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Implementation of Hybrid Parallel Computation for Complex and Fine Reservoir Model Using Cluster Technology

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Abstract

Pertamina EP plays an important role in maintaining the oil production supply for national energy stability. However, there is big challenge in the field development plan preparation since they are not fully equipped with the advance computing technology to boost the reservoir modeling and simulation phase. To face the challenge, Pertamina EP evaluated the possibility to create a cluster technology that can accommodate high intensity of simulation numbers and high load of simulation process.

This paper described the success story and innovation of a complex simulation and finer scale reservoir model using the hybrid parallel-computing technology with a set of 8 nodes high performing computer. Three models were tested with satisfying results. This paper discusses the parallel scalability of complex computing systems of multi-CPU clusters. Multi-CPU distributed memory computing system is proven to be able to improve and accelerate the reservoir modeling and simulation time when it is used in combination with a new so called "hybrid" approach. In this approach, the common Message Passing Interface (MPI) synchronization between the cluster nodes is being interleaved with a shared memory system thread-based synchronization at the node level.

The model with the longest simulation time has been accelerated by magnitude of 60%. The most exhausted model with highest number of simulation steps has been accelerated by magnitude of 80%. The model with the greatest number of grid (21.7 million active grids) has finally finished its simulation just in 27 minutes where previously was impossible to have it open and run. The successful study case is then followed by the implementation of the cluster computing technology for two pilot POD projects which led to the very good result.

Keywords: POD, Hybrid Parallel Computation, Complex and Fine Reservoir Model, Cluster Technology, multiple reservoir realizations

Introduction

Almost all fields that operated by Pertamina EP has almost 70 years of production history. They are known for its complex multi-reservoirs geology, sophisticated waterflood program of giant proportions, and has more than 150 wells for each reservoir. However, due to extreme complexity, only highly upscaled models have been used as seen in **Figure 1**.

To make plans for infill drilling and various workovers, the most production units were relying on sector models that have necessary spatial resolution but had obvious areal coverage limitations in the areal coverage of the field. Up to now, all the sector models built for planning of infill drilling, workovers, EOR and waterflood optimization were not directly related to the full-field model. In fact, these models can be considered as "single use" tools designed for addressing ongoing challenges of the specific local part of the oil field.

The main reason for such outcome is the fact that the full-field model has much coarser grid. Consequently, its improvements that made for selected sectors cannot be directly integrated.

One of the main goals in advancing the hardware and software technology is to allow the use of comprehensive and detailed geological realm which putting together a self-consistent system for sector and full-field model.

The other important factors influencing large field model development is the calculation time. Upscaling parameters are often chosen based on the available time frame and the computer's performance, not on any physical sense. At the same time, present-day approaches to the hydrodynamic modeling allow us to remove these limitations and perform direct calculations on a geological scale. A combination of several factors, like the availability of more economical parallel computer platforms available on the hardware market and software that efficiently utilizes it to provide optimal parallel performance, helps to reduce the computation time of the reservoir models significantly. For a large reservoir simulation model project implementation, fast calculations should be made possible.

Hierarchic architecture of modern computer clusters

A cluster is a set of computers (referred to as cluster nodes), connected by high-capacity communication channels. Each of the nodes usually contains two (or more rarely four) physical processors and its own Random-Access Memory (RAM), where the operating system is running. Access to the other node's memory is provided via connection lines, and the entire system is entirely integrated from the user point of view. Users communicate with the cluster through the master node that supports system task queues and distributes tasks between the nodes.

These days, the clusters have become economical and easy-to-use machines. It has been demonstrated that the reservoir simulation time can be efficiently scaled on the modern Central Processing Unit (CPU) -based workstations and clusters if the simulation software is implemented properly to support the features of modern hardware architecture. It is fair to conclude that the simulation time is no longer a principal bound for the projects, as it can always be reduced by adding extra computational power. In addition to in-house hardware one can consider simulation resources available on the clouds based on pay-per-use model. This makes the reservoir modeling solutions much more scalable in terms of time, money, human and computational resources. Reservoir engineers from large and small companies can have access to nearly unlimited simulation resources and are able to reduce the simulation time to a minimum whenever needed.

Understanding hybrid

In clusters programming, MPI is de facto the standard interface. The costs of data exchange between the logical processors can be reduced to a minimum if the node just have two processors. Based on this fact, it is found that some of processors can interact more efficiently and caused the MPI programs even more complicated and did not produce significant gain. That changes occurred when the nodes have more than ten logical processors. Loss of performance has reached many-fold numbers and could not be neglected anymore. This led to the development of hybrid applications, where the interaction between the nodes occurs through the MPI, when OpenMP or direct operating system threads are used within the similar nodes to any shared memory platform.

This approach is obviously has the advantages. With the example of a cluster with 20 nodes, 12 cores each. The total number of processors is 240. Traditionally, such a system would use 240 MPI processes which normally leads to limitations due to scalability problems. With the hybrid approach, one needs to use 20 MPI processes (one for each node) and 12 system threads at each node.

Pertamina EP long term Plan of Development (POD) plan for the upcoming 5 years

In order to help maintain national production supply, Pertamina EP has a massive field development plan which consist of waterflood projects from thirty-three structures across Indonesia within 5 years. Some of those structures will also continue to perform tertiary recovery using CO2 and Polymer injection as the Enhanced Oil Recovery effort.

