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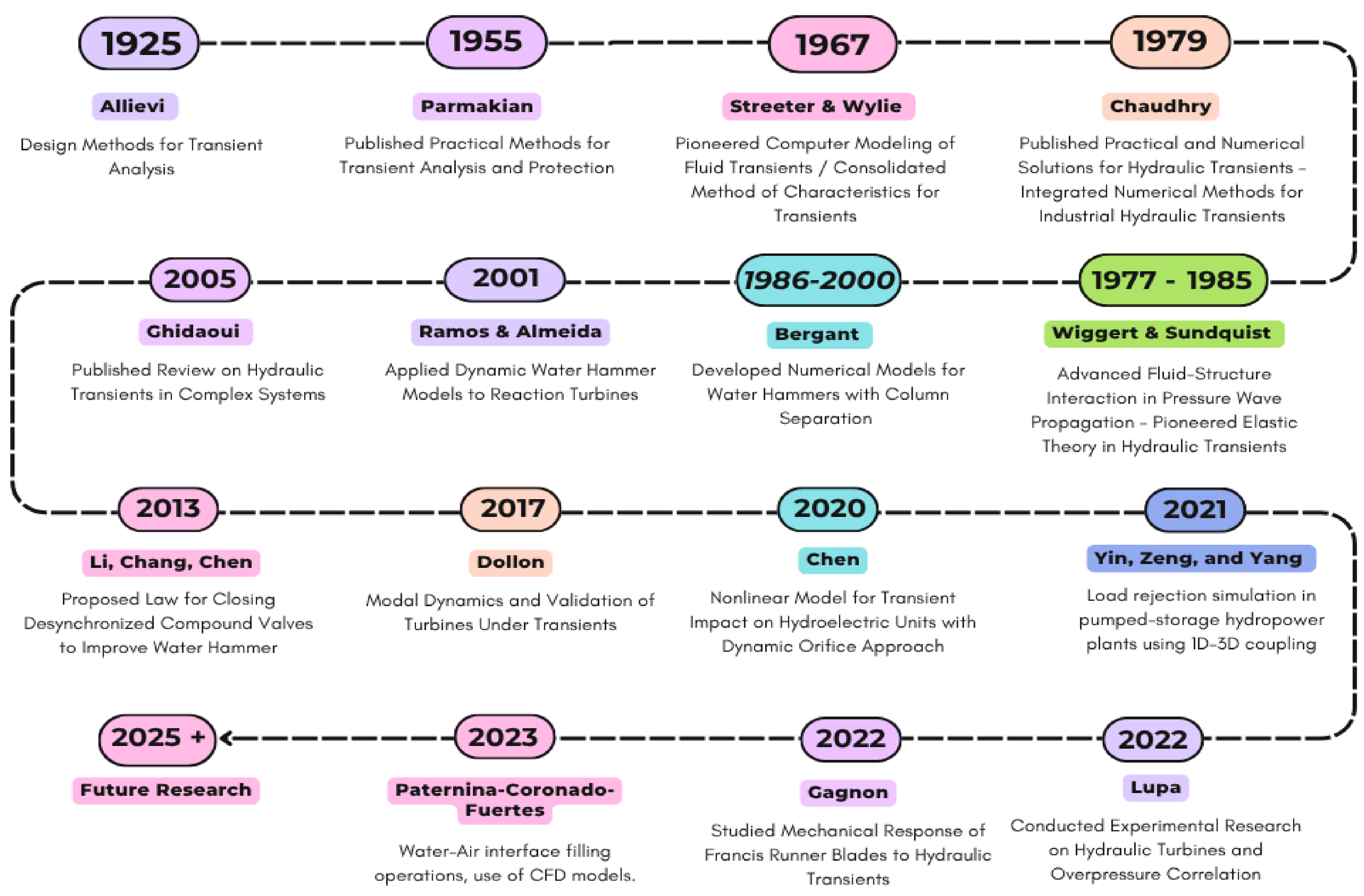
Historical Evolution and Software Selection Criteria for Transient Hydraulic Analysis with Hydro-Pneumatic Protection

