

Modelling Variations in Newborn Life Support Procedure Using Colored Petri Nets

Alfian Tan

Resilience Engineering Research Group, University of Nottingham, United Kingdom. E-mail:

alfian.tan@nottingham.ac.uk,

Industrial Engineering Department, Parahyangan Catholic University, Indonesia. E-mail: alfian.tan@unpar.ac.id

Rasa Remenye-Prescott

Resilience Engineering Research Group, University of Nottingham, United Kingdom. E-mail: r.remenye-

prescott@nottingham.ac.uk

Michel Valstar

Computer Vision Lab., University of Nottingham, United Kingdom. E-mail: michel.valstar@nottingham.ac.uk

Don Sharkey

Centre for Perinatal Research, School of Medicine, University of Nottingham, United Kingdom. E-mail:

don.sharkey@nottingham.ac.uk

This research is conducted to study variations in the Newborn Life Support procedure. This procedure follows an evidence-based protocol to resuscitate and stabilize newborn babies requiring assistance at birth. Errors and ineffective actions in this procedure may cause disability or even death of the baby. Therefore, a detailed understanding of variations in this procedure is essential. The Colored Petri Nets approach is applied to model the procedure. Its properties are used to describe the main steps of the procedure, their conditional rules, the required checks, and repetition of necessary steps. A Monte Carlo simulation of the Petri Nets model is used to observe the proportion of babies with unsatisfactory outcome. In-field data and literatures are used to determine the parameter values of the model. Some scenarios with variations relating to the maximum number of trials of respiratory procedure are implemented in the simulation. The results demonstrate that, for example, the higher the maximum limit of the standard ventilation trials is, the lower the proportion of babies with unsatisfactory condition becomes. This type of approach can be utilized to explore additional improvements in the way that the clinical procedure can be performed to enhance newborn care.

Keywords: Newborn Life Support, Clinical Practice Variations, Colored Petri Nets, Simulation

1. Introduction

Variations in clinical practice are very common. These may relate to the number and type of treatment used, the duration of clinical tasks, the type of drug used, etc. Unfortunately, some of these variations may cause undesirable consequences such as unnecessary pain for patients, longer waiting time, and higher cost of healthcare services (Shukla 2012; Carter 2016). Therefore, an understanding of types of possible variations in a clinical procedure and their effects are essential to minimize such unwanted outcomes so that it can enhance the healthcare service delivery.

There are many factors that may cause variations in a clinical procedure. These may relate to patient's health condition (Moran, Jacobs, and Mason 2017), resource availability (Shukla 2012), availability of unified guideline (Sherafat et al. 2019), etc. Some but not all these factors, such as patient's clinical profile, can justify the existence of variations in a particular clinical procedure. Some efforts should be considered to minimize variations that are difficult to justify. To understand variations of a clinical procedure in a non-intrusive way, a model that can capture key aspects of variations and model their consequences can be of great be-

-nefit to decision makers and healthcare providers.

Several works in healthcare service modelling have been conducted. Diagrammatic method (Ashoori et al. 2014), analytical model (Bhattacharjee and Ray 2014), simulation model, and their combinations (Evenden et al. 2020; Reed, Remenyte-Prescott, and Rees 2017) are applied to model and observe the variations in the procedure. As an outcome, suggestions are made on how to improve the procedure, based on the evidence obtained from the model.

Based on this idea, the research presented in this paper is conducted to model and study variations in the Newborn Life Support (NLS) procedure. This protocol is used to resuscitate and stabilize a compromised newborn. Accurate and timely actions are essential to save the baby's life. Unfortunately, errors are frequent with rates between 15.9% and 54.5% (Thomas et al. 2006). Some errors include inadequate respiratory management, failure to remove wet linen, and unawareness of the status of the NLS steps (Yamada, Yaeger, and Halamek 2015; Maskrey 2008). Human limitation in identifying and processing information, lack of skill, and poor communication are some causes of these errors. Further study on key aspects of variations that may cause such undesirable outcomes in the NLS procedure should be able to not only increase safety of newborn care but also improve outcomes.