On the other hand, SKKMigas published new Pedoman Tata Kerja (PTK) about POD in 2018 which demand the probabilistic approach which honor and capture the uncertainties, upside and downside potential, subsurface risk and execution mitigation plan. This new approach requires multiple case definitions and evaluations.

The advance technology in hardware development seems promising to help them in current situation. Moreover, there is also massive development in reservoir simulator technology that will enable the process of multiple simulation jobs, allows the running of detailed fine reservoir models, and to integrate geological modeling and dynamic modeling into one complete process, without rebuild the model from the scratch.

Data and Method

Optimal applications for modern high-performance clusters

Internal benchmarking was concluded that 8 nodes with 20 cores per node configuration is the optimum scenario for typical Pertamina EP reservoir model, where the runtime acceleration factor reach the highest improvement as depicted in **Figure 2**. It is better to add more nodes rather than more cores based on the cost point of view. This configuration result is then reported to Pertamina EP IT department as the guidance of the optimum cluster specification requirement that fit their needs.

There are three models tested to get the optimum configuration for the brand-new cluster computer that are going to be built. They are coming from the analog reservoir outside organization which was chosen based on the similarity with the existing fine geological model of Pertamina EP. The resulted cluster setup as can be seen at **table 1** shows that selected configuration is proven to accelerate the simulation time where the first two models with lower number of total active cells can be reduced by the magnitude of 30%, by the addition of the compute nodes where the remaining model is reduced by a factor of 50%. The more complex and higher the active grid numbers, more efficient this parallel computation will be.

This promising benchmark is then become the justification to build the following cluster setup that is now available in Pertamina EP.

The configuration is:

Nodes number : 8
CPU : 20 Cores, 2x Intel® Xeon E5-2630v4 2.20 GHz,25M,8.00 GT/s, LGA2011-R3 (85W), DDR4-2133, 10-Cores (Broadwell-EP), 14nm
DRAM : 64GB DDR4-2133MHz ECC Reg
Interconnection : FDR Infiniband 56Gb/s

Master node
CPU : 20 Cores, 2x Intel® Xeon E5-2630v4 2.20 GHz,25M,8.00 GT/s, LGA2011-R3 (85W), DDR4-2133, 10-Cores (Broadwell-EP), 14nm
DRAM : 64GB DDR4-2133MHz ECC Reg
Interconnection : FDR Infiniband 56Gb/s
Capacity : 60Tb, RAID50

Miscellaneous
Switch Infiniband 56Gb/s 36 port
Switch Ethernet 22 1Gb/s port + 2 10Gb/s port
KVM+IPMI 20 nodes

The main part of the cluster itself are the head node and all the compute nodes which are used for project dispatcher, as well as the engines for the computing and processing purposes. Since the simulator used with this cluster is the one that support hybrid parallel computation, so infiniband was chosen for data interconnection after the ethernet for faster communication between the nodes to access memory. It is because infiniband implement the Remote Direct Memory Access (DMA), which is an operation to access the memory directly from the Network Interface Controller (NIC) without involving CPU and can reach the bandwith up to 100 GB/s.

The network infrastructure was set by assigning a dedicated server for floating license server installation that connect to all system including client's local PC, directory server, head node and compute nodes as shown in **figure 5**. It enables all the users as the client to connect to the cluster anytime and anywhere across the company's network. Cluster that was built by Pertamina EP allows users to run reservoir simulation model start from only using 1 core processor up to 160 cores in total, for each individual user. The cluster nodes can also be allocated up to 8 reservoir engineers who wants to run the reservoir simulation in parallel at the same time.

User Acceptance Test in Pertamina EP organization

As the quality check process, Pertamina EP conducted user acceptance test consists of: physical acceptance test to the

installed hardware components, power redundancy and connection test to from the license server, Application Delivery Platform (ADP), master node and each compute node based on the designated installation topology.
Another evaluation was also conducted for the software implementation in the cluster system. The software selected for this evaluation was the one that can maximize full capability of the installed hardware. This acceptance test was conducted to compare the performance behavior between the existing process using the ADP system, with the proposed new technology using the cluster system.

The evaluation steps consist of:
1) Run full simulation process of selected reservoir model using existing ADP environment.
2) By using the same file, run full simulation process using the new installed High Performing Computer (HPC) cluster system with several power computing configurations using different number of nodes and cores per simulation run.
3) Compare the overall simulation time required by both hardware environment and for each configuration cases.

There were three existing dynamic models selected for the evaluation of the hardware specification setup, as seen in **table 2**. Those models also consider the extreme cases of the complexity and the simulation experiences. The chosen models are Sago structure which has around 500 thousand active grid blocks, Limau Barat – Limau Tengah structure which has around 650 thousand active grid blocks, and one sample model from Rock Flow Dynamics (RFD) that is commonly used for the hardware speed test evaluation which has around 21.7 million active grid blocks. If the performance is acceptable, Pertamina EP will rebuild the dynamic model for each structure using the updated geological static model without upscaling. This was previously impossible because of the limitation of existing hardware and software in Pertamina EP.