Óscar Javier Burgos-Méndez[1]*, Modesto Pérez-Sánchez[2], Óscar Enrique Coronado-Hernández[3], Helena M. Ramos[4], Alfonso Arrieta-Pastrana[5]

[1] Universitat Politècnica de València, Spain | [2] Universitat Politècnica de València, Spain | [3] Universidad de Cartagena, Colombia | [4] University of Lisbon, Portugal | [5] Universidad de Cartagena, Colombia
Corresponding author*: oburmen@doctor.upv.es

INTRODUCTION & AIM

Hydraulic transients have been studied for more than three centuries, from the early formulations of Newton and Euler to modern numerical methods.
This study presents a historical synthesis of key theoretical developments and proposes a methodological framework for selecting suitable simulation software for pressurised systems protected with hydro-pneumatic tanks. The research integrates classical models such as the Elastic and Rigid Water Column Methods (EWCM and RWCM) with a decision-matrix analysis and machine learning, improving both accuracy and efficiency in transient modelling..



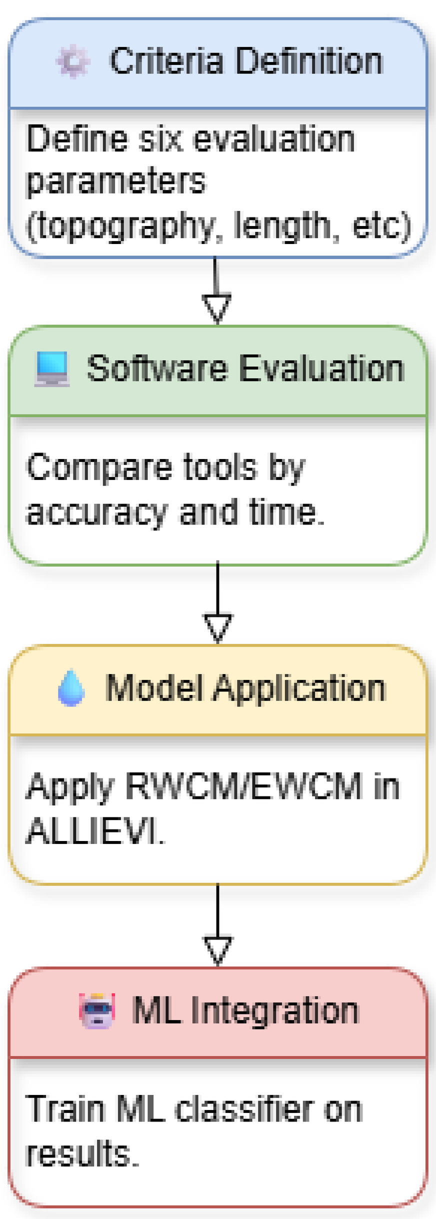
Bridging centuries of hydraulic theory with modern intelligent modelling.

METHOD

The proposed framework integrates technical, operational, and computational aspects to support the selection and application of transient analysis models.

The methodology consists of four sequential stages:
1.Definition of evaluation criteria – Six key parameters were established: topographic profile, pipeline length, number of protection devices, wave speed, operational complexity, and time/resources available.
2.Software comparison – A decision matrix was developed to evaluate several simulation tools based on accuracy, computational time, usability, and cost.
3.Model application – The selected software (ALLIEVI) was used to simulate both the Elastic and Rigid Water Column Models (EWCM and RWCM).
4.Integration of machine learning – The simulation results were used to train a Coarse Tree model for risk classification.