In this paper, a process modelling approach using the Colored Petri Nets (CPN) and Monte Carlo simulation is developed as a novel method to investigate the variations in the NLS procedure. The ability of Petri Nets to accurately model a real system (Ryan and Heavey 2006), which is complemented by a simulation to observe dynamic properties of the procedure, form the basis for implementing these two methods in this study. However, Petri Net is also considered to have weaknesses regarding their complexity while modelling large and complex systems and processes (Ryan and Heavey 2006). Yet, the use of color in Petri Nets can reduce the number of model constituents so that it may reduce the size and the complexity of the model. The NLS CPN model in this paper is validated by observing the simulation results. This model is then used to analyze the effects of some NLS variations on the outcomes of the procedure.

The remainder of this paper is organized as follows: Section 2 describes the research methodology. Section 3 explains the model of the NLS procedure. Section 4 presents some results and discussions regarding the model and NLS variation scenarios. Section 5 summarizes the results and proposes some direction for future work.

2. Research Methodology

The NLS procedure, considered in this paper, is described in detail in the NLS guidelines, published in 2021 by the Resuscitation Council UK (Fawke et al. 2021). A discussion with one of the co-authors of this paper as an expert in neonatal medicine and additional literature studies are conducted to further understand practical details in the guidelines. The main steps of the simplified NLS procedure based on these guidelines are listed below:

- (i) Dry, warm, and stimulate
- (ii) Assess baby condition
- (iii) Ensure an open airway
- (iv) If gasping/not breathing, give 5 inflations
- (v) Reassess heart rate and chest movement
- (vi) If chest is not moving, check and repeat inflation
- (vii) Once chest is moving, continue with ventilation
- (viii) If there is no increase heart rate, consider chest compression
- (ix) Consider drug administration if heart rate remains low

The Colored Petri Nets method is used to diagrammatically model the NLS protocol. All the notations for the CPN are adopted from (Jensen 1997). There are 50 transitions and 43 places in the model. Most transitions in the CPN are used to model the steps of the NLS procedure, while some other transitions are used to control the flow of tokens. A token is used to represent a particular NLS action/job that must be performed at a particular point of time. A token present at a certain place denotes either a status of task completion or a trigger for some subsequent tasks to be initiated.

Furthermore, the token in the CPN model has a set of color. The individual colors are used to carry information about the clinical profile of a baby (such as gestational age, breathing effort, overall health condition, etc.) and the status of a certain task (such as the number of administrated

ventilation breaths, the duration of previous ventilation, intubation status, etc.). This information is used to determine the condition of transition (i.e., task/action) of the NLS procedure which involves the response of a baby to the given action, the duration of the task, and the decision to repeat the same task. There are 36 colors attached to the CPN token. The way the transitions switches is based on the token colors. This process is defined by functions attached to each transition. There are 37 functions involved in the model.

This CPN model is then translated into a Monte Carlo simulation model. The C++ programming language is used to code and perform the simulations. Probabilistic parameter values of task duration are obtained from the combination of in-field data and literature. If in-field data exists, the durations of tasks are estimated based on the most appropriate probability distribution among the five most commonly used types of probability distributions for task durations, i.e., Weibull, Gamma, Lognormal, Loglogistic, and Beta (Law 2007). The highest P-value of probability distribution fitness test is used as an indicator. In addition, the Uniform probability distribution is used when there is only information about the minimum and the maximum duration of a task. A deterministic time duration is applied when only a single value of statistic is available in literature. Other probabilistic parameter values, regarding the response of a baby to a given treatment, the clinical profile of the baby, and the probability of error in the procedure, are either assumed from some qualitative data or derived from some quantitative data available in literature.

The model is simulated 200,000 times to obtain sufficient data for model validation purpose. The statistical estimations use 95% confidence level and the maximum 10% of the estimation error. The validation process considers three model outcomes, i.e., the proportion of babies who need full resuscitation, the proportion of babies who achieve stabilization without the need for cardiopulmonary treatment, and the time point of eight key events in the resuscitation procedure. These outcomes are statistically compared with the reference value estimated from (Fawke et al. 2021) and (Heathcote, Jones, and Clarke 2018).

Some modifications in the initial CPN model are made in terms of the value of parameters, the mechanism of chest compression and drug administration procedure, as well as the rule of administrating a set of standard ventilation procedure.

Finally, a number of scenarios of common variations in the NLS procedure are developed. A plot of effects of variations regarding the maximum number of trials of respiratory procedures is obtained using the simulation model in order to calculate the proportion of babies with an unsatisfactory condition.

