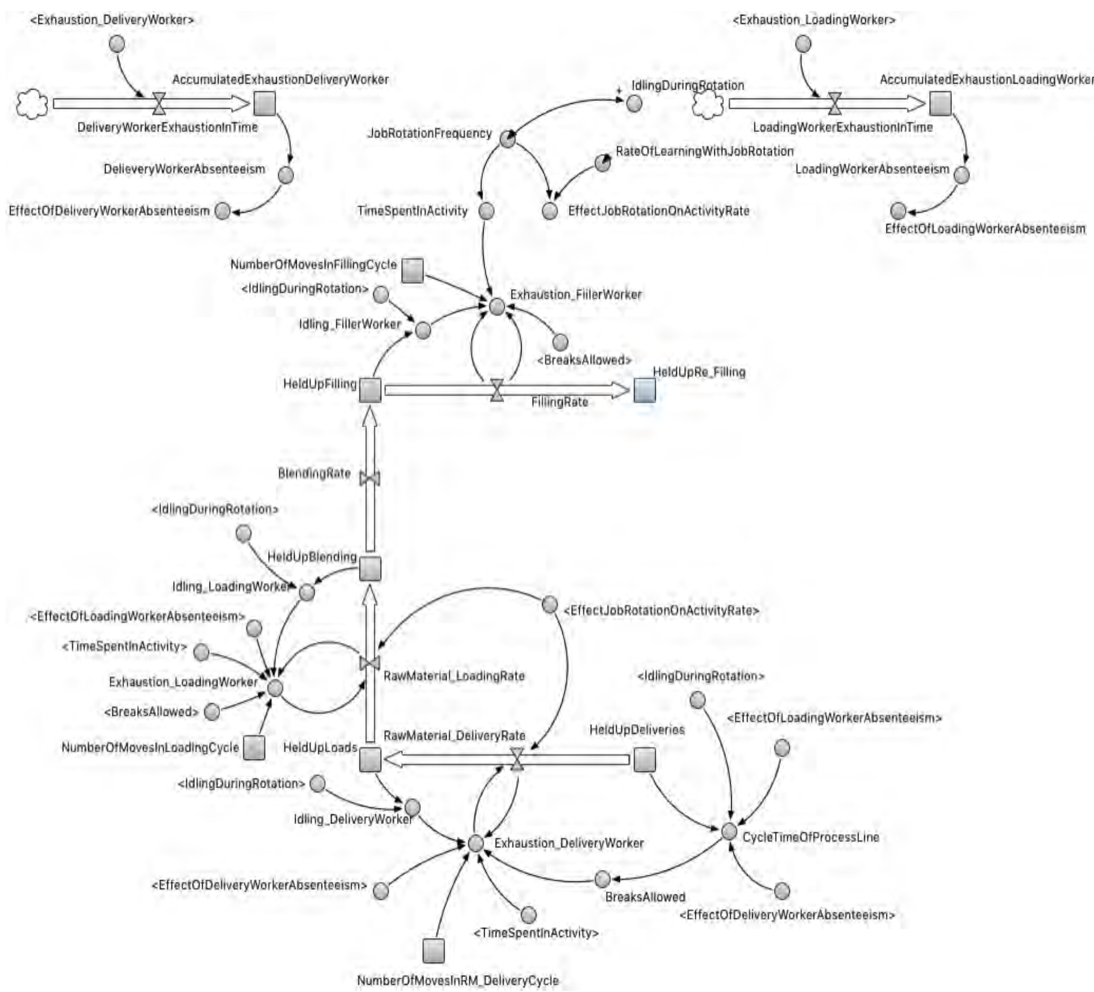

Figure 3: Excerpt of SFD for the case problem description.