Selection of Pilot POD to create standard operating procedures and process guidance

Currently the team is moving forward to a modern approach that is believed to improve the reservoir prediction and expectation using probabilistic and multi-scenario method. This approach is also aligned with the recent SKKMIGAS regulation on POD deliverability in PTK-037/SKKMA000/2018/S0–Rev–02. This method is the attempt to estimate and compensate the uncertainty in reservoir model by combining the deterministic and probabilistic approach so that upside and downside potential can then be discovered and considered for a complete project evaluation.

Pertamina EP EOR department has 33 structures of POD study related to waterflood optimization that need to be completed with the average target of completion of 4 structures per year. An example of reservoir simulation process in Pertamina EP, the model with 500,000 active grid blocks takes approximately 75 minutes to be completed using a full core single workstation. It takes 50 minutes to complete full simulation to run the same model using the server computer of ADP system that is proved provides better computer specs and higher number of cores.

Assuming that if 1 structure need 500 history matching simulation cases in average together with the forecast, then the current ADP system will need 50 days to complete the project. Moreover, the engineering evaluation time to quality check and property adjustment by trial and error can delay the completion of the project which is also depends on the reservoir model complexity and the available computing cores that can be utilized. This means that only 2 structures out of 4 the target structures are feasible to be completed each year.

Therefore, the HPC and robust reservoir simulation that support the latest parallel computing advancement is categorized as urgent. As the result, two of ongoing POD projects are chosen as the pilot implementation of the probabilistic multi scenario simulation to see the improvement that can be achieved in its first year of implementation. Limau Barat and Limau Tengah (LBLT) structure of Pertamina EP Asset 2 and Kenali Asam (KAS) structure of Pertamina EP Asset 1 are chosen for the pilot implementation. The selected reservoir models are chosen based on the complexity, urgency and the most time consuming, where those are the key issues that need to be focused if Pertamina EP wants to improve its business process.

Result and Discussion

Analog Benchmark result from three giga model in terms of simulation time and number of cores effect

The measurements of parallel performance for a different number of CPU nodes and cores were performed for all considered models. From the benchmark test of three different analog reservoir models, the result looks promising where acceleration factor from adding node is around 25 – 50%, as seen in **Table 1**. Slope of simulation runtime from 2 nodes run pack show a relatively more stable variation as shown in **Figure 3**. Two nodes can improve the simulation time from an average of 17 hours with a slope variation of about 8x10-7, to an average of 10 hours with a slope variation of around 3 x 10-7. It was concluded that those typical reservoir model will perform well with the addition of computer cluster.

The first model with 3 million of active grid blocks was chosen to be used for further evaluation. It consists of three phases reservoir model coming from one of Pertamina asset. As shown in **Figure 4**, the simulation was performed in a combination of 4 different nodes configuration ranging from 1 node, then increased by 2 times from 2 nodes, and 4 nodes until 8 nodes. Based on the results described, it is clear that the addition of computing nodes significantly decreases the simulation time. The first attempt using 1 node takes 4 hours and 43 minutes to complete the simulation, while second attempt using 2 nodes takes 3 hours 23 minutes to finish that is approximately takes one hour faster than the first attempt. The third trials using 4 nodes can reduce the simulation time even better with 1 hour 40 minutes needed to complete. Then the fourth attempts can summarize everything with only 1 hour needed to complete the full simulation span. It was concluded that the higher the nodes count will result in better acceleration time. One hour runtime to complete the simulation of 3 million active grid cells that consists of 1360 steps and 25 years of lifespan is surprisingly beyond the initial expectation. Thus, it is a strong justification to strengthen previous evaluation to equip cluster with 8 computing nodes.

Chosen cluster configuration and infrastructure to be implemented in Pertamina EP

Figure 5 shows the configuration that was built in Pertamina EP by stacking 8 nodes into a single system connected to the main master nodes that used as controller and dispatcher. Infiniband was also used to complete and ensure the better communication between the compute nodes. This HPC is connected to the local server network to enable reservoir engineer as the end user to connect to the machine using their local workstations. Information Center and Technology (ICT) team can also monitor the submitted job queue, real time job progress and computing nodes load. Since this HPC will be used to run big data, the simulation results will be stored using a large, dedicated storage

The number of structure completion target was calculated based on the model prepared using the assumptions of grid size, expected runtime and expected number of runs. **Table 3** shows the assumption of required number of storages per study which is 1 TB for a single study with additional of 20% free space and 2 years retention time. Thus, 16.8 TB of the maximum active storage will be needed for this study with consideration that the files that exceeded the retention time will be archived. This table also described that it will takes 5 to 10 months in the first year to complete the projects, and it takes just 5 months the completion of project in the following years, with assumptions that each project may require 300 cases to be run.

User acceptance test result from Pertamina existing fine reservoir model

After the completion of cluster installation in Pertamina EP, user acceptance test was also performed. The objective of this test is for quality check of the selected cluster performance in Pertamina EP using their own existing real field data. This information is written in **Table 2**. Two random reservoir models were selected from the current active POD projects. Since the existing reservoir model is considerably light and less complicated, the huge reservoir model that consist of 21 million active grid blocks which previously used for the benchmark test is also selected to be checked in the user acceptance test.