3. CPN Model

The CPN model developed for the NLS procedure can be grouped into some higher level of activities. Fig 1 shows a CPN model for a group of initial supporting procedure activities that covers steps (i) to (iii) in the simplified NLS algorithm. The squares and the circles in the CPN model in Fig 1 correspond to transitions and places, respectively. Some of the individual tasks modelled by the transitions depicted in Fig 1 can be shown in Table 1.

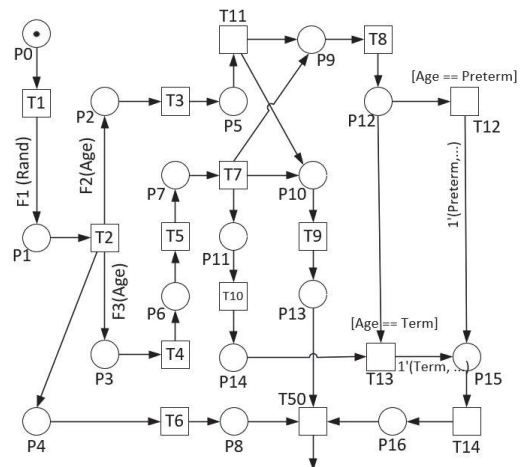


Fig 1. CPN Model of the Initial Supporting Procedure

Not all the transitions in the CPN model represent a task that exists in the NLS algorithm, T2 and T13 are examples of such cases. Transition T2 determines a route of the procedure where a token will be passed. This process depends on the gestational age of the baby. Transition T13 is used to pull and combine some tokens to produce a new token, as a signal to initiate the next NLS task.

Table 1. List of Initial Procedure Transitions

| Transition | Description |
|------------|---|
| T2 | Initial Job Assignment |
| T3 | Cover infant with Polythene bag |
| T4 | Dry the infant |
| T8 | Cover the infant's head with cap |
| T9 | Assess the heart rate |
| T12 | Generator of completed job status for maintaining the temperature of preterm baby |
| T13 | Generator of completed job status for maintaining the temperature of term baby |

As mentioned in Section 2, there are 36 colors attached to the CPN token. Two color variables that can be noticed from the CPN module shown in Fig. 1 are 'Age' (Boolean type) and 'Rand' (Float type). These colors respectively refer to the category of the gestational age of a newborn (i.e., Term or Preterm) and the generated random number (between 0 to 1) for determining the gestational age of the baby in the NLS procedure. This information will be carried and updated based on a set of functions to mimic the dynamic of the NLS procedure.

The expression $F(X)$ (e.g., $F2(\text{Age})$) refers to a function which governs how the transition works and produces an output token based on color information X . There are three functions that are defined for the initial NLS supporting procedure which relate to the two colors found in Fig. 1. These functions can be shown in Eq. (1) – Eq. (3).

$$\begin{aligned}
 F1(\text{Rand}) = & \\
 & \text{if } (\text{Rand} < P(\text{Preterm})) \text{ then} \\
 & \quad 1'(\text{Age} = \text{"Preterm"}, \dots) \\
 & \text{else} \\
 & \quad 1'(\text{Age} = \text{"Term"}, \dots)
 \end{aligned} \tag{1}$$

$$\begin{aligned}
 F2(\text{Age}) = & \\
 & \text{if } (\text{Age} == \text{"Preterm"}) \text{ then} \\
 & \quad 1'(\dots) \text{ else empty}
 \end{aligned} \tag{2}$$

$$\begin{aligned}
 F3(\text{Age}) = & \\
 & \text{if } (\text{Age} == \text{"Term"}) \text{ then} \\
 & \quad 1'(\dots) \text{ else empty}
 \end{aligned} \tag{3}$$

Function $F1$ (Eq. (1)) determines the proportion of preterm and term babies who take part in the NLS procedure. This function assigns a value of either 'Preterm' or 'Term' to the variable Age according to the random value and the threshold value of the preterm newborn probability (i.e., $P(\text{Preterm})$). On the other hand, Functions $F2$ (Eq. (2)) and $F3$ (Eq. (3)) only read the value of variable Age and use $T2$ to initiate the movement of a token on a route in the model which meets the condition in the relevant function. These two functions help to determine appropriate treatments for a baby based on the gestational age. According to the NLS guideline, preterm babies need to be covered immediately by polythene bag instead of drying them with a dry towel. Therefore, this algorithm is modelled in the CPN by $F2$, which will selectively deliver a token of preterm baby to a route corresponding to $T3$ as the next action. After this specific treatment, the subsequent procedure will intersect with the one for term baby (e.g., cover the head with cap- $T8$ and assess the heart rate- $T9$).