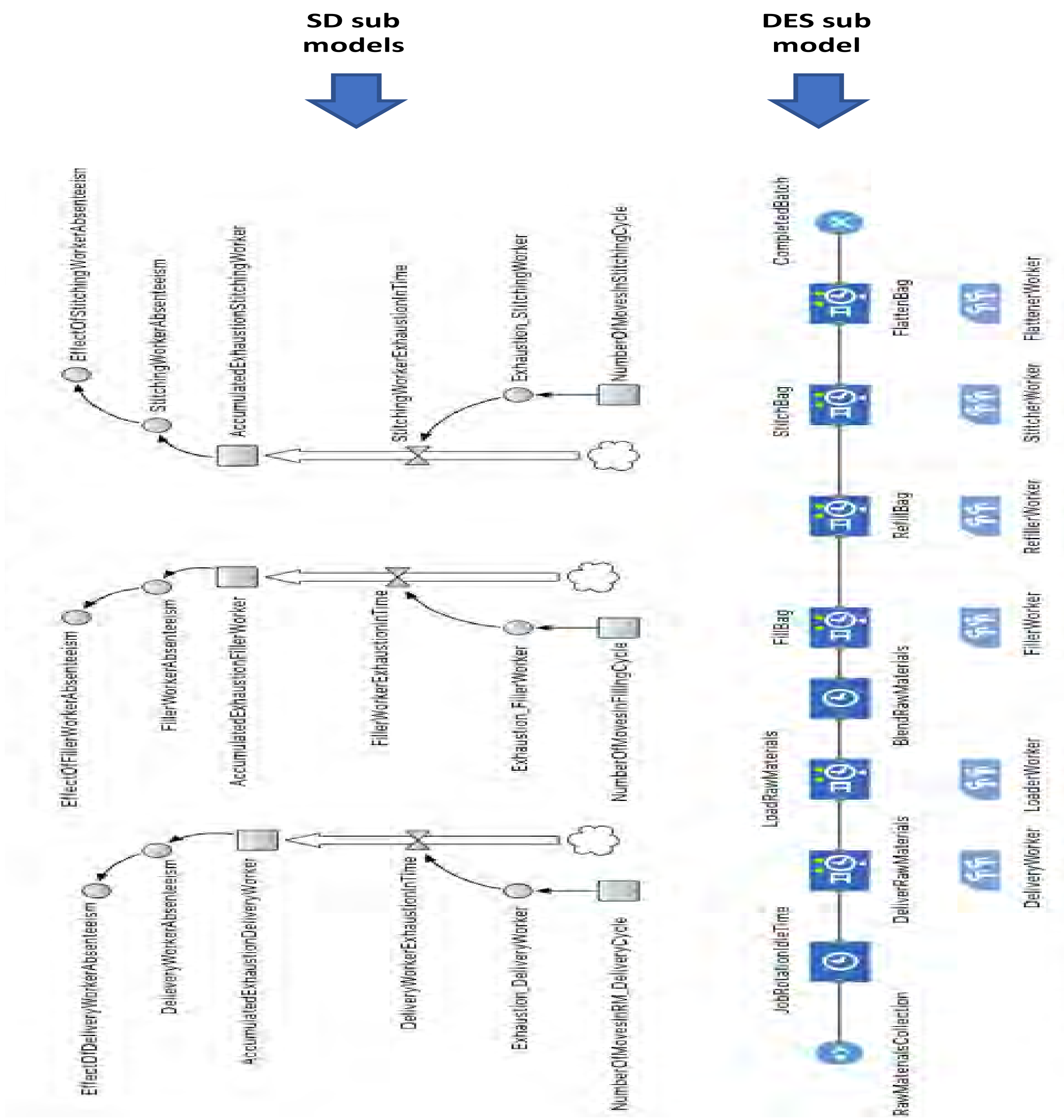

Figure 4: Excerpt of conceptualized hybrid for the case.

Identifying what variables would send and receive data between the sub-models could prove baffling. One simply needs to regard the DES sub-model as a variable (or sub-model consisting of many variables) within the SD model, since it was extracted from it. In SD modelling, variables affect and are affected by other variables, through the continuous updating of their values. The same information that was intended to be passed between variables when the SFD was conceptualized, is the same information that would be communicated when the variables are modelled in the respective sub-models. Conceptualizing the data exchange is therefore based on the notion that the DES concept was adapted from the SFD concept. Table 1 is an excerpt of the list of variables that exchange data between the sub-models.

4.3 Build and Code The SD-DES Hybrid Simulation Model

Time and motion studies were undertaken during the assessment of the plant. Cycle time for each key activity was repeatedly timed over the course of the workday as a function of the number of moves (movements) the worker undertakes. A logarithmic relationship that is typical of the effect of worker fatigue on worker performance was found (Michalos et al. 2013). The percentage increase in task completion time is an indication of the increase in worker exhaustion. In the hybrid model, the values are used to update the activity delay times in the appropriate DES elements of the hybrid model.

Some movements are less strenuous than others. Flattening involves stepping on the already filled/stitched bag so as to level it and allow it to be properly stacked on each other in the store. Flattening is less exerting than lifting the bag to pour its contents into the blender hopper. In fact, the downstream activities are less strenuous than the upstream activities. This information is useful as it means that the starting activities can be used as the baseline activity to normalize other (finishing) activities when using accumulated moves as a measure of accumulated exhaustion.

Job rotation was assigned nominal values: 1 for no job rotation (representing current status); 2 if job rotation is applied. If status quo is maintained, i.e. there is no job rotation, there is no effect of job rotation on task completion time. When job rotation is implemented, there is an initial effect on task completion time. Taking a worst-possible position, it can be estimated that at the start of implementation of job rotation, the average activity cycle time will increase by 100%. It is also estimated that it will take about three months for workers to be fully familiar with multi-skilling. These variables have been modelled as parameters which can be changed to test their effect on the system, so estimating them seems appropriate at this stage. The learning or skill improvement curve was estimated using an exponential curve (Azizi et al. 2010; Oliva 1996).