The first model has around 500 thousand active grid blocks, 107 active wells and 952 timestep. It took very long time to simulate the models in Pertamina EP local ADP system where it resulted to only half of simulation span finished after two and a half hours of running. The test using cluster provided satisfying result with only two hours needed to finish the complete simulation span by using 1 node, and one hour needed for all available nodes.
The second model has around 650 thousand active grid blocks, 129 active wells and around 1000 timestep. The existing ADP system took almost one hour to finish the complete simulation where cluster was proven to improve up to 13 minutes using 1 node. Additional number of nodes was also proven to accelerate even more up to 6 minutes.

The last model has 21 million active grid blocks and 39 wells. The attempts of running the model in ADP system was failed as the model was unable to be run due to its huge size. Cluster shown its main capability in this case where the machine performed very well to open and run this model with runtime significantly accelerated from hours up to become only 27 minutes.

All of these evaluations were successfully concluded the effectiveness of cluster installation in Pertamina EP environment and used as the background of the implementation of the ongoing POD projects.

Pilot POD with cluster implementation results of LBLT and KAS history matching and forecast

The ultimate objective of implementing this cluster technology is to apply full-scale probabilistic approach to determine the uncertainties and true potential of POD projects. Two ongoing projects were selected as the pilot projects based on its urgencies. Both projects were in the static modelling phase when it was decided.

After the implementation, not only geoscientist can work closely with reservoir engineers as they shared the common platform, but it also increases the reliability of the result because they now can model and run a full-field model. Additionally, the application that was used, enables the capability to integrate between the static geological modeling, dynamic modeling and history matching as an extended loop of workflow that can be seen in **Figure 6**. Now the history match will not only be limited to dynamic properties evaluation and adjustments but also to the static modeling part as well.

LBLT field is one of the reservoir models that was selected for pilot implementation. LBLT projects consists of multi tanks model with commingle production was chosen for fully integrated workflow because the model imposed more heterogeneity in both petrophysical modeling and its structural modeling. The workflow, as described in **Figure 7**, will help the static model validation process since all the steps from static modeling until history matching will be performed in connecting loop. This allows more evaluations for all the variables ranges from the selected geological uncertainties.

The total completion time for LBLT field development study was around 6 months. The reservoir model consists of around 700,000 active grid blocks with individual grid dimension of 50 x 50 x 1.4 meters (XYZ). Total 3,150 cases were simulated for the history matching part as shown in **Figure 9**. The number of experimental is quite big because the initial base case model simulation result was very far deviated with the history data. Number of optimization runs are also quite big because there was an issue in the production test and measurement done in the year of 1970-1980s that led to the history misinterpretation.

The process improved by time from the huge deviated liquid profile which gradually improved and finally matched with less than 1% deviation of history to simulation profile. It can also be seen that the workflow used can confirm static uncertainties such as the leaking fault, its transmissibility and fluid contact.

The second model that was selected is KAS. Finally, KAS reservoir also have a full field dynamic model and the simulation is now possible to be performed. KAS model was selected for the implementation of partially integrated workflow since the reservoir does not impose many variations in structural uncertainty. It was later believed that the petrophysical modeling uncertainty will be covered enough by incorporating the percentile 30, 50 and 90 of the deterministic static models, as shown in **Figure 8**. This process is slightly different but still enables user to assess the geological model in limited way.

Total completion time for KAS field development study was around 9 months, slightly longer than LBLT because the model vertical resolution is relatively higher. KAS reservoir model consists of 1,888,359 active grid blocks with individual grid dimension of 50 x 50 x 0.6 meters (XYZ). Total 594 cases were simulated in the history matching part. The number of experimental designs is relatively lower than in LBLT because the quality of the base case is relatively better in representing the history measurement, as can be seen in **Figure 10**. The average simulation time is also three times longer for this field and it requires more time for the evaluation since it has more active wells to be matched. In general, the model history matching progress is gradually improved to very good liquid, oil production profile and region pressure matched as can be seen in the picture.

As result, completion of both fully integrated and partially integrated workflow produced two standard operating procedure workflow options that will be applied for upcoming POD projects in Pertamina EP. The general process of integrated history matching method with help of assisted history matching application started with experimental design and sensitivity analysis to quantify and verify the discovered uncertainties. The experimental design process will normally lead to the more suitable base case model to be used as the first guess for the history matching optimization tool, that will automatically do the majority part of history matching tasks. Eventually, the reservoir engineers can verify the results and do the quality verification to all the completed jobs.

LBLT and KAS projects output along with the generated integrated workflows has been approved and selected as guideline for probabilistic modeling of POD proposal to SKKMIGAS especially for Pertamina EP because it provides user to assess the extended uncertainty evaluation from reservoir static modeling, dynamic modeling until history matching. The output will become the probabilistic solution of matched model that can be used for the field forecast. This approach is proven to provide multiple forecast realizations that is aligned with the background of history matching idea which is non-unique solution. The possible range of outcomes will then be evaluated in terms of decision analysis to decide the maximum production and economically optimum development for the field.

Conclusions

A parallel Hybrid algorithm mixing MPI and system threads at the node level was tested for various full-field models of real oil and gas fields and demonstrated a parallel acceleration record exceeding of 70% in 8 nodes cluster. In the extreme case scenario, an acceleration factor of 80% was reported where a “black oil” model with 21 million active grid blocks was run in a cluster with up to 160 cores. This model also enables the possibility to run the full fine field model that was previously impossible when using existing resource.