Another component of the CPN model used in this research is called a 'guard', which is expressed in a square bracket above a transition. A guard in this model determines a specific type of token that a transition can pull or consume. For example, $T12$ can only consume a token in $P12$ only if the token in that input place has an Age variable value of preterm, otherwise, the $T12$ will not switch.

Regarding probability values in the model, some equations use a constant probability, such as in Eq. (1), i.e., the probability of a preterm baby (i.e., $P(\text{Preterm})$). Several other examples of such parameter values are shown in Table 2 (Bjorland et al. 2019; Root et al. 2019; Fawke et al. 2021; Finer et al. 2009). Based on literatures, it can be found that some parameter values also depend on whether the baby is preterm or term, such as the second parameter in Table 2.

In addition to a constant probability value, some probability parameters are modelled as depending on other factors. This approach is used to model the probability of continuing standard ventilation. The mathematical model for this probability value is shown in Eq. (4). This equation describes the probability rule of how a standard ventilation can be continued after a previous t second ventilation was applied. This

probability rule is estimated from the observed ventilation fraction data in (Skåre et al. 2016).

Table 2. Constant Probability Parameter

| No | Parameter | Value |
|----|---|-----------------------------|
| 1 | Probability of preterm | 0.413 |
| 2 | Probability of gasping after birth | Pre: 0.645, Term: 0.5175 |
| 3 | Probability of developing chest movement after first inflation breath | 0.6 |

$$P(\text{Continuing ventilation} \mid T = t) = \begin{cases} 0.784, & t < 10 \\ 0.7, & 10 < t < 20 \\ 0.769, & 20 < t < 30 \\ 0.267, & t \geq 30 \end{cases} \quad (4)$$

T = duration of previous standard ventilation action (second)

Another typical characteristic of a task relates to its duration. Some of the probability distribution models applied for the task duration can be shown in Table 3. The Uniform probability distribution is modelled based on (Chamnanvanakij and Perlman 2000), while the deterministic approximation uses the data from (Fawke et al. 2021). The rest of probability distributions are fitted into the in-field data that are collected along with the work of (Henry et al. 2021).

Table 3. Task Duration Probability Distribution

| No | Activity | Duration (second) |
|----|-----------------------|------------------------------|
| 1 | Face mask application | Beta (0.0211, 0.0563) |
| 2 | Ventilation | Loglogistic (3.5273, 0.2567) |
| 3 | Inflation breath | Weibull (23.9518, 2.5100) |
| 4 | Chest Compression | Uniform (30, 60) |
| 5 | Volume replacement | Deterministic (120) |

Different from other task duration models, the domain value of Beta distribution function only ranges from 0 to 1. Therefore, to get the actual duration, a task with Beta probability function is adjusted by using the minimum and

the maximum duration of the task. An example of these values (min, max) for the first task in Table 3 is (3.12, 8.92).

Finally, due to lack of data on some aspects of the NLS procedure, assumptions are made. These include:

- The duration of tasks which are approximated by either the duration of other individual tasks or the combination of them.
- Some decision-making tasks, such as determining whether an inflation procedure has been performed sufficiently, is considered as a 0-duration action.
- The probability of success for a multiple efforts of similar resuscitation action is assumed to be higher as technical problems of the previous unsuccessful action have been fixed.

4. Results and Discussion

Three outcomes of the simulation model are compared with the values in (Fawke et al. 2021) and (Heathcote, Jones, and Clarke 2018) for validation purposes. A single sample hypothesis test is used to compare the statistics of proportion obtained from the simulation with the reference values. This test uses the Normal distribution approximation which is considered acceptable for a large number of samples obtained from the simulation. The null and the alternative hypothesis are determined based on the reference values. An independent two-sample hypothesis test is used for the statistics of mean of the NLS key event time points. A large sample size and variance values that can be estimated from samples, both for the reference value and the simulation outcome, are the reasons why this method is applied (Montgomery and Runger 2010). Student's t-distribution underlies this two-sample hypothesis test procedure. All the hypothesis tests use a 5% significance level.

Based on these statistical tests, the outcomes of the simulation are considered comparable to the reference. Table 4 shows some of the results. The first two indicators are the proportions, while the remaining two relate to the time points of some NLS key events.