For exhaustion to have an impact on absenteeism, it needs to be sustained over long periods (Oliva 1996). An extended study would be needed to gather data and establish the actual relationship in the plant. There was insufficient time to do a study of the effect of exhaustion on worker absenteeism rate. So as not to exclude this phenomenon because of unavailability of data, the relationship needed to be estimated Sterman (2000) ; Oliva (1996) ; Cox et al. (2000) and have researched the frequency of worker absenteeism rate as a result of work-related stress. Their submissions and the authors' familiarity with and experiences in various production plants were used to generate a relationship plausible for use in the current model. In section four, we discuss the relevance and benefit of estimating relationships and the effect on the study outcomes.

The model was coded with relevant logics needed for the hybrid to mimic the real-life situation. For example, logic to reset the accrued moves at the beginning of each 8-hour shift to mimic how workers start the day or shift work rejuvenated and logic to reset the accrued moves when workers are rotated. When frequency of job rotation is increased, time to become familiar is reduced, on the assumption that workers learn faster when they do the same jobs more frequently. In addition, logic needed to model stoppage time when workers are being rotated. Coding of the hybrid model also includes coding the data exchange logic. The use of a mixed-method simulation modelling toolset makes this process a seamless one. If the sub models were built in separate platforms, one could make use of High Level Architecture Run Time Infrastructure software and a middleware such as Excel (with Visual Basic Application) to act as a database source for both sub models to send to and receive data from (Venkateswaran and Son 2005).

4.4 Verify the Hybrid Model

The CLD enabled a basic structure verification test of the hybrid model. The CLD architecture is grounded on theory. The relevant variables and concepts, including the interactions and key feedback structures, were all captured in the CLD. All these were transmitted to the eventual hybrid model, ensuring the hybrid did not fail to capture the relevant variables, concepts and interactions. In addition, the hybrid model was run to crosscheck that there were no model errors and that the logics worked correctly to mimic the real system

Table 1: Excerpt of conceptualized data exchange operation for the hybrid model.

Sender		**Receiver**		**Info passed**
Variable	**Sub-model**	**Variable**	**Sub-model**	
DeliverRawMaterials	DE	NumberOfMovesInRM_DeliveryCycle	SFD	Count of number of completed tasks
Exhaustion_DeliveryWorker	SFD	DeliverRawMaterials	DE	Change in activity duration
EffectOfDeliveryWorkerAbsenteeism	SFD	DeliverRawMaterials	DE	

4.5 Validate and Experiment With The Hybrid

4.5.1 Validating the Model

Specific simulation results were used to validate the model. For example, the throughput was flat at about 120 bags per hour, see status quo result in Figure 5. This is consistent with the current value and trend for throughput in the actual plant. In addition, while the hybrid model was run, the utilization rate of each worker in the model was observed. The worker utilization rates outputted by the hybrid model were not different from what exists in the actual system.

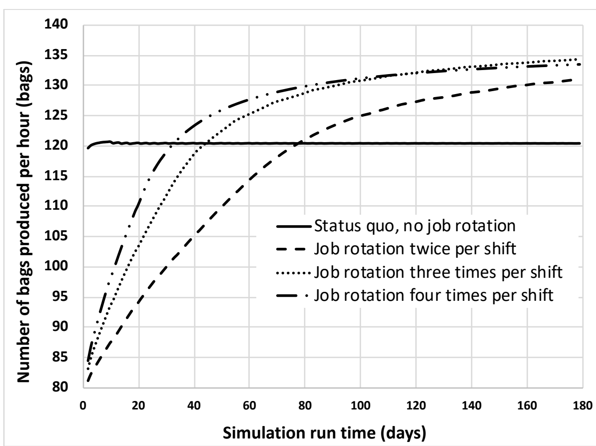

Figure 5:Simulation results for the case.

4.5.2 Identifying Improvements Through Model Experimentation

The hybrid model was constructed with the notion that job rotation frequency would be experimented with. This was the only policy decision being considered for the current case. The hybrid simulation results for implementing the different job rotation types are shown in Figure 5. The results show that three job rotations per shift is the best option, resulting in an increase of about 11.5% in throughput. Increasing the job rotation beyond this may lead to an eventual decrease in throughput as was evidenced with the marginal decrease when implementing four job rotations per shift. The possible reason for this is the total number of disruptions and idle time per shift. If one were to take day 0 to day 40 of the simulation results, it may be argued that four rotations per shift was able to achieve quicker returns. However, in the long run, the three-rotation-per shift strategy seems better, if an extrapolation were to be done. The hybrid model could easily have been run to 360 days or even 720 days. We did not think this was necessary, since the main purpose of the study is to demonstrate our framework and its uniqueness.