Based on the observation, turns out that comparing simulation from the field based on grids with different spatial resolutions, one could conclude that with additional vertical resolution creates noticeable differences in the estimations of internal reservoir energy and, consequently, causes differences in forecast calculations. It appears that the original full-field model with coarser active grid blocks must be upgraded to a model with additional resolution using finer active grid blocks, and this model should become a new base case for all the simulations of fluid and gas migrations, and global history matching at the field level.

It appears that with parallel Hybrid technology, history matching of giant reservoirs gets a significant boost when a higher number of CPU cores/node is used. The most optimum full cluster infrastructure for Pertamina EP is by implementing 8 computing nodes which each node consists of 20-cores Intel Xeon E5-2630 configurations. The proposed technology helps to remove several important performance bottlenecks and solves the “simulation scale problem” related to building, validating up to predicting dynamic models of giant reservoirs.

As a result, nearly “ideal” scalability and record acceleration for clusters have been observed and there is no evidence of the establishment of saturation point in parallel acceleration. The proposed technology allows running history matching of large models into team effort using personal workstations and large corporate cluster systems in the most effective manner.

Most importantly, the requirement to provide probabilistic POD proposal to SKKMIGAS is now become realistic and is easier to be completed. Strengthened by the possibility to couple geological subsurface modeling with dynamic simulation, up to surface production network constraint, allow the complete and realistic binary interaction between all uncertain and certain variables in each asset. It improves the quality of the POD proposal as the final product while also completed the risk evaluation with mitigation plan on downside potential.

Two pilot POD projects as the introduction implementation have been successfully performed which also resulted in the project template and process guideline. Assuming that the duration of this project will be similar with the other upcoming POD projects, then all the thirty-three structures completion target will be able to be done within the expected timeframe.

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Acknowledgements

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TABLE 1

ANALOG MODEL PROPERTIES FOR BENCHMARK AND RESULT

Field	**A**	**B**	**C**
Area	Indonesia	New Zealand	Siberia
Grid size (cells)	3,000,000	4,700,000	20,000,000
Runtime (hour) with 1 node/ case	11.75	12.9	26
Runtime (hour) with 2 nodes/ case	8.5	7.75	13.12

TABLE 2

USER ACCEPTANCE TEST MODEL PROPERTIES AND EVALUATION RESULT

Nama Project	**Model Complexity**	**Simulation Runtime with ADP (hours)**	**Simulation Runtime with Cluster (hours)**
SAGO	Number of Active Grid: 517,775 Timestep: 952 Wells: 107 Calculated steps: 6,176	02:30:00 (unfinished - terminated at 48% progress due to long simulation time)	- 1 node -> 02:12:03 - 8 nodes -> 00:59:07
LIMAU BARAT - LIMAU TENGAH	Number of Active Grid: 655,556 Timestep: 1,016 Wells: 129 Calculated steps: 1,897	0:52:23	- 1 node -> 00:13:24 - 8 nodes -> 00:06:18 - 5 nodes (2 user A) -> 00:07:14 - 2 nodes (2 user A) -> 00:09:00
SAMPLE PROJECT from Siberia	Number of Active Grid: 21,770,901 Wells: 39 Calculated steps: 762	N/A	- 1 node -> 01:41:06 (unfinished - terminated at 54% progress due to long simulation time) - 8 nodes -> 00:27:07

TABLE 3

NODE REQUIREMENT EXPECTATION TO FULFILL THE 5-YEAR SHORT TERM POD PLAN

Year	**2019**	**2020**	**2021**	**2022**	**2023**
Grid Size	75,496,044	73,896,491	62,009,083	67,786,233	60,517,690
Max grid size	18,795,300	20,962,742	19,462,994	27,118,000	22,417,085
Min grid size	2,553,122	3,539,760	12,622,500	4,222,542	10,721,676
Total struktur	8	6	4	4	4
Node / struktur	1	2	2	2	2
Kebutuhan Node	8	8 *	8	8	8
Max Runtime (hour) / case	24.11	13.28	12.83	15.13	13.72
Min Runtime (hour) / case	11.12	8.05	10.78	8.26	10.21
Max Runtime (hour) / 300 case	7,234.27	3,983.71	3,848.73	4,537.68	4,114.60
Min Runtime (hour) / 300 case	3,336.15	2,415.64	3,233.09	2,477.09	3,062.01
Max Runtime (MONTH) / 300 case	10.05	5.53	5.35	6.30	5.71
Min Runtime (MONTH) / 300 case	4.63	3.36	4.49	3.44	4.25

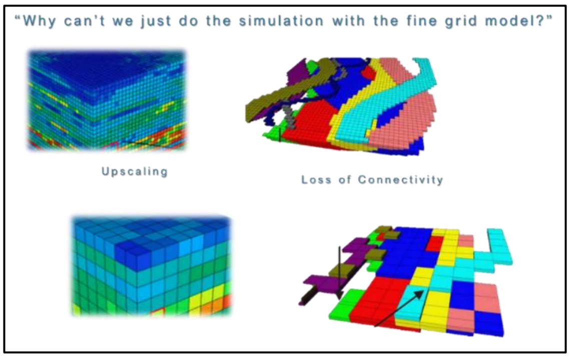

Figure 1 - Fine grid vs upscale grid fundamental.