Nine scenarios of variations regarding the maximum number of repetitions of some respiratory supports are developed to observe how they affect the proportion of babies with an

unsatisfactory condition at the end of the procedure. These scenarios represent possible variations in the standard procedure of a clinical task. There are three kinds of respiratory support observed. Each respiratory procedure has three levels of maximum number of trials of actions that clinical staff can pursue before opting for another clinical action. Table 5 shows the scenarios.

Table 4. Validation Result

| No | Indicator | Reference | Model |
|--|--|-------------|----------------|
| 1 | Proportion of babies who need full resuscitation | < 0.33% | 0.23% |
| 2 | Proportion of babies who achieve stabilization by standard procedure | > 86.6% | 98.37% |
| Time point (mean, std. deviation) --second | | | |
| 3 | Chest movement is achieved | 90, 54.17 | 96.64, 45.01 |
| 4 | Central venous access is secured | 630, 461.34 | 510.96, 181.38 |

Table 5. Scenarios of Variation

| No | Parameter | Level |
|----|--|---------|
| 1 | Max number of adjusted inflation procedure | 1, 2, 4 |
| 2 | Max number of advanced ventilation procedure | 1, 2, 4 |
| 3 | Max number of standard ventilation procedure | 2, 4, 6 |

An example of the first scenario in Table 5 provides 3 alternative maximum number of repetitions that clinical staff can pursue for a single episode of adjusted inflation. For instance, the moderate level of 2 repetitions means that the staff may try to give one more inflation if the first adjusted inflation trial cannot induce a good response from a baby. In case the baby still doesn't respond to the second action, the adjusted inflation will be terminated, and other actions will be considered.

The simulation model for each scenario is run 200,000 times and the results can be depicted in Fig 2. The LOW and the HIGH horizontal axis label in Fig 2 refer to the lowest and the highest value of the level used for each parameter in Table 5.

Based on Fig 2, the proportion of babies with unsatisfactory condition at the end of the procedure

slightly decreases as a higher maximum number of trials of standard ventilations is applied, while it is the opposite for the effect of the advanced ventilation. Meanwhile, there is no effect of variations that can be observed from the adjusted inflation through the three scenarios.

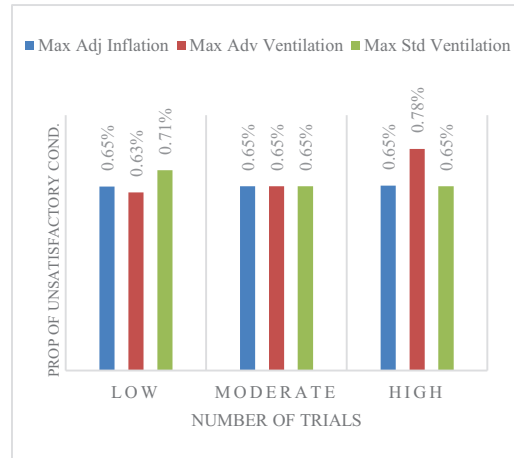


Fig 2. Variations in the NLS Performance

Based on these results, a higher maximum trial of standard ventilations is worth a further study. This respiratory support is given to a baby when breathing activities can be initiated or recovered. It enhances and maintains breathing activities that have already been established. The application of standard ventilations can also be found in a baby who is already able to initiate a good response after going through a series of advanced treatments. The aim of the procedure is similar, i.e., it is used to enhance the good response of the baby. Therefore, intensive attempts of standard ventilations are important to be pursued right after the baby has shown a good response so that it can increase the ability of baby's recovery. As the proportion of babies with an unsatisfactory condition decreases, it brings the NLS procedure to achieve a higher reliability performance.

On the contrary, modeling results show that the maximum number of advanced ventilations should be kept to a minimum. This procedure is commonly performed to trigger a state change of health indicators of a baby. While after an improvement can be observed, the setting of ventilations returns to the standard ones. Efforts during advanced ventilations may include oxygen concentration and pressure adjustment. This procedure may be riskier but is not necessarily

effective. Therefore, the clinical staff will always consider several alternatives of actions and their combinations for the baby to obtain an improved response. By keeping the advanced ventilation trials to the minimum number, other more promising actions (i.e., have a higher probability of success) to recover the baby's condition can be applied earlier before the time limit of considering terminating the resuscitation is achieved. Instead of wasting the time by repeating the same advanced procedure which happens to give no improvement to the baby's condition, the clinical staff can make the best of the resuscitation time by trying alternative effective actions.