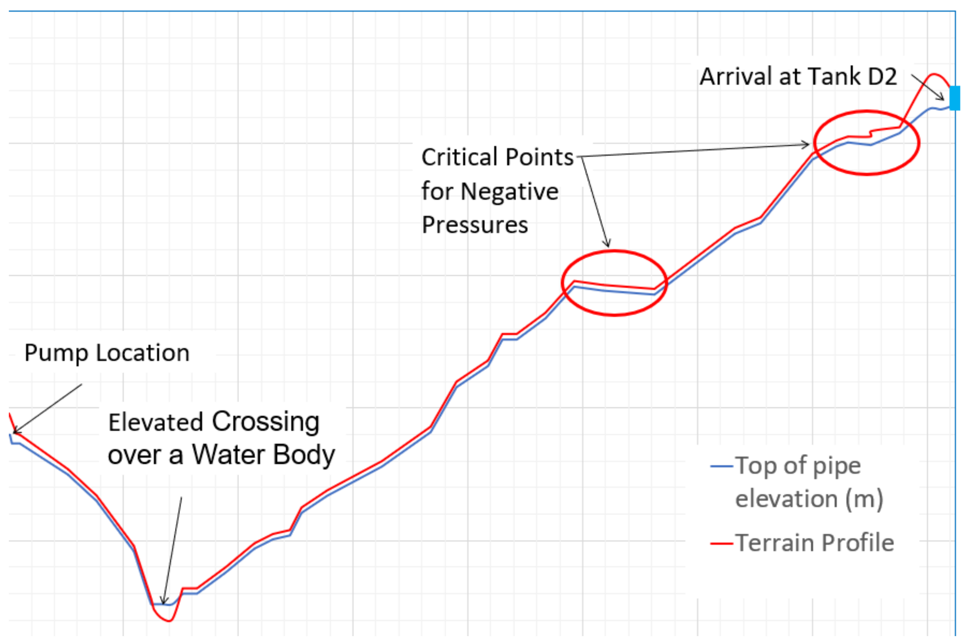
This multi-stage approach combines classical hydraulic theory with data-driven analysis to enhance model reliability and practical decision-making