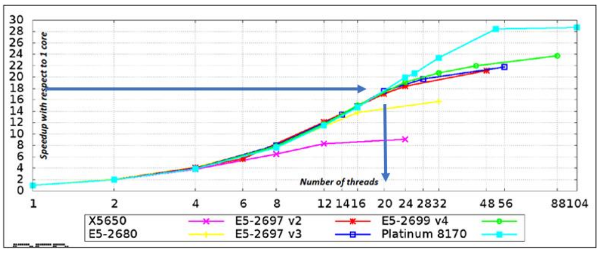

Figure 2 - Parallel computing threads sensitivity in regards with acceleration time.

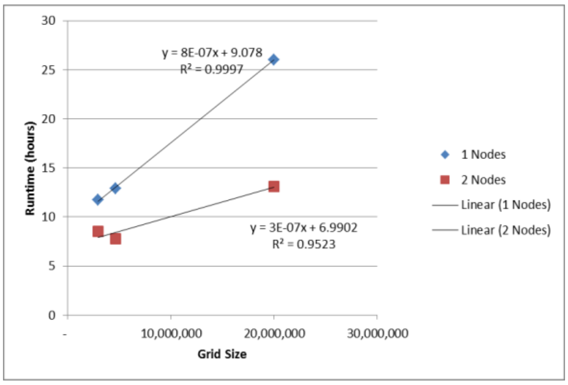

Figure 3 - Benchmark result on cluster configuration selection.

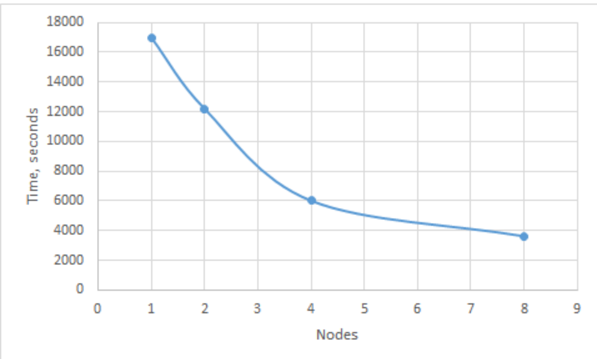

Figure 4 - Further benchmark result of model 1 from Pertamina EP analog reservoir sample.

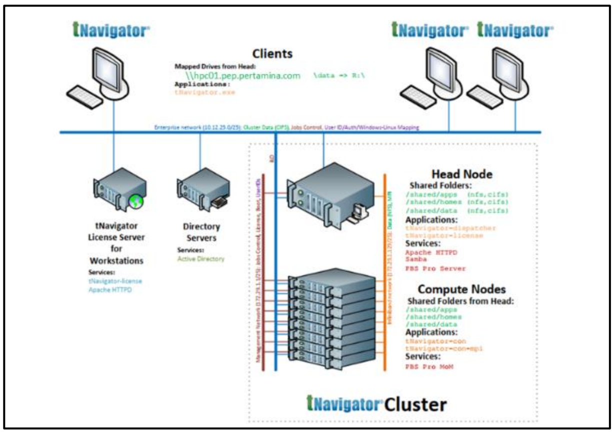

Figure 5 - Cluster infrastructure and flow process in Pertamina EP.

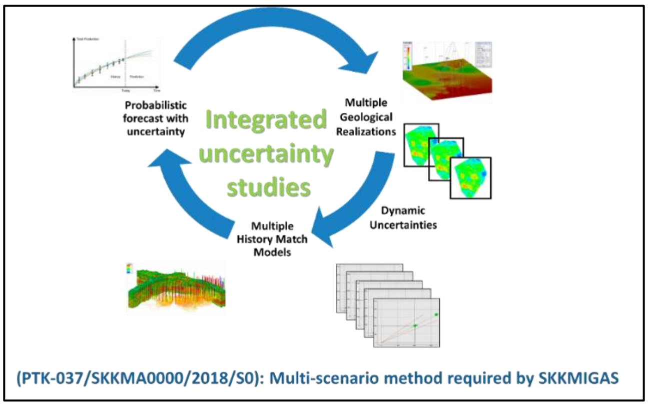

Figure 6 - Probabilistic history matching and forecast standard workflow.