5. Conclusion and Future Works

In this research, the CPN and the simulation approach has been proposed and it has been demonstrated to be able to model variations in the NLS procedure. The method shows its ability to help to study a complex clinical procedure. All the task duration parameters in the model are estimated from the most recent in-field data the researchers can access, while other parameters are derived from literatures by considering the similarity of the procedure with the one modelled in this paper. Different parameter values from sources not covered in this paper are expected to affect the exact numerical outcomes of the model. Yet, the general conclusion is expected to be similar. Further sensitivity analysis is useful in the future to gain a deeper understanding on how far the outcomes of the model will be affected.

The experiment performed using the model is essentially useful to enrich the understanding about the NLS procedure by clarifying effects of variations in this protocol. This can be beneficial for predicting the outcome of variations which cannot be directly observed in the real-life situation. In discussions with medical experts, the proposed approach might be able to suggest improvements in the outcomes of the NLS procedure.

Future work will focus on observing and modeling effects of other possible parameters and common variations in the NLS procedure, considering other relevant performance indicators, as well as other causal factors of variations in the procedure, such as differences in the clinical staff skill level and resource availability. As a team-oriented procedure, both the aspect of individual and collective works will be influential for the NLS

outcomes. Incorporating the aspect of communication quality and leadership of the NLS teamwork in the workflow model is a possible and challenging future direction.

Acknowledgement

I would like to thank the Indonesia Endowment for Education (LPDP) for supporting this PhD research. I also want to thank Dr. Thomas Smith for sharing his research and data.

D.S. is supported by the National Institute of Health Research Children and Young People MedTech Co-operative. The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR, or of the Department of Health.

References

- Ashoori, Maryam, Catherine M Burns, Barbara d'Entremont, and Kathryn Momtahan. 2014. "Using Team Cognitive Work Analysis to Reveal Healthcare Team Interactions in a Birthing Unit." *Ergonomics* 57 (7): 973–86. <https://doi.org/10.1080/00140139.2014.909949>.
- Bhattacharjee, Papiya, and Pradip Kumar Ray. 2014. "Patient Flow Modelling and Performance Analysis of Healthcare Delivery Processes in Hospitals: A Review and Reflections." *Computers & Industrial Engineering* 78: 299–312. <https://doi.org/https://doi.org/10.1016/j.cie.2014.04.016>.
- Bjorland, Peder Aleksander, Knut Øymar, Hege Langli Ersdal, and Siren Irene Rettedal. 2019. "Incidence of Newborn Resuscitative Interventions at Birth and Short-Term Outcomes: A Regional Population-Based Study." *BMJ Paediatrics Open* 3 (1): 13–16. <https://doi.org/10.1136/bmjpo-2019-000592>.
- Carter, Patrick. 2016. "Operational Productivity and Performance in English NHS Acute Hospitals: Unwarranted Variations." https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/499229/Operational_productivity_A.pdf.
- Chamnanvanakij, Sangkae, and Jeffrey M Perlman. 2000. "Outcome Following Cardiopulmonary Resuscitation in the Neonate Requiring Ventilatory Assistance." *Resuscitation* 45 (3): 173–80. [https://doi.org/https://doi.org/10.1016/S0300-9572\(00\)00184-2](https://doi.org/https://doi.org/10.1016/S0300-9572(00)00184-2).