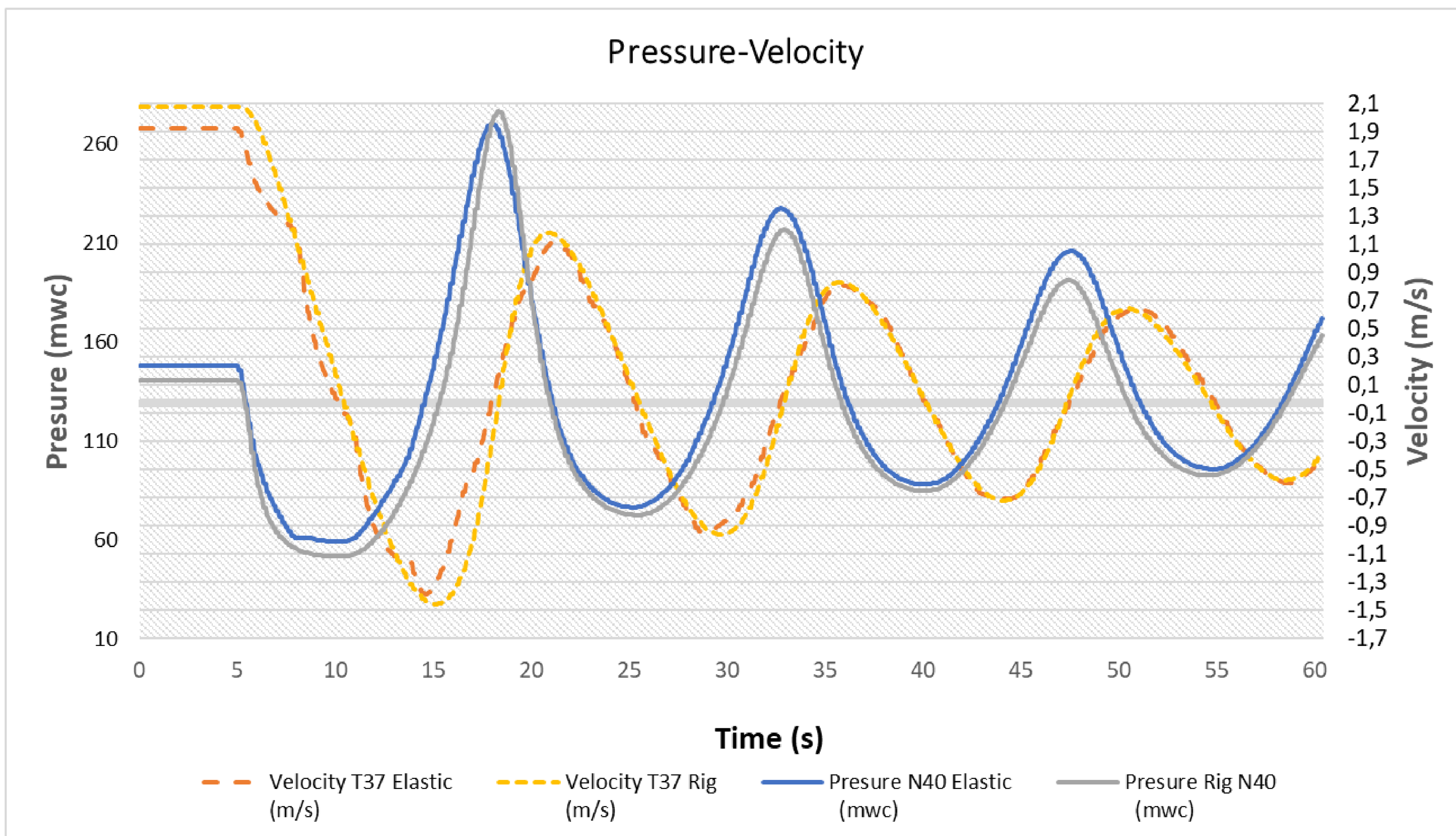
Criterion	Description (short)	Category Range
Topographic profile	Pipeline slope and elevation pattern	Simple / Moderate / Complex
Pipeline length	Total length of the pressurised section	Short / Medium / Long
Protection devices	Number of tanks, valves, or air chambers	Low / Medium / High
Wave speed	Pressure wave propagation speed	<500 / 500–1000 / >1000 m·s^{-1}
Operational complexity	No. of pumping stations and valves	Low / Medium / High
Time & resources	Project budget and deadlines	Ample / Moderate / Limited

A structured link between classical hydraulic reasoning and intelligent digital modelling.

RESULTS & DISCUSSION



Metric	Elastic (EWCM)	Rigid (RWCM)
Computation time (s)	110	27
Max pressure (mwc)	≈ 265	≈ 260
Wave speed (m/s)	1148	9185
Accuracy difference	–	< 2 %



The comparison between the Elastic Water Column Model (EWCM) and the Rigid Water Column Model (RWCM) shows a strong correlation in transient behaviour for protected systems. Pressure and velocity profiles at the critical node (blue = elastic, grey = rigid) demonstrate that RWCM captures the main dynamics while slightly underestimating extreme peaks.

Computation time was 110 s for EWCM and 27 s for RWCM, representing a 75 % reduction without significant loss of accuracy.

This efficiency makes RWCM suitable for preliminary analyses or scenarios with limited computational resources.

The machine-learning classifier achieved over 95 % accuracy in detecting overpressure and sub-atmospheric events, confirming the robustness of the combined framework.

RWCM maintains acceptable accuracy while reducing computation time by over 70 %

CONCLUSION

• The Rigid Water Column Model (RWCM) achieves comparable accuracy to the Elastic Water Column Model (EWCM) while reducing computation time by approximately 70% in protected systems.

• The proposed framework provides a simple and reproducible approach to support the selection of transient analysis software.

• Integrating machine learning improves the ability to detect overpressure and sub-atmospheric risks, offering a bridge between traditional modelling and intelligent analysis.

FUTURE WORK / REFERENCES

Future work will focus on integrating this framework within a Digital Twin environment for real-time hydraulic simulation.