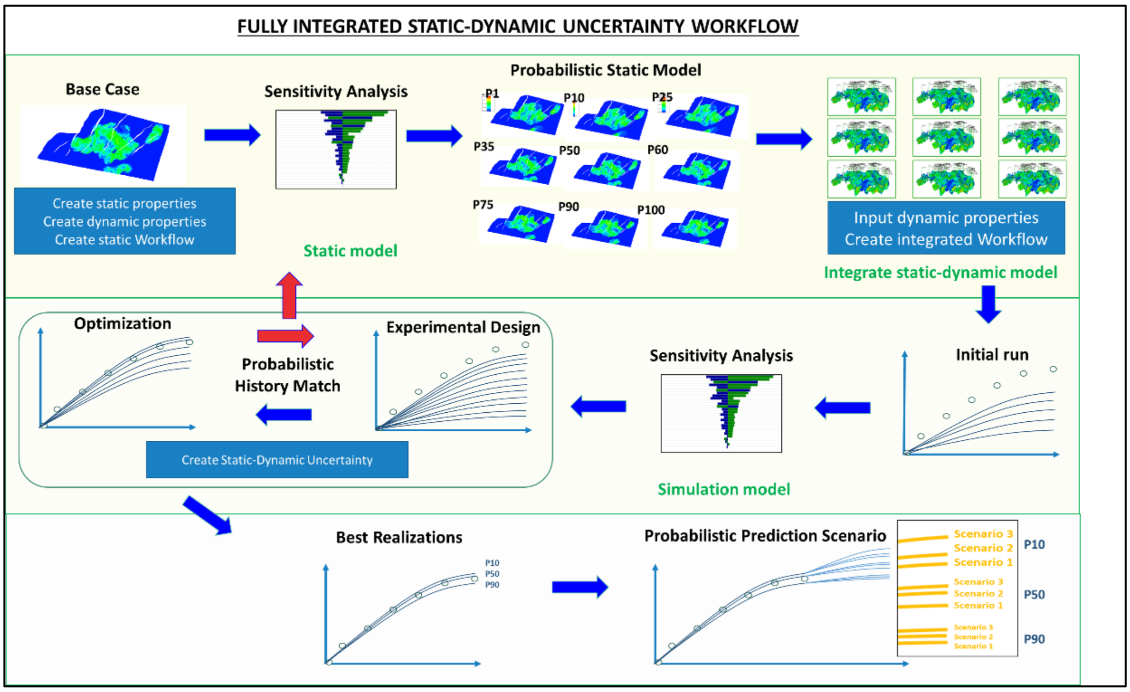

Figure 7 - New guidance and template of probabilistic plan of development process (1. full cycle integration).

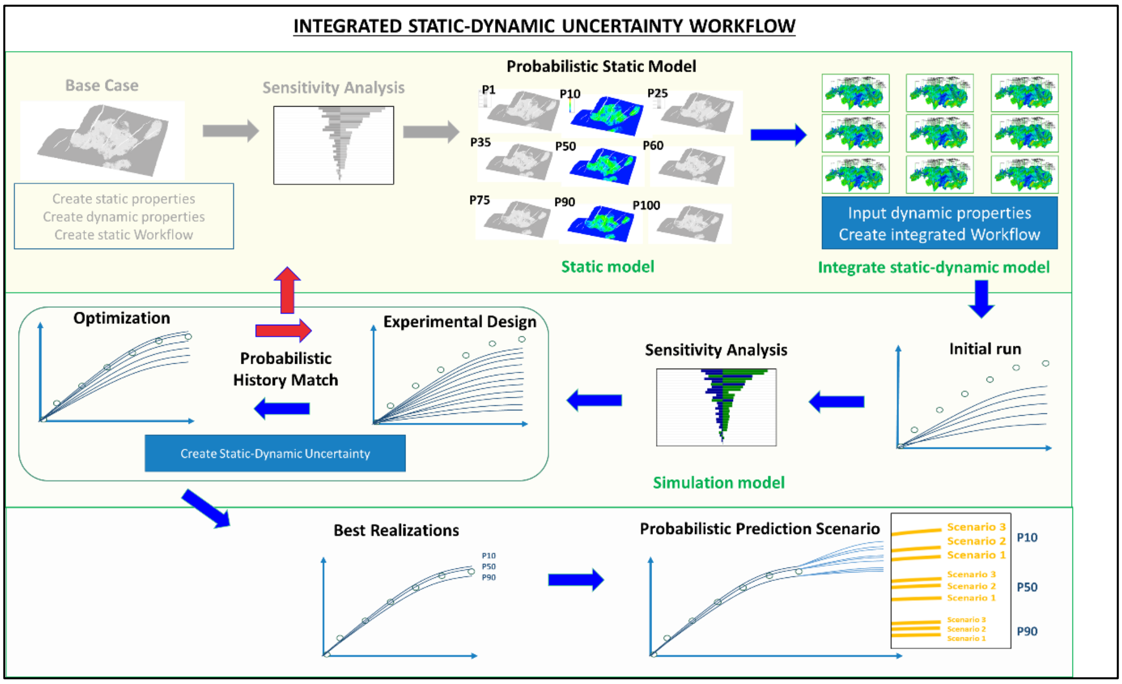

Figure 8 - New guidance and template of probabilistic plan of development process (2. partial integration).