5 DISCUSSION AND CONCLUSIONS

The hybrid modelling framework is unique in the sense that it commences with a CLD and SFD. This way one is assured that the key variables and concepts important to modelling the problem, have all been considered. It is only after the SFD has been conceptualized did we justify the use of DES. Others would first justify the need for SD-DES hybrid modelling before proceeding with the model build. We believe that our approach makes SD-DES hybrid modelling pliable to a variety of situations, because the eventual model and how it would be used is what justifies the need for the hybrid. After transmitting the SFD to the hybrid model for the case, it was evident that many of the short-term feedback structures had been subsumed within the DES sub-model. This is an interesting finding. Firstly, it shows that DES can be used (and is probably more suitable) to model those feedback structures that occur and change rapidly. Secondly, it demonstrates that the boundaries between DES and SD are sometimes not so distinct. This is because a number of variables, phenomena and feedback structures which (if not for the hybrid framework) would have been modelled using SD, were eventually modelled using DES. What this means is that when modellers choose to use either SD or DES, it is worth considering a hybrid of both for added benefit. In addition the DES enabled a simplification of coding the eventual simulation model. Our approach is also useful such that from the SFD, one can establish if SD-only, DES-only, SD-DES mixed (as separate sub models without hybriding) or SD-DES hybrid modelling should be used. We believe that there are few problems that would not warrant a hybrid model if one has mapped it using a SFD and if a realistic simulation model is to be developed. One can say that the hybrid modelling framework presents a coherent and straightforward approach that includes the main tasks in SD-DES hybrid modelling, such as: problem structuring; delineation of variables to be modelled in the SD and DES respectively; conceptualizing the data exchange operation; coding the hybrid model and experimenting with the hybrid model. We believe all these would make the promoted framework easily adaptable and the steps standardized, since a standard way of framing SD-DES hybrid modelling is still lacking. It seems as if there is none at the moment if one were to rely on what has been advanced prior (Abduaziz et al. 2015; Albrecht et al. 2014; Chahal et al. 2013; Moradi et al. 2017; Rabelo et al. 2015).

The simulation results (Figure 5) show a worse-before-better likelihood of implementing job rotation. If the plant had gone ahead to implement job rotation without the prior knowledge of the simulation results, managers may have abandoned the implementation at the initial stage. This is because there would most likely be a decrease in cycle time performance as workers are not used to the change. It would also appear chaotic, not even knowing what frequency of job rotation to apply. With the simulation results from the hybrid, the guess work is eliminated and the plant managers are aware that cycle time would be affected negatively, before it eventually improves above the current situation. In other words, they would not be surprised if cycle time decreases initially. There may be resistance to job rotation at the start. Workers may not approve a downgrade of roles, but others whose roles are upgraded will be more enthusiastic, so a cancelling out exists. In any case, the demotivated workers actions can be accounted for under the learning curve.

Sometimes, estimating data based on expert judgement is needed when modelling in SD. The use of estimates seems appropriate in the absence of factual data, otherwise one would need to conduct an extensive research in order to model the relationships (Åhsberg et al. 1997). The estimates used in the current study have been grounded on existing theories, as well as on the authors' knowledge gathered from years of familiarity working in various manufacturing environments. The intended users of the hybrid model were informed about the reasons behind the use of the estimates and the likely effect on the simulation results. Moreover, sensitivity tests can quickly be conducted on the hybrid model to establish how the system would behave for various settings (and their combinations) of those data that were estimated. The use of estimated data does not detract from the framework's excellence. The study in its entirety is sufficient for managers in the plant to want to take a closer look at job rotation. The simulation results are enough justification, in the absence of real-life trial and error experiments with the attendant disruptions and uncertainties.

If one were to go by the ease of progressing the hybrid simulation model from the conceptual to the coding and experimentation parts, one can say that the CLD/SFD conceptualization offers a panacea for overcoming a number of the complex issues that one may encounter when modelling with a SD-DES hybrid format. Firstly, if one starts the model building process with a SD concept in view (by starting with a CLF/SFD concept) it is unlikely one will miss the key feedback structures and the non-physical elements as well as how all variables interact in the complex whole. If one were to start with a DES, it is possible these may be missed. If one were to start with a parallel build it may be possible that concepts are duplicated and it becomes confusing what to place in the SD and DES sub-models respectively. Secondly, it simplifies how variables are demarcated by the individual SD and DES sub-models. Not only does it allow for easy allocation of variables to the respective sub-models, it shows one the level of detail that may be needed in the model.

Although using a multi-method simulation modelling software like Anylogic further simplified the hybrid modelling process, it would be interesting to apply the framework in a situation where two different software packages are used to build the sub-models. Future works will be to test this dual-software use with the promoted hybrid framework. Another future work is to extend the application of the hybrid to test its reuse by others in a variety of problem situations.

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