- Evenden, D C, S C Brailsford, C M Kipps, P J Roderick, and B Walsh. 2020. "Hybrid Simulation Modelling for Dementia Care Services Planning." *The Journal of the Operational Research Society*, 1–13. <https://doi.org/10.1080/01605682.2020.1772020>.
- Fawke, Joe, Sean Ainsworth, Adam Benson Clarke, T'ng Chang, Andy Coleman, Karen Cooper, Jonathan Cusack, et al. 2021. *Newborn Life Support*. Edited by Sean Ainsworth and Joe Fawke. 5th ed. London, England: Resuscitation Council UK.
- Finer, Neil N, Wade Rich, Casey Wang, and Tina Leone. 2009. "Airway Obstruction During Mask Ventilation of Very Low Birth Weight Infants During Neonatal Resuscitation." *Pediatrics (Evanston)* 123 (3): 865–69. <https://doi.org/10.1542/peds.2008-0560>.
- Heathcote, Adam Charles, Jacqueline Jones, and Paul Clarke. 2018. "Timing and Documentation of Key Events in Neonatal Resuscitation." *European Journal of Pediatrics* 177 (7): 1053–56. <https://doi.org/10.1007/s00431-018-3160-8>.
- Henry, Caroline, Lara Shipley, Carole Ward, Siavash Mirahmadi, Chong Liu, Steve Morgan, John Crowe, James Carpenter, Barrie Hayes-Gill, and Don Sharkey. 2021. "Accurate Neonatal Heart Rate Monitoring Using a New Wireless, Cap Mounted Device." *Acta Paediatrica* 110 (1): 72–78. <https://doi.org/https://doi.org/10.1111/apa.15303>.
- Jensen, Kurt. 1997. *Coloured Petri Nets: Basic Concepts, Analysis Methods and Practical Use*. Vol. 1. Springer Science & Business Media.
- Law, Averill M. 2007. *Simulation Modeling and Analysis / Averill M. Law*. 4th ed. Boston: Boston : McGraw-Hill.
- Maskrey, Simeon. 2008. "Neonatal Resuscitation." *Clinical Risk* 14 (2): 46–48. <https://doi.org/10.1258/cr.2008.080015>.
- Montgomery, Douglas C, and George C Runger. 2010. *Applied Statistics and Probability for Engineers*. John Wiley & Sons.
- Moran, Valerie, Rowena Jacobs, and Anne Mason. 2017. "Variations in Performance of Mental Health Providers in the English NHS: An Analysis of the Relationship Between Readmission Rates and Length-of-Stay." *Administration and Policy in Mental Health and Mental Health Services Research* 44 (2): 188–200. <https://doi.org/10.1007/s10488-015-0711-4>.
- Reed, Sean, Rasa Remenyte-Prescott, and Ben Rees. 2017. "Effect of Venepuncture Process Design on Efficiency and Failure Rates: A Simulation Model Study for Secondary Care." *International Journal of Nursing Studies* 68: 73–82. <https://doi.org/https://doi.org/10.1016/j.ijnurstu.2016.12.010>.
- Root, Laura, Henriette A van Zanten, Maria C den Boer, Elizabeth E Foglia, Ruben S G M Witlox, and Arjan B te Pas. 2019. "Improving Guideline Compliance and Documentation Through Auditing Neonatal Resuscitation ." *Frontiers in Pediatrics* . <https://www.frontiersin.org/article/10.3389/fped.2019.00294>.
- Ryan, John, and Cathal Heavey. 2006. "Process Modeling for Simulation." *Computers in Industry* 57 (5): 437–50. <https://doi.org/https://doi.org/10.1016/j.compind.2006.02.002>.
- Sherafat, Asghar, Aliakbar Vaezi, Mohammadreza Vafaenasab, Mohammadhassan Ehrampoush, Hossein Fallahzadeh, and Hossein Tavangar. 2019. "Responsibility-Evading Performance: The Experiences of Healthcare Staff about Triage in Emergency Departments: A Qualitative Study." *Iranian Journal of Nursing and Midwifery Research* 24 (5): 379–86. https://doi.org/10.4103/ijnmr.IJNMR_217_18.
- Shukla, Nagesh. 2012. "Unwarranted Variations Modelling and Analysis of Healthcare Services Based on Heterogeneous Service Data."
- Skåre, Christiane, Anne-Marthe Boldingh, Britt Nakstad, Tor Einar Calisch, Dana E Niles, Vinay M Nadkarni, Jo Kramer-Johansen, and Theresa M Olasveengen. 2016. "Ventilation Fraction during the First 30s of Neonatal Resuscitation." *Resuscitation* 107: 25–30. <https://doi.org/https://doi.org/10.1016/j.resuscitati.2016.07.231>.
- Thomas, E J, J B Sexton, R E Lasky, R L Helmreich, D S Crandell, and J Tyson. 2006. "Teamwork and Quality during Neonatal Care in the Delivery Room." *Journal of Perinatology* 26 (3): 163–69. <https://doi.org/10.1038/sj.jp.7211451>.
- Yamada, Nicole K, Kimberly A Yaeger, and Louis P Halamek. 2015. "Analysis and Classification of Errors Made by Teams during Neonatal Resuscitation." *Resuscitation* 96: 109–13.