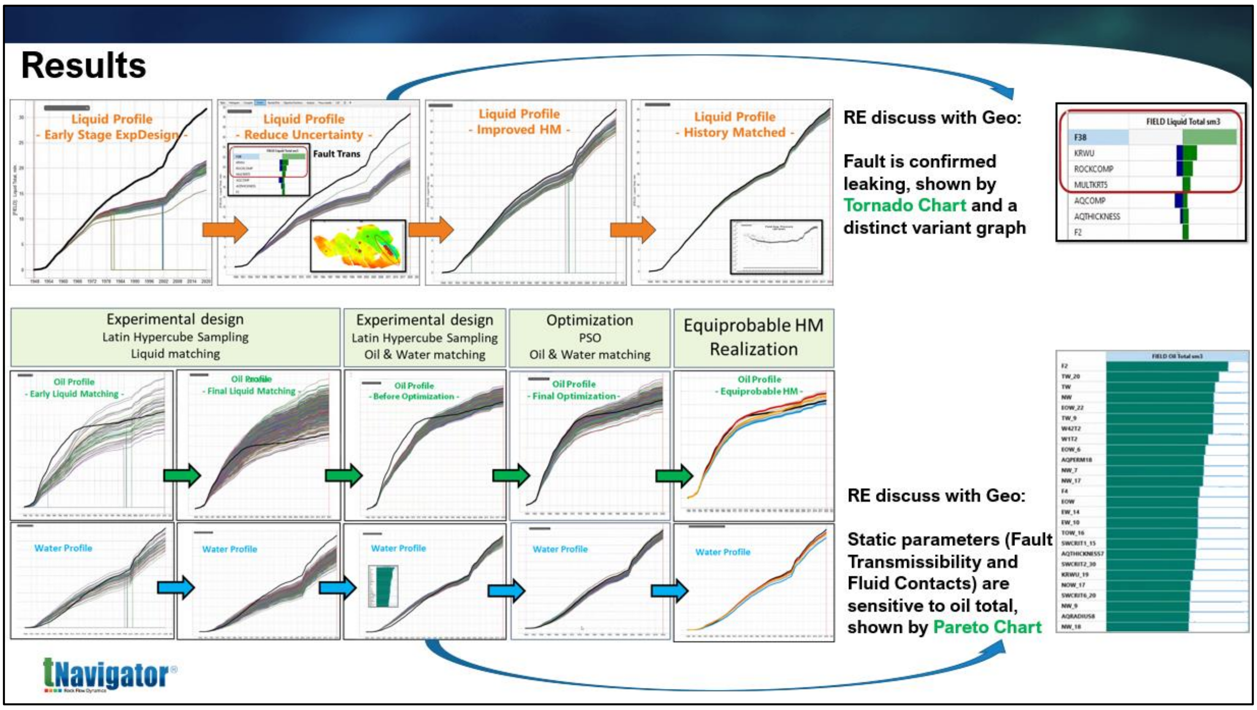

Figure 9 - Pilot projects result (LBLT POD).

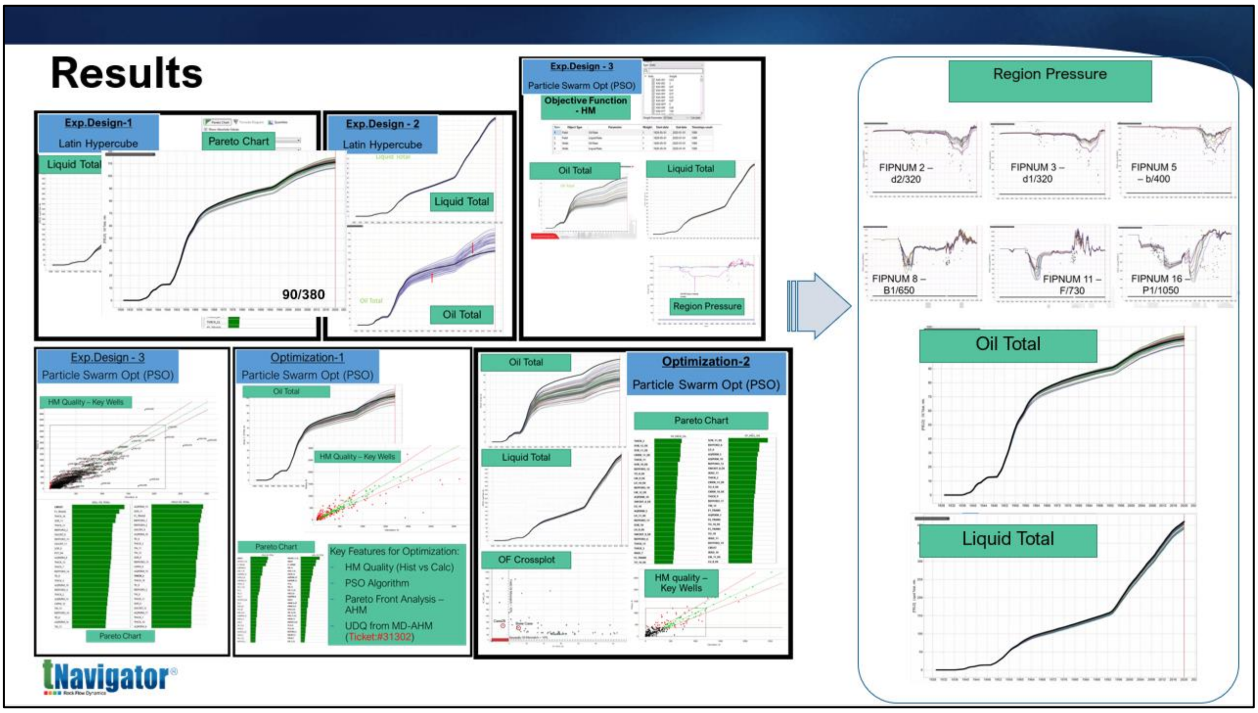

Figure 10 - Pilot projects result (KAS